Sentinel Monitoring for Climate Change in the Long Island Sound Estuarine and Coastal Ecosystems of New York and Connecticut

Volume 1 (2011)

Authors
Dr. Juliana Barrett, University of Connecticut/Connecticut Sea Grant
Dr. Julie Rose, NOAA Fisheries, Milford Laboratory
Sarah Deonarine, NY State Lead, NYS Department of Environmental Conservation and the Long Island Sound Study
Antoinette Clemetson, NY Sea Grant
Jennifer Pagach, CT State Lead, CT Department of Environmental Protection
Mark Parker, CT Department of Environmental Protection and the Long Island Sound Study
Mark Tedesco, US EPA Long Island Sound Study

Funding Sources
Support for the Sentinel Monitoring for Climate Change in Long Island Sound Program is provided by the US EPA Long Island Sound Study and the US EPA Climate Ready Estuaries Program.

TABLE OF CONTENTS

BACKGROUND

I. Mission, Goals, and Objectives

Mission

The Sentinel Monitoring for Climate Change in Long Island Sound Program (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 presented here. The strategy is a dynamic document which will evolve as data become available and are analyzed.

Goals of the Program and this Strategic Plan

The SMCCP was developed to quantify local changes in the environment brought about by climate change (Rozsa, 2008). The goal of the SMCCP is to 1) collect and synthesize data that will indicate how LIS and its associated habitats, biota and processes are changing; and, 2) utilize sentinel data to provide scientists and managers with the information necessary to prioritize climate change impacts and determine appropriate adaptation and mitigation strategies for these impacts to the LIS ecosystem. These impacts include but are not limited to: loss or changes in ecosystem functions and processes; disruption in fisheries, aquaculture and other economic commodities; and changes in species population dynamics, including both the loss of and introduction of new species.

This strategy makes recommendations, based on current information, what parameters should be measured and assessed in order to provide early-warning (sentinel) detection of climate change impacts to LIS and associated habitats, biota and processes. This strategy provides recommendations for sentinel monitoring in the short term, referred to as the pilot program (1-2 years), as well as long range priorities for sentinel monitoring of climate change in Long Island Sound. Additionally, data gaps for significant parameters are identified.

Objectives

The specific objectives of the SMCCP and of the strategic plan presented here are:

1. Summarize the state of knowledge on observed and potential climate change impacts on LIS habitats, biota and processes.

2. Develop and fund a pilot-scale adaptive monitoring program to begin the effort to measure and evaluate sentinel indicators and associated parameters that would signal the magnitudes and rates of change in LIS habitats, biota, and processes caused by climate change.

3. This strategy and the pilot-scale program are intended to be used to leverage funding from other climate-change initiatives available at the state, regional, and federal level.

4. Identify opportunities for collaboration(s) to establish critical research programs (if they do not already exist), foster needed technological advancements, and implement long term monitoring.

5. Create a data citation clearinghouse that will serve as a master research web page to organize, coordinate, and promote awareness of LIS data, research, and researchers. The clearinghouse will provide access to the types, locations, and dates of data collection pertaining to climate change in LIS.

6. Synthesize and review outcomes of the pilot program to provide regular assessments of indicators and determine if changes should be made in parameters measured.

7. Provide data and model predictions from the pilot program to managers such that management decisions and adaptation strategies may be developed and implemented.

II. Definition of 'Sentinel' and Ideal Attributes

A Long Island Sound climate change sentinel is a measurable variable (whether an abiotic factor, a system, process, or species) in the Long Island Sound estuarine or coastal ecosystems that is likely to be affected by climate change and that can be monitored.

Ideal Attributes

The indicators that will be the most effective sentinels of climate change ideally will possess all of the following attributes:

- They can be measured at multiple sites, so that comparison between sites can be made;
- The climate change signal for the indicator can be distinguished from natural variations or anthropogenic stressors with the appropriate sampling resolution;
- For biological indicators, they are:
    - representative of regional biological communities, processes, ecosystems and/or
    - a species at the edge of its range (fringe) or in a habitat that is limited
- They have an existing or potential data record that would allow comparison of historic, current, and future conditions

- They can be measured and studied feasibly with respect to cost and available technology (or new technology can be developed in order to support their measurement).

The term "indicator" as used here is consistent with EPA's Climate Ready Estuaries program (see Appendix A for a Glossary of Terms and List of Abbreviations).

III. Background of the Sentinel Monitoring for Climate Change in Long Island Sound Program

Description of Long Island Sound Study Area

Long Island Sound (LIS) is a large urban estuary that separates Long Island from Connecticut. LIS is a unique estuary in that it has two connections to the Atlantic Ocean, The Race to the east and the East River to the west, as well as having several major rivers flowing into it. Eighty percent of the fresh water flowing into the Sound comes from these rivers. The area encompasses numerous coastal and estuarine habitats and provides critical feeding, nesting, breeding, and nursery habitat for numerous plant and animal species. The SMCCP does not encompass the entire LIS watershed area, but is not limited to the LIS study area or coastal boundary (see Figure 1). For the purpose of this document, we shall refer to the area of study as estuarine and coastal ecoregions.

As of 2010, nearly 9 million people live in the LIS watershed, with the Sound contributing approximately $8 billion annually to the regional economy through commercial and recreational activities. Population pressures have impacted the area through development and increases in certain pollutants such as hydrocarbons, pathogens, and PCBs.

Overview of the Long Island Sound Study

The Long Island Sound Study (LISS) was formed in 1985 by the United States Environmental Protection Agency (EPA), and the States of New York (NY) and Connecticut (CT) to restore and improve the environmental health of the Long Island Sound (LIS) ecosystems (Figure 1). This bi-state partnership includes federal and state agencies, multiple non-governmental organizations, universities and researchers, the general public, and other groups working to restore, conserve, and protect the Sound. A Comprehensive Conservation and Management Plan (CCMP) was completed in 1994 by the LISS that identified seven priority issues: low dissolved oxygen (hypoxia), toxic contamination, pathogen contamination, floatable debris, living resources and habitat management, land use and development, and public involvement and education. Significant advancements have been made in these areas; however, climate change was not formally recognized as a major issue until recently. For more information on the LISS, see http://www.longislandsoundstudy.net

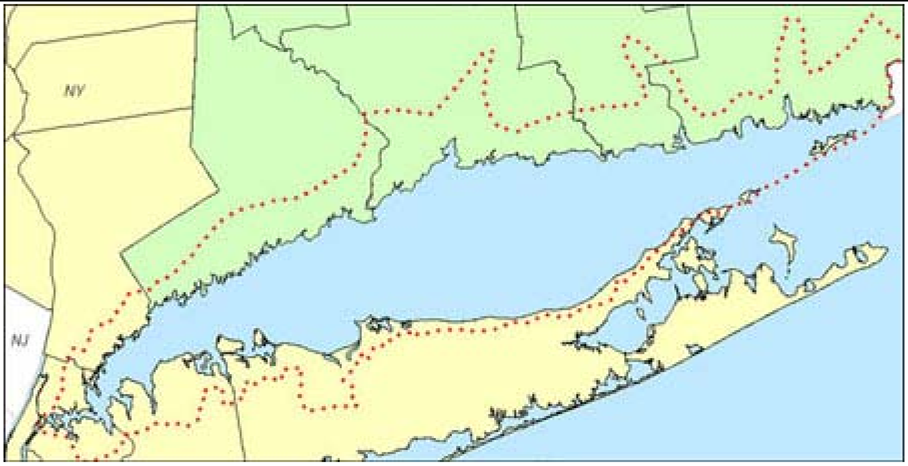


Figure 1. Map of coastal boundary established by LISS, prepared by the Southern New England Coastal Program Office, United States Fish and Wildlife Service

Background of the Sentinel Monitoring for Climate Change in Long Island Sound Program

Since the development of the LISS CCMP in 1994, global climate change impacts have come to the forefront in current science and management issues. The complexities of a changing climate and the subsequent impacts on different ecosystems have caused many estuary programs to revisit their management plans to take into consideration regional climate changes. Since it is extremely difficult to scale down global climate models to the regional level, local-, watershed-, and state-level information on climate change impacts information was and is still largely unavailable. The SMCCP is a novel approach in that it combines available regional-scale predictions and climate drivers (top down) with local monitoring information (bottom up) to identify candidate sentinels of change. Current and predicted climate changes within LIS estuarine and coastal ecosystems include changes in: air and water temperatures; wind (speed and direction); precipitation and storm climatology; sea level rise rates; and water chemistry; followed by changes in habitats and biological systems (See Appendix B for details on predicted changes in the physical and biological systems of LIS). The importance of long-term monitoring to the understanding and planning for climate change impacts on LIS ecosystems are becoming more apparent. Baseline studies of many climate-related environmental indicators are either missing or incomplete making it difficult for scientists and resource managers to track changes and identify trends over time. Recognizing the importance of baseline indicators as well as long-term monitoring to track climate change impacts, the LISS proposed a sentinel monitoring for climate change program in Long Island Sound "as a means of quantifying environmental changes from climate change (Rozsa 2008)." The ecosystem-level approach to identifying climate change impacts on the LIS estuarine and coastal ecosystem has been novel among coastal climate-change programs in the United States.

The vision of the LISS is that the SMCCP will begin with a pilot program that focuses on local changes to selected sentinels at a specific site(s) instead of trying to develop a region-wide monitoring and assessment program from the outset. Initially, the approach considered was to have one core location in each state for each basin of the Sound (western, central, eastern; total of six core sites) and "roving" stations around the core sites to give a broader range of information on local climate change effects. However, due to budget constraints, it was decided that the pilot program be focused on one site in each state on which future monitoring could be built and from which future monitoring could be expanded, pending additional or outside sources of funding. Such a pilot program would not be a mini-monitoring program in itself, but a small subset of a larger monitoring program.

> The vision of the LISS is that the Sentinel Monitoring for Climate Change in Long Island Sound Program will begin with a pilot program that focuses on local changes to selected sentinels at a specific site(s).

A climate change vulnerability assessment, such as this SMCCP, is the first step towards adaptation. Implementation of the SMCCP will yield results on current conditions in LIS and, over time, will highlight resources or processes that are vulnerable to climate change. Once sentinel responses to climate change are identified, it is expected that the Management Conference partners will be able to develop recommendations for action based on significant early-warning findings. Current policy does not take into account the pressures of climate change on the LIS ecosystem and this monitoring program should yield results that will guide policy in the LIS estuary and larger watershed.

In October 2008, the LISS awarded the states of New York and Connecticut $75,000 each to develop an overarching strategy for their portion of the LIS watershed (year 1) and to implement a pilot program (year 2). At the February 2009 Scientific and Technical Advisory Committee meeting, it was agreed that this timeline was too ambitious and required an extension to allow for a complete strategy and thorough peer-review. It was agreed between New York and Connecticut representatives that both states would develop a larger sentinel monitoring strategy and, from that, develop a pilot program for initial implementation.

> This strategy is intended to be dynamic and involve future re-evaluation and synthesis in order to redirect efforts and identify data gaps.

Initially there was some debate as to the utility of planning a comprehensive program when the planned funding level from LISS was only pilot in scale. However, the recommendations for a larger-scale program were recognized as crucial to guiding future efforts and taking advantage of future funding opportunities. Additionally, it was recognized that most environmental monitoring is not a comprehensive single program, but usually a combination of sources that leverage one another. This strategy is intended to be dynamic and involve future re-evaluation and synthesis in order to redirect efforts and identify data gaps.

Program Development

The SMCCP was originally proposed as a “sentinel site” project, with the selection of a location-based starting point and the secondary selection of appropriate parameters based on the chosen site. The process was inverted to first consider climate drivers and parameters and then choose appropriate sites based on these selected indicators/sentinels. There was also discussion as to how far inland monitoring could and should extend as the program was not intended to be limited to just the open water. Both work groups thought that the habitat and biota of the coastal fringe would be able to capture more change than other parts of the ecosystem (due to impacts of multiple climate change drivers such as sea level rise). It was envisioned from the beginning that an awardee for pilot implementation would be scouted through a RFP (request for proposals) process and that the awardee would be the best entity for site selection.

Later discussions among several LISS committees highlighted the potential advantages of choosing locations at Stewardship sites. In 2006, the Long Island Sound Stewardship Initiative (LISSI) identified 33 areas along the Sound with high ecological and recreational values (for map, please see http://longislandsoundstudy.net/issues-actions/stewardship/). The Sound’s estuarine and coastal habitats can be divided into beaches, tidal wetlands, tidal flats, subtidal habitats, open waters, and freshwater tidal habitats of tributaries. Coupling siting of sentinel monitoring locations in or around these stewardship areas would have the benefit of working in protected locations and would promote the long-term viability of this program.

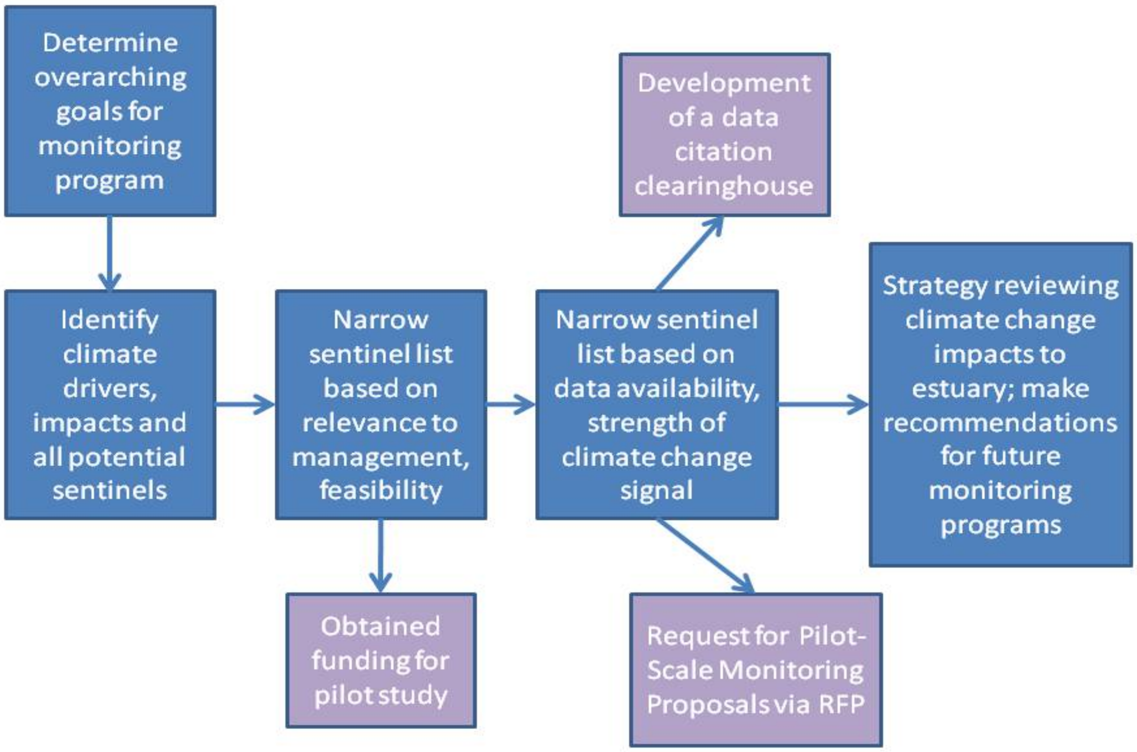


Chart 1. This flow chart describes the sequential approach applied by the SMCCP work groups to create a comprehensive strategy for climate change monitoring in Long Island Sound (blue boxes). The purple boxes are additional projects undertaken by the bi-state work group, which developed out of steps in the strategy development process. Each step in the strategy development process was coordinated by the bi-state work group with scientific and technical input from the state level work groups.

IV. Climate Change Work Groups

Connecticut and New York technical advisory work groups (Appendix C) worked independently on developing specific recommendations for climate change indicators, but consistently communicated through the state leads. NY and CT Sea Grants were funded to assist in the development of state-specific recommendations as well as work with the bi-state technical work group (Appendix D) to bring together the final bi-state strategy that allows flexibility as to how each state implements elements of that strategy. NY developed an exhaustive table of indicators, while CT work group members developed an extensive list of climate drivers which led to indicator development (Appendices E, F and G). The bi-state work group was formed to coordinate the state-level efforts and was comprised of state leads, Sea Grant representatives and

EPA staff. The two states' indicator lists were then compared and later synthesized into the Long Island Sound Matrix of Climate Change Sentinels (Appendix H).

During the first year of development (2008 – 2009), the Long Island Sound Study's Science and Technical Advisory Committee had two graduate fellows, Santiago Salinas in New York and Mark Hoover in Connecticut, who completed projects in conjunction with the Sentinel Monitoring for Climate Change in Long Island Sound Program. Fellows attended their state's technical work group meetings (described below). They also completed a research white paper (Appendix I) aimed at guiding development based on similar monitoring in different estuaries around the world. Santiago developed a Google Earth *kmz file (LISSdata.kmz) that maps current monitoring stations in Long Island Sound. He also recommended performing a statistical analysis of sentinels selected for the pilot program before the actual monitoring was begun so as to determine the necessary replicate number.

Connecticut Work Group

Connecticut Department of Environmental Protection (CTDEP) and the University of Connecticut (UConn) assembled a group of Connecticut and regional experts in January 2008 to begin discussion of climate change in Long Island Sound. Other scientists and resource managers joined this group (Appendix C), forming the CT technical work group.

During 2008, CT DEP worked with scientists and managers to develop an on-line database of current and historical monitoring efforts in LIS and, through the work group, identified three subregions within the Sound, each to have monitoring tailored to subregional needs. Again, the SMCCP was originally conceived as a "site" based program. Additionally, six climate change drivers were identified with questions developed for each driver category. Following discussions with the work groups, the decision was made to focus on these drivers and indicators, with site selection based on priority indicators/sentinels. The CT work group recognized early on the importance of defining a sentinel and its key attributes. Following consensus within the work group on the definition and attributes of a sentinel, the group focused on determining the major questions that the SMCCP should answer (Appendix E). These attributes and questions formed the basis for the CT work group to move forward with the development of a list of candidate sentinels for LIS. This list was then integrated with the products of the NY work group.

New York Work Group

NY State Department of Environmental Conservation (NYSDEC) assembled a group of New York experts (Appendix C) in February 2009, forming the NY technical work group. Meetings were held, on average, once per month until June 2010. At that point in time, the bi-state work group (described below) took the recommendations of both state work groups and began combining them into a cohesive strategy.

The NY technical work group took the approach of generating a list of all potential sentinels for consideration by the program and then held a series of discussions to narrow the list. They grouped potential sentinels into three categories: changes in physical/chemical parameters, changes in community structure, and changes in existing habitat, creating a matrix of climate change sentinels for Long Island Sound (See Appendix F for the New York Technical Work Group Discussions and Appendix G for the NY matrix). The NY group developed a ranking system in an effort to choose indicators for a pilot program (Appendix F). Eventually, the bi-state work group used this framework to develop their own ranking approach.

All sentinels identified in the matrix (Appendix H) are still recommended in the long term monitoring program, though many have been deemed inappropriate for a pilot program.

The ideal list of attributes for sentinels, developed by the CT work group, was discussed by the NY work group and vetted between the two states until a common definition and criterion list was decided upon. These desired attributes served as a way to whittle down the list of potential sentinels. All sentinels identified in the matrix (Appendix H) are still recommended in the long term monitoring program, though many have been deemed inappropriate for a pilot program because there is a reduced likelihood of detecting a climate change signal in these sentinels in the short-term. Both state work groups provided input on narrowing the complete list of sentinels down to a pilot-scale program through an on line survey described below.

The bi-state work group eventually melded CT and NY products into a single matrix of climate drivers, candidate sentinels, and existing monitoring (Appendix H). NY's discussion of this matrix is available in Appendix F.

Bi-state Work Group

The Sentinel SMCCP bi-state work group formed in April 2009 during the preparation of a successful proposal to EPA's Climate Ready Estuaries (CRE) program. The bi-state work group coordinated efforts between states to develop a strategy beginning in the summer of 2009. The bi-state work group met frequently (two or more times per month) via teleconference and the work group members were in constant electronic contact through email and online documents. The functions of the bi-state work group were to use the technical work group discussions as the basis to achieve consensus for the strategic plan development, set the stage to plan and implement a pilot study, conduct outreach about LIS sentinel monitoring for climate change coordination, and serve as liaison to the LISS Management Committee. Some of the bi-state work group's accomplishments include successful surveys of experts, an implementable list of pilot-specific indicators, grant awards, presentations both to the LISS and at national conferences, and this strategic plan. The timeline and milestones for this program are detailed in Appendix J.

EPA's Climate Ready Estuaries Program

During the spring of 2009, the bi-state work group applied for and received a technical assistance grant through the EPA's Climate Ready Estuaries Program (http://www.epa.gov/climatereadyestuaries). The purpose of the Direct Technical Assistance grant program was "to accelerate efforts already underway to develop and implement climate adaptation plans". This program provided $75,000 of direct technical assistance in the form of contractors provided by the EPA.

The bi-state work group worked with contractors from ICF International, who provided outside research assistance, resulting in three technical memoranda delivered to the LISS. These documents contained information and recommendations in the following topic areas: a review and synthesis of information on climate change drivers and responses in Long Island Sound; steps to develop a prioritized list of indicators for monitoring climate-driven change; review of monitoring programs and references for developing a monitoring strategy; glossary of common terms; and potential additions to the draft monitoring program already in development.

The memoranda are posted in their original form on the SMCCP website (http://longislandsoundstudy.net/research-monitoring/sentinel-monitoring/). Additionally, they have served as an important starting point for many of the bi-state work group activities. The review and synthesis of information on climate change drivers and responses in Long Island Sound has been expanded by technical and bi-state work group members and is included as Appendix B of this strategy. The indicator selection flow chart that was developed by ICF was adapted and incorporated in the strategic plan and the bi-state work group's final version is included above in Chart 1.

V. Core Parameters

A set of core parameters was identified that should be measured or otherwise collected in addition to sentinel indices. These core parameters are physical or chemical 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 sentinel column of the matrix (Appendix H). However, the work groups recommended that eventual site selection for the pilot study be influenced by the availability of several of these core parameters from other monitoring programs. The core parameters listed here are taken from the climate related factors column and are in no hierarchical order:

- precipitation
- stream flow (runoff and baseflow)
- sea level
- water temperature
- salinity
- wind (speed and direction)
- relative humidity
- groundwater levels
- pH; it was noted that while pH is considered a “core parameter,” it is not well characterized in LIS.

VI. Matrix Development with Sentinels and Sentinel Indices

Given the two different approaches used by the CT and NY state-level work groups, it was necessary to reconcile the approaches and the information generated by each work group, as well as the documents generated by the EPA contractor ICF International. A table format was used to generate a preliminary matrix of LIS climate change impacts and indicators. Numerous discussions were held to clarify terms and definitions, as well as how best to organize the information (see Appendices E and F for discussions of the issues and concerns expressed by work group participants). The final matrix document (for the purposes of this strategic plan) features four tables:

(1) Water Quality/Quantity,
(2) Pelagic/Benthic Systems and Associated Species,
(3) Fisheries of Long Island Sound and Associated River Systems, and
(4) Coastal Habitats of Long Island Sound and Associated Species/Systems.

Each table includes a list of sentinels, and for each sentinel there are the following categories: monitoring question(s), ecological drivers of climate related change to the sentinel, responses of the sentinel to climate related factors, sentinel indice(s) (i.e. how is the sentinel measured or quantified), and what data have been collected to date. In addition, the following question is asked for each sentinel: Can climate change effects be distinguished from other stressors? The answer to this question may change as our knowledge grows. In addition, we anticipate that other sentinels will be added to the document in the future. This matrix of four tables (Appendix H) with sentinels and sentinel indices was then used to determine priorities for pilot monitoring (Section VII) along with an agreed-upon list of core parameters (Section V).

Each of the four table categories is briefly described below:

A. Water Quality/Quantity

The physical and chemical characteristics of water that impact the biological abundance and diversity of plants and animals of LIS are important indicators in tracking impacts to cold water and warm water species as well as the areal extent of habitat favorable to those species. The problem of summertime low dissolved oxygen (hypoxia) in the western and central Sound is strongly influenced by density stratification separating surface and bottom water. Water column stratification is driven by temperature and salinity differences in water masses. As sea level rises and precipitation is predicted to increase in the region, it is expected that brackish tidal areas will shift, an overall lowering of salinity may occur, as well as warming of cold water habitats. Water quality monitoring funded by the LISS at open water sites in the Sound has provided a rich data set of parameters for water temperature, salinity, dissolved oxygen, and turbidity spanning 25 years and is a great resource to the region. With the increased awareness of ocean acidification impacts due to climate change, CTDEP also began monitoring pH in 2010. Increased ocean acidity could have an adverse impact on the region's shellfish industry if this process impinges calcification at various stages in shellfish growth and development. The major focus of monitoring by the Long Island Sound Study has been on open waters, but a number of citizens volunteer monitoring groups in New York and Connecticut have accumulated a good data set of embayment parameters that could serve as a base to determine trends as part of a sentinel monitoring for climate change program.

B. Pelagic and Benthic Systems and Associated Species

The distribution and abundance of invasive species has been projected to increase as changes in temperature, salinity and pH regimes may increase the ability of invasive species from a wide range of plant and animal groups to compete with native species. Within benthic communities, infaunal and epifaunal invertebrates have been predicted to migrate with changes in water temperature and salinity. However, it was noted by the technical work groups that these phenomena are difficult to monitor and that direct linkages to climate change may also be difficult to establish due to existing anthropogenic stressors in LIS. Both phytoplankton and zooplankton community composition may change with increasing water temperatures and new species may be introduced to the Sound. The earlier occurrence of spring phytoplankton blooms has been observed in other locations around the world and changes to the timing and extent of phytoplankton blooms may occur in LIS as well. Shifts from crustacean zooplankton (e.g. copepods) to gelatinous zooplankton (e.g. jellyfish) may also be associated with increased temperature and ocean acidity. Finally, changes in the finfish community are already being observed within survey catch data, with increasing water temperatures linked to a movement of species northward and warm-adapted species replacing cold-adapted species in Long Island Sound.

C. Fisheries of Long Island Sound and Associated River Systems

Temperature is only one of a complex group of variables that individually or collectively drive ecological changes in LIS. Subsequently, it is difficult to definitively attribute or project changes in crustaceans, mollusks, and finfish populations without considering other environmental influences. The net effect of increased temperature on fish (crustaceans, bivalves, finfish) populations may be negative or positive. It is foreseeable that synergies may exist between climate change and other major stressors. Generally, finfish have the ability to actively migrate to avoid unfavorable conditions. However, if unfavorable conditions persist indefinitely, this creates an entirely new habitat that would have far-reaching ecological consequences. In the case of marine species that are being exploited in LIS, climate related impacts would be a result of temperature, low dissolved oxygen, and reduced pH (acidification). The severity of these impacts may be different at various life stages. Climate change places additional pressure on exploited marine fish stocks that are already subject to over exploitation and other stressors (Harley et. al, 2006).

D. Coastal Habitats of Long Island Sound and Associated Species/Systems

The coastal habitats associated with LIS include both estuarine and terrestial systems and the numerous species associated with each. Terrestrial systems including coastal forests, shrublands, and grasslands will experience increased air temperatures causing changes in phenology, as well as distribution and abundance of species. Coastal bluffs and escarpments will likely experience increased erosion from stronger storm events as well as from increased precipitation and runoff. Additional climate-related changes that will likely impact these systems are changes in precipitation, changes in groundwater (including salinity and height of the groundwater table) and, depending on location, sea level rise. Marshes and intertidal systems and their associated plant and animal species will experience (or already are) experiencing impacts from sea level rise. Other climate related factors that will impact these areas include changes in salinity, precipitation, and groundwater flow. Subtidal communities are expected to be impacted by changes in salinity, sea level rise, pH, and increased precipitation and runoff can lead to increased nutrient loading and turbidity.

VII. Pilot Sentinel Survey to State Work Groups and Recommendations for Pilot Scale Monitoring

After generating a long list of candidate sentinels for monitoring in Long Island Sound and its coastal ecoregions (see Sentinel Indices Matrix, Appendix H), the list of sentinels were prioritized for potential inclusion in a pilot program. The set of desired sentinel attributes that was agreed upon by the technical work groups was also used in the prioritization process. These attributes were as follows:

- They can be measured at multiple sites, so that comparison between sites can be made;
- The climate change signal for the indicator can be distinguished from natural variations or anthropogenic stressors with the appropriate sampling resolution;
- For biological indicators, they are:
    - representative of regional biological communities, processes, ecosystems and/or
    - a species at the edge of its range (fringe) or in a habitat that is limited
- They have an existing or potential data record that would allow comparison of historic, current, and future conditions
- They can be measured and studied feasibly with respect to cost and available technology (or new technology can be developed in order to support their measurement).

Although all five attributes were considered during creation of the Sentinel Indices Table, the bi-state work group decided to focus on the first two attributes to prioritize the list of sentinels for pilot scale implementation. The first attribute was selected as a requirement for the success of any proposed sentinel. The second attribute was chosen due to the temporal and budgetary restrictions of a pilot-scale study. The remaining attributes had been used previously by the technical work groups to narrow the list of sentinels in the matrix. The technical work groups advised that analysis of historical/existing monitoring data could yield information in the short-term on climate change signals already present in Long Island Sound. The pilot study is intended to obtain information for use by managers within a two to three year time frame, to be used to leverage funding for a larger, longer-term monitoring program, and to be as cost-effective as possible. For these reasons, a pilot-scale study that combines analysis of existing data with on-the-ground monitoring has been identified as the optimal approach.

A pilot-scale study that combines analysis of existing data with on-the-ground monitoring has been identified as the optimal approach.

An online survey was designed that focused on these two attributes for prioritization of the candidate sentinels. The survey link was distributed to the two state-level technical work groups and each member was asked to rate each sentinel based upon the main attributes, which were described in the survey as follows: 1) A sufficient data record exists to allow comparison of current conditions to relative historic conditions for the sentinel in question in order to identify long-term trends that may be occurring (or have occurred) related to climate change; and, 2) A climate change signal could in theory be distinguished from natural variations or anthropogenic stressors with the appropriate sampling resolution. The categories for rating were: Strongly Disagree, Disagree, Agree, Strongly Agree or Unsure. Four categories of rating were deliberately chosen in order to force participants to give an opinion and avoid the statistical middle in responses. Technical work group members were asked to only respond to sentinels for which they felt comfortable assigning a rating. If they lacked sufficient knowledge to assign a rating, they were asked to respond with "Unsure". Work group members were given approximately one month to respond to the survey and reminders were periodically sent.

Twenty-three work group members from Connecticut and ten work group members from New York responded to the survey. For a complete list of survey results, please see Appendix K. Responses were assigned a numerical rating: Strongly Disagree (1), Disagree (2), Agree (3) and Strongly Agree (4). "Unsure" ratings received no number and did not affect the analysis. Data from the two states was analyzed separately to prevent the larger response from Connecticut from biasing the outcome. The average rating for each attribute was generated for each of the 37 candidate sentinels. An average rating of 2.5 or higher was considered general agreement by work group members of a sentinel's potential value. Sentinels were included in the short list if their average rating for both attributes, by both state work groups, was greater than or equal to 2.5. Of the 37 original candidates, this left 17 priority sentinels. These 17 priority sentinels were as follows:

1) Areal extent and distribution of eelgrass
2) Areal extent, diversity, and composition of brackish marshes
3) Areal extent, diversity, and composition of freshwater tidal marshes
4) Areal extent, diversity, and composition of salt marshes
5) Changes in diadromous fish run timing
6) Changes in distribution and marine transgression of marshes
7) Distribution, abundance, and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl
8) Distribution, composition, and abundance of terrestrial invasive species
9) Extent and distribution of barrier beaches/islands
10) Extent and distribution of coastal forests, shrublands and grasslands
11) Extent and distribution of habitats associated with coastal embayments (e.g., fringe marsh, shorelines and tidal creeks)
12) Extent and distribution of sea cliffs/bluff and escarpments
13) Extent and distribution of unvegetated nearshore (submerged and intertidal) habitats (e.g., mudflats, sandflats, rocky intertidal)
14) Finfish biomass, species composition, and abundance
15) Lobster abundance (based on fishery-independent measurements)
16) Phytoplankton biomass, species composition, and timing of blooms
17) Species composition within coastal forests, shrublands, and grasslands

Before moving forward with development of a Request for Proposals based on these 17 sentinels, the bi-state work group worked to verify data availability in both states. Datasets identified during earlier technical work group meetings were compiled, technical work group members provided additional information, and state agencies were consulted for data availability. The datasets identified through this process are listed in Appendix L and will be listed in the data citation clearinghouse (see Section VIII). The list of candidate sentinels was then further narrowed down based on the availability of existing data in both states in multiple locations as sentinels with greater data availability were ideal for a pilot study, as indicated above. Again, this does not diminish the potential importance of sentinels with little or no current data availability to a larger program, but suggests that they are not appropriate for a small-scale, short-term pilot study. The details of this discussion to narrow the candidate sentinels is included with the data availability in Appendix L. The final list is as follows:

1) Distribution, abundance, and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl
2) Finfish biomass, species composition, and abundance
3) Lobster abundance (based on fishery-independent measurements)
4) Phytoplankton biomass, species composition, and timing of blooms
5) Species composition within coastal forests, shrublands, and grasslands
6) Areal extent, diversity, composition, and marine transgression of salt marshes

There are two important considerations for the pilot-scale awardee: 1) Ensure ready access to data collected at sites chosen for monitoring; 2) If there are multiple sites, data collection will have to be replicated at each site; therefore, methods must be standardized.

VIII. Database Development

There is currently no central repository of research pertaining specifically to climate change in LIS, even though there are many such research and monitoring projects underway. An online data citation clearinghouse will help address the need to synthesize existing data to identify the effects of climate change on the various ecosystems of Long Island Sound as well as identify early warnings of significant climate change impacts. The clearinghouse, developed through a project agreement between CTDEP, CT Sea Grant, and UConn Department of Marine Sciences, will document Long Island Sound climate change-relevant research and monitoring through a searchable and, where appropriate, geospatial database, as well as citations of relevant research. The goals of the web-based research database are to facilitate collaboration, encourage data assessment and synthesis, and aid in the identification of data gaps. In addition to the research database, the clearinghouse will include documents and methodology pertaining to the development of the LISS Sentinel Monitoring Strategic Plan, as well as contain links to pertinent climate change websites.

The clearinghouse will feature a database of researchers and research programs relevant to climate change in the Long Island Sound estuarine and coastal ecosystems. The database will be initially populated based on the compilation of monitoring research by the state technical work groups and the report of the Science and Technical Advisory Committee Fellows (Appendix I). Actual data will not be included, but rather types of data/research in a geospatial format, where applicable, as well as a point of contact for each available data set. Information on the Sentinel Monitoring for Climate Change in Long Island Sound Program will also be included on the web page, as well as other climate/sentinel monitoring related resources. This web page will be housed at the Long Island Sound Resource Center (LISRC) website (http://www.lisrc.uconn.edu/) and will be on-line, interactive, and publicly accessible.

This clearinghouse will advance the Sentinel Monitoring for Climate Change in Long Island Sound Program by facilitating the synthesis of the research and knowledge pertaining to the physical, chemical, and biological changes with respect to climate change in Long Island Sound. This will assist in coordinating research and aid in improved management of resources and climate adaptation Sound-wide.

LOOKING FORWARD

IX. Priorities for Long Term Sentinel Monitoring and Data Gaps

A goal of this strategy is to provide long term sentinel monitoring priorities for climate change in LIS, as well as identify data gaps. Based on individual state results of the survey described in Section VII , the following sentinels were identified by each state work group as high priorities for climate change monitoring. These sentinels ranked high with regard to having a distinguishable climate change signal but have limited data availability and would be better suited to a long term program as opposed to a pilot study.

High priority sentinels identified by NY (scored 3.0 or above on survey with regard to strength of climate change signal, but data availability limited):

- Ocean acidification
- Increased incidence of calcinosis in lobster
- Disease occurrence in lobster
- Acidification impacts on shellfish and crustaceans
- Disease occurrence in mollusks (e.g. Eastern oyster, Northern quahog, bay scallops)

High priority sentinels identified by CT (scored 3.0 or above on survey with regard to strength of climate change signal, but data availability limited):

- Areal extent, diversity, and composition of freshwater tidal and brackish marshes
- Extent and distribution of habitats associated with coastal embayments, e.g. fringe marsh, shorelines and tidal creeks

Five other sentinels were identified in the survey as priorities. These sentinels have an average rating (by both state work groups) for both strength of climate change signal and data availability greater than or equal to 2.5. However, actual data availability was not considered sufficient by the bi-state work group for inclusion in a pilot program. These sentinels are listed below:

- Areal extent and distribution of eelgrass
- Changes in diadromous fish run timing
- Extent and distribution of sea cliffs/bluffs and escarpments
- Extent and distribution of unvegetated nearshore (submerged and intertidal) habitats, e.g. mudflats, sandflats, rocky intertidal areas

The eleven sentinels listed above are considered priorities for monitoring beyond the pilot monitoring program, with some having clearly defined data gaps. It is important to note that not only is additional data collection needed for these sentinels, but analysis of existing data is critical in the development of sentinel tools that will lead to predictions of climate change impacts.

These research priorities and data needs are based on survey results and are dependent upon our current understanding.. It is recognized that sentinel monitoring is a dynamic process and that sentinels and their priority status may change as new and additional research efforts are undertaken.

X. 2011-2012 Next Steps

There are a few short-term steps to be taken to continue moving this initiative forward toward pilot implementation. First, the bi-state work group will finalize and distribute this dynamic strategy. Subsequently, the work group will develop and release an RFP to select an awardee to design and implement a pilot program. Currently, work is beginning on the online data citation clearinghouse website. It is the intention that this online clearinghouse will be completed and available for access by the scientific community in spring 2012. Once that is complete or nearly complete, the work group will seek funding for data synthesis to identify climate change signals in the existing data, in addition to any such work that will be conducted by the pilot program.

XI. Long-term Next Steps

Since the LISS requests findings from a pilot study within two years, we define long-term steps as those that begin a year from the release of this strategy and continue for at least five years henceforth. These steps include implementing and overseeing the pilot program, analysis of collected data for climate change trends and making recommendations to the LISS Management Committee about adaptation strategies. State and federal agencies which would oversee implementation of management actions are represented on the LISS Management Committee, so recommendations would be taken back to the state leads.

Given this strategy is intended to be a dynamic document, the bi-state work group recommends that it is reviewed in five years. In the long-term, the SMCCP will also seek funding for a full-fledged sentinel monitoring program. At a minimum, additional funding must be acquired in order to continue the pilot monitoring. Funding for long-term monitoring will need to come from outside sources, as LISS has committed only to funding a short-term pilot study.

XII. References and Related Documents

Caldeira, K., and M.E. Wickett. 2003. Anthropogenic Carbon and Ocean pH. Nature 425:365.

Caldeira, K., and M.E. Wickett. 2005. Ocean Model Predictions of Chemistry Changes from Carbon Dioxide Emissions to the Atmosphere and Ocean. 2005. Journal of Geophysical Research 110:1-12.

Cardillo, M. 2003. Biological determinants of extinction risk: why smaller species are less vulnerable? *Animal Conservation*. 63-69.

Cheung, W.W.L., et al. 2009. Projecting global marine biodiversity impacts under climate *Fish and Fisheries*. 10:235–251.

Crossin, G., S. A. Al-Ayoub, S. H. Jury, W. H. Howell, and W. H.Watson III. 1998. Behavioral thermoregulation in the American lobster (*Homarus americanus*). *J. Exp. Biol.* 201: 365–374.

Doney, S.C., V.J. Fabry, R.A. Feely, and J.A. Kleypas. 2009. Ocean Acidification: The Other CO2 Problem. Annual Review of Marine Science 1:169–192.

Erwin, R.M., G.M. Sanders, D.J. Prosser, and D.R. Cahoon. 2006. High tides and rising seas: potential effects on estuarine waterbirds. In: Terrestrial Vertebrates in Tidal Marshes: Evolution, Ecology, and Conservation. [Greenberg, R. (ed.)]. Studies in avian biology number 32. Cooper Ornithological Society, Camarillo, CA, pp. 214-228.

Fogarty, M., L. Incze, R. Wahle, D. Mountain, A. Robinson, A. Pershing, K. Hayhoe, A. Richards, and J. Manning. 2007. Potential Climate Change Impacts on Marine Resources of the Northeastern United States.

Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. 2007. *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions*. Synthesis report of the Northeast Climate Impacts Assessment (NECIA). Cambridge, MA: Union of Concerned Scientists (UCS).

Gazeau, F., C. Quiblier, J.M. Jansen, J-P. Guttuso, J. J. Middleburg, and C.H.R. Heip. 2007. Impact of Elevated CO2 on Shellfish Calcification. Geophysical Research Letters 34:1-5.

GCRP (United States Global Changes Research Program). 2009. *Global Climate Change Impacts in the United States*. Cambridge University Press. Available at: http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/full-report

Gornitz, V. 2001. Sea-Level Rise and Coasts. Pages 21-46 in Rosenzweig, C. and W.D. Solecki (Eds.). Climate Change and a Global City: The Potential Consequences of Climate Variability and Change—Metro East Coast. Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States, Columbia Earth Institute, New York. 224 pp.

Gornitz, V., S. Hale, K. Larsen, N. Levine, C. Rosenzweig, and L. Sacks, 2004: Bracing for Climate Change in the Constitution State: What Connecticut Could Face. Environmental Defense.

Harley, C. D. G., R. A. Hughes, K. M. Hultgren, B. G. Miner, C. J. B. Sorte, C. S. Thornber, L. F. Rodriguez, L. Tomanek, and S. L. Williams. 2006. The impacts of climate change in coastal marine systems. *Ecol. Lett*., 9: 228–241.

Hartig, E.K. A. Kolker, D. Fallon, and F. Mushacke. 2001. Wetlands. Pages 67-86 in Rosenzweig, C. and W.D. Solecki (Eds.). Climate Change and a Global City: The Potential Consequences of Climate Variability and Change—Metro East Coast. Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States, Columbia Earth Institute, New York. 224 pp.

Herrick, F.H. 1911. Natural history of the American lobster. *Bull. U.S. Bur. Fish*. 29:149-408.

Hoegh-Guldberg, O., P.J. Mumby, A.J. Hooten, R.S. Steneck, P. Greenfield, E. Gomez, C.D. Harvell, P.F. Sale, A.J. Edwards, K. Caldeira, N. Knowlton, C.M. Eakin, R. Iglesias-Prieto, N. Muthiga, R.H. Bradbury, A. Dubi, and M.E. Hatziolos. 2007. Coral reefs under rapid climate change and ocean acidification. Science 318:1737-1744.

Holst, L., R. Rozsa, L. Benoit, S. Jacobsen, and C. Rilling. 2003. Long Island Sound Habitat Restoration Initiative,Technical Support for Habitat Restoration, Section 1: Tidal Wetlands. EPA Long Island Sound Office, Stamford, CT, p. 1-7, Available at: http://www.longislandsoundstudy.net/habitat/index.htm.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

Jonsson, N., B. Jonsson, and L. P. Hansen. 2005. Does climate during embryonic development influence parr growth and age of seaward migration in Atlantic salmon (*Salmo salar*)? Can. J. Fish. Aquat. Sci. 62: 2502-2508.

Joos, F., G.K. Plattner, T.F. Stocker, O. Marchal, and A. Schmittner. 1999. Global warming and marine carbon cycle feedbacks and future Co2. *Science* 284: 464-476.

Jury, S. H. and Watson, W. H., 3rd (2000). Thermosensitivity of the lobster, *Homarus americanus*, as determined by cardiac assay. *Biol. Bull.* 199, 257-264.

Kennedy, V. S. and J. A. Mihursky. 1971. Upper temperature tolerances of some estuarine bivalves, Ches. Sci., 12: 193–204. Referenced in: Pyke, C. R., R. G. Najjar, M. B. Adams, D. Breitburg, M. Kemp, C. Hershner, R. Howarth, M. Mulholland, M. Paolisso, D. Secor, K. Sellner, D. Wardrop, and R. Wood. 2008. Climate Change and the Chesapeake Bay: State-of-the-Science Review and Recommendations. A Report from the Chesapeake Bay Program Science and Technical Advisory Committee (STAC), Annapolis, MD. 59 pp.

Kirshen, P., C. Watson, E. Douglas, A. Gontz, J. Lee, and Y. Tian. 2008. Coastal Flooding in the Northeastern United States due to Climate Change. Mitigation and Adaptation Strategies for Global Change V13: 5-6. June 2008.

Kjesbu, O. S., D. Righton, M. Krüger-Johnsen, A. Thorsen, K. Michalsen, M. Fonn., and P. R. Witthames. 2010. Thermal dynamics of ovarian maturation in Atlantic cod (*Gadus morhua*). Can. J. Fish. Aquat. Sci. 67: 605-625.

Koch, E.W. and S. Beer. 1996. Tides, light and the distribution of *Zostera marina* in Long Island Sound, USA. *Aquatic Botany* 53(1-2), 97-107. Referenced in: Short, F.A. and H.A. Neckles. 1999. The effects of global climate change on seagrasses. *Aquatic Botany* 63 (3-4):169-196.

Kurihara, H., and Y. Shirayama. 2004. Effects of Increased Atmospheric CO2 on Sea Urchin Early Development. Marine Ecology Progress Series 274:161–169.

Lassalle, G. and E. Rochard. 2009. Impact of twenty-first century climate change on diadromous fish spread over Europe, North Africa and the Middle East. Global Change Biology. 15: 1072-1089.

Lawton, P. and K. L. Lavalli. 1995. Postlarval, juvenile, adolescent, and adult ecology. In: J.R. Factor (ed). Biology of the lobster, *Homarus americanus*. New York: Academic Press. pp. 47-88.

Lenton, T. M., H. Held, E. Kriegler, J. W. Hall, W. Lucht, S. Rahmstorf and H. J. Schellnhuber (2008) Tipping elements in the Earth's climate system, Proceedings of the National Academy of Sciences USA 105(6), 1786–1793.

Limburg Karin, and John R. Waldman. 2001. Biodiversity, status and conservation of the world's shads. 4: 308 pp. 1912-1915. Proceedings of Shad 2001: a conference on the status and conservation of shads worldwide. American Fisheries Society. Baltimore, Maryland, USA. 369 p.

Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 315-356.Orth, R. J.,and K. A. Moore. 1983. Chesapeake Bay: An unprecedented decline in submerged aquatic vegetation. Science, 222: 51–53.

LISS (Long Island Sound Study). 2003. Long Island Sound Habitat Restoration Initiative: Technical Support for Coastal Habitat Restoration. February 2003. http://www.longislandsoundstudy.net/habitat/LIS.Manual.pdf

LISS (Long Island Sound Study). 2011. Long Island Sound - By the Numbers. http://longislandsoundstudy.net/about-the-sound/by-the-numbers/

Mitsch, W.J. and J.G. Gosselink. 2003. Wetlands. Van Nostrand Reinhold, New York.

Moore, K. A. and J. C. Jarvis. 2008. Environmental factors affecting recent summertime eelgrass diebacks in the lower Chesapeake Bay: implication for long-term persistence. Journal of Coastal Research SI 55:135-147.

Moy, A.D., W.R. Howard, S.G. Brayl, and T.W. Trull. 2009. Reduced Calcification in Modern Southern Ocean Planktonic Foraminifera. Nature Geoscience 2:276–280.

NECIA (Northeast Climate Impacts Assessment). 2006. *Climate Change in the U.S. Northeast*. Published October 2006. Available at: http://www.climatechoices.org/assets/documents/climatechoices/NECIA_climate_report_final.pdf

Nicholls, R.J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden and C.D. Woodroffe, 2007: Coastal systems and low-lying areas. Climate

Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Lenton

NYSDEC (New York State Division of Coastal Resources). 2004. Significant Coastal Fish and Wildlife Habitats: Long Island Sound and Long Island. Available at: http://nyswaterfronts.com/waterfront_natural_narratives.asp.

O'Donnell, James as cited in Burgeson, John. "Tropical Fish are Moving in as Long Island Sounds Heats Up." ctpost.com 19 July 2010. Accessed 16 Feb. 2011 http://www.ctpost.com/news/article/Tropical-fish-are-moving-in-as-Long-Island-Sound-581383.php#page-2.

Orth, R. J. and K.A. Moore. 1986. Seasonal and year-to-year variations in the growth of Zostera marina L. (eelgrass) in the Lower Chesapeake Bay. Aquatic Botany 24:335-341.

Perry, Allison L, Paula J. Low, Jim R. Ellis, and John D. Reynolds. 2005. Climate Change and Distribution Shifts in Marine Fishes. *Science*. 24: 308 pp. 1912-1915.

Pew Center for Global Climate Change. 2009. The Science and Consequences of Ocean Acidification. Science Brief 3, August 2009. Available at: http://www.pewclimate.org/docUploads/ocean-acidification-Aug2009.pdf

Roy, K., D. Jablonski, and J. W. Valentine. 2001. Climate change, species range limits and body size in marine bivalves. *Ecology Letters.* 4: 366-370.

Rozsa, R. 2008. Climate Change - Coastal Sentinel Site Network Long and Fishers Islands Sounds. 5 pp. Retrieved from http://longislandsoundstudy.net/research-monitoring/sentinel-monitoring/

Shirayama, Y. and H. Thornton. 2005. Effect of Increased Atmospheric CO2 on Shallow Water Marine Benthos. Journal of Geophysical Research 110:1-7.

Short, F.A. and H.A. Neckles. 1999. The effects of global climate change on seagrasses. *Aquatic Botany* 63(3-4):169-196.

Spierre S and CP Wake (2010) Trends in Extreme Precipitation for the Northeast United States, 1948-2007. Carbon Solutions New England Report and Clean Air-Cool Planet Report.

Stewart, L.L; 1972. Seasonal movement, population dynamics and ecology of the lobster, Homarus americanus, off Ram Island, Connecticut. PhD. Dissertation University of Connecticut.

Strange, E.M. 2008. North Shore, Long Island Sound and Peconic Estuary. Section 3.2 in: Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1, J.G. Titus and E.M. Strange (eds.). EPA 430R07004. U.S. EPA, Washington, DC.

Sullivan, B. K., D. Van Keuren, and M. Clancy. 2001. Timing and size of blooms of the ctenophore *Mnemiopsis leidyi* in relation to temperature in Narragansett Bay, R.I., Hydrobiologia, 451: 113–120.

Talmage, S. and C. Gobler. 2009. The effects of elevated carbon dioxide concentrations on the metamorphosis, size, and survival of larval harf clams (Mercenaria mercinaria), bay scallops (Argopecten irradians). Amd Eastern oysters (Crassostrea virginica). *Limnol. Oceanogr.*, 54(6), 2009, 2072–2080.

Teal, J.M. 1986. The Ecology of Regularly Flooded Salt Marshes of New England: A Community Profile. Biological report 85(7.4). U.S. Fish and Wildlife Service, Washington, DC, 69 pp.

Tin, Tina. 2005 http://www.geog.mcgill.ca/climatechange/ReportsMap/lobsterRpt.pdf

Titus, J., and C. Richman. 2001. Maps of Lands Vulnerable to Sea Level Rise: Modeled Elevations Along the U.S. Atlantic and Gulf Coasts. Long Island modeled elevation map available at http://www.epa.gov/climatechange/effects/downloads/linyc.pdf. Accessed October 13, 2009.

USAID (U.S. Agency for International Development). 2006. Managing freshwater inflows to estuaries : a methods guide. PN-ADH-650. Available at: http://pdf.usaid.gov/pdf_docs/PNADH650.pdf.

USEPA (U.S. Environmental Protection Agency). 2009a. Ecosystem Services Research Program: Wetlands Research. Available at: http://epa.gov/ord/esrp/quick-finder/wetlands-research.htm. Accessed October 7, 2009.

USEPA (U.S. Environmental Protection Agency). 2009b. Marshes. Available at: http://www.epa.gov/owow/wetlands/types/marsh.html. Accessed October 8, 2009.

USEPA (U.S. Environmental Protection Agency). 2008. National Coastal Condition Report III: Chapter 3: Northeast Coastal Region. Office of Research and Development/Office of Water, EPA/842-R-08-002, December 2008, Washington, DC 20460. Available at: http://www.epa.gov/nccr.

USEPA (U.S. Environmental Protection Agency). 2007. National Estuary Program Coastal Condition Report. Chapter 3: Northeast National Estuary Program Coastal Condition, Long Island Sound Study. Published June 2007.

USGS (United States Geological Survey). 2000. Water Quality in the Long Island–New Jersey Coastal Drainages New Jersey and New York, 1996–98: U.S. Geological Survey Circular 1201. Available at http://pubs.water.usgs.gov/circ1201/

Waddy, S. L., Aiken, D. E. and De Kleijn, D. P. V. 1995. Control of growth and reproduction. In: J.R. Factor (ed). Biology of the lobster, *Homarus americanus*. New York: Academic Press. pp. 217-266. San Diego: Academic Press.

Wood, A.J.M., J.S. Collie, and J.A. Hare. 2009. A comparison between warm-water fish assemblages of Narragansett Bay and those of Long Island Sound waters. Fish. Bull. 107:89–100.

Wootton, T.J., C.A. Pfister, and J.D. Forester. 2008. Dynamic Patterns and Ecological Impacts of Declining Ocean pH in a High-Resolution Multi-Year Dataset. Proceedings of the National Academy of Sciences 105:18848–18853.

Worden, M.K., C.M. Clark, M. Conaway, and S. A. Qadri. 2006. Temperature dependence of cardiac performance in the lobster *Homarus americanus*. *J. Exp. Biol*. 209. 1024-1034.

Yin, J., Schlesinger, M., and R. Stouffer. 2009. *Model projections of rapid sea-level rise on the northeast coast of the United States*. Nature GeoScience 2:262-266. March 15, 2009.

APPENDICES

List of Appendices

A. Glossary and List of Abbreviations

Some of the definitions presented here are standard definitions taken from EPA documents, particularly the document *Developing and Implementing an Estuarine Water Quality Monitoring, Assessment, and Outreach Program* (U.S. EPA, 2002a).

Acidification In the context of climate change, acidification is a decrease in the pH of a solution, such as seawater, due specifically to the incorporation of carbon dioxide (CO_2) into the water. The pH of seawater is typically 7.5-8.4 (reference: a pH of 7.0 indicates a neutral solution and a pH of greater than 7.0 indicates a basic solution).

Adaptation Adjustment in natural or human systems to a new or changing environment. Adaptation to *climate change* refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC Third Assessment Report Working Group III: Mitigation).

Algae A group of aquatic, photosynthetic, eukaryotic organisms ranging from unicellular to multicellular forms, and generally possess chlorophyll but lack true roots, stems and leaves characteristic of terrestrial plants (Biology Online).

Anthropogenic A process or impact that is due to human activity.

.

Bathymetry The measurement of the depth of an ocean or other large body of water (U.S. EPA, 2002a).

Benthos organisms living on or in ocean, sea or lake bottoms – or as in this case, Long Island Sound.

Carbon Dioxide (CO_2) A gas that is generated through both natural and anthropogenic activities. When dissolved in water, CO_2 and water combine to form carbonic acid, resulting in acidification of seawater.

Chlorophyll *a* A green pigment in phytoplankton that transforms ultraviolet (UV) light energy into chemical energy during the process of *photosynthesis* (U.S. EPA, 2002a).

Climate Drivers The major climate drivers, or forcing phenomenon, that have an effect on Earth's changing climate. These include greenhouse gases such as carbon dioxide, as well as the tilt and wobble of the earth, sun heat and magnetic variation, ocean circulation, and others.

Climate forcing A way to measure how substances such as greenhouse gases affect the amount of energy that is absorbed by the atmosphere. An increase in climate, or radiative, forcing leads to warming, while a decrease produces cooling (U.S. EPA, 2010).

Decomposition The breakdown of organic matter by bacteria and fungi (U.S. EPA, 2002a).

Dissolved Oxygen (DO) The concentration of free molecular oxygen that is dissolved in water, usually expressed in milligrams per liter (mg/L), parts per million (ppm), or percent of saturation. DO allows fish and other life to live in water. Levels of 5 mg O_2/L are optimal for sustaining life; most fish cannot survive prolonged periods at low levels of dissolved oxygen. (U.S. EPA, 2002a).

Drivers see Climate Drivers and Ecological Drivers

Ecological Drivers are climate related factors that cause measurable changes in properties of the physical, chemical and biological environment. Examples of ecological drivers are factors such as variability in rainfall and available nitrogen.

Ecosystem An ecosystem is a biotic community together with its physical and chemical environment, considered as an integrated unit (USACE, 1999).

Estuary A semi-enclosed coastal body of water that has free connection with the open sea and within which sea water is diluted by fresh water from land drainage (U.S. EPA, 2002a).

Eutrophication Overenrichment of a water body by nutrients, such as phosphorus and nitrogen.

Harmful Algal Blooms (HAB) A small percentage of algal species cause harm to humans and the environment through toxin production or excessive growth. HABs occur naturally, but human activities that disturb ecosystems in the form of increased nutrient loadings and pollution, food web alterations, introduced species, and water flow modifications have been linked to the increased occurrence of some HABs (Lopez et al, 2008).

Hypoxia According to Long Island Sound Study standards, hypoxia is defined as dissolved oxygen concentrations less than 3.0 mg O_2/L.

Impervious surfaces Are usually constructed surfaces such as roads and roofs that are covered by impenetrable materials. These materials prevent the infiltration of water. Highly compacted soils in urban environments are also considered impervious surfaces.

Indicator A representative of the state of certain environmental conditions over a given area and a specified period of time (EPA Indicators Report: http://www.epa.gov/climatechange/indicators.html).

Invasive species A species that is: 1) non-native (or alien) to the ecosystem under consideration, and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health. (Executive Order 13112).

Land Use modification of the natural environment by humans for agricultural, commercial, residential, recreational or other uses.

Metric A set of measurements that quantify results (http://management.about.com/cs/generalmanagement/g/metrics.htm).

Nonpoint source (NPS) a source of water pollution that is not a “point source” as defined by section 502(14) of the Clean Water Act as *any discernible, confined and discrete conveyance.* NPS pollution comes from many diffuse sources and is caused by rainfall or snowmelt moving over and through the ground. As this water, or runoff, moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters and ground waters (U.S. EPA, 2010c).

Parameter A variable, measurable property whose value is a determinant of the characteristics of a system (taken directly from: http://www.epa.gov/OCEPAterms/pterms.html) (USEPA 2011).

Pathogens Disease-causing organisms (U.S. EPA, 2002a).

Pelagic living in or related to open oceans and seas (or here, Long Island Sound).

pH Scale Scale used to determine the alkaline or acidic nature of a substance. A pH of 1.0 indicates a pure acid and 14 is a purely alkaline (basic) substance. Pure water is neutral (pH of 7.0) (U.S. EPA, 2002a).

Phytoplankton Phytoplankton are microscopic floating photosynthetic organisms in aquatic environments, both freshwater and seawater (Encyclopedia of Earth, 2008).

Salinity Amount of salts dissolved in water, usually expressed in parts per thousand (ppt). Within an estuary, salinity levels are referred to as oligohaline (0.5-5.0 ppt), mesohaline (5.0-18.0 ppt), or polyhaline (18.0-30.0 ppt) (U.S. EPA, 2006b).

Sentinel a measurable variable that is susceptible to some key aspect of climate change and which is being monitored for the appearance of climate change.

Stress From an ecological perspective, a stress is a change that causes a response in a system or population of interest. (taken directly from: http://www.ozcoasts.org.au/glossary/def_s-t.jsp; Oz Coasts 2011).

Stressors Major physical, chemical and/or biological components of the environment that, when changed by human or other activities, can cause adverse effects on ecosystems and natural resources (Oz Coasts 2011; U.S. EPA 2011).

Submerged Aquatic Vegetation (SAV) Vascular, rooted aquatic plants, living at or near the water's surface.

Turbidity Measure of water clarity (degree to which light is blocked due particulate matter suspended in the water column; U.S. EPA, 2002a).

Watershed All land and water areas (such as streams and rivers) that drain toward a given water body, such as an estuary, wetland, or ocean. Also sometimes called a drainage basin, they are separated from others by a drainage divide (U.S. EPA, 2002a).

List of Abbreviations

ANS	Aquatic Nuisance Species
CCE	Cornell Cooperative Extension [Suffolk County, NY]
CCMP	Comprehensive Conservation and Management Plan
Chl a	Chlorophyll *a*
CO_2	Carbon Dioxide
CPUE	Catch Per Unit Effort
CRE	Climate Ready Estuaries [USEPA]
CRESLI	Coastal Research and Education Society of Long Island
CSHH	Coalition to Save Hempstead Harbor
CSO(s)	Combined Sewer Overflow(s)
CT	Connecticut

CTDEP	Connecticut Department of Environmental Protection
CT DA	Connecticut Department of Agriculture
CT DA/BA	Connecticut Department of Agriculture Bureau of Aquaculture
CTDPH	Connecticut Department of Public Health
CTSG	Connecticut Sea Grant
CVI	Coastal Vulnerability Index [USGS]
DO	Dissolved Oxygen (expressed in milligrams per liter [mg/l])
EPA	United States Environmental Protection Agency
FFY	Federal Fiscal Year
FOB	Friends of the Bay [Oyster Bay]
FY	Fiscal Year
GPS	Global Positioning System
HAB	Harmful Algal Bloom
HPLC	High-performance liquid chromatography
ICF	ICF International, Inc.
IEC	Interstate Environmental Commission
IPCC	Intergovernmental Panel on Climate Change
LI	Long Island
LIS	Long Island Sound
LISFF	Long Island Sound Futures Fund
LISO	Long Island Sound Office [USEPA]
LISRC	Long Island Sound Resource Center
LISS	Long Island Sound Study
LISRA	Long Island Sound Restoration Act
MADL	Marine Animal Disease Laboratory [Stony Brook University]
MC	Management Committee
NEIWPCC	New England Interstate Water Pollution Control Commission
NEMO	Non-point source Education for Municipal Officials
NECIA	Northeast Climate Impacts Assessment
NEP	National Estuary Program [USEPA]
NFWF	National Fish and Wildlife Foundation
NGO	Non-Governmental Organization
NMFS	National Marine Fisheries Service [NOAA]
NOAA	National Oceanic and Atmospheric Administration

NPS	Nonpoint Source [pollution]
NRCS	Natural Resources Conservation Service
NY	New York (referring to the state)
NYC	New York City
NYCDEP	New York City Department of Environmental Protection
NYDOT	New York Department of Transportation
NYS	New York State
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
NYSDOS	New York State Department of State
QAPP	Quality Assurance Project Plan
RFP(s)	Request for Proposal(s)
SAV	Submerged Aquatic Vegetation
SBU	Stony Brook University [SUNY]
SETs	Surface Elevation Tables
SLR	Sea level rise
SMCCP	Sentinel Monitoring for Climate Change in Long Island Sound Program
SoMAS	School of Marine and Atmospheric Sciences [Stony Brook University]
spp.	species
STAC	Science and Technical Advisory Committee
SUNY	State University of New York
TNC	The Nature Conservancy
UConn	University of Connecticut
UCS	Union of Concerned Scientists
USCG	United States Coast Guard
USDA	United States Department of Agriculture
USDOI	United States Department of the Interior
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

B. Scope of Regional Climate Related Changes in the Long Island Sound Area

This section qualitatively characterizes the type, relative magnitude, and degree of uncertainty of key predicted changes in climate to LIS and its estuarine and coastal ecosystems and summarizes how those changes may interact with non-climate stressors. Many of the projected impacts described here apply to similar estuarine habitats along the Northeast (NECIA, 2006). Wherever possible, this section focuses on local impacts, however, as described in both published and unpublished documents and online sources concerning the Long Island Sound watershed (Figure 1). A number of significant climate changes have been observed within the Long Island Sound watershed over recent decades, and are projected to continue for the foreseeable future. While climate change is global in scale, as detailed in the Intergovernmental Panel on Climate Change (IPCC) 2007 Synthesis Report (the Fourth Assessment Report, known as AR4; IPCC, 2007), the magnitude and type of expected changes vary regionally (GCRP, 2009; NECIA, 2006). Sea-level rise, for example, could be more rapid and pronounced along regional coastlines in the Northeast (defined here and after as the states of New Jersey and Pennsylvania, northward; Yin et al., 2009; GCRP, 2009).

The following sections summarize information on:

- Uncertainties associated with climate change predictions;
- Projected local and regional changes in climate, including projected changes in air temperatures; the amount and timing of precipitation and storm climatology; the rate and amount of sea-level rise; and changes in ocean conditions;
- Implications for existing stressors; and
- Risks to the Sound's ecosystems.

i. Assessing Magnitudes of Change and Degress of Uncertainty

The climate of the Earth is extremely sensitive. Small changes in various physical processes that control climate may lead to large scale results. Some feedback loops are poorly understood, such as how climate change affects clouds and cloud cover, and many are difficult to model. So the climate's propensity to amplify any small change makes predicting how much and how fast the climate will change inherently difficult. In addition, scientists have identified climatic tipping points - the point in which the global climate changes irreversibly from one state to a new state. Examples of tipping points include boreal forest dieback, loss of Arctic and Antarctic sea ice and melting of Greenland and Antarctic ice sheets, and disruption of the Indian and West African monsoons (Lenton et al. 2008). Therefore, there will always be some level of uncertainty with regard to the magnitude of predicted changes in climate as uncertainty is a fundamental characteristic of weather, seasonal climate, and hydrological prediction.

Uncertainty is an overarching term that refers to the condition whereby the state of a system cannot be known unambiguously. The degree of uncertainty varies for different climatic variables (e.g., temperature, precipitation, sea level rise) and the degree of change will vary with geographic location. For example, while IPCC AR4 (2007) expresses a high level of confidence in observed and predicted changes in global average temperature (for all emissions scenarios), sea level rise projections are more uncertain. While scientific observations indicate that global sea level rise is occurring and will continue to occur, the magnitude of future sea level rise will depend heavily on rates of Greenland and Antarctica ice sheet melt, changes in ocean circulation due to additional freshwater inflow (from melting ice), and naturally-cyclic hemispheric climate patterns. According to IPCC AR4 (2007), "[b]ecause understanding of some important effects driving sea level rise is too limited, [the AR4] report does not assess the likelihood, nor provide a best estimate or an upper bound for sea level rise." There is also a great deal of uncertainty regarding "the extent to which society resolves to reduce further emissions of heat trapping gases" (NECIA, 2006). It *is* certain that CO_2 emissions will continue to rise for at least the next several decades regardless of future actions to reduce emissions (IPCC, 2007; Copenhagen Synthesis Report, 2009). Uncertainty is not formally addressed in this plan, as most of the cited papers do not discuss uncertainty in a manner that could be consistently presented across the study topics.

ii. Projected Changes in Climate Patterns of Connecticut and New York

1. Changes in Air Temperature

Globally, air temperature has increased an average of 1.5°F since 1970. In the Northeastern U.S., the average annual temperature has increased considerably more, by as much as 4°F in winter averaged over the period 1970 to 2000 (NECIA 2006). The average increase in annual temperature per decade has been 0.14°F over the full period of record; however the rate of temperature increase has been accelerating, averaging 0.5°F per decade between 1970 and 2002. Under a high-emissions scenario (continued heavy reliance on fossil fuels), average temperatures in the Northeast by 2100 could increase 8-12°F above historical levels in winter and 6-14°F in summer. Under a low-emissions scenario (a shift away from fossil fuels) increases would be about half as much (NECIA, 2006).

The frequency of summer days with a high heat index (temperature, with wind and humidity as factors) is also projected to increase. There will be more days with high temperatures reaching 90+°F in many Northeastern cities. Projections indicate that Hartford could see more than 30 days reaching 100+°F (NECIA, 2006). According to the Northeast Climate Impact Assessment (NECIA), "the typical northeastern summer day is projected to feel 12 to 16°F warmer than it did on average between [the reference period] 1961 and 1990" (NECIA, 2006). NECIA's analysis indicates that by the end of the century under a high emissions scenario, summers in the NYC Tri-State Region are likely to feel similar to South Carolina summers of today (NECIA, 2006).

2. Changes in Precipitation and Storm Climatology

a. Changes in Seasonal Precipitation

Over the last several decades, the Northeast has experienced measurable changes to precipitation patterns; changes in these patterns are expected to continue and are likely to accelerate during this century. The primary observed change in precipitation over the region is a marked increase in annual precipitation of 5 to 10 percent since the turn of the twentieth century. By 2100, the region could see an additional four inches of precipitation annually, compared to the 1961-1990 reference period (NECIA, 2006). The greatest increases are expected with winter precipitation, with projected changes of 11 to 16 percent by 2050 and 20 to 30 percent by 2100. Additionally, as air temperatures rise, the Northeast can expect a continuation of recent trends in the type of precipitation experienced during winter (i.e. less snow and more rain; NECIA, 2006).

b. Changes in the Climatology of Heavy Precipitation Events

In addition to changes in seasonal and annual average precipitation, heavy precipitation events are expected to continue late-twentieth century trends, increasing in both frequency and intensity. By 2050, the amount of precipitation for a "rainy day" event is expected to increase eight to nine percent, with an increase of 10 to 15 percent by 2100. The frequency of such events is also likely to increase by as much as 13 percent by the end of the century. Kirshen et al. (2008) suggest that the 100-year Northeastern coastal storm event (by the 2005 definition) will increase in frequency to every 70 years by 2050 and to every 50 years by 2100. Heavy winter storms are also projected to reach the Northeast (becoming "Nor'easters") with increasing frequency (NECIA, 2006). A recent study (Spierre and Wake 2010) looked at trends in extreme precipitation events for the northeastern US from 1948 to 2007. Analysis of data found an increase in extreme precipitation events and in annual precipitation with both occurring mainly during the spring and fall.

iii. Projected Changes in Long Island Sound and the Larger Northeastern Region of the United States

1. Sea Level Rise

Among the impacts of climate change are those projected to affect the world's oceans. Global sea level has been increasing due to thermal expansion of surface waters and increasing freshwater flow from melting glaciers and ice sheets at high latitudes. In the last century, the planet has witnessed a sea level rise of eight inches, compared to almost no rise for the previous 2,000 years (GCRP, 2009). The amount of sea level rise varies depending on local conditions, such as subsidence and uplift. Following retreat of the glaciers, coastal areas began to rebound from the removal of the tremendous weight of the ice. However, the earth's crust warped due to the weight and present-day Connecticut was slightly uplifted. Following glacial retreat, Connecticut is subsiding at a rate of approximately 0.03 - 0.035 inches/year (0.76 - 0.89 mm/yr; Gornitz et al. 2004). An assessment of NOAA tidal gauge data (measuring relative sea level change) for New London, CT, for 1938-2005, indicates that the average rate of sea level rise over that period was 0.08 inches/year (2.13 mm/yr; Kirshen et al., 2008). In Bridgeport, CT (1964 - 1999) and Montauk, NY (1947 - 1999) the relative sea level rise was 0.10 inches/year (2.54 mm/yr; Gornitz 2004).

The Intergovernmental Panel on Climate Change (IPCC) projects a global average sea level rise of up to two feet by 2100, even without accounting for the current break-up of Greenland ice sheets (IPCC, 2007). Another recent study, also not accounting for recent ice sheet break-ups, indicates that global sea level could rise 2.0 to 4.5 feet by 2100, compared to the 2005 global average sea level (Frumhoff et al., 2007). A 2009 study projects that, when ice sheet melting and the associated changes in ocean currents are considered, coastlines of the Northeast could see an even greater rise in sea level compared to the global estimate. Boston and New York City, for example, could see a rise of 3.9 feet by the end of the century (Yin et al., 2009).

It should be noted that strong storm events exacerbate the threat of sea level rise. Kirshen et al.'s (2008) analysis indicates that in 100 years, during 100-year storm events, the maximum sea level at New London, CT could be about 10.2 feet (3.1 m) above base sea level. For comparison, the current maximum sea level height expected at New London during 100-year storm events is about 7.2 feet (2.2 m) above average sea level (Kirshen et al., 2008).

Several tools on projected sea level rise and storm surge impacts within the Long Island Sound watershed are available. The Connecticut Department of Environmental Protection has a draft Connecticut coastal hazards website with a visualization tool that includes sea level rise: http://coastalhazards.uconn.edu/. Another tool focused on sea level rise impacts to salt marshes along the Connecticut coast was developed by Mark Hoover, http://clear.uconn.edu/publications/research/tech_papers/Hoover_et_al_ASPRS2010.pdf. The Nature Conservancy and numerous partners have also developed a coastal resilience tool for Long Island, http://coastalresilience.org/. All tools have a goal of assisting with coastal planning and resource management.

2. Water Chemistry

a. Temperature

While confounded by many factors such as depth and relatively rapid seasonal changes in water temperature, different currents, and limited data availability, there is general agreement that Long Island Sound (LIS) waters are increasing in temperature by approximately one degree Celsius (1.8 degrees Fahrenheit) every 100 years (O'Donnell 2010). This trend is resulting in profound impacts on biological communities such as fish and shellfish.

b. Acidity (pH)

Although the impact of increased atmospheric carbon dioxide (CO_2) is most often linked to the warming of the atmosphere, it is also responsible for acidification of ocean waters. Ocean acidification occurs when CO_2 dissolves in seawater, initiating a series of chemical reactions that increases the concentration of hydrogen ions and makes seawater more acidic, measured as a decline in pH. An important consequence of this change in ocean chemistry is that the excess hydrogen ions bind with carbonate ions, making the carbonate ions unavailable to marine organisms for forming the calcium carbonate minerals (mostly aragonite or calcite) that make up their shells, skeletons, and other hard parts (Doney et al., 2009; Pew Center, 2009).

Under preindustrial conditions, the atmospheric concentration of CO_2 did not change over many millennia (Caldeira and Wickett 2003). However, as emissions have increased, there has been an accumulation of CO_2 in the atmosphere and a net flux of CO_2 from the atmosphere to the oceans. As a result, the pH of today's ocean has declined in relation to the pre-industrial period by 0.1 pH unit (on a log scale), representing a 30-percent increase in ocean acidity (Caldeira and Wickett 2003). The pH and carbonate ion concentrations of the world's oceans are now lower than at any time in at least the past 420,000 years (Hoegh-Guldberg et al. 2007). By 2100, depending on the emissions scenario modeled, the average ocean pH could decline by 0.3 to 0.5 pH units in relation to pre-industrial levels (Caldeira and Wickett 2005).

3. Projected Changes in Sea Floor Geochemistry

Directly tied to changes in LIS water chemistry are projected changes in sea floor geochemistry. Changes in water temperature and dissolved oxygen levels may lead to a reduction of oxygen in surface sediment as well as cause leaching of contaminants out of the surface sediments. Such changes have the potential to impact numerous organisms. Data compilation, analysis and further data collection including food web impacts are a need for this subject area.

4. Projected Changes in Selected Ecosystems of Long Island Sound Biological Communities and Processes of Long Island Sound

a. Coastal Barriers, Beaches, and Dunes

Headland erosion is the main process of beach development along the north shore of Long Island, creating narrow strips of beach below bluffs and steep cliffs. The Connecticut shoreline overlays bedrock, making erosion much less likely (LISS 2003). Where beaches occur, beach retreat in response to sea level rise depends on the average slope of the beach profile. It is estimated that in the region from Maine to Maryland, a one-meter rise in sea level would result in beach retreat of 50-100 m (Gornitz 2001). Sandy beaches not only serve as popular recreational areas, they also provide protection of nearby property against erosion from wind and coastal storm surges.

Beaches also provide habitat for a wide variety of species. The invertebrate infauna of the foreshore, between the highest and lowest tide zones, provides forage for migrating shorebirds. The maritime beach community between mean high tide and the primary dunes provides nesting sites for horseshoe crabs and several rare bird species, including piping plover, American oystercatcher, black skimmer, least tern, common tern, and roseate tern. This area also provides habitat for horseshoe crabs and the northeastern beach tiger beetle (thought to be extirpated in NY, but occurs in CT), which is federally listed as threatened. Dunes and the upper back barrier beach provide nesting habitat for diamondback terrapins (Strange 2008 and references therein).

b. Tidal Wetlands

The extraordinarily high primary production of tidal wetlands supports an extensive estuarine food web. Wetlands also filter sediments and contaminants; protect against erosion and flooding; and provide habitat for both aquatic and terrestrial wildlife (Teal 1986; Mitsch and Gosselink 2003).

Tidal wetlands are an important coastal habitat in Connecticut, but are a relatively uncommon along the north shore of Long Island because of the area's steep uplands and sea cliffs. Most salt marshes are found in embayments, such as Mount Sinai and the three large bays of western Long Island Sound (Little Neck Bay, Manhasset Bay, and Hempstead Harbor; NYDEC, 2004), as well as along numerous coves and embayments along the Connecticut coast.

Tidal wetlands can respond to sea-level rise in a number of ways depending on local elevation, geomorphology, and land use. As seas rise, tidal wetlands can migrate inland if not impeded by geological features or human-made barriers, such as seawalls and roads, and if the rate of migration exceeds the rate of erosion at the seaward edge. Wetlands that are unable to accrete sufficient sediment to keep pace with sea level rise will become increasingly flooded and will eventually convert to open water or tidal flat. High marsh may convert to low marsh and, in situations where the coastal plain is not obstructed, upland habitat may convert to salt marsh. There may also be changes in the relative abundance of marsh vegetation, with increases in the invasive *Phragmites australis*, which tolerates lower salinity. Over the past few decades, local scientists have noted marsh submergence in some areas, and emergent marsh (particularly low marsh) is converting to tidal flats along many of the tidal rivers draining to the Sound (Ron Rozsa, unpublished observations). A sea-level rise of up to 4 feet, projected for the Northeast by Yin et al. (2009) during the 21st century, would make it less likely marshes will be able to fully compensate for the rise in sea level.

Salt marsh islands provide nesting sites for a number of bird species, particularly colonial nesting waterbirds. Gull-billed terns, common terns, American oystercatchers, and black skimmer commonly nest on marsh islands. Saltmarsh sparrows and seaside sparrows, both of which are very high conservation priorities in southern New England, nest in Connecticut salt marshes. Studies show that the submergence and erosion of marsh islands as a result of sea level rise are already affecting bird species that depend on these areas for protection from predators (Erwin et al., 2006).

c. Tidal Flats

Sediments eroded from bluffs along the north shore of Long Island are carried by longshore drift, primarily east to west, and later deposited to form tidal flats and shoals. Tidal flats provide invertebrate forage for waterbirds and habitat for shellfish such as clams. One of the largest areas of tidal flat in the Sound occurs near Conscience Bay, Little Bay, and Setauket Harbor, where there are large beds of hard clams, soft clams, American oysters, and ribbed mussels (NYSDCR, 2004).

The largest threat to the tidal flats of Long Island Sound is sea level rise. Initially, rising seas may convert low marsh to tidal flat, but eventually tidal flats will become entirely submerged, making the invertebrate infauna of the flats inaccessible to foraging waterfowl and shorebirds. Accessibility of invertebrate forage is directly tied to the ability of shorebirds to thrive (Nicholls et al., 2007).

d. Subtidal Zone

Subtidal habitats include nearshore benthic habitats of unconsolidated sediments (ranging in size from clays to gravel) and areas of submerged aquatic vegetation, mostly eelgrass. Eelgrass provides food, shelter, and nursery habitats for many economically-valuable species, including shellfish such as lobsters, scallops, clams, and mussels, and finfish such as Atlantic cod, Atlantic herring, and several varieties of flounder. Some bird species feed on eelgrass. Eelgrass was once common throughout the shallow coastal waters of Long Island Sound. Many of the eelgrass beds were lost due to a large scale die off in the 1930's, but reestablished in eastern LIS by the 1950's. Today eelgrass populations are impacted by pollution, with nitrogen loading thought to be particularly problematic.

Light is the primary factor affecting eelgrass distribution and abundance. As sea levels rise, these remaining seagrass beds may fail to thrive because of reduced light penetration. Short and Neckles (1999) predicted that a 50 cm (19.7 in) increase in water depth as a result of sea level rise, which could occur by 2100, would reduce the light available for seagrass photosynthesis by 50 percent, resulting in a 30-40 percent decline in seagrass growth worldwide. The movement of eelgrass beds shoreward as sea levels rise could be impeded in areas with steep shores or where there is erosion and water turbidity in front of shoreline protection structures such as seawalls and bulkheads. Rising water temperatures also pose a problem for eelgrass, which becomes stressed if water temperatures exceed 86° Fahrenheit for extended periods (Orth and Moore,1986; Moore and Jarvis 2008).

Benthic animals such as molluscs (e.g., clams) and crustaceans (e.g., lobsters) may also fail to thrive as waters warm. However, soft clams (*Mya arenaria*), which require temperatures near 32° C (Kennedy and Mihursky, 1971 cited in Pyke et al., 2008), may increase in relative abundance as waters warm. There is also evidence that warmer waters may enhance production of blue crab in Long Island Sound (Fogarty et al., 2007).

e. Open Waters

The plankton and finfish of the Sound's open waters are vulnerable to a number of changes in physio-chemical conditions that are expected to result from climate change. Open water species may experience adverse effects with increases in water temperatures, lower dissolved oxygen as waters warm, and increased nutrient loadings from increased runoff and freshwater inflow resulting from an increase in the frequency or intensity of heavy precipitation events. Plankton are an important food source for finfish. Larval fishes feed on zooplankton and their growth and survival can be reduced if the peak in zooplankton abundance does not coincide with the presence of fish larvae. Excessive phytoplankton blooms or changes in the timing of blooms, initiated by the timing of the spring freshet, can result in adverse effects on finfish and other open water species. If phytoplankton blooms do not occur when fish move inshore to spawn, larvae may lack sufficient zooplankton resources since zooplankton depend on the spring phytoplankton bloom. At the same time, excessive blooms, promoted by higher nutrient levels resulting from increased runoff, can deplete dissolved oxygen, harming both zooplankton and fishery species.

Ocean warming is already having a discernable effect on the a number of species in the region. Scientists have observed a shift from coldwater finfish species such as winter flounder to species found in warmer waters to the south (Wood et al., 2009). In Narragansett Bay, warmer waters have led to an overlap in the presence of early life stages of winter flounder and comb jellies (*Mnemiopsis leidyi*), which feed on winter flounder eggs and larvae, contributing to reductions in winter flounder populations (Sullivan et al., 2001).

f. Freshwater Tributaries

The Sound's tributaries provide a number of ecological values that support resident and migrant species of the Sound. Important freshwater wetlands are found along the lower Connecticut River. The river was designated a Wetland of International Importance under the Ramsar Convention because it supports the best examples of fresh and brackish marshes and submerged aquatic vegetation (SAV) beds in the Northeastern U.S. Depending on the amount and timing of precipitation and freshwater flow in spring, these areas provide freshwater impoundments that are important for migrating birds (LISS, 2003). Freshwater wetlands may support greater bird diversity than any other wetland type (Mitsch and Gosselink, 2003). Freshwater inflow from the Sound's tributaries, including the Connecticut, Housatonic, Thames, and Quinnipiac Rivers, helps determine surface water conditions in the estuary. Heavy precipitation events, expected to increase in severity and frequency over the coming decades, may periodically reduce the salinity of the waters of the Sound and increase nitrogen and sediment loadings. Low salinity can lead to localized die-offs of shellfish and finfish and, if prolonged, reduce the spatial extent of benthic habitats such as SAV seagrass beds. The Connecticut River watershed drains 11,000 square miles from the Canadian border south to Long Island Sound. While scientists have documented an increase in extreme precipitation events and in annual precipitation in the northeastern United States, these increases are occurring mainly in the spring and fall (Spierre and Wake, 2010). If less precipitation falls as snow within the watershed, then the annual spring freshet of the Connecticut River may be reduced. Predicted decreases in the volume of the spring freshet will inhibit ponding and the formation of natural freshwater impoundments, which are important for migrating waterfowl during the early spring. As sea-level rise raises salinity in tributaries, freshwater wetlands will convert to brackish marshes. Eventually only vegetation favored by high salinity will remain. Increases in storm intensity may accentuate marsh fragmentation. Increased runoff carries heavier loads of nutrients (such as nitrogen), pathogens, and harmful chemicals. Additional runoff could not only overwhelm the ability of tributary wetlands to filter these elements before entering LIS, but could also directly damage the health of animal and plant species in these habitats (Nicholls et al., 2007).

g. Fisheries of Long Island Sound and Associated River Systems

Temperature is only one of a complex group of variables that individually or collectively drives ecological changes in LIS. Subsequently, it is difficult to definitively attribute or project changes in crustaceans, mollusks, and finfish populations without considering other environmental influences. The net effect of increased temperature on fish (crustaceans, bivalves, finfish) populations may be negative or positive. It is foreseeable that synergies may exist between climate change and other major stressors. Generally, fish have the ability to actively migrate to avoid unfavorable conditions. However, if unfavorable conditions persist indefinitely, this creates an entirely new habitat that would have far-reaching ecological consequences. In the case of marine species that are being exploited in LIS, the climate-related impacts would be a result of temperature, low dissolved oxygen, and reduced pH (acidification). The severity of these impacts may be different at various life stages. Climate change places additional pressure on exploited marine fish stocks that are already subject to over exploitation and other stressors (Harley et. al, 2006).

h. Bivalves

Talmage and Gobler (2009) studied the effects of reduced pH (ocean acidification) on the larvae of three bivalves – hard clam, bay scallop and Eastern oyster (*Mercenaria mercenaria, Argopecten irradians,* and *Crassostrea virginica*) – and observed significantly stunted growth and lower rates of metamorphosis. The ability of calcifying organisms to synthesize calcium carbonate shells could become seriously diminished and organisms that adapt and survive may have fragile shells that offer less protection from predators and pathogens. This sensitivity of the calcium carbonate shell towards ocean acidification is believed to be exacerbated in the larval stage. These effects would not be confined to wild fisheries, shellfish growers could be dealing with new challenges in the grow-out phase of production. Combined with the prognosis by Joos et al. (1999) that the 'thinning effect' will be more significant in states of higher altitudes and colder waters, these fisheries may become reduced or possibly even extinct in LIS. Furthermore, these projections could influence the success (or failure) of planned shellfish restoration efforts in LIS. If seeds do not have good survival rates, then it will be extremely difficult to rebuild the wild population.

i. American Lobster

The greatest concern for American lobster (*Homarus americanus*) populations may be the result of temperature regime shifts. American lobsters inhabit most of the eastern coast of North America from northern Labrador to North Carolina (Herrick, 1911). Presently, LIS represents the southern end of the inshore range (Stewart, 1972; Lawton and Lavalli, 1995). Tin (2005) suggests an average of four degree increase in global climate would move American lobster populations from the southern range to waters at higher latitudes. So called 'climate change-induced range shifts' have been studied by other scientists (Chueng et al., 2009). American lobsters can acclimate and survive temperatures ranging from -1 ºC to 30.5 ºC (Lawton and Lavalli, 1995), with demonstrated thermal preference of about 16 ºC. Under unfavorable conditions, these animals actively migrate because they cannot control their own body temperature. Seasonal migration is important and the occurrence of a long term warming regime would result in a net loss of favorable habitat. Moreover, if American lobsters survive in unfavorable habitats, these populations may have seriously compromised neurological and metabolic functions (Worden et al., 2006). A noticeable absence of American lobsters from named habitats will have far-reaching impacts on the ecosystem, as well.

j. Marine Finfish

Finfish can actively avoid unfavorable conditions and several studies predict climate is most likely to force species ranges towards higher latitudes (Perry et al., 2005). For marine fishes, distribution and abundance are being driven by temperature impacts on growth, spawning, and changes in food source. Perry et al. (2005) further concludes that latitude shifts will be accompanied by shifts in depth, which could create new challenges in fisheries. Given the high mobility, marine fish will shift their ranges more quickly than sedentary organisms, unless they are being confined by habitat or dispersal capability. If the marine fish species has a slower life history and is commercially viable, these populations may be unable to sustain the fishing pressures while adapting to climate driven range shifts (Perry et al., 2005). It may become necessary to change fishing operations.

Temperature affects the biology (i.e., growth, timing of spawning, quality of eggs) of marine finfish. Previous studies suggest large females are more likely to spawn earlier, which could prompt revisions to conservation plans. While studying the thermal dynamics of ovarian maturation in Atlantic cod (*Gadus morhua*), Kjesbu et al. (2010) observed females being held above the ambient temperature displayed improved appetite and invested more energy in growth. Although a better nutrition level enhances the condition indices and increased egg production (fecundity), trade-offs in other health factors are to be expected, such as impinged liver, and noticeably poorer egg quality. Compromised health of individuals could have an overall adverse effect on population dynamics (e.g., inadequate recruitment levels to sustain exploitation).

k. Diadromous Fish

Diadromous fish have been reported as keystone species in ecosystems by serving unique roles (referenced in Lassalle and Rochard, 2009). Striped bass populations in LIS spend a part of their life in the Chesapeake Bay, and a major loss in habitat foreseen in this estuary (Chesapeake) would have a domino effect on LIS populations (Lassalle and Rochard, 2009). Limburg and Waldman (2009) in their review attributes the loss of the boreal rainbow smelt (*Osmerus mordax*) in the Hudson River to a continuum of climate-driven range shifts; it is possible this species may no longer exist in waters south of Maine in the future. The gizzard shad (*Dorosoma cepedianum*) was also reported to be presently embarking upon a northward migration after establishing large populations in the Hudson River through Maine. Climate has been known to accelerate the spawn timing by more than a day for several diadromous prey fish, which may have severe trophic interaction implications.

Jonsson, Jonsson, and Hansen (2005) discovered environmental conditions encountered early in the life cycle of Atlantic salmon do have an influence on their development. In fact, warm and mild winters promote growth in the first year, forcing young of the year to migrate from their river nurseries to the sea at a younger age. This type of biological consequence has been reported in other species, including sockeye salmon (*Oncorhynchus nerka*) that have been observed to arrive up to one month earlier before historical spawning, when river temperature was below 19°C (Hodgeson and Quinn, 2002 referenced in Jonsson, Jonsson, and Hansen, 2005). In general, climate plays a significant role in diadromous fish early development because egg incubation is improved in warmer temperature causing larvae to emerge earlier.

For citations listed above, see the References section.

C. Technical Workgroup Participants (NY and CT)

New York
Leader: Sarah Deonarine

NYSDEC
Karen Chytalo
Heather Young
Charlie deQuillfeldt
Kim McKown
Sarah Deonarine, lead

Stony Brook University, SoMAS
Dr. Larry Swanson
Dr. Anne McElroy
Dr. Kirk Cochran
Dr. Bob Cerrato
Dr. Bob Wilson
Dr. Christopher Gobler
William Wise
Santiago Salinas, STAC fellow

NY Sea Grant
Antoinette Clemetson

NY USGS Water
Chris Schubert
Richard Cartwright

IEC
Pete Sattler

NYS Department of State
Barry Pendergrass
Terra Sturn

Suffolk County Department of Environment and Energy, Division of Water Quality Improvement
Camilo Salazar

Nassau County Office of the County Executive
Erin Reilley (representing Bradford Tito)

Westchester County Department of Planning/ Soil and Water Conservation District
Robert Doscher

Westchester County Parks Conservation Division
Jeff Main

NY TNC
Dr. Nicole Maher
Jon Kachmar, CT

Edith G. Read Natural Park and Wildlife Sanctuary
Jason Klein

Coalition to Save Hempstead Harbor
Carol DiPaolo

Cornell Cooperative Extension
Dr. Matthew Sclafani

Long Island Sound Office
Louise Harrison, USFWS Liaison
Dr. Julie Rose, NOAA Liaison
Mark Tedesco, Director

Queens College
Dr. Yan Zheng
Dr. Gillian Stewart

Long Island University, C.W. Post
Dr. Stephen Tettelbach

NYC Department of Environmental Protection
Beau Ranheim

Connecticut
Co-leaders: Jennifer Pagach and Dr. Juliana Barrett
(list includes only those who provided responses)

CT DEP
Mark Parker
Kevin O'Brien
Harry Yamalis
Rick Huntley
Brian Thompson
Mark Johnson
Penny Howell
Paul Capotosto
Roger Wolfe
Steve Gephard
Matthew Lyman
Christine Olson
Ron Rozsa (retired)
David Carey
Jennifer Pagach, co-lead

University of Connecticut
Charlie Yarish
James O'Donnell
Robert Whitlach
Ivar Babb
Peter Auster
Sylvain DeGuise
Jamie Vaudrey
Chris Elphick

CT Sea Grant
Tessa Getchis
Sylvain DeGuise
Nancy Balcom
Juliana Barrett, co-lead

Connecticut College
Scott Warren

Audubon Connecticut
Patrick Comins

University of New Haven
Roman Zajac

US Fish and Wildlife Service
Sharon Marino
Andrew MacLachlan

USGS
Jon Mullaney

D. Bi-State Technical Work Group

Dr. Juliana Barrett, CT State Co-Lead, University of Connecticut/Connecticut Sea Grant
Dr. Julie Rose, NOAA Fisheries, Milford Laboratory
Sarah Deonarine, NY State Lead, NYS Department of Environmental Conservation and the Long Island Sound Study
Antoinette Clemetson, NY Sea Grant
Jennifer Pagach, CT State Co-Lead, CT Department of Environmental Protection
Mark Parker, CT Department of Environmental Protection and the Long Island Sound Study
Mark Tedesco, US EPA Long Island Sound Study

E. Connecticut Technical Work Group Discussions

This appendix is presented here to document work and discussions of the CT technical work group, however, it is important to note that not all work group suggestions represented here were incorporated into the bi-state plan. The Connecticut Technical Work Group developed a sentinel definition and list of desired attributes that was modified during discussions with the New York Technical Work Group (see section II of the main body of this document above). The original definition and attributes are as follows:

Definition of sentinel being a measurable variable that is susceptible to some key aspect of climate change and which is being monitored for the appearance of climate change. A sentinel was further defined as having the following attributes:

1) sensitive to climate change
2) natural variations over time do not cause a signal similar to climate change
3) existing stressors are not causing changes (or need to be able to separate changes due to existing stressors and climate change)
4) spatial distribution: can be measured at multiple sites or one fixed site
5) needs to be feasible to measure (cheaper the better) OR technology can be readily developed to measure
6) for habitats: representativeness of a community
7) sentinels that are comparable to other areas better
8) for species: species at edge of range or habitat limited
9) needs to help make management decisions

The following questions were developed:

1. What are the current major stressors to LIS?
   The list of current stressors that were identified includes: Land Use and Land Use Change (including coastal flooding and erosion), Altered freshwater inflow, Harmful algal blooms, Excess nutrients, Hypoxia, Pathogens, Overfishing, Altered trophic and interaction webs, Invasive species, Toxic substances (e.g., heavy metals), Other existing forms of disturbance (e.g., ice, storm events, fishing gear).
2. What changes have been observed in the physical and chemical environment that might influence the ecosystems of LIS and are linked to climate change?
   Changes in: air temperature, wind speed and direction, seasonal precipitation, climatology of heavy precipitation events, sea level rise, chemistry of the water column and sediment (e.g., ocean acidification)
3. What are the characteristics of LIS biota that determine their resilience or susceptibility to these changes in climate?
4. What future changes to biodiversity, including species composition and ecological processes, might be expected in LIS ecosystems if the environment continues to change?

a. Do populations of intertidal species change over time?
b. Are there shifts in trophic interactions?
c. Are there changes in community structure and patterns of diversity?
d. How could rates of changes in biodiversity that result from climate change be measured in the short term and monitored over longer terms?

5. What research is necessary to reduce uncertainty in LIS projections of future climate change and its impacts?

F. New York Technical Work Group Discussions

This appendix is presented here to document work and discussions of the NY technical work group, however, it is important to note that not all work group suggestions represented here were incorporated into the bi-state plan.

The NY work group agreed that a strategy document ultimately had to address the following:

1. A statement regarding anthropogenic and climate change influences, their interplay, and the difficulty of teasing them apart
2. A definition of the overall goals of this monitoring program
3. A list of the categories and parameters that were developed and tweaked by all work groups during the course of this project and the changes in the environment necessary to identify under each category

As mentioned previously, the NY work group spent considerable time developing and editing a matrix of indicators. It was thought that such a matrix would be important for helping to identify the cross-cutting parameters. In the development of this matrix, the NY work group recognized the strong linkage between the physical parameters and climate change, less so for chemical parameters, and even less so for the biological parameters.

The NY group slowly developed a ranking system in an effort to choose indicators for a pilot program. It was necessary to first define the different monitoring "feasibilities." "Very feasible" was defined as a parameter that was economic to measure at a temporal extent appropriate for that parameter. This was also applied to parameters that are already being monitored. Lower feasibility rankings were assigned based on cost of assessment and labor intensity associated with making the assessment (e.g., rates). However, all the parameters are extremely important in assessing climate change impacts regardless of feasibility.

The NY work group defined three "categories" and then three "tiers" within those categories based on such criteria as feasibility, monitoring time scales, and whether an indicator was already being monitored. It was originally envisioned that a pilot study would be taken from a subset of the indicators in the first and second tier. The NY work group outlined criteria that make a sentinel high priority as follows:

- If it is not being adequately monitored; however this must be tempered such that indicators currently being monitored are not neglected and are synthesized in the context of climate change
- If it cuts across multiple sentinels and answers multiple questions
- Sentinels for which climate impacts are more readily determined may be ideal for a pilot monitoring program, especially since this could lead to more funding.

The categories were defined as A) Very important, but not being collected sufficiently; B) Very important, data already being collected sufficiently over time and space (i.e., various sites covering LIS are being sampled on sufficient time scales); and, C) Not appropriate for this program. Within those categories, the tiers were defined as follows:

Tier 3 – important parameter to be addressed, but not suited for this monitoring program, recommend for future funding

Criteria: (a) climate change would have a small impact on the parameter/indicator as compared to other factors acting on that parameter; or
(b) More hypothesis-driven research as compared to monitoring that will yield changing results over time (e.g., temperature tolerance of phenotypes); and/or
(c) Monitoring likely to continue in the long term (but we should recommend project(s) continue to receive funding).

Tier 2 – second-rung suggested monitoring

Criteria: (d) Data can be extrapolated from other sources; and/or
(e) Longer time scale to see change, but still a priority

Tier 1 – first-rung suggested monitoring

Criteria: (f) most sensitive to climate change and may also be likely to yield relatable results, particularly over the short time scale of a pilot study.

(See Appendix G for application of the above)

Eventually, the bi-state work group went with a different, but similar ranking approach. Both state work groups ranked the sentinels through an online survey described in the main body of this strategy.

The New York work group was occasionally lacking in specific technical expertise during discussions of individual sentinels. During these times, experts in the field were invited to individual meetings to fill the knowledge gap. For example, when discussing potential climate change impacts on disease prevalence in striped bass and shellfish, the NY work group leader contacted Bassem Allam and Mark Fast from the School of Marine and Atmospheric Sciences, Stony Brook University, who reported that disease prevalence in their studied species is affected by temperature and climate changes. This approach was used for other sentinels as well.

Notes on specific indicators: The NY work group spent considerable time discussing the identified indicators and the table in which they were organized. There are specific discussion notes on particular indicators, most notably:

- Most meteorological parameters are already being measured, however, it must be determined if those measurements work with this program (i.e., temporal and spatial scales). Many of the physical/chemical parameters can be measured together making the list slightly less extensive.

- Harmful algal blooms may have a connection to climate change, but they are not a great indicator because so many different factors affect blooms and they vary widely from year to year normally.
- Issues with salt wedge changes in rivers may not be important to NY, but it should still be considered since it is important in CT.
- Seasonal changes in the spring bloom may serve to track important aspects of the ecological community.

NY Technical Work Group discussion on the creation of a melded, bi-state matrix: At the meeting, Juliana Barrett explained that she took each NY "parameter" and placed it within the combined matrix where it fit best, which, for the most part, was in the second column of the matrix. The NY work group also discussed the columns overall. The work group expressed that 'Data availability' seemed very important because it indicates what data we have historically and aids in identifying data gaps.

A lot of detail from NY seemed lost in the creation of a single matrix. There was some support for writing up a "module" for each resource that would be very detailed in order to provide the information from NY that was not included in the table. However, the amount of staff time this would entail made this approach not feasible at the time of this strategy development. Concern was also expressed by work group members about the focus of the matrix on issues related to resource management.

During this discussion, NY identified several cross-cutting climate change factors that must be a part of any monitoring program which is now the preface to the matrix. This list became the set of core parameters, described in section V, and include: precipitation, temperature, stream flow (runoff and base flow), sea level, salinity, wind speed and direction, relative humidity, pH, and groundwater levels.

	Parameter	How is this expected to change?	Sources of Data/Monitoring Programs	What is the quality/value of the monitoring?	Is new monitoring needed?	Strategy Recommendations	Tier	Ranking reasons	Reasons it would not be suited for this program
	Table 1. Changes in Chemical/Physical Parameters								
	Meteorological								
Being Collected Sufficiently	Air temperature	increase	Bridgeport-Pt. Jeff Ferry since 2003, research quality, CCE, NOAA, CSHH (T, wind, & precip), CCE LIHREC (LT Temp) in Suffolk County. CCE & NOAA volunteers monitoring; FOB (T, wind)	All are being monitored in central basin as well as through other monitoring programs (perimeter of LIS).	If maintained, no, but may want mets station right at site.	Include data in monitoring synthesis, do different analyses than currently being done. Simple calculations of degree-days (heat units) would speak to climate trends from a historic view.	B-3	c	
	Wind speed/direction								
	Air pressure								
	Radiation	increase							
	Precipitation	increase							
	Specific humidity	Does water vapor change at increased temperatures?	NOAA??		Y		B-2	d	
	Watershed								
Being Collected Sufficiently	Run-off/river flow changes	Increased flow	USGS	USGS has a gauge at every major fw source along LIS (6 total in NY); measures daily mean flow. East River is largely unmonitored & unmodeled, yet is a large source of fw to LIS. Important for modeling.	N - except in E River		B-3	c	
	Water table	Unknown, but the amount, timing and duration of precipitation effects ground-water-level elevations.	USGS	Good, USGS monitoring at wells.	N		B-3	c	
	Earlier spring thaw/later fall frost; changes to river ice-out		Ag. Department, Farm Bureau.		Y/N	This can probably be derived from run-off & met data.	B-2	d	
Not Being Collected Sufficiently	Salinity of GW in shallow systems (Salt water intrusion, drift of inundated zone and reduction of vadose zone = climate change + SLR)	There won't be a huge change with gradual SLR.	Tom Kowalsick @ CCE Griffin Avenue; USGS not monitoring (except in Brooklyn and Queens because of water withdrawals in deeper aquifers)	It will be important for individual marshes; will vary from site to site.	N		A-3	a/d	This is very long term and the human-induced effects are much more important.
Not Appropriate	Salt wedge in rivers	SLR may move salt wedge inland; river flow may increase pushing wedge out.	none	Not a priority in NY. More important for CT, NY fw sources are dammed			C		not important to NY

	Parameter	How is this expected to change?	Sources of Data/Monitoring Programs	What is the quality/value of the monitoring?	Is new monitoring needed?	Strategy Recommendations	Tier	Ranking reasons	Reasons it would not be suited for this program
	Table 1. Changes in Chemical/Physical Parameters								
	Water column								
Being Collected Sufficiently	Sea level (water level & tidal variation)	increase	USGS	continuously monitoring at 4 north shore estuary sites; Montauk & Battery tide gauges	N		B1	f	
	Temperature	increase	USGS; ferry; CSHH (through water column), FOB	USGS continuously monitoring at 3 north shore estuary sites.	N		B-3	c	
	Salinity	depends on many factors	USGS; ferry; CSHH (water column); FOB	USGS continuously monitoring at 3 north shore estuary sites. Data also collected by the ferry.	N		B-3	c	
	Turbidity; light penetration; TSS		USGS, ferry, CSHH; FOB (secchi)	USGS measures turbidity via LED-backscatter method; continuously monitoring at 1 north shore estuary sites. CSHH uses EPA approved LaMott turbidity meter (NTUs), also secchi.	N		B-3	c	
	Stratification (also currents & circulation)	intensify??	CTDEP	Can be extrapolated from CTDEP water column profile of T & S.	N		B-2	d	
	Water column DO		CTDEP (2xmonthly), IEC (weekly), CSHH, LISICOS buoys, USGS Flax Pond; FOB	Continuous monitoring is a requirement if an accurate assessment of DO variability (for example, as it relates to hypoxia/anoxia and supersaturation) is desired.	N		B-1	needs to be continuously monitored	
	Nutrients (N, P)	Not necessarily specific to climate change.	CTDEP, CSHH (nitrate, nitrite, and ammonia)			Some nutrient electrodes can now be added to arrays, but there aren't many arrays in LIS.	B-3	a&c	
	Nutrients (C, Si)	Not necessarily specific to climate change.	CTDEP			Some nutrient electrodes can now be added to arrays, but there aren't many arrays in LIS.	B-3	d&e	
	Timing of marine ice occurrence		National Snow and Ice Data Center http://nsidc.org/index.html			Could be noted as part of another monitoring program.	B2		

	Parameter	How is this expected to change?	Sources of Data/Monitoring Programs	What is the quality/value of the monitoring?	Is new monitoring needed?	Strategy Recommendations	Tier	Ranking reasons	Reasons it would not be suited for this program
	Table 1. Changes in Chemical/Physical Parameters								
Not Being Collected Sufficiently	pH & CO2 system	Expect acidification with increased atmospheric CO2	USGS; ferry; CSHH (pH); FOB (pH)	USGS continuously monitors pH at 1 north shore estuary site.	N		A-1	f	
Not Being Collected Sufficiently	Seston/DOM			Not being categorized, but captured in turbidity measurements.			A-1		
Not Being Collected Sufficiently	Nitrogen cycling	Not necessarily specific to climate change.					A-2		
	Benthic								
Not Being Collected Sufficiently	Nutrient/metal fluxes across sed-water interface	Changes in production, water temperature and stratification will change patterns of bioturbation and fluxes across the sediment-water interface. In turn this will modify the contribution of bottom sediments to hypoxia in LIS.	1970's: Yale University; 1980's: EPA Long Island Sound Study		Y	Continuous monitoring is not needed, but sampling at reference stations should be conducted periodically for comparison with the 1970's and 1980's patterns.	A		
Not Being Collected Sufficiently	Bioturbation pattern and rates	Increase	Above plus 1993: PULSE project	"	Y		A		
Not Being Collected Sufficiently	Redox state/cycling	Increase	1970's: Yale University; 1980's: EPA Long Island Sound Study	"	Y		A		
Not Being Collected Sufficiently	Pore water DO, nutrients, HS, Fe, Mn	Uncertain	1970's: Yale University; 1980's: EPA Long Island Sound Study		Y		A		
Not Being Collected Sufficiently	Toxin/pollutant concentrations	Uncertain	USGS; Long Island Sound Study (EPA); no LT data sets		Y		A		

	Parameter	How is this expected to change?	Sources of Data/Monitoring Programs	What is the quality/value of the monitoring?	Is new monitoring needed?	Strategy Recommendations	Tier	Ranking reasons	Reasons it would not be suited for this program
	Table 2. Community Structure/Function								
	Water Column:								
Being Collected Sufficiently	Changes in natural toxins associated with HAB occurrences		SoMAS, NYSDEC shellfish unit				B-3	c	Too many other contributors to HABs, it's difficult to tease out the causes.
Being Collected Sufficiently	Chlorophyll		NOAA east coast remote sensing node. CTDEP has pigment data at limited sites & times.	Hans Dam & Jim O'Donnell are synthesizing CTDEP data, includes chl.			B-1		
Being Collected Sufficiently	other pigments (e.g., phycoerythrin)		NOAA remote sensing				B-1	f	
Being Collected Sufficiently	Spring bloom timing	Earlier timing.	NOAA remote sensing; Gobler/Lonsdale starting a study			Look up other people's strategies for monitoring.	B-1	f	
Being Collected Sufficiently	Increased pathogens due to increased run-off	Increased pathogens due to increased run-off	NYSDEC shellfish		N		B-3	c	Fluctuates a lot. SPDES & MS4 restrictions & other factors would change these numbers.
Not Being Collected Sufficiently	Shifts to jellyfish from crustacean plankton	Shifts to jellyfish from crustacean plankton	No historial data. Scientist at Yale starting a CLIS 2xmonth gelat. Monitoring program.		Y	Important to keep track of because it's a public concern.	A-1	f	May not be a good indicator because it's affected by many things.
Not Being Collected Sufficiently	Differences in temperature tolerance of different eelgrass genotypes (NY vs. VA)	Southern genotypes move north	None				A-3	b	Not necessarily for monitoring, more research. May not be feasible in NY b/c not many beds. Many things contribute to production & demise
	Benthic:								
Being Collected Sufficiently	Changes in LIS American Lobster abundance which are at the southern limit of their range	Decreased populations	CTDEP trawls, landing data, ASMFC surveys	T may not be only reason for change, but physiology is understood and we have physical parameters.	N	Incorporate already existing data into this program.	B-3	c	
Being Collected Sufficiently	Changes in abundance and distribution of blue crabs which are at the northern edge of their range	Increased populations	CTDEP trawls, possibly NYSDEC in future				B-2		Reported harvest is more variable than lobsters.
Not Being Collected Sufficiently	Changes in benthic faunal distributions (migration of infaunal and epifaunal invertebrates)				Y		A-2	a	It's also tough to monitor and get an accurate picture. There are multiple stressors in LIS, including hypoxia/anoxia, and the benthos integrates the effects of all of them.

	Parameter	How is this expected to change?	Sources of Data/Monitoring Programs	What is the quality/value of the monitoring?	Is new monitoring needed?	Strategy Recommendations	Tier	Ranking reasons	Reasons it would not be suited for this program
	Table 2. Community Structure/Function								
Not Appropriate	Filtering capacity (suspension feeders, habitats such as marshes)		Chesapeake?	Fishery issue.			C		This is not necessarily an indicator, changes in suspension feeders are cyclical with little reason for change. From R. Cerrato: Habitat loss, decline in population abundances will cause changes.
	Watershed:								
Being Collected Sufficiently	Plant diseases	potential increase; powdery mildew disease in lilacs is directly related to humidity	Margery Daughtrey Horticultural Lab; studies powdery mildew in lilacs						
Not Being Collected Sufficiently	Changes in timing of plant blooms	Earlier	Historical info (100y) from horticortural societies (Bronx) & arboretums (CCE; Andy Senesac (Suffolk County weed scientist)); LI Botanical Society (Bob Kent); Perhaps migratory beekeepers	Cornell is tracking the timing of flower blooms through a volunteer network (not locally). Cheap & easy to implement. Linked to heat units.		If implemented, also need to track anomolous early blooms (e.g., December daffodils)	A-2	e	
Not Being Collected Sufficiently	Changes in mosquito populations, abundances, and distributions		Suffolk Co. Vector Control routinely monitors	Suffolk Co. developing a GIS database to monitor distribution and location of mosquito presence through time	N		A-2		
Not Being Collected Sufficiently	New southern insect species arriving and surviving	either a change in their tolerance (adaptation) and/or change in the climate that allows such creatures to survive here. Slight changes in the climate might affect winter survival (+ or -). In general, insects might be good indicators if other factors are also considered		Invasive spp. that are doing damage are being monitored. Research or a survey.	Y		A-1	f	

	Parameter	How is this expected to change?	Sources of Data/Monitoring Programs	What is the quality/value of the monitoring?	Is new monitoring needed?	Strategy Recommendations	Tier	Ranking reasons	Reasons it would not be suited for this program
	Table 2. Community Structure/Function								
	All locations:								
Being Collected Sufficiently	Community structure (plankton, benthos, fish)		CTDEP, NEAMAP			This area can be feasible if specific communities are targeted, but this has been addressed in other indicators, so it's covered.Continue research (e.g., Hans Dam)	B-2	addressed in other indicators; b	Modeling research, not monitoring.
Not Being Collected Sufficiently	Species richness/biodiversity (succession)	Timing & distribution changes.	Nissequogue, Flax Pond (this summer), NYSDEC RIBS (methodology would need to be adapted), Audubon Christmas bird count (100+years)	Nothing in the open LIS	Possibly	24h bioblitz spp. survey using volunteers 3x per year, gets public involved, it's cheap and easy, but may not be an indicator of climate change. Also could use CTDEP trawl survey data to look at species richness/biodiversity changes over time	A2	e	
	Primary production (rate)	Linked to N-inputs, not necessarily climate change.		This affects the food chain, also need to consider wetlands & uplands. Timing and intensity of spring bloom is		Continue estimating. remote sensing for timing of growth (need leaf-on)	A-2	f	
	Secondary production					Incorporate metabolism.	A-3		
	Non-native species in relation to water temperature	shifts in geography; hard to tie only to clim. Change		Nancy Balcom, CTSG; NYSDEC PRISMS; trawl surveys; Sandy Shumway - algae; could be found through other processes		Have to chose one that has ties to temperature and not other vectors (e.g., tiger prawn, if lionfish survive winter).	A-2/3		
	Disease prevalence of selected species		Lobster shell disease (SoMAS); surf clam population (NYSDEC); tree diseases	just starting, incomplete	Y		Lobster-B-1	f	
	Perkinsus marinus (also called Dermo) and Haplosporidium nelsoni (also called MSX) in oysters, QPX (or quahog parasite unknown) in hard clams.	main factor = T, secondary S; linked with warming trends	SoMAS			Monitoring of sentinel wild stocks twice a year, once in spring and once in late summer/early fall. In case of constraints to reduce the number of species/pathogens to be monitored, focus the effort on oyster monitoring and drop the clams.	A-1	f	

	Parameter	How is this expected to change?	Sources of Data/Monitoring Programs	What is the quality/value of the monitoring?	Is new monitoring needed?	Strategy Recommendations	Tier	Ranking reasons	Reasons it would not be suited for this program
	Table 2. Community Structure/Function								
Not Being Collected Sufficiently	Mycobacteria in striped bas	strongly influenced by temp and dO (increased incidence and severity)	SoMAS			Data should be collected in Spring (May-June) and Fall (September - November) as we want to get the different temps but also juveniles in spring to see if there are any changes there, and larger returning fish in Fall - most likely to harbor infections.	A-1	f	
	Shifts in juvenile fish species in local nursery habitat		CTDEP, NYSDEC striped bass-would need a consistent protocol.	Data is being captured, but a lot is hit & miss. Could target specific spp.	N/Y	State programs require further funding	A-2		
	Pests to fisheries management (e.g.,	Species richness	Audubon; John Waldman (Queens Coll)	Research		Bio blitz.	A-3	a, b	Research, not monitoring
	Endangered spp. (e.g., if turtles stay year round)	Could relate to clim. Change if there's a decrease in the incidence of cold-stunning.	Riverhead Foundation; CRESLI; Montauk Whale Watches	Very little historical data & difficult to monitor. Perhaps cold-stunned strandings data. Important to the public. Endangereds are probably monitored to the extent they can be			A-2	e	
Not Appropriate	Landings (overall)	depends on species	CTDEP, NYSDEC	Lobster data is already collected & it's charismatic (public response). LT lobster trends could be seen in landings. NYDEC also collects blue crab data - probably CTDEP does too.			C		Reflects effort

	Parameter	How is this expected to change?	Sources of Data/Monitoring Programs	What is the quality/value of the monitoring?	Is new monitoring needed?	Strategy Recommendations	Tier	Ranking reasons	Reasons it would not be suited for this program
	Table 3. Changes in Existing Habitat								
	Natural Watershed/Edge:								
Being Collected Sufficiently	Loss of beach breeding grounds with sea level rise	Coastal erosion is a big problem and may affect these systems differently.	NYSDEC does population surveys	Could be extrapolated from other data (SLR)	Y	Important to monitor on annual time scales (5-10y) utilizing aerial photography, LiDAR, etc. Not going to change rapidly. We could monitor beach breeding populations to note changes; utilize LiDAR. Can also create a reference point of water level at specific breeding spots.	B-1	e	
Being Collected Sufficiently	Change in groundwater	elevation and salinity	USGS	Water levels are measured in about 600 wells, island-wide very year. Salinity measured in a handful of deep (non-water table) wells	N		B-2	e	
Not Being Collected Sufficiently	Loss/accretion rate (marsh, shellfish reef, beach, SAV, etc.)			Limited monitoring; some SETs installed	Y	Could be monitored via air photo analysis/remote sensing	A-2	e	
Not Being Collected Sufficiently	Increased abundance of the invasive plant species Phragmites with increased freshwater from the land		Invaseive Plant Council-Consortium of Agencies; some NYSDEC work		Y	Important to the public; Recommend plot surveys every 5 years (+/-);	A-2	e	
Not Being Collected Sufficiently	Shifts in forest plant species with changes in local water salinity	Move from fw species to sw-tolerant species			Y	Need good baseline, we have some reports (Shu Swamp/Southold). Need protected, low-lying area like Alley Pond.	A-3	e	Difficult to detect, it's quicker & easier to look directly at gw.
	Human-influenced Edge:								
Not Appropriate	Shoreline hardening	Coastal erosion is a big problem. Will probably increase Question: Are humans responding in an environmentally detrimental manner?	permit applications & law suits (issue compounded by increased coastal development)				C		There are a lot of local factors, some places may allow hardening, others may not.
Not Appropriate	Dredging	Increased storms --> increased sedimentation --> increased dredging activity Question: Are humans responding in an environmentally detrimental manner?	permit applications & law suits; increases in violations (disregarding laws & environment)				C		Many different other factors, not a good indicator.

	Parameter	How is this expected to change?	Sources of Data/Monitoring Programs	What is the quality/value of the monitoring?	Is new monitoring needed?	Strategy Recommendations	Tier	Ranking reasons	Reasons it would not be suited for this program
	Table 3. Changes in Existing Habitat								
	Natural Benthic:								
Not Being Collected Sufficiently	Sedimentation rate (subtidal habitats)	Could be indicator of CC, but it's also tied to many other things (e.g., human activities on land).					A-3	a	
	Shoreward migration of habitats (e.g., wetlands, SAVs) with rising sea levels		Look for historical transects.			Suffolk Co. Community College has transects, compare with 1970s imagry. Would be captured through the above. Permanent transects combined w/ routine photos & remote sensing.	A-2	e	

H. 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**[1]	**Sentinel Indice**	**Data Availability**[2]
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?	Hypoxia in LIS and embayments	• Increased water temperature • Wind change in speed and direction	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)	No	• Dissolved oxygen (DO) • Duration of hypoxia • Area affected, and severity, • Wind speed and direction	• Mark Altabet (UMASS Dartmouth) research, LISS 2008 project: Geochemical Budgeting of Dissolved Gases for Understanding Long Island Sound Hypoxia. • LIS Monitoring Program (1994-present)
Is there an increasing trend in the salinity of groundwater? Is the depth to water declining?	Changes in groundwater quantity and quality	• Sea level rise • Changes in precipitation • Changes in salinity of groundwater • Groundwater levels and base flow	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 water and failure of on-site	Maybe (There won't be a huge change with gradual SLR)	Salinity Elevation of groundwater Water temperature	• 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

[1] This column may change in the future as our knowledge also changes.
[2] This column does not stress importance, only pulls together information.

TABLE 1. WATER QUALITY/QUANTITY						
Monitoring Question	**Sentinel**	**Ecological Drivers**	**Responses to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors[1]**	**Sentinel Indice**	**Data Availability[2]**
			wastewater treatment systems. Groundwater acidity could change if the soil is unable to buffer CO2.			
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	• 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)	• 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 bed closures	# of bed closures, duration of closures per year	CT DA/BA; NYSDEC
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	Aqueous CO_2 concentrations tend to increase and carbonate ion concentrations	Yes	pH Thickness of crustaceans shells = some species would	• USGS continuously monitors pH at 1 north shore estuary site; ferry; CSHH (pH); FOB (pH); CTDEP just began sampling

TABLE 1. WATER QUALITY/QUANTITY						
Monitoring Question	**Sentinel**	**Ecological Drivers**	**Responses to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors[1]**	**Sentinel Indice**	**Data Availability[2]**
		increases)	CO_3^{2-} would tend to decrease = new conditions would affect the ability of marine calcifying organisms to form biogenic calcium carbonate ($CaCO_3$).		develop thinner shells (oysters, clams, mussels), others would develop thicker shells (crabs, shrimps, lobsters)	• 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)	• 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	• Turbidity (not secchi) • Sediment accumulation rates	• USGS,UConn, SBU, EPA?, ACOE

TABLE 1. WATER QUALITY/QUANTITY						
Monitoring Question	**Sentinel**	**Ecological Drivers**	**Responses to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors[1]**	**Sentinel Indice**	**Data Availability[2]**
Is there an increasing trend in the frequency, distribution and/or severity of HABs in LIS?	Harmful algal blooms (HAB)	• Increased precipitation • Increased runoff • Changing temperature patterns • Increased groundwater discharge	Increases in precipitation and runoff carry excess nutrients from upstream sources, resulting in "blooms" of toxic algae. 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. Disturban-ces of sediments as a result of increased storm activity could activate resting cysts, potentially initiating a HAB.	No	Cell counts (with species ID); algal toxins 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)	• Chris Gobler (SUNY Stony Brook) is r Alexandrium but unsure how long his s • 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.

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 Indice**	**Data Availability**
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)?	Distribution, abundance of aquatic invasive species or new occurrences, particularly from a shellfish production and natural resource perspective.	• Water temperature • pH • Salinity • Precipitation • Runoff	Changes in water temp may lead to changes in invasive species ability to compete with native species Increased nutrient loading from precipitation and runoff	Maybe	Invasive species distribution and abundance	• Robert Whitlach (UConn) research • Nancy Balcom, CTSG • NYSDEC PRISMS • trawl surveys • Sandy Shumway (UConn) –algae; • data from other research projects
Are trends evident in the LIS Benthic Index? Are there any thresholds that are being exceeded?	Composition, abundance of benthic (shallow and deep) fauna	• Water temperature • pH	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)	No	Long Island Sound Benthic Index (under development by Robert Whitlach (UConn) REMOTS Benthic camera	80 stations in LIS (per ICF document)

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 Indice**	**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	• 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)	• 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	• 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 • Shifts to jellyfish	Maybe	• Annual biomass • species composition • species identification analysis	• 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

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 Indice**	**Data Availability**
			from crustacean plankton			
Have there been long term declines in cold-water species in LIS and increases in warm-water species? Is there any evidence that habitat of nearshore fishes are being harmed by increases in coastal erosion related to sea level rise?	Finfish (Distribution and Abundance)	• 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	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 Penny Howell (CTDEP)/Peter Auster (UConn) paper NY DEC beginning surveys on N shore of LI
Are there changes in the distribution and abundance of benthic algae species that are associated with climate-related factors?	Benthic Macroalgae	• Precipitation • Increased turbidity • Water temperature	Some marine species could decrease locally if freshwater overwhelms current habitat Increased turbidity could decrease available light necessary for photosynthesis and reproduction.	Likely	• Specific species studies	There is published work on light levels and temperature requirements. Monitoring by Millstone Environmental Lab.

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 Indice**	**Data Availability**
			Many cold water LIS algae, including kelp, are at their southern temperature range in LIS. Populations could die with warmer water temperatures.			
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 regimes	Yes	Distribution and abundance of shallow water suspension feeders; macroalgae; Benthic foraminifera	Historic datasets from Peter Auster (UConn)(various times and locations) could provide general patterns Foram data: 1996/97 E. Thomas et al.(Yale) 1961/62 M. Buzas; 1948 F. Parker

TABLE 3. FISHERIES OF LONG ISLAND SOUND and ASSOCIATED RIVER SYSTEMS						
Monitoring Questions	**Sentinel**	**Ecological Drivers**	**Sensitivity and Linkages to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors**	**Sentinel Indice**	**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	• 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; NYSDEC 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 (*Neoparamoeba pemaquidensis*) (a parasite that attacks the nervous system of lobsters)	Maybe	Distribution in the water column; also invaded soft tissue, however, it is uncertain whether or not this infection is primary or	Limited data collection occurred in CT 2001-2002, 2007. Pathogen not currently monitored Molecular test was developed and is available

TABLE 3. FISHERIES OF LONG ISLAND SOUND and ASSOCIATED RIVER SYSTEMS						
Monitoring Questions	**Sentinel**	**Ecological Drivers**	**Sensitivity and Linkages to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors**	**Sentinel Indice**	**Data Availability**
					secondary	
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?			Metabolic reaction to chronic exposure to elevated temperatures; respiratory stress at temperatures> 20°C documented in lab studies	Yes	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	• pH • alkalinity • CO_2 concentration	Chris Gobler (SUNY Stony Brook) current shellfish research
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	Eastern Oysters (shellfish): Changes in populations due to Dermo and/or MSX; ocean acidification; potentially invasive species that are	• Water temp (primary factor) • Salinity (secondary factor) for both Dermo and MSX. Both linked to increased precipitation	Changes in oyster populations due to Dermo and/or MSX: Two protozoan parasites reduce the survival of infected oysters, including *Perkinsus marinus*, which causes the	Yes	% oyster infected per square area (need to take into account disease prevalence AND intensity)	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 locations and frequency)

TABLE 3. FISHERIES OF LONG ISLAND SOUND and ASSOCIATED RIVER SYSTEMS						
Monitoring Questions	**Sentinel**	**Ecological Drivers**	**Sensitivity and Linkages to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors**	**Sentinel Indice**	**Data Availability**
linked to increases in salinity and water temperature?	predatory or compete for resources		disease Dermo, and *Haplosporidium nelsoni*, which causes MSX. The incidence of both diseases has been linked to increases in water temp and salinity (Ford, 1996) pH change effects on calcification (Table 1)			
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	• 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;	Increased precipitation Decreased salinity Further loss of habitat (eelgrass) Increased nutrients leading to degraded	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

TABLE 3. FISHERIES OF LONG ISLAND SOUND and ASSOCIATED RIVER SYSTEMS						
Monitoring Questions	**Sentinel**	**Ecological Drivers**	**Sensitivity and Linkages to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors**	**Sentinel Indice**	**Data Availability**
	potentially invasive species that are predatory or compete for resources	water quality				
Is there a change in finfish pathogen abundance and occurrence?	Finfish	• Temperature • Increased precipitation • Salinity	Pathogens (i.e., Mycobacteria): Climate change could affect Bluefish ecotoparasite prevalence, abundance, seasonality, location, pathology. Not enough info yet to link Viral Hemorrhagic Septicemia (VHS) and climate change (better as intermittent research rather than continuous monitoring).	Maybe	Proportion of population infected with the pathogen or annual index of mortalities directly attributable to this disease (difficult) Parasite prevalence, abundance, seasonality, location, pathology: including but not limited to: Lironeca, Lernanthropus, Lernaeenichus	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
Are changes in seasonal water temps affecting the timing of diadromous fish runs to/from ocean waters?	Diadromous fish	• Water temperature • Sea Level Rise • Runoff & precipitation • Stream Flow	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	Maybe (manage-ment activities hard to separate)	Trend analyses (similarity coefficient /regression) of survey catch data; correlation of adaptation group abundance and individual species,	LISS indicators program gets info from Greenwich, Norwich, Holyoke Dam

TABLE 3. FISHERIES OF LONG ISLAND SOUND and ASSOCIATED RIVER SYSTEMS						
Monitoring Questions	**Sentinel**	**Ecological Drivers**	**Sensitivity and Linkages to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors**	**Sentinel Indice**	**Data Availability**
			unless thermal gradients become so high that cold water anadromous fish don't go up as far.		with 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 Indice**	**Data Availability**
Is there evidence of inundation of tidal flats? Are hard clam landings declining in association with decreases in the area of tidal flats?	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)	• Water temperature • pH • Precipitation changes • runoff • Sea level rise and changes in habitat • increased predators/ invasives with changing habitat	Sea level rise will cause inundation of tidal flats Molluscan reef impacts??	Maybe	• 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	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

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 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?	Salt marshes and associated species	• Sea level rise • Salinity • Precipitation • Stream flow • Runoff • Groundwater flow • Wind	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 input from increased precipitation = increased Phragmites; changes in sediment supply (linked to changes in precipitation)	Maybe	• 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)	• 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
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	Brackish and freshwater tidal marshes and associated species	• 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	Maybe	• m² by marsh type; • transects in marshes; • 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)

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**
wetland changes are affecting fish and wildlife species?			migrate landward; changes in spring freshet may impact marshes; changes in groundwater supply could affect plant species composition			
Is there evidence of changes in the composition or abundance of coastal vegetation communities? Are any changes associated with climate-related factors (*e.g.* sea level rise inundation, changes in water or air temps)?	Coastal forests, shrublands, grasslands	• Air temperature • Changes in precipitation • Sea level rise • Changes in groundwater (salinity, height of groundwater table, etc)	Increased air temps will affect phenology, distribution and abundance of terrestrial plants Move from freshwater species to saltwater-tolerant species; increases in invasive species	Yes	• Invasive species distribution and abundance; • Veg transects/plots; • Species composition; • Changes in timing of plant blooms	Permanent plots in just a few sites Bloom timing: Historical info (100y) from horticultural societies (Bronx) & arboretums LI Botanical Society; Perhaps migratory beekeepers.
Is erosion of sea cliffs/bluffs/ escarpments showing an increasing trend in association with climate-related factors (*e.g.* increased storm activity)?	Sea Cliffs/Bluffs and Escarpments (Primarily NY)	• 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	m² lost (possibly using aerial photos)	

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**
				change effects)		
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? Is there an overall loss of barriers due to sea level rise?	Barrier beaches/islands	Sea level rise	Sea level rise erodes barriers; loss of barriers increases coastal vulnerability to higher/stronger storm surges	No (except for inundation as a direct result of relative sea level rise)	USGS Coastal Vulnerability Index (CVI)	USGS Coastal Vulnerability Index (CVI)
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	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	• 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

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**
waterfowl (residents or seasonal migrants) showing decreasing population trends as a result of climate-related factors including loss of habitat due to SLR?						
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 related to temperature changes (*e.g.* 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?	Insects	• 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 Increased abundance and distribution of mosquitoes and other insects	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
Is there evidence of new terrestrial invasions associated with climate related factors?	Distribution and Abundance of Terrestrial Invasive species (plant and animal)	• Increased air temp • Changes in precipitation			Distribution and abundance of new invasive species	CT/NY Invasive plant groups
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 (*e.g.* for protection, as a nursery habitat, for food)?	Eelgrass (*Zostera marina*) and organisms that depend on eelgrass habitat/food	• Salinity • Precipitation • Runoff • Sea level rise • Increased water temp • Salinity • pH • Groundwater • Winds	Increases in precipitation and runoff can increase nutrient loadings and increase turbidity and epiphytic growth. Turbidity also increases with algae blooms at the surface. Loss of habitat due to SLR Eelgrass sensitive to water temp, salinity, and pH changes Southern (VA) genotypes could move north	Maybe	• Secchi depth (light penetration) • Eelgrass distribution • Salinity	• USFWS 2002, 2006, 2009 to be released soon • Jamie Vaudrey (UConn) and Jim Kremer (UConn) research

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 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)	• Precipitation • Runoff • Increased turbidity • Increased nutrients • SLR • Water temperature • Salinity (salt wedge) • pH	Increases in precipitation and runoff can increase nutrient loadings and increase turbidity	Maybe	• Secchi depth (light penetration • SAV abundance and distribution • Salinity • Water temperature • pH	CT River Study (1995-97) Juliana Barrett (CTSG)
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	• 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	Maybe; this is important to the public	• Distribution Data	Riverhead Foundation, CRESLI, Woods Hole Institute, Norwalk Aquarium, Mystic Aquarium

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**
			could decrease the incidence of cold-stunning; Runoff linked to increased pathogen occurrence			
Question(s) will depend on habitat within the embayment including open water, fringe marsh, shoreline and tidal creek.	Coastal Embayments including fringe marsh, shorelines, and tidal creeks	• Sea level rise • Salinity • precipitation • Runoff • Erosion	Inundation and changes in salinity due to sea level rise may alter distribution and abundance of marsh, drown/erode shoreline and drown tidal creeks	Maybe	Dependent on question	

I. Review of Current Monitoring Efforts in Coastal Ecosystems
(STAC Fellows Report)

Review of current monitoring efforts in coastal ecosystems

09 February 2009

Long Island Sound Study
Science and Technical Advisory Committee

Mark Hoover
Santiago Salinas

Section I

Introduction

The scientific community has come to the consensus that anthropogenic emissions of greenhouse gases are changing the earth's climate. Climate change will have many detrimental effects on the environment, especially in coastal regions (NERRS 2008). To mitigate the effects of climate change many environmental organizations are beginning to draft monitoring and adaptation strategies. It is important to get these programs started now in order to effectively address future climate change impacts.

Currently, there are many programs designed to monitor and protect the environment. While some programs have had success, climate change will aggravate current environmental problems by adding another dimension to the causes and rates of variability in the ecosystem (GOOS 2003). One of the biggest issues in managing climate change is the range of variability. In order to understand how climate change is affecting our coastal resources, there needs to be better long-term, continuous environmental monitoring (CBP STAC 2007, FAO 2005).

In order to understand the effects of climate change on an ecosystem there needs to be long-term continuous data. Many organizations are using data that has already been collected for other projects over long periods of time (GOM 2004). For accurate mitigation strategies, the data collection needs to be updated frequently, and at multiple temporal and spatial scales (Brush et al. 2007). Also, it is important to realize that the data collected is not useful if it is not given to the proper authorities. Therefore many organizations are beginning to promote sharing of data with other agencies to support numerous mitigation plans (GOOS 2008). While data collection is needed to observe the impacts of climate change, continuous monitoring can also be used to assess the effectiveness of mitigation strategies (GOOS 1998).

Monitoring is crucial for developing mitigation strategies for climate change. It is impossible to detect what change is occurring if there is no baseline to compare the change to. In other words, monitoring can be used to provide improved understanding of the earth's system variability, and thus detect change (FAO 2005).

Monitoring cannot only be used to detect change but also used to predict what changes will occur. There are many models that can predict the effects of climate change, but their efficacy can be improved with in situ data (GOOS 2003). Monitoring will produce a better understanding of dynamic coastal processes, which will enhance the prediction of the effects of climate change and therefore help organizations prepare accordingly (Pyke 2008, GOOS 2008, Barton 2003, NOAA 2007)

Ideally one would like to monitor everything all the time; however, this is clearly impossible. Therefore it is becoming common practice to develop sentinel systems and indicator species. The goal is that by studying some region or species intensely the effects observed can be extrapolated to entire ecosystems (GOOS 2008).

Funding often limits the scope of many monitoring programs. To overcome this, many organizations are developing well understood, intensely monitored, sentinel sites which can be used to detect change at broader scales. By focusing all resources in a localized region, it is possible to develop a better understanding of the ecosystem as a whole. Sentinel sites can therefore be used as a warning system, because if change starts to occur in these regions it can often be assumed that it will occur in similar ecosystems (FAO 2005).

Another monitoring strategy is the use of indicator species. Indicator species are organisms that are studied intensely, to predict larger changes in the ecosystem (GOM 2004). Indicator species are normally organisms that have a large effect on their ecosystem, meaning that a change in them would provide useful information about the condition of the ecosystem as a whole (GOM 2004). Some studies are beginning to establish which environmental indicators are the most sensitive and insensitive to climate change so that the best indicators can be used (Pyke 2008).

Section II

Monitoring programs

There are several large-scale monitoring programs that have been developed to detect climate change in the oceans and coasts. These programs have gone through much of the same planning that the Long Island Sound Study is currently going through, such as site selection, choosing indicator species, and end product designation. As such, by looking at these other monitoring programs our organization can learn strategies to use right here in Long Island Sound.

Global Earth Observing System of Systems (GEOSS)

The Global Earth Observing System of Systems is a collection of monitoring programs developed by the United Nations to detect and predict large scale regional change (Christian 2007). There are two main programs in GEOSS: the Global Terrestrial Observing System (GTOS) and the Global Ocean Observing System (GOOS). For the purpose of Long Island Sound we will be looking at GOOS as well as at a small section in GTOS, the Coastal Global Terrestrial Observing System (C-GTOS) (Christian 2005)

Coastal Global Terrestrial Observing System (C-GTOS)

C-GTOS is a system designed to make global observations that will provide a better understanding of earth system variability and change in the coastal zone (Christian 2007). The primary goal of C-GTOS is to detect, assess, and predict global and large scale regional change associated with land-based wetland and freshwater ecosystems along the coast. At several workshops experts derived the following variables of concern for C-GTOS.

C-GTOS	
Indicators of Concern	-Human dimensions (Land use/Land cover) -Sediment loss and delivery -Water cycle and water quality -Effects of sea level rise, storms and flooding

C-GTOS is a bridge between the Global Terrestrial Observation System (GTOS) and the Global Ocean Observation System (GOOS). C-GTOS can be broken down into two phases.

The first phase is to produce a set of readily achievable products that are designed to provide tests of concepts for the mature observation system. The products were chosen based on the needs of the program and are representative of the topics of concern.

C-GTOS	
1st Phase Goals	-Enhancement of Terrestrial Monitoring Systems (TEMS) -Distribution and rate of change of population, urbanization, and land use/land cover in the coastal zone -Vulnerability of ecosystem services in deltaic systems -Management of conservation of cultural sites in the coastal zone -Distribution of sites appropriate for analysis of delivery systems

The first objective of the initial phase of C-GTOS is the enhancement of TEMS. TEMS are current stations used in GTOS. To enhance them, C-GTOS aims to improve their geographic coverage, add additional coastal monitoring variables and indicators, integrate satellite images with ground truth, and enhance the outreach of TEMS through the web.

The second objective is to estimate the distribution and rate of change of population, urbanization, and land use/land cover in the coastal zone. It is believed that using current datasets these rates can be estimated within 1 person year.

The third goal is to assess the vulnerability of ecosystems in deltaic systems. Deltaic systems are being threatened through anthropomorphic actions as well as sea level rise. C-GTOS aims to create a series of maps through models showing the vulnerability of deltaic systems. C-GTOS will focus on a small subset of 50 deltaic systems for which there is suitable data available. This product should be completed in 1-2 years and updated with new information every 5-10 years.

The fourth short term goal is the management of conservation of cultural sites in the coastal zone. These are areas that people have designated as worthy of preservation and protection. These sites may already have data available and could serve as sentinel sites for global change. C-GTOS plans on creating a web service that would allow users to access information regarding these cultural sites such as maps, encyclopedic information, and monitoring efforts. These products should be able to be produced quickly, within 6 months, and at low cost.

The final short term goal is the distribution of sites appropriate for analysis of delivery systems. For this goal C-GTOS will select a network of sites across a range of geographical, socioeconomic, environmental conditions to analyze the delivery systems. The aim is to provide timely support to C-GTOS.

The development of these five short term goals is the first phase of C-GTOS and is designed to provide tests of concept and garner support for the second phase which is the establishment of a mature monitoring system. The mature system will provide coastal observation information to address the four indicators of concern.

Currently C-GTOS is still in its first phase of development. It has been several years since the publication of their implementation strategy and as such they have begun the development of the five short term products. For example they are currently using a geophysical analysis to produce delta extent maps for 12 deltas worldwide, have a pilot study on the Nile delta using satellite images from 3 decades to record delta loss, and they have begun a preliminary identification of cultural sites that may be suitable to provide the web products. These are just a few of the projects currently ongoing (GOOS 2005).

Global Ocean Observing System (GOOS)

Another component of the Global Earth Observing System of Systems (GEOSS) is the Global Ocean Observing System (GOOS). GOOS was formally established in 1991 by the Intergovernmental Oceanographic Commission (GOOS, 2008). GOOS is an international, ocean-based monitoring program, designed specifically to detect, assess, and predict change in the ocean.

GOOS	
Overall Goals	-Monitor, understand and predict weather and climate -Describe and forecast the state of the ocean -Improve management of marine and coastal ecosystems and resources -Mitigate damage from natural hazards and pollution -Protect life and property on coasts and at sea -Enable scientific research

The initial focus of GOOS was physical measurements as they are the easiest to monitor. As GOOS develops, more biological and chemical components will be included, but members felt that at the time of development the science was not sufficient to decide what should be measured to meet the needs of coastal resources. GOOS uses a combination of Remote Sensing sources and in situ measurements

The development of GOOS is done through a pilot project approach. New projects and programs are developed by the GOOS Scientific Steering Committee. Upon approval the pilot project runs for 3-5 years after which it becomes a fully functioning operational system. The pilot projects demonstrate operational techniques, and user demand for products (GOOS 1998b).

GOOS has become established internationally through several regional alliances. The developed regional alliances include EuroGOOS, Mediterranean GOOS, Black Sea GOOS, North East Asian Regional (NEAR) GOOS, PL GOOS, Indian Ocean GOOS, IOCARIBE GOOS, Africa GOOS, and US GOS. Each of these alliances are run by partner countries and organizations. It is through the cooperation of these alliances that GOOS functions as one international organization. For the purpose of simplicity I will now go into further detail regarding two of the previously described regional alliances; Black Sea GOOS, and NEAR GOOS.

Black SEA GOOS

The main objective of the regional Black Sea GOOS is to produce a reliable, international observing network that will collect marine data to observe and predict the variability of the Black Sea. Existing observation and monitoring networks are the basis for the program. These monitoring networks were designed to be systematic, routine, and cost effective.

The Black Sea GOOS is an ongoing project and it is currently still in the implementation phase. They are working on defining an optimal observation network building off existing observation stations and installing some new sensors and equipment when needed. Also they are trying to establish and automate standards for quality control.

The monitoring networks are operated through two modules: Marine Service Module (MSM) and Regional Management and Analysis Module (RMAM) (IOC 2003) In the MSM module observations will be designed to address specific problems. The MSM will incorporate many existing programs as appropriate and also incorporate new measurements.

Black Sea GOOS		
Climate Change Effects	-Water and salt budget changes -Identification of trends in marine system parameters -Possible regional correlations between long term external and local processes -Determination of the open sea areas having enough data to support regular observations -Living marine resources -Changes in abundance and distribution	
MSM Measurements	Standard hydro-meteorological parameters	Wind, temp, humidity, cloud cover, precipitation, evaporation, tide gauge
	Monthly measurements from small vessels along selected transects	pH sensor, biological sampling, fluormeters, temperature, salinity, current, light transmission, SST, BODI, BODS, particulate and dissolved TOC, alkalinity, H_2S, redox potential, orthophosphate, total phosphorous, ammonium, nitrate, nitrite, total nitrogen and silicate, cadmium, mercury, chlorophyll a, phytoplankton, zooplankton, primary production, bacterial biomass, fluorescence, organic pollutants
	Measurements along selected section using self contained auto logging instrumentation packages on ships of opportunity	Regular meteorological data, upper layer water column stratification, sea surface temperature conductivity and biooptical variables, currents, biological sampling, plankton
	Automatic measurements by drifters and ARGO type floats	Current, thermistors, fluorometer, beam transmitter, water samples
	Satellite Observation	Biological production, plant biomass, sea surface temperature, sea surface type

The RMAM module can be broken down into two components: coastal management and analysis, and open sea management and analysis. The coastal zone management is designed to monitor pollutants, while the open sea management is designed to study climate change and variability in chemical and physical parameters (GOOS 2003).

North East Asian Regional (NEAR) GOOS

The primary goal of NEAR GOOS is to facilitate the sharing of oceanographic data gathered by partner countries. The NEAR GOOS was established in 1996 and has been a product of two phases.

The first phase of NEAR GOOS was to facilitate the sharing of oceanographic data gathered by agencies of the partner countries, using the internet. This phase has been initiated and been successful by establishing a web server that held 45GB of data in 2007. Furthermore, the countries of China and South Korea are now updating data in real time.

NEAR GOOS	
Physical Data Collected	-Temperature -Salinity -Current and wind waves -Data from surface buoys, drifting buoys, towers, coastal stations, research vessels, observations ships, and satellite data.

NEAR GOOS is now undertaking its second phase of development which aims to address the following goals.

NEAR GOOS	
Goals of 2nd Phase	-Meet the perceived needs of the participating agencies -Facilitate the coordinated and cooperative development of scientific and technological capacity, knowledge and expertise within the member states

The NEAR region is currently working on developing projects to fulfill the goals of the 2nd phase. In particular they are establishing a generic suite of data products, initiating ground truthing for remote sensing platforms, introducing QA/QC protocols, and attempting to reduce the delay in data transmission. Finally, they are working to conduct a needs assessment for capacity building in NEAR (GOOS 2008).

Coastal GOOS

Under the auspices of GOOS is a smaller organization focused solely on coastal resources. It is referred to as Coastal GOOS or C-GOOS and overlaps to some degree with C-GTOS. C-GOOS monitors the physics, chemistry, biology, biogeochemistry, and socioeconomics of the coastal zone. C-GOOS will provide data and information on coastal ecosystems worldwide to address six goals.

C-GOOS	
Overall Goals	-Improve the capacity to detect and predict the effects of global climate change on coastal ecosystems -Improve the safety and efficiency of marine operations -Control and mitigate the effects of natural hazards more effectively -Reduce public health risks -Protect and restore healthy ecosystems more effectively -Restore and sustain living marine resources more effectively

C-GTOS is organized into regional coastal ocean observing stations. These observing stations have been established, but coordination between them has been limited. Ultimately, the coordination of the regional stations will develop a Global Coastal Network (GCN).

C-GOOS	
Goals of Global Coastal Network	-Measure, manage, and analyze common variables needed by all or most of the coastal nations and regions -Establish sentinel and reference stations -Implements internationally accepted standards and protocols for measurements, data management, and modeling

Using common variables at each regional site is essential for assessment of global change.

C- GOOS		
Common Variables	Geophysical	Sea level and bathymetry, shoreline position, temperature, salinity, currents and surface waves, sediment grain size
	Chemical	Sediment organic content, dissolved inorganic nitrogen, phosphorous, and silicon, dissolved oxygen
	Biological	Benthic biomass, phytoplankton biomass, fecal indicators
	Biophysical	Attenuation of solar radiation

These common variables were chosen as indicators of change in the ecosystem. C-GTOS derived these indicators by developing a checklist for indicator development.

- does the indicator provide info on the status or condition of important ecosystem, habitat or living resources on appropriate scales?

- is the indicator based on generally accepted models of the structure and function of the system to which it is applied?

- is the indicator reliable and what is the evidence for this?

- have the data requirements for calculating the indicator repeatable at appropriate rates with known accuracy and precision been determined?

- are the required quality controlled data available in real time or post time?

- what technical and conceptual skills must the data providers poses for users to have confidence in the indicator?

- is the indicator comparable or compatible with indicators in use elsewhere?

- is the indicator cost effective in terms of the cost of providing the required data and its effectiveness to decision makers?

Currently C-GTOS is implementing several pilot projects. These pilot projects are organized, planned activities designed to show promise as potential factors in the overall system. Current projects are aimed at building capacity in the developing world and improving operational capabilities (GOOS, 2005).

National Estuarine Research Reserve System (NERRS)

Another monitoring program is being implemented by the National Estuarine Research Reserve System (NERRS). NERRS believes that the impact of climate change will be first felt and severe among coastal regions. The NERRS program has 27 sites encompassing different bio-geographic regions of the US and has been monitoring weather and water quality for more than 10 years. Each reserve is managed by a lead state agency or university.

NEERS	
Overall Goals	-Contribute to scientific understanding of climate change and monitor ecosystem changes -Assess climate change impacts on human and estuarine ecosystem communities, vulnerability of the communities and their adaptation and mitigation -Provide educational opportunities and training related to effects of climate change on human and estuarine systems to increase public awareness and foster behavior change

The fulfillment of the three main goals in NERRS can be broken down into long term and short term objectives. Most of the projects refer to the System Wide Monitoring Program (SWMP) which is the current monitoring program of NERRS.

NEERS System Wide Monitoring Program (SWMP)	
SWMP Capabilities	-108 abiotic monitoring platforms -27 weather stations -18 bio-monitoring resources -Habitat monitoring and mapping -Baseline and historical data from reserve ecological chart

To meet the first goal intertidal and emergent habitats are being mapped to provide a baseline for monitoring future climate change induced habitat changes. Other short term activities are expanding the SETs network, and obtaining high resolution imagery. Additionally the NERRS system will improve harmful algal bloom forecast models through partnerships with NOAA. In the long term, the NERRS program will do more biological monitoring through the SWMP, and develop Digital Elevation Models (DEMs) and GIS mapping capabilities. NERRS has undergone an assessment of needs, and three areas have been identified: acquiring Light Detection and Ranging (LiDAR) data, creating higher classification maps, and incorporating the SWMP sites into the National Spatial Reference System.

The second overall goal of NERRS will be achieved through several small steps which include developing monitoring protocols for key ecological components across the reserve system. Also, the reserves will be used as sentinel sites to assess estuary change throughout the country. The sentinel sites will use existing monitoring capabilities. Currently the SWMP is sufficient to monitor changes in the salt wedge extent, precipitation, mean water temperature, and sea level change. Some long term activities are to produce maps of projected sea level change as well as a data synthesis every five years, focused on the ecological effects of sea level change within the system.

The NERRS system is a robust monitoring program that will aid in the understanding of ecosystem and climate change. In addition to monitoring, the NERRS program will serve as an educational platform (NERRS 2008).

There are several other regional- or state-based monitoring programs. These programs may best represent how a monitoring program would look for Long Island Sound. The first program is being conducted by the Chesapeake Bay Program.

Chesapeake Bay Program (CBP)

The Chesapeake Bay Program (CBP) developed a monitoring network because they felt that an understanding of the spatial and temporal dynamics associated with the physical processes driving the system is essential in developing mitigating strategies for these challenges. The Chesapeake Bay Program asserted that climate change can influence the estuary in a number of ways. The CBP also predicted the physical response of the bay as it will mediate and change through dynamics that will either amplify or buffer the magnitudes of change. Finally, since climate is a driver and organizing factor in ecological processes it is likely that several areas of living resources will be affected by climate change(Pyke et al. 2008)..

Chesapeake Bay Program		
Effects of Climate Change on Estuaries	-Direct effect of changing atmospheric composition on the chemistry of the estuary -Changes in water temperature -Changes in freshwater inflow quality and quantity due to climatic shifts in the watershed -Changes in forcing from the open ocean, including sea level rise	
Physical Response of Bay to Climate Change	-Increased tidal range of 15-20% with 1m rise in sea level -Changes in salinity in which increased stream flow from more winter precipitation will decrease salinity -More intense precipitation will increase suspended sediment	
Effects of Climate Change on Living Resources	Plankton and biogeochemical processes	-Projected increase in winter spring precipitation will increase nutrient loading and thus change when planktonic productivity surges -As temperature rises small phytoplankton could become dominant -Harmful algal blooms could occur earlier and expand their range
	Wetlands	-Sea level rise could lead to inundation and vegetation change due to changes in duration of inundation - CO_2 fertilization -Coastal development and shoreline hardening

The Chesapeake Bay program has developed a base of the physical drivers of change in the Bay. However, climate change research remains fragmented and incomplete. The current supply of timely and relevant climate information to support management is inadequate and uncoordinated (Pyke et al. 2008).

Delaware Estuary (Climate Ready Estuaries program)

Delaware has partnered with the Environmental Protection Agency to develop a climate adaptation strategy. Delaware is one of six pilot studies taking part in the "Climate Ready Estuaries" initiative. The Delaware project has three case studies: wetlands, drinking water, and shellfish (CRE 2008).

Delaware Climate Ready Estuaries	
Effects of Climate Change on Estuaries	-Sea level -Salinity -Temperature -Freshwater inputs -Sediment supplies -Tidal flooding
Effects of Climate Change on Shellfish	-Salinity -Temperature -Water quality -Increased storm intensity -Altered weather patterns

The drinking water could be threatened by sea level and salinity rise. The shellfish are one of the best sentinel indicators of ecosystem conditions.

The Delaware pilot study will produce a final report. This report will summarize the vulnerability, monitoring needs, and potential actions that can be taken to mitigate climate change. Also, the report will create maps which will show the location of resources deemed vulnerable.

Albemarle-Pamlico Estuary (Climate Ready Estuaries Program)

The Albemarle-Pamlico Estuary, located in the border of Virginia and North Carolina, is also a part of the Climate Ready Estuaries program. The Albemarle-Pamlico Sounds region—30,000 square miles of watershed—is the second largest estuarine system in the United States, second only to the Chesapeake Bay.

The Albemarle-Pamlico Estuary Science and Technical Advisory Committee has based its monitoring efforts from the identification of a number of drivers and responses (APE STAC 2008).

Albermarle-Pamlico Estuary –Climate Ready Estuaries Program		
Driver	-Sea Level Rise -Storm intensity and frequency -Annual average precipitation -Temperature	
Responses Responses	Physical Systems	- Increased rates of coastal erosion on ocean and estuarine shorelines - Possible disruption of continuous barrier island segments by formation of breaches and new inlets - General salinity increase in estuaries in response to drought, long-term sea-level rise and barrier changes - Possible rapid salinity increase in response to threshold collapse of barriers in response to major storm impacts - Alteration of estuarine circulation patterns due to changing salinity and temperature structure - Greater susceptibility to thermal stratification and hypoxic bottom waters, resulting in increased fish kills - Possible increase in tidal prism, accelerating estuarine shoreline erosion, modifying sediment transport and wetland communities, and increasing flooding of low-lying areas - Wetland migration and accretion, net losses in human modified areas resulting from bulkheads or other obstructions to migration - Reduced carbon storage in wetland soils due to flooding by saline water, increased sulfate reduction, increased organic matter degradation, increased erosion

	Natural Biological Systems	- Cascading impacts on aquatic ecosystems (plankton, nekton, benthos, submerged aquatic vegetation (SAV), wetlands) via changes in salinity, temperature, circulation, stratification, hypoxia - Expected community change and migrations - Changes in SAV distribution (e.g., eel grass replaced by turtle grass) and emergent vegetation - increased number of threatened and endangered species with possible extinctions - Expansion of the range of exotic species (e.g., Lionfish, snakehead fish, Codium in mesohaline regions, *Phragmites*). Additionally, it will become necessary to identify exotics before they dominate and produce detrimental effects, and distinguish between them and the natural succession in response to global warming and barrier/estuarine changes
	Human Systems	-Changes to coastal development patterns with associated concerns regarding preservation of infrastructure, coastal hardening, water resources, drainage ditches, surface water impacts, and water management structures -Changes to social and economic structures of coastal communities; loss of fisheries, tourism, agriculture, silviculture, infrastructure, property and associated tax base; emigration -Increased introduction of toxins into coastal systems as coastal communities are increasingly flooded

-

Section III

Current monitoring efforts on LIS

Current monitoring efforts on Long Island Sound are varied. Some of the existing monitoring variables have the potential to greatly enhance the sentinel site program. Below we summarize the ongoing monitoring efforts that are directly relevant to climate change.

Variable	Climate change relevance	Monitoring efforts	
		Spatial extent	Temporal extent
	Abiotic		
Air/water temperature, water level, barometric pressure, wind speed/direction/gust	Drivers of many of the changes observed in the Sound	1 station on Kings Point, NY (Center for Operational Oceanographic Products and Services, NOAA)	Ongoing since 1998
Dissolved oxygen	Hypoxic and anoxic events expected to worsen in duration and severity—and possibly change spatially—with increasing water temperatures	52 stations throughout LIS (LIS Monitoring Program and NYUSGS)	Ongoing since 1994
Nitrogen / phosphorus	With precipitation and discharge expected to increase, N and P loading is expected to rise. Uncertainty remains as to the exact mechanisms and long-term trends of these chemicals in estuaries	52 stations throughout LIS (LIS Monitoring Program) -- Nitrogen load from all coastal and riverine inputs in CT (USGS and CT DEP)	Ongoing since 1994 -- Ongoing since 1991
Salinity	Likely to change due to climate change effects on FW flow	52 stations throughout LIS (LIS Monitoring Program and NYUSGS)	Ongoing since 1994

Sediment transport	Erosion of riverbeds expected to increase and water circulation patterns may change, altering sediment transport dynamics	Sound-wide (USGS's Woods Hole Science Center)	Numerical simulation model (depends on extent of data series needed as inputs)
Water temperature	Changes in season mean and season extremes can have vast consequences. Large dataset can be used to find correlations with other phenomena and aid in forecasting	52 stations throughout LIS (LIS Monitoring Program and NYUSGS)	Ongoing since 1994
Variable	**Climate change relevance**	**Monitoring efforts** Spatial extent	Temporal extent
		Biotic	
Benthic index[1]	Effects could be many and of wide-ranging consequences	~80 sites throughout the Sound (EPA's National Coastal Assessment)	Ongoing since 2000
Chemical contaminants in bivalve mollusks	Harmful algal blooms likely to increase in duration and intensity	5 stations throughout the Sound (NOAA's National Status and Trends)	Ongoing since 1986
Chlorophyll a	Growth and phytoplankton succession dynamics known to depend strongly on temperature and hydrographic features (e.g., water column stability)	52 stations throughout LIS (LIS Monitoring Program)	Ongoing since 1994
Finfish and invertebrate abundance	Could show patterns of non-linear change in community dynamics (see below). Warm- and cold-water species were shown to exhibit different trends	43 stations throughout LIS (CT DEP trawl surveys)	Ongoing since 1984

Marsh elevation	Water level rise likely to impact marshes	3 sites in CT (Shimon Anisfeld, Sentinel Site database) -- 6 sites in NY (SET sites)	Ongoing since 2005 – Recently established
Nesting birds (e.g., osprey, piping plover, least tern)	Water level rise may impact nesting habitat	Unknown spatial extent (CT DEP and NY DEC)	Ongoing since 1984
Oyster, lobster, and hard clam abundance	Many potential effects on these invertebrates. Low abundances will directly affect humans (consumption and aesthetics/cultural importance)	Oyster and hard clam landings data: extent unknown (CT DEP and NY DEC) -- Lobster: 7 sites (Colleen Giannini, Sentinel Site database)	Ongoing since 1995 – Ongoing since 1984
Sediment quality index[2]	Geologic processes likely to change with sea level rise. Biological activity also impacted	~80 sites throughout the Sound (EPA's National Coastal Assessment)	Ongoing since 2000
Shellfish beds and eelgrass distribution	Sea level rise and harmful algal blooms may impact shellfish beds. Changes in temperature, sea level, salinity, and light attenuation will probably affect eelgrass distributions	Sound-wide (CT Dept. of Agriculture and NY DEC)	Ongoing since 1995

[1] Data could be disaggregated into components: Gleason's D diversity measure normalized by salinity, number of tubificids normalized by salinity, and abundance of spionid polychaetes.

[2] Data could be disaggregated into components: grain size, total organic carbon, sediment chemistry, benthic community structure, and sediment toxicity.

Section IV

Limitations of current indicators and non-linear changes

Limitations of current indicators

After reviewing a variety of monitoring efforts, we concur with Niemi et al. (2004) in finding the current monitoring practices lacking in a variety of ways.

Causal relationships. In most cases, specific indicators are not linked to specific drivers, lacking any possibility of establishing a causal relationship. Without pinpointing a cause, it will be impossible to remediate the state of the indicator. Clever planning (e.g., designation of sites across a stress continuum) may aid in circumventing this problem.

Multiple stressors. Somewhat related to the previous point, it is clear that a number of stressors (anthropogenic perturbations, natural phenomena, climate change-related alterations) act simultaneously. Separating these has proven remarkably difficult because it is unclear how the many potential stressors interact (e.g., additively, multiplicatively, non-linearly). Experimentation and modeling will be likely needed to resolve this.

Spatial and temporal scales. Explicitly addressing how different stressors and responses vary over spatial and temporal scales is seldom considered. This could lead to erroneous conclusions of their interaction.

Statistical analyses. Power analysis and sample size estimation do not appear to be undertaken. Power analysis establishes how large a sample is needed to enable statistical judgments that are accurate and reliable (i.e., how likely a statistical test will be to detect effects of a given size in a particular situation). Not conducting these statistical analyses before the start of monitoring will likely result in a waste of resources (e.g., not sampling an indicator enough to obtain statistically meaningful results, or oversampling an indicator when less sampling would have sufficed).

Thresholds and non-linear changes

Current prediction and adaptation strategies rely heavily on progressive, linear changes, driven by physical phenomena. This, however, appears to be the exception, rather than the norm, in biological systems (Burkett et al. 2005). An ecological threshold (also commonly referred as tipping point, regime shift, or alternative/multiple stable state) is defined as “the point at which there is an abrupt change in an ecosystem quality, property, or phenomenon, or where small changes in one or more external conditions produce large and persistent responses in an ecosystem" (CCSP 2009). Ecological theory and models are now predicting these types of changes regularly (e.g., Sugihara and May 1990, Hanski et al. 1993, Scheffer and Carpenter 2003) and empirical evidence is mounting at an extraordinary pace (e.g., Hsieh et al. 2006, or, for a review, see Burkett et al. 2005). As Wiens (2007) stated, "These thresholds exist because all organisms and species have limits to their environmental tolerances. The physiological tolerances of individuals to heat, moisture, salinity, soil nutrient levels, and the like determine the conditions in which they can function normally. Outside these zones, their performance suffers – thresholds have been passed. These effects on individuals influence population dynamics, in some cases promoting population declines beyond sustainable levels. Individuals and populations have the options to move elsewhere, adapt, or die."

One well-studied example of this regime-shift phenomenon occurred in the North Pacific, over the winter of 1976-1977 (reviewed in Hare and Mantua 2000). It is believed that small changes in climate over 1-3 years were responsible for the wide-ranging consequences to the ecosystem. The shift led to an increase in Alaskan salmon populations, decreases in Alaskan shrimp and west coast salmon populations, California current zooplankton abundance, and worsening in the oyster condition index. Following the triggering event, the North Pacific ecosystem was rapidly reorganized into a different stable state that included different community structure and organization, food-web dynamics, predator–prey interactions, and distribution and abundance of various species.

More locally, the coastal fish and invertebrate community of Narragansett Bay appears to have shifted from a vertebrate- and benthic-dominated community to one dominated by invertebrates and pelagic fishes (Collie et al. 2008). The shift in species composition can be attributed to the spring-summer sea surface temperature, and is obviously altering food web dynamics and the relative abundance of other species in the Bay (Collie et al. 2008).

To counteract abrupt change, it is essential to recognize that a threshold has been reached and to apply strong pressure against the stressor (or to manage in such a way as to minimize the effect—e.g., if a critical corridor is being hampered by sea level rise, manually create another). If done in a timely fashion, this could tip the system back to its original state (CCSP 2009). Thus, understanding the non-linear patterns and processes of the Long Island Sound ecosystem is essential to effectively adapt to changes brought about by climate change. However, predictability is perhaps the most difficult task when facing abrupt changes; the ability to forecast changes in stable states is in its infancy. Nonetheless, some key concepts have arisen from analysis of case studies. For instance, changes in variance across space and time may be a primary indicator of incipient non-linear change (Carpenter and Brock 2004). Further, monitoring ecosystem stress (in the form of key components of the ecosystem, like abundance of individual species or guilds) may be more informative than monitoring of species of commercial or aesthetic importance (CCSP 2009). To achieve a successful monitoring program that takes into account abrupt changes, monitoring the biological community as a whole is imperative.

Section V

Conclusions

1) Sound-wide indicators in place already may be used to detect biotic and abiotic changes due to climate change

2) CT DEP data on fishes and invertebrates could be analyzed for evidence of non-linear dynamics

3) Special consideration should be given to the planning stage to obtain answers to specified questions (e.g., if interested in disentangling causal effects, location of sites should be considered carefully)

4) Biological responses will be more effectively observed if a community approach is taken

Section VI

References

Barton, J. 2003. Estuarine health monitoring & assessment review. State Water Quality Monitoring and Assessement Committee, Victoria, Australia. 92pp.

Brush, M.J., K.A. Moore, and E.D. Condon. 2007. Synthesis of data from the National Estuarine Resaerch Reserve System-Wide Monitoring Program for the Mid-Atlantic Region. A report submitted to the NOAA/UNH Cooperative Institute for Coastal and Estuarine Environmental Technology.

Burkett, V.R., D.A. Wilcox, R. Stottlemyer, W. Barrow, D. Fagre, J. Baron, J. Price, J.L. Nielsen, C.D. Allen, D.L. Peterson, G. Ruggerone, and T. Doyle. 2005. Nonlinear dynamics in ecosystem response to climatic change: case studies and policy implications. *Ecol Complex* 2:357-394.

Carpenter, S.R. and W.A. Brock. 2004. Spatial complexity, resilience, and policy diversity: Fishing on lake-rich landscapes. *Ecology and Society* 9:8.

CCSP. 2009. *Thresholds of climate change in ecosystems*. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [Fagre, D.B., C.W. Charles, C.D. Allen, C. Birkeland, F.S. Chapin III, P.M. Groffman, G.R. Guntenspergen, A.K. Knapp, A.D. McGuire, P.J. Mulholland, D.P.C. Peters, D.D. Roby, and George Sugihara]. U.S. Geological Survey, Reston, VA. 156 pp.

Christian, R.R. and S. Mazzilli. 2007. Defining the coast and sentinel ecosystems for coastal observations of global change. *Hydrobiologia* 577:55-70.

Collie, J.S., A.D. Wood, and H.P. Jeffries. 2008. Long-term shifts in the species composition of a coastal fish community. *Can J Fish Aquat Sci* 65:1352-1365.

CRE. 2008. The Delaware estuary climate ready pilot study. A Report by the Climate Ready Estuaries (CRE) program. Wilmington, DE. 2pp

FAO. 2005. Coastal GTOS draft strategic design and phase 1 implementation plan. By R.R. Christian, D. Baird, R.E. Bowen, D.M. Clark, P.M. DiGiacomo, S. de Mora, J. Jiménez, J.

Kineman, S. Mazzilli, G. Servin, L. Talaue-McManus, P. Viaroli, and H. Yap. GTOS Report No. 36. FAO, Rome. 93 pp.

GOM. 2004. Northeast coastal indicators workshop. A Report by the Gulf of Maine (GOM). 4pp.

GOOS. 1998a. Implementation of Global Ocean Observations for GOOS/GCOS: First Session. GOOS Report No. 64. UNESCO; Paris. 25pp.

GOOS. 1998b. Implementation of Global Ocean Observations for GOOS/GCOS: Second Session. GOOS Report No. 65. UNESCO; Paris. 16pp.

GOOS. 2003. *Black* Sea GOOS strategic action and implementation plan. GOOS Report No. 133. UNESCO; Paris. 75pp.

GOOS. 2005. An implementation strategy for the coastal module of the Global Ocean Observing System (GOOS). GOOS Report No. 148. 151pp.

GOOS. 2008. A strategic plan for the NEAR-GOOS in its second phase. GOOS Report No. 166. 45pp.

Hanski, I., P. Turchin, E. Korpimaki, and H. Henttonen. 1993. Population oscillations of boreal rodents: regulation by mustelid predators leads to chaos. *Nature* 364:232-235.

Hare, S.R. and N.J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. *Progr Oceanogr* 47:103-145.

Hsieh, C.H., C.S. Reiss, J.R. Hunter, J.R. Beddington, R.M. May, and G. Sugihara. 2006. Fishing elevates variability in the abundance of exploited species. *Nature* 443:859-862.

NERRS. 2008. Climate change: Science, education and stewardship for tomorrow's estuaries. A Report by the National Estuarine Research Reserve System (NERRS). 16pp.

Niemi, G., D. Wardrop, R. Brooks, S. Anderson, V. Brady, H. Paerl, C. Rakocinski, M. Brouwer, B. Levinson, and M. McDonald. 2004. Rationale for a new generation of indicators for coastal waters. *Environ Health Perspect* 112:979-986.

NOAA. 2007. NOAA Integrated Ocean Observing System (IOOS) Program: Strategic Plan 2008-2014. A Report by the National Oceanic and Atmospheric Adminsitration (NOAA). 17pp.

Pyke, C.R., R.G. Najjar, M.B. Adams, D. Breitbur, M. Kemp, C. Hershner, R. Howarth, M. Mulholland, M. Paolisso, D. Secor, K. Sellner, D. Wardrop, and R. Wood. 2008. Climate Change and the Chesapeake Bay: State-of-the-science review and recommendations. A Report from the Chesapeake Bay Program Science and Technical Advisory Committee (STAC), Annapolis, MD. 59pp.

Scheffer, M. and S.R. Carpenter. 2003. Catastrophic regime shifts in ecosystems: Linking theory to observation. *Trends Ecol Evol* 18:648-656.

Sugihara, G. and R.M. May. 1990. Nonlinear forecasting as a way of distinguishing chaos from measurement error in time series. *Nature* 344:737-741.

"What is GOOS?" The Global Ocean Observing System. 25 January 2008. <http://www.ioc-goos.org/content/view/12/26/>

Wiens, J. 2007. *Ecosystem thresholds and climate tipping points: Implications for policymakers*. Environmental and Energy Study Institute, Washington, DC.

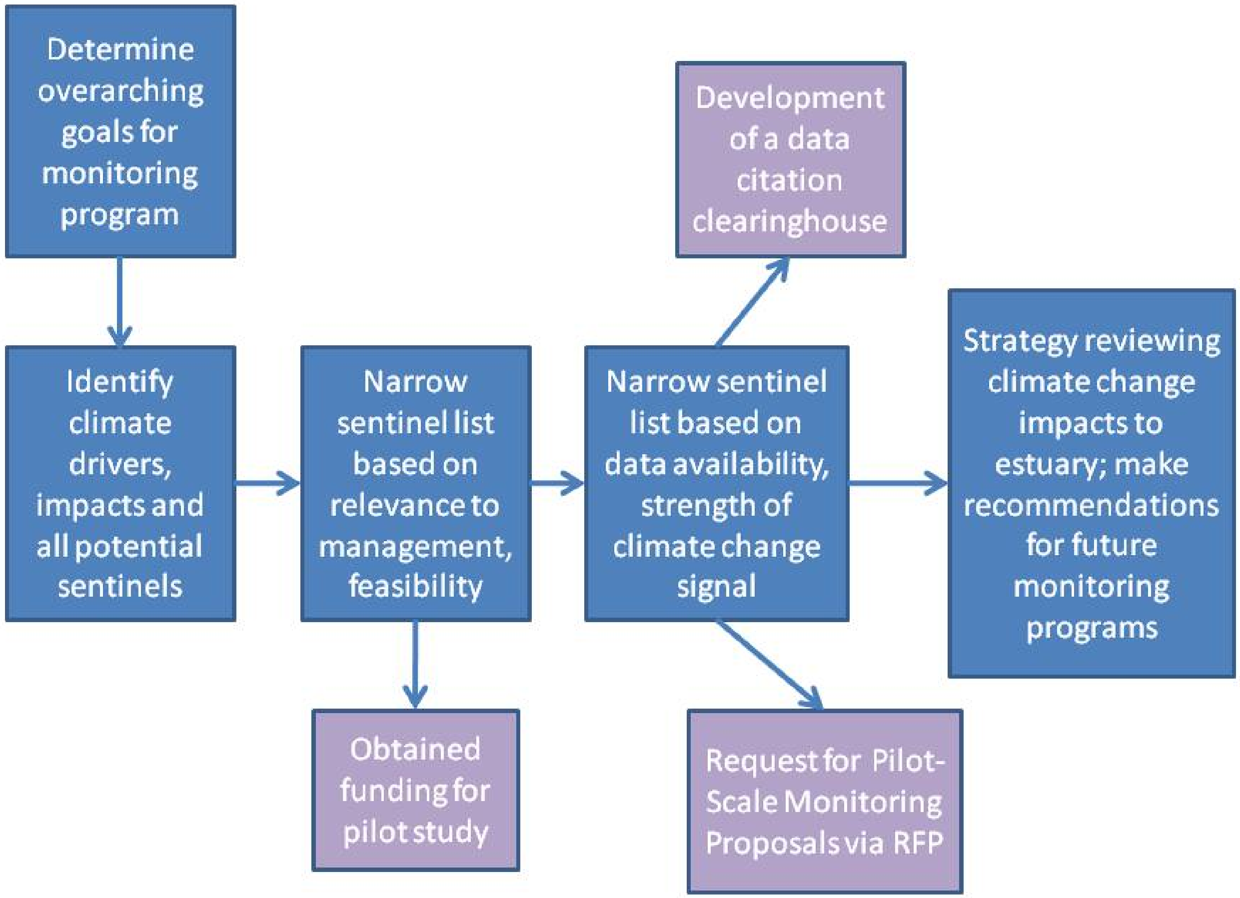
J. Timeline and Milestones for the Sentinel Monitoring for Climate Change Program Table

MILESTONE/STEP	DESCRIPTION	ACTIVITIES/PRODUCTS
1. Plan Development	A. CT: CT Work group began with a CTDEP/UCONN/Sea Grant partnership in 2008. Series of meetings with expanding work groups in 2008 and 2009, as well as emails soliciting information and input from non-attendees and related experts. B. NY: Series of meetings with conference calls beginning February 2009. Gathering of scientists, stakeholders, managers with climate change interests to create a comprehensive list of all potential Long Island Sound climate change indicators and debate the merits of each from a New York perspective.	The two state technical work groups identified habitats, species, processes, drivers etc. in LIS ecosystems that would potentially be affected by climate change. Groups also discussed the relative merit of available and future indicators of climate change. The bi-state work group compiled all of CT and NY state work group recommendations. State Technical Work group assistance was sought to set priorities for sentinel monitoring in LIS.
2. Sentinel Criteria Standardization	Developed criteria to evaluate and select indicators that will serve as major sentinels to measure climate change impacts in LIS ecosystems: ● Measurable at multiple sites ● Discrete from natural variations or anthropogenic stressors ● Representative ● Used to establish reference point for comparisons ● Feasibility to be measured or studied	Agreement on five (5) criteria to help prioritize scientifically valid sentinels within the context of climate change. Provided information on research and data availability Identified a set of core physical and/or chemical parameters that are currently monitored around LIS and should accompany a pilot study.
3. Sentinel Selection	Online poll to prioritize comprehensive list of climate drivers and indicators matrix	Selection and modification to six sentinel indicators
4. General Coordination	Formed a bi-state technical work group to coordinate state recommendations for Sound-wide monitoring strategy (August 2009). Assess and review technical documents from CRE Technical	Liaise with technical work groups to reconcile discussions and needs identified. Developed consensus on key issues that help define the recommendations in the Strategic Plan. Reports prepared by ICF under the CRE

MILESTONE/STEP	DESCRIPTION	ACTIVITIES/PRODUCTS
	Assistance Grant. Develop and execute Sea Grant agreement to sub-contract part-coordinators	Technical Assistance Grant were reviewed and modified to fit the needs of the LIS Strategic Plan Contracts issued and under way.
5. Literature Review	A. Extensive literature review performed. Synthesized current climate change literature in order to assess potential climate change impacts on Long Island Sound ecosystems. B. Reviewed sources to access archival data sets that monitor indicators of climate change (global observation systems, regional observation systems, monitoring in LIS)	A. CT LISS representatives completed extensive literature review and provided to work groups. CRE Technical Assistance from ICF ***Synthesis of Climate Change Drivers and Responses in Long Island Sound***. 17 pg. Created 11/13/09.Incorporated revisions in the Strategic Plan. B. STAC fellow report ***Review of Current Monitoring Efforts In Coastal Ecosystems***. 28 pg. Created 02-11-09.
6. Vision Statement	Defined the vision, established goals and objectives and identified tasks/steps and elements necessary to develop a Strategic Plan for Sentinel Monitoring for Climate Change in LIS.	Consensus statement incorporated in the Strategic Plan.
7. Sentinel Monitoring Framework	Established a sequential approach to evaluate and select indicators to include in a long term monitoring program.	(Figure 1) Drafted by the CT Work group and ICF as part of the CRE technical assistance grant and modified by the bi-state work group.
8. LIS Sentinel Selection	Applied sentinel criteria (step 3) to evaluate the indicators identified on the preliminary list (step 2) Used historical data availability and strength of the climate change signal to rate sentinels for inclusion in a pilot-scale monitoring program	Revised and reorganized LIS indicators matrix developed by ICF (memo dated 01-22-2010) and evaluated by technical work groups. Obtained sentinel ratings from technical work group members using an online survey tool
9. Bi-State Strategic Plan Development	Detailed report describing background, status, activities, and recommendations to establish climate change sentinel monitoring program.	***Sentinel Monitoring for Climate Change in the Long Island Sound Estuarine and Coastal Ecosystems of New York and Connecticut*** 26+ pgs and Appendices.

MILESTONE/STEP	DESCRIPTION	ACTIVITIES/PRODUCTS
10. Data Citation Clearing House (web-based)	The creation of an on-line interactive, publicly accessible database of historic, current, and emerging research is intended to facilitate the synthesis of existing Long Island Sound data in the context of climate change.	Funding obtained from the Long Island Sound Study FY 2010 budget. Project Agreement between CTDEP and UConn is in place and work plan is under development (March 2011 – March 2012; $65,496 from LISS).
11. Pilot Study	Small scale monitoring program (subset of the larger Sound-wide strategy) designed to assess climate change impacts and leverage additional funding from outside sources. Outline strategy to implement pilot study. Request for Proposals from the states of CT and/or NY for pilot-scale monitoring	Funding obtained from the Long Island Sound Study FY 2008 and 2010 budgets. *Recommendations to LISS for Development of Pilot Projects to Monitor Climate Change.* ICF 7 pg Memo RFP in development by bi-state work group
12. Fiscal Assurance	Identify future funding to continue support of sentinel monitoring coordination in LIS. Sought funding from EPA Climate Ready Estuary (CRE) Program to enhance sentinel monitoring planning. Participation in climate conferences Synthesis of existing data to determine emerging climate change trends in LIS.	Prepare and submit a work plan to LISS annually (first submitted September 2009). Leverage the strategic plan to secure more funding for further implementation. CRE application was approved (September 2009) and ICF assigned contract to provide technical assistance. LISS representation in the EPA CRE partners workshop. Priority acknowledged in the technical work groups and identified as a priority for funding in bi-state work group annual work plan to the LISS Management Committee.

Chart 1. Flow chart outlining the steps taken by the technical and bi-state work groups to develop the strategic plan and list of proposed sentinels



Appendix K. Technical work group survey results used to narrow the list of candidate sentinels for a pilot study. Each sentinel was rated based on two questions. The results for each state and for each sentinel are listed separately.

1 = Strongly Disagree, 2 = Disagree, 3 = Agree, 4 = Strongly Agree, U = Unsure

	State	**NY**	**NY**	**NY**	**NY**	**NY**	**NY**	**NY**	**NY**	**NY**	**NY**	**NY**
	Respondent	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
	Question 1. A sufficient data record exists to allow comparison of current conditions to relative historic conditions for the sentinel in question in order to identify long-term trends that may be occurring (or have occurred) related to climate change.											
Water Quality/Quantity	Harmful Algal Bloom frequency/severity/etc.	2	1	U	2	2	U	1	3	3	3	2
	Hypoxia areal extent/severity/duration/timing of onset (both nearshore and offshore)	2	3	2	3	4	3	2	3	3	3	2
	Groundwater quantity and quality within coastal areas	3	3	3	2	2	U	1	3	U	3	2
	Abundance of human pathogen indicator species	2	3	U	3	3	3	1	U	U	U	2
	Amount and duration of shellfish bed closures	U	3	U	3	3	3	2	3	3	3	3
	Ocean acidification	4	1	1	2	3	U	1	3	3	2	2
	Turbidity of the water column	1	2	2	3	3	3	1	U	2	3	2
Pelagic/Benthic Systems	Distribution, occurrence and abundance of aquatic invasive species	2	1	U	U	4	U	1	3	2	2	2
	Composition and abundance of benthic (shallow and deep) fauna	3	1	U	U	3	U	2	3	3	3	2
	Phytoplankton biomass, species composition and timing of blooms	2	3	U	U	3	U	2	3	2	3	3
	Zooplankton biomass, species composition and abundance	U	2	U	U	3	U	2	3	2	3	2
	Finfish biomass, species composition and abundance	3	1	U	U	3	3	2	3	3	U	3
Fisheries	Increased incidence of calcinosis in lobster	2	U	U	U	4	2	1	3	U	3	2
	Disease occurrence in lobster	2	U	U	U	4	2	1	3	U	U	2
	Lobster abundance (based on fishery-independent measurements)	2	U	U	U	4	3	2	3	U	3	2
	Acidification impacts on shellfish and crustaceans	3	U	U	U	3	U	1	U	3	3	2
	Disease occurrence in mollusks (e.g. Eastern oyster, Northern quahog, Bay scallops)	U	U	U	U	4	3	2	3	U	U	2
	Disease occurrence in finfish	U	U	U	U	4	U	2	3	U	U	2
	Changes in diadromous fish run timing	3	U	U	3	U	U	2	3	U	U	2

	State	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY
	Respondent	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
	Question 1. A sufficient data record exists to allow comparison of current conditions to relative historic conditions for the sentinel in question in order to identify long-term trends that may be occurring (or have occurred) related to climate change.											
Coastal Habitats	Areal extent, diversity and composition of brackish marshes	U	3	U	3	U	U	U	3	3	2	2
	Areal extent, diversity and composition of freshwater tidal marshes	U	U	U	U	3	U	U	3	3	2	2
	Changes in distribution and marine transgression of marshes	U	3	2	3	U	U	3	3	3	3	2
	Extent and distribution of coastal forests, shrublands and grasslands	U	3	U	3	U	U	U	3	U	2	2
	Species composition within coastal forests, shrublands and grasslands	3	2	U	U	U	U	U	3	U	U	2
	Extent and distribution of sea cliffs/bluff and escarpments	3	3	2	3	3	U	U	3	U	U	2
	Extent and distribution of unvegetated nearshore (submerged and intertidal) habitats, e.g. mudflats, sandflats, rocky intertidal)	U	U	2	3	3	U	2	3	3	U	2
	Extent and distribution of barrier beaches/islands	3	3	2	3	3	U	2	3	3	U	2
	Extent and distribution of habitats associated with coastal embayments, e.g. fringe marsh, shorelines and tidal creeks	3	U	2	3	U	U	2	3	3	U	2
	Areal extent, composition and distribution of submerged aquatic vegetation other than eelgrass	U	2	U	U	U	3	2	U	U	U	2
	Areal extent and distribution of eelgrass	3	3	U	3	3	3	3	U	U	U	3
	Distribution, abundance and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl	3	1	U	3	3	U	U	3	U	U	3
	Distribution, composition and abundance of insect species associated with coastal habitats	U	1	U	U	U	U	U	3	U	U	2
	Distribution, composition and abundance of terrestrial invasive species	U	U	U	U	3	U	U	3	U	U	3
	Distribution, composition and abundance of macroalgae	3	2	U	3	3	U	U	U	U	U	2
	Marine mammals and sea turtles distribution and incidence of cold-stunning	U	U	U	U	3	U	U	3	U	U	2

	State	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY
	Respondent	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
	Question 2. A climate change signal could in theory be distinguished from natural variations or anthropogenic stressors with the appropriate sampling resolution											
Water Quality/Quantity	Harmful Algal Bloom frequency/severity/etc	2	3	U	U	2	U	U	U	2	3	2
	Hypoxia areal extent/severity/duration/timing of onset (both nearshore and offshore)	2	2	3	3	3	U	1	3	2	3	2
	Groundwater quantity and quality within coastal areas	3	2	3	3	2	U	1	4	U	2	2
	Abundance of human pathogen indicator species	2	2	U	2	3	U	1	U	U	2	2
	Amount and duration of shellfish bed closures	2	2	U	3	3	U	1	U	3	2	2
	Ocean acidification	4	4	4	3	4	U	4	3	4	3	3
	Turbidity of the water column	U	1	3	U	2	U	1	U	2	2	2
Pelagic/Benthic Systems	Distribution, occurrence and abundance of aquatic invasive species	2	2	U	U	3	U	2	3	2	2	2
	Composition and abundance of benthic (shallow and deep) fauna	3	2	U	3	3	U	3	3	3	3	2
	Phytoplankton biomass, species composition and timing of blooms	2	3	U	3	2	U	3	3	3	3	3
	Zooplankton biomass, species composition and abundance	U	2	U	3	2	U	U	3	3	3	2
	Finfish biomass, species composition and abundance	3	2	U	3	3	U	3	U	3	U	2
Fisheries	Increased incidence of calcinosis in lobster	U	U	U	U	4	U	U	U	U	3	2
	Disease occurrence in lobster	U	U	U	U	4	U	3	U	U	U	2
	Lobster abundance (based on fishery-independent measurements)	U	U	U	U	4	U	U	3	3	3	2
	Acidification impacts on shellfish and crustaceans	3	U	U	3	4	U	3	U	3	3	2
	Disease occurrence in mollusks (e.g. Eastern oyster, Northern quahog, Bay scallops)	U	U	U	U	4	U	U	U	U	U	2
	Disease occurrence in finfish	3	U	U	U	3	U	U	U	U	U	2
	Changes in diadromous fish run timing	3	U	U	3	U	U	3	3	3	U	2

	State	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY	NY
	Respondent	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
	Question 2. A climate change signal could in theory be distinguished from natural variations or anthropogenic stressors with the appropriate sampling resolution											
Coastal Habitats	Areal extent of molluscan reefs	U	U	U	3	3	U	2	U	U	U	2
	Areal extent, diversity and composition of salt marshes	3	U	3	2	3	U	U	U	2	3	2
	Areal extent, diversity and composition of brackish marshes	3	U	3	2	U	U	U	U	2	3	2
	Areal extent, diversity and composition of freshwater tidal marshes	3	U	3	2	U	U	U	U	2	3	2
	Changes in distribution and marine transgression of marshes	U	U	3	2	U	U	U	U	3	3	2
	Extent and distribution of coastal forests, shrublands and grasslands	3	U	U	3	U	U	U	U	U	U	2
	Species composition within coastal forests, shrublands and grasslands	3	U	U	U	U	U	U	U	U	3	2
	Extent and distribution of sea cliffs/bluff and escarpments	3	U	3	3	U	U	U	U	U	U	2
	Extent and distribution of unvegetated nearshore (submerged and intertidal) habitats, e.g. mudflats, sandflats, rocky intertidal	U	U	3	2	3	U	U	U	U	U	2
	Extent and distribution of barrier beaches/islands	3	U	3	2	3	U	3	U	U	U	2
	Extent and distribution of habitats associated with coastal embayments, e.g. fringe marsh, shorelines and tidal creeks	3	U	3	3	3	U	U	U	U	3	2
	Areal extent, composition and distribution of submerged aquatic vegetation other than eelgrass	U	U	U	3	U	U	U	U	U	3	2
	Areal extent and distribution of eelgrass	3	U	U	3	3	U	U	U	U	3	2
	Distribution, abundance and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl	3	U	U	3	3	U	U	3	U	3	2
	Distribution, composition and abundance of insect species associated with coastal habitats	U	U	U	3	U	U	U	3	U	3	2
	Distribution, composition and abundance of terrestrial invasive species	3	U	U	U	3	U	U	3	U	U	2
	Distribution, composition and abundance of macroalgae	3	U	U	U	3	U	U	U	U	U	2
	Marine mammals and sea turtles distribution and incidence of cold-stunning	3	U	U	U	3	U	U	U	U	U	2

	State	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT
	Respondent	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**
	Question 1. A sufficient data record exists to allow comparison of current conditions to relative historic conditions for the sentinel in question in order to identify long-term trends that may be occurring (or have occurred) related to climate change.											
Water Quality/Quantity	Harmful Algal Bloom frequency/severity/etc.	2	3	2	U	2	U	U	U	U	1	3
	Hypoxia areal extent/severity/duration/timing of onset (both nearshore and offshore)	2	3	3	4	3	U	U	3	3	1	3
	Groundwater quantity and quality within coastal areas	2	2	2	U	2	U	U	U	3	1	2
	Abundance of human pathogen indicator species	2	3	2	U	3	U	U	U	3	1	2
	Amount and duration of shellfish bed closures	3	3	2	U	2	U	U	U	4	U	3
	Ocean acidification	1	1	3	2	2	U	U	U	3	3	U
	Turbidity of the water column	2	2	2	U	3	U	U	3	4	U	2
Pelagic/Benthic Systems	Distribution, occurrence and abundance of aquatic invasive species	1	3	3	3	2	3	U	U	3	U	3
	Composition and abundance of benthic (shallow and deep) fauna	1	3	3	3	1	2	U	U	3	U	3
	Phytoplankton biomass, species composition and timing of blooms	2	3	3	3	2	U	U	3	3	U	3
	Zooplankton biomass, species composition and abundance	2	2	3	U	2	U	U	3	3	U	U
	Finfish biomass, species composition and abundance	2	3	3	4	3	3	U	U	4	U	3
Fisheries	Increased incidence of calcinosis in lobster	2	2	3	2	2	U	U	U	3	U	3
	Disease occurrence in lobster	2	2	3	3	1	U	U	U	3	U	U
	Lobster abundance (based on fishery-independent measurements)	2	3	3	3	3	U	U	2	3	U	U
	Acidification impacts on shellfish and crustaceans	2	2	2	2	1	U	U	U	3	U	U
	Disease occurrence in mollusks (e.g. Eastern oyster, Northern quahog, Bay scallops)	2	3	3	U	1	U	U	U	3	U	3
	Disease occurrence in finfish	2	2	2	2	1	U	U	U	3	U	U
	Changes in diadromous fish run timing	2	3	3	3	3	U	U	U	4	U	U

	State	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT
	Respondent	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**
	Question 1. A sufficient data record exists to allow comparison of current conditions to relative historic conditions for the sentinel in question in order to identify long-term trends that may be occurring (or have occurred) related to climate change.											
Coastal Habitats	Areal extent of molluscan reefs	U	2	2	U	2	U	1	2	2	U	2
	Areal extent, diversity and composition of salt marshes	U	2	3	3	2	4	4	U	4	U	4
	Areal extent, diversity and composition of brackish marshes	U	2	3	U	2	4	4	2	4	U	4
	Areal extent, diversity and composition of freshwater tidal marshes	U	2	3	U	2	4	4	2	4	U	4
	Changes in distribution and marine transgression of marshes	U	3	3	3	2	4	4	2	4	U	3
	Extent and distribution of coastal forests, shrublands and grasslands	U	3	3	U	2	3	U	2	3	U	3
	Species composition within coastal forests, shrublands and grasslands	U	3	3	U	2	3	U	2	3	U	3
	Extent and distribution of sea cliffs/bluff and escarpments	U	2	3	U	3	3	4	U	3	U	4
	Extent and distribution of unvegetated nearshore (submerged and intertidal) habitats, e.g. mudflats, sandflats, rocky intertidal	U	3	3	3	3	3	2	2	3	U	U
	Extent and distribution of barrier beaches/islands	U	3	3	3	3	3	4	2	3	U	3
	Extent and distribution of habitats associated with coastal embayments, e.g. fringe marsh, shorelines and tidal creeks	U	2	3	3	2	3	U	2	3	U	3
	Areal extent, composition and distribution of submerged aquatic vegetation other than eelgrass	U	3	U	2	2	3	4	2	2	U	U
	Areal extent and distribution of eelgrass	U	3	3	3	3	4	4	2	3	U	3
	Distribution, abundance and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl	U	3	3	U	2	3	U	2	3	U	U
	Distribution, composition and abundance of insect species associated with coastal habitats	U	2	U	U	1	2	U	2	3	U	2
	Distribution, composition and abundance of terrestrial invasive species	U	3	3	U	2	U	3	2	3	U	3
	Distribution, composition and abundance of macroalgae	U	2	3	U	2	U	U	U	3	U	3
	Marine mammals and sea turtles distribution and incidence of cold-stunning	U	2	2	U	2	U	U	2	3	U	U

	State	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT
	Respondent	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**
	Question 2. A climate change signal could in theory be distinguished from natural variations or anthropogenic stressors with the appropriate sampling resolution											
Water Quality/Quantity	Harmful Algal Bloom frequency/severity/etc	2	1	3	U	2	U	U	U	3	1	2
	Hypoxia areal extent/severity/duration/timing of onset (both nearshore and offshore)	2	1	3	3	3	U	U	U	3	1	3
	Groundwater quantity and quality within coastal areas	2	1	2	U	3	U	U	U	U	U	1
	Abundance of human pathogen indicator species	2	1	2	U	2	U	U	U	U	U	1
	Amount and duration of shellfish bed closures	2	1	2	U	2	U	U	U	U	U	3
	Ocean acidification	1	2	3	2	3	U	U	U	U	3	3
	Turbidity of the water column	2	1	2	U	3	U	U	U	U	U	2
Pelagic/Benthic Systems	Distribution, occurrence and abundance of aquatic invasive species	1	1	3	4	3	2	U	U	3	U	3
	Composition and abundance of benthic (shallow and deep) fauna	1	1	3	4	3	2	U	U	3	U	3
	Phytoplankton biomass, species composition and timing of blooms	2	1	3	4	3	U	U	U	3	U	U
	Zooplankton biomass, species composition and abundance	2	1	3	4	3	U	U	U	3	U	U
	Finfish biomass, species composition and abundance	2	1	3	4	3	3	U	U	4	U	3
Fisheries	Increased incidence of calcinosis in lobster	2	1	3	3	3	U	U	U	3	U	3
	Disease occurrence in lobster	2	1	2	3	2	U	U	U	3	U	U
	Lobster abundance (based on fishery-independent measurements)	2	1	3	3	3	U	U	U	3	U	3
	Acidification impacts on shellfish and crustaceans	2	1	3	3	1	U	U	U	3	U	4
	Disease occurrence in mollusks (e.g. Eastern oyster, Northern quahog, Bay scallops)	2	1	2	3	2	U	U	U	3	U	3
	Disease occurrence in finfish	2	1	U	U	2	U	U	U	3	U	U
	Changes in diadromous fish run timing	U	2	4	3	4	U	U	U	4	U	U

	State	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT
	Respondent	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**
	Question 2. A climate change signal could in theory be distinguished from natural variations or anthropogenic stressors with the appropriate sampling resolution											
Coastal Habitats	Areal extent of molluscan reefs	U	2	3	U	3	U	U	U	3	U	2
	Areal extent, diversity and composition of salt marshes	U	2	3	3	3	4	4	U	4	U	4
	Areal extent, diversity and composition of brackish marshes	U	2	3	3	3	4	4	U	4	U	4
	Areal extent, diversity and composition of freshwater tidal marshes	U	2	3	3	3	4	4	U	4	U	4
	Changes in distribution and marine transgression of marshes	U	3	3	3	3	4	4	U	4	U	4
	Extent and distribution of coastal forests, shrublands and grasslands	U	2	3	3	3	2	4	U	3	U	2
	Species composition within coastal forests, shrublands and grasslands	U	2	3	3	3	3	4	U	3	U	U
	Extent and distribution of sea cliffs/bluff and escarpments	U	2	2	3	4	U	4	U	2	U	U
	Extent and distribution of unvegetated nearshore (submerged and intertidal) habitats, e.g. mudflats, sandflats, rocky intertidal	U	2	2	3	4	3	4	U	2	U	U
	Extent and distribution of barrier beaches/islands	U	2	2	3	4	4	4	U	2	U	3
	Extent and distribution of habitats associated with coastal embayments, e.g. fringe marsh, shorelines and tidal creeks	U	2	3	3	3	4	4	U	3	U	3
	Areal extent, composition and distribution of submerged aquatic vegetation other than eelgrass	U	2	2	3	3	3	4	U	2	U	2
	Areal extent and distribution of eelgrass	U	2	2	3	3	3	4	U	3	U	2
	Distribution, abundance and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl	U	2	3	U	3	3	U	U	3	U	2
	Distribution, composition and abundance of insect species associated with coastal habitats	U	2	3	U	3	2	U	U	3	U	3
	Distribution, composition and abundance of terrestrial invasive species	U	2	3	3	3	U	4	U	3	U	3
	Distribution, composition and abundance of macroalgae	U	2	3	3	3	U	U	U	3	U	U
	Marine mammals and sea turtles distribution and incidence of cold-stunning	U	2	3	U	3	U	U	U	3	U	U

	State	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT
	Respondent	**W**	**X**	**Y**	**Z**	**AA**	**BB**	**CC**	**DD**	**EE**	**FF**	**GG**
	Question 1. A sufficient data record exists to allow comparison of current conditions to relative historic conditions for the sentinel in question in order to identify long-term trends that may be occurring (or have occurred) related to climate change.											
Water Quality/Quantity	Harmful Algal Bloom frequency/severity/etc.	2	U	U	3	U	U	U	2	U	3	3
	Hypoxia areal extent/severity/duration/timing of onset (both nearshore and offshore)	2	U	3	3	4	U	U	3	4	3	3
	Groundwater quantity and quality within coastal areas	U	U	U	U	U	U	U	U	1	1	U
	Abundance of human pathogen indicator species	3	U	U	U	U	U	U	U	U	3	3
	Amount and duration of shellfish bed closures	4	U	3	3	3	U	U	U	4	3	U
	Ocean acidification	1	U	U	U	3	U	U	2	1	3	U
	Turbidity of the water column	2	U	U	U	3	U	U	2	3	2	U
Pelagic/Benthic Systems	Distribution, occurrence and abundance of aquatic invasive species	2	U	U	2	3	3	U	2	4	3	3
	Composition and abundance of benthic (shallow and deep) fauna	2	U	U	2	3	U	U	2	2	2	U
	Phytoplankton biomass, species composition and timing of blooms	2	U	U	U	3	U	U	U	U	U	U
	Zooplankton biomass, species composition and abundance	2	U	U	U	3	U	U	U	U	U	U
	Finfish biomass, species composition and abundance	2	4	3	4	3	3	U	3	3	3	U
Fisheries	Increased incidence of calcinosis in lobster	1	U	U	U	U	U	U	U	3	3	U
	Disease occurrence in lobster	3	U	2	U	U	U	U	U	U	3	U
	Lobster abundance (based on fishery-independent measurements)	1	4	3	U	U	U	U	U	3	3	U
	Acidification impacts on shellfish and crustaceans	2	U	2	U	U	U	U	U	1	2	U
	Disease occurrence in mollusks (e.g. Eastern oyster, Northern quahog, Bay scallops)	2	U	U	U	U	U	U	U	3	3	U
	Disease occurrence in finfish	1	U	2	U	U	2	U	U	U	3	U
	Changes in diadromous fish run timing	2	4	3	2	U	3	U	U	U	3	U

	State	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT
	Respondent	**W**	**X**	**Y**	**Z**	**AA**	**BB**	**CC**	**DD**	**EE**	**FF**	**GG**
	Question 1. A sufficient data record exists to allow comparison of current conditions to relative historic conditions for the sentinel in question in order to identify long-term trends that may be occurring (or have occurred) related to climate change.											
Coastal Habitats	Areal extent of molluscan reefs	2	U	2	3	U	U	U	2	U	3	U
Coastal Habitats	Areal extent, diversity and composition of salt marshes	3	U	U	3	3	3	3	3	3	3	3
Coastal Habitats	Areal extent, diversity and composition of brackish marshes	3	U	U	3	3	U	3	3	3	3	3
Coastal Habitats	Areal extent, diversity and composition of freshwater tidal marshes	2	U	U	3	3	U	U	3	3	3	3
Coastal Habitats	Changes in distribution and marine transgression of marshes	3	U	U	3	3	3	U	U	U	3	3
Coastal Habitats	Extent and distribution of coastal forests, shrublands and grasslands	3	U	U	3	3	U	U	3	3	3	3
Coastal Habitats	Species composition within coastal forests, shrublands and grasslands	U	U	U	2	3	U	U	U	3	3	3
Coastal Habitats	Extent and distribution of sea cliffs/bluff and escarpments	U	U	3	3	3	U	U	2	3	3	3
Coastal Habitats	Extent and distribution of unvegetated nearshore (submerged and intertidal) habitats, e.g. mudflats, sandflats, rocky intertidal	3	U	U	2	U	3	U	2	U	2	U
Coastal Habitats	Extent and distribution of barrier beaches/islands	3	U	3	3	3	3	U	2	3	3	3
Coastal Habitats	Extent and distribution of habitats associated with coastal embayments, e.g. fringe marsh, shorelines and tidal creeks	2	U	U	3	3	3	U	3	3	3	3
Coastal Habitats	Areal extent, composition and distribution of submerged aquatic vegetation other than eelgrass	2	U	2	2	3	U	U	2	3	3	U
Coastal Habitats	Areal extent and distribution of eelgrass	1	U	2	3	3	3	U	3	3	3	U
Coastal Habitats	Distribution, abundance and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl	2	U	U	2	3	U	2	U	U	3	3
Coastal Habitats	Distribution, composition and abundance of insect species associated with coastal habitats	1	U	U	U	U	U	1	U	U	2	3
Coastal Habitats	Distribution, composition and abundance of terrestrial invasive species	1	U	U	U	3	3	3	U	U	3	3
Coastal Habitats	Distribution, composition and abundance of macroalgae	1	U	2	U	3	U	U	U	U	2	U
Coastal Habitats	Marine mammals and sea turtles distribution and incidence of cold-stunning	2	U	U	2	U	U	U	U	U	3	U

	State	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT
	Respondent	**W**	**X**	**Y**	**Z**	**AA**	**BB**	**CC**	**DD**	**EE**	**FF**	**GG**
	Question 2. A climate change signal could in theory be distinguished from natural variations or anthropogenic stressors with the appropriate sampling resolution											
Water Quality/Quantity	Harmful Algal Bloom frequency/severity/etc	2	4	U	3	3	U	U	U	3	U	3
	Hypoxia areal extent/severity/duration/timing of onset (both nearshore and offshore)	2	4	U	U	U	U	U	2	3	U	3
	Groundwater quantity and quality within coastal areas	2	4	3	U	U	U	U	3	3	4	U
	Abundance of human pathogen indicator species	2	4	U	U	U	U	U	U	U	4	3
	Amount and duration of shellfish bed closures	2	4	U	U	U	U	U	U	U	4	U
	Ocean acidification	2	4	3	U	4	U	U	3	U	U	U
	Turbidity of the water column	2	4	U	U	3	U	U	2	U	U	U
Pelagic/Benthic Systems	Distribution, occurrence and abundance of aquatic invasive species	1	4	3	3	3	2	U	U	4	2	3
	Composition and abundance of benthic (shallow and deep) fauna	1	4	3	U	U	U	U	3	U	2	U
	Phytoplankton biomass, species composition and timing of blooms	2	4	3	3	3	U	U	3	U	U	U
	Zooplankton biomass, species composition and abundance	2	4	3	3	3	U	U	3	U	U	U
	Finfish biomass, species composition and abundance	1	4	3	4	U	2	U	3	4	2	U
Fisheries	Increased incidence of calcinosis in lobster	1	4	U	U	U	U	U	3	U	2	U
	Disease occurrence in lobster	2	4	U	U	U	U	U	3	U	2	U
	Lobster abundance (based on fishery-independent measurements)	1	4	3	U	U	U	U	3	U	2	U
	Acidification impacts on shellfish and crustaceans	1	4	3	U	U	U	U	U	U	2	U
	Disease occurrence in mollusks (e.g. Eastern oyster, Northern quahog, Bay scallops)	1	4	U	U	U	U	U	U	U	2	U
	Disease occurrence in finfish	1	4	U	U	U	2	U	U	U	2	U
	Changes in diadromous fish run timing	1	4	3	4	U	3	U	U	U	3	U

	State	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT
	Respondent	**W**	**X**	**Y**	**Z**	**AA**	**BB**	**CC**	**DD**	**EE**	**FF**	**GG**
	Question 2. A climate change signal could in theory be distinguished from natural variations or anthropogenic stressors with the appropriate sampling resolution											
Coastal Habitats	Areal extent of molluscan reefs	2	4	U	U	U	U	U	U	U	2	U
	Areal extent, diversity and composition of salt marshes	2	4	3	4	4	U	U	3	3	3	3
	Areal extent, diversity and composition of brackish marshes	2	4	3	U	4	U	U	3	U	3	3
	Areal extent, diversity and composition of freshwater tidal marshes	3	4	3	3	4	U	U	3	U	3	3
	Changes in distribution and marine transgression of marshes	3	4	3	4	4	U	U	3	U	3	3
	Extent and distribution of coastal forests, shrublands and grasslands	2	4	3	3	4	U	U	3	U	3	3
	Species composition within coastal forests, shrublands and grasslands	2	4	3	U	4	U	U	3	U	3	3
	Extent and distribution of sea cliffs/bluff and escarpments	1	4	3	3	4	U	U	U	U	3	3
	Extent and distribution of unvegetated nearshore (submerged and intertidal) habitats, e.g. mudflats, sandflats, rocky intertidal	1	4	3	3	3	2	U	3	U	2	3
	Extent and distribution of barrier beaches/islands	3	4	3	3	U	2	U	U	U	3	3
	Extent and distribution of habitats associated with coastal embayments, e.g. fringe marsh, shorelines and tidal creeks	2	4	3	4	4	2	U	3	U	3	3
	Areal extent, composition and distribution of submerged aquatic vegetation other than eelgrass	1	4	3	3	3	2	U	3	3	2	U
	Areal extent and distribution of eelgrass	1	4	3	2	3	2	U	3	3	2	U
	Distribution, abundance and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl	1	4	3	3	3	U	U	3	U	2	3
	Distribution, composition and abundance of insect species associated with coastal habitats	1	4	3	U	U	U	U	U	U	2	3
	Distribution, composition and abundance of terrestrial invasive species	1	4	3	U	U	2	U	U	3	2	3
	Distribution, composition and abundance of macroalgae	1	4	3	U	U	U	U	U	3	U	U
	Marine mammals and sea turtles distribution and incidence of cold-stunning	1	4	3	U	U	U	U	U	U	2	U

L. Data Availability

Data Availability for Core Parameters and 17 Priority Sentinels

Data Availability for Core Parameters

A group of core parameters have been identified that are physical and chemical factors typically measured in most monitoring programs, either by multiple groups or by one group but over a large geographic area. The technical work groups recommended that these parameters be removed from the list of candidate sentinels, with the idea that they would be included in a pilot study. The work group believed that since these core parameters are currently measured in many locations in the Sound, a pilot study should be able to leverage existing data/monitoring programs to acquire these data in complement to the new sentinels proposed. These core parameters are: precipitation, stream flow (runoff and baseflow), sea level, temperature, salinity, wind (speed and direction), relative humidity, pH, and groundwater levels. While pH is considered a “core parameter,” it is not well characterized in LIS and has only recently been added to the LIS Water Quality Monitoring program. pH is recognized to be a critical parameter in ocean acidification.

Existing data that could potentially be assessed for climate-related trends in the core parameters

Core parameters: precipitation, stream flow (runoff & baseflow), sea level, water temperature, salinity, wind (speed & direction), relative humidity, pH, groundwater levels

1. Meteorological data (wind speed/direction, precipitation, relative humidity)
    a. Sources: Bridgeport/Port Jeff ferry since 2003; Cornell Cooperative Extension; NOAA; Coalition to Save Hempstead Harbor; LISICOS buoys; National Climatic Data Center (NCDC); Center for Operational Oceanographic Products and Services (NOAA/NOS); LISICOS (UConn).
    b. **Suggested assessment**: trends and interannual variability, Specific humidity can be calculated from other available meteorological data.
    c. Recommendations: maintain current monitoring.
2. Water column physical parameters (sea level, temperature, salinity)
    a. Sources: USGS monitoring at 4 north shore estuary sites (sea level, temperature, salinity, turbidity); CTDEP monitoring monthly at 18 stations in LIS (temp, salinity, turbidity), LISICOS buoys (temp, salinity, turbidity); ferry monitoring (temp, salinity); Center for Operational Oceanographic Products and Services (NOAA/NOS); Coalition to Save Hempstead Harbor (through water column); Friends of the Bay; Interstate Environmental Commission; NOAA remote sensing
    b. **Suggested assessment:** trends and interannual variability. General trends could be extrapolated to surrounding areas of similar characteristics.
    c. Recommendations: Maintain current monitoring.
3. Water column pH
    a. Sources: USGS (Flax Pond);The Coalition to Save Hempstead Harbor (CSHH) has measured pH in Hempstead Harbor since 1992, for the months of May through October.); FOB (pH), IEC
    b. **Suggested assessment:**

4. Changes in groundwater elevation: Amount, timing and duration of precipitation effects ground-water-level elevations. Most recharge on Long Island occurs during the Winter months (non-growing season) when evapotranspiration is minimal. If changing climatic patterns result in more precipitation during the growing season, it may not have a noticeable effect on ground water levels; however, if precipitation amounts increase during the colder months, increased recharge would be expected. A caveat to this is the duration of the precipitation events. Typically, heavy downpours result in greater amounts of direct run-off (and therefore less recharge) when compared with less intense, slower and more frequent events. Accordingly, there is much uncertainty in the extent to which climate change will result in increased recharge from precipitation.
    a. Sources: USGS monitoring at wells; maintain current monitoring
    b. **Suggested assessment**: trends and interannual variability. Compare data collected by meteorological stations (i.e. NOAA) and hydrogeologic data from USGS to study correlation
    c. Recommendations: Maintain current monitoring.
5. Run-off/River flow changes
    a. Sources: USGS gauges at every major freshwater source along LIS measuring mean flow (USGS supplied a spreadsheet in Microsoft Excel of all their current monitoring stations in CT river basins as well as precipitation and groundwater networks.)
    b. **Suggested assessment:** trends and interannual variability.
    c. Recommendations: Maintain current monitoring; pursue East River monitoring.

Data Availability for 17 Priority Sentinels:

1. Changes in diadromous fish run timing
    a. Sources:
        - In Connecticut, Steve Gephard (CTDEP) sends out weekly updates on fishway counts from April through the end of June. These include 11 fishways along the CT River (including dams in MA and VT; four are in CT) with numbers for 9 species. The updates also include 16 fishways in other parts of Connecticut with numbers for 8 species. Data sets variable in length; for shad/alewife/salmon in CT River data goes back to 1960s/70s but for many fishways only back to early 2000s.
        - Seatuck and NYSDEC have just started an alewife survey on the north shore of Long Island;
        - NYSDEC diadromous unit reports approximately 20 years of data documenting when and where bass were caught during the survey as well as physical data (air temperature, water temperature, DO, and salinity, as well as meter transects in each bay).
        - Cooperative Angler database has years of information on recreational catch data (DEC has access to this; http://www.dec.ny.gov/outdoor/7899.html).
    b. Group Discussion:
        - Currently the data set is almost entirely in Connecticut. We are going to investigate available data sets in NY. If NY turns out to have a lot of data, then we can add it to shortlist.

- **Decision for inclusions in priority list of sentinels for pilot study: No (for now)**

2. Distribution, abundance and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl

a. Sources:
   - CT DEP and NYSDEC have limited data (Migratory Bird Data Center - collecting Atlantic flyway data, 1991 to present) http://www.ct.gov/dep/cwp/view.asp?Q=472822&A=4013 and https://migbirdapps.fws.gov/mbdc/databases/afsos/aboutafsos.html);
   - From C. Elphick (UConn): detailed data for saltmarsh and seaside sparrows, general data on other species that frequent salt marshes during the summer. Data for some sites dates back to 2002 - BUT, sites have not been visited annually - some visiting in one year, others in the next. Collectively they span ~ 16-locations spread across ~ 40 marshes. These sites also have vegetation sampling. There are other published data sets from earlier years too (Benoit and Askins, Shriver et al). Also, Elphick and colleagues recently received a grant to survey tidal marsh bird populations from Virginia to Maine using a standardized protocol. This project is seen as a pilot for a national program for monitoring tidal marsh birds, and thus will be coordinated with USFWS, USGS, state agencies, various refuges, NPS, etc. If breeding bird species are to be part of the monitoring it would make sense to tie in with this national program.
   - International Shorebird Survey (data sets extend back to 1974) http://www.shorebirdworld.org/template.php?c=11&g=5
   - eBird (http://ebird.org/ebird/eBirdReports?cmd=Start)
   - Christmas Bird Count. (http://birds.audubon.org/historical-results) Results searchable by species and by state and go back to 1900;
   - Long-term avian surveys at Connecticut College Arboretum (Bob Askins)
   - Colonial Nesting Birds - surveys began in 1972 by David Duffy; continued every 3 years until 1977. CT DEP Surveys continued, beginning in 1980 and 1983 - maybe 1986 but then CT DEP Wildlife hired their first non-game expert. CT DEP OLISP created a GIS for colonial seabirds circa 1995 and gave it to Wildlife (hardcopy files only).
   - In CT: Avian Summit work group headed by Min Huang (CTDEP) coordinating regionally and in-state; good potential point of contact if we move forward with this sentinel.
   - NYSDEC monitors for Terns, Skimmers and Plovers every year. Gulls, Herons, Egrets and other breeding colonial waterbirds every three years. Some of these data are used in the LISS environmental indicators program.

b. Group Discussion
   - There appears to be a lot of local interest in this candidate sentinel
   - There is data from a variety of groups working on this, for both states
   - Potential connections between birds and some of the bird habitat that has also been proposed as sentinels
   - **Decision: Yes**

3. Distribution, composition and abundance of terrestrial invasive species
   a. Sources:
      - New York Invasive Plant Council (www.ipcnys.org); data availability not clear
      - Connecticut Invasive Plant Council (http://nbii-nin.ciesin.columbia.edu/ipane/ctcouncil/CT_invasive.htm); data availability not clear
      - IPANE - Invasive Plant Atlas of New England (http://nbii-nin.ciesin.columbia.edu/ipane/) This database does not include New York. Not clear how far back the records extends;
      - Connecticut Agriculture Experiment Station (http://www.ct.gov/caes/site/default.asp) aquatic invasive species surveys started in 2002; no description of terrestrial invasive surveys on their site.
   b. Group Discussion
      - As of right now, there seems to be less data available for this sentinel than others.
      - If more data sets are uncovered as we move forward with the data citation clearinghouse, this could be a good opportunity for future assessment work.
      - **Decision: No**

4. Finfish biomass, species composition and abundance
   a. Sources:
      - LIS Trawl Survey: 1984-present, 200 stratified random samples chosen annually from 310 stations in LIS plus directly sampling in WLIS. Abundance information on 99 species. Annual reports can be downloaded here: http://www.ct.gov/dep/cwp/view.asp?a=2696&q=322718
      - Penny Howell (CTDEP) and Peter Auster UConn) have submitted a paper analyzing changes in species composition since 1984; Howell reports that there are other publications that present analyses of Trawl Survey Data.
      - CTDEP and NYSDEC striped bass surveys (http://longislandsoundstudy.net/2010/07/striped-bass/);
      - NYSDEC striped bass young-of-the-year survey in western Long Island Bays which include Little Neck Bay, Manhasset Bay, Oyster Bay and Hempstead Harbor from the north shore. This survey is used by ASMFC (Atlantic States Marine Fishery Council) as part of a collective data set of population and recruitment status info that is used in stock management decisions. Survey has been going on for nearly 30 years (though not all those years cover all these bays; sampling locations changed).
      - Fishway data from CT as described in #1
      - Alewife survey beginning in NY as described in #1
   b. Group Discussion
      - This sentinel has been the topic of recent analysis
      - Could be good place to fund tool development
      - **Decision: Yes**

5. Lobster abundance (based on fishery-independent measurements)
   a. Sources:

- Lobster abundance is reported in the LIS trawl survey, data go back to 1984 (see #4);
- NYSDEC has some data on lobster health (from 1977 - NYSDEC];
- Other data available on calcinosis, parameobiasis and heat shock protein. Based upon recent info forthcoming from the American lobster shell disease research, there is a consensus that elevated temperature do have a role in this disease (not linear relationship). Perhaps monitoring the continued southern spread of this epidemic would be a worthy candidate, too.
- Penny Howell (CTDEP) has extensive data from the commercial lobster fishery in the Sound; these data include length frequencies of legal (harvestable) and sublegal sizes; sex ratios; percentages of egg-bearing females; percentages of shell disease, etc. These data are used in assessment of the local population as well as contributing to assessment of the SNE stock. Howell also has NY data.
- NYSDEC Crustacean Unit staff, with the aid of a contracted commercial fisherman, deployed and sampled NYSDEC lobster traps at 16 sites per week in WLIS from June through November. Survey protocols were changed in this final year of the project to match the standardized lobster trap survey funded by the Atlantic States Marine Fisheries Commission. The sites were located in WLIS from the NY side to the CT side and from Stony Brook to the Throgs Neck Bridge. The purpose of this survey is to monitor lobster populations and determine how populations respond to environmental variables. Funding for this work was provided by Federal Disaster Relief funding through NOAA for the lobster die-off in the late 1990s. 2009 was the final year of the study, not sure how far back it goes.
- Ending in 2009, NYSDEC and Cornell Cooperative Extension (CCE) staff with the aid of contracted fishermen sampled NYSDEC ventless lobster traps at 24 sites throughout the entire LIS twice a month from July through September. This was part of a greater fisheries-independent, standardized survey, funded by the Atlantic States Marine Fisheries Commission, which occurs along the coast from Maine to New York. This project began in NY in 2006 and is strictly a population monitoring and assessment survey which does not take into account environmental factors.

b. Group Discussion

- Data available is Sound-wide and lengthy data set available from trawl survey
- Wording of sentinel may be subject to change, based on information noted by Penny Howell on value of information from the commercial fishery, also we may want to incorporate the concept of ecological niche
- **Decision: Yes**

6. Phytoplankton biomass, species composition and timing of blooms

a. Sources:

- LIS Water Quality Monitoring program; Chla: 1994 - present, 17 stations monthly, more in summer;
- IEC Water Quality Monitoring; Chla, 2002-present, far western Sound, twice monthly in summer, data is on Storet;

- SeaWiFS satellite data for chlorophyll http://oceancolor.gsfc.nasa.gov/SeaWiFS/ launched 1997; also Satellite Chlorophyll data - http://www.nodc.noaa.gov/General/chloro.html some of this may be accessible through NERACOOS/MACOORA) Global goal is to incorporate into models - NERACOOS has yet to do this.
- HPLC-based phytoplankton abundance and composition: 2002 - present; 10 stations monthly
- Microscopy-based phytoplankton abundance and composition: 2001-2003, 2007 - 10 stations monthly in LIS
- CTSG working with NOAA on Volunteer Phytoplankton Monitoring Network for LIS (P. VanPatten CTSG)
- Ferry monitoring - Chlorophyll a eight times per day on a transect between New London/Orient Point http://www.po.gso.uri.edu/~codiga/foster/main.htm 2004-06 (D. Codiga URI). Based on the website it appears that the BP/PJ ferry does not have a chlorophyll sensor. (http://www.stonybrook.edu/soundscience/main.html)
- Include the chlorophyll on buoys as well as those on ferries. Both would require intercalibration with the ship obs. (Jim O'Donnell UConn)
- CTDA/BA have been and are currently monitoring phytoplankton - The DA/BA examines plankton tows and shellfish meats as necessary to evaluate the potential for marine biotoxins that can be formed by certain types of phytoplankton.
- Riley data (at Yale?). Riley collection of articles was acquired by R.Rozsa (CTDEP-retired) and scanned by Ralph Lewis (CTDEP-retired) http://www.lisrc.uconn.edu/lisrc/bingham.asp.
- Yarish and Capriulo - Capriulo, G.M., Smith, G., Wikfors, G., Yarish, C., Troy, R., Richards, S., Pettet, J., and Welsh, B.. 1996. Alteration of the planktonic food web of Long Island Sound due to eutrophication. Hartford, CT: Connecticut. Department of Environmental Protection. Office of Long Island Sound Programs. Final Report submitted to the Connecticut Department of Environmental Protection, Hartford, CT, under Grant Number CWF 315-R, 185 p. Full record/report at LISRC. Also published in Hydrobiologia, vol 475-476, pages 262-333, DOI: 10.1023/A:1020387325081.

b. Group Discussion

- A wide variety of data is available Sound-wide, from multiple sources. Some historical data is available and monitoring is ongoing.
- **Decision: Yes**

7. Species composition within coastal forests, shrublands and grasslands

a. Sources:

- Flower bloom timing historical information may be available from horticultural societies (Bronx) (e.g. the Horticultural Society of New York http://www.hsny.org/index.html although specific data availability not clear from their website) and arboretums (CCE http://cce.cornell.edu/Ag/Pages/default.aspx but data availability not clear); Andy Senesac (Suffolk County weed scientist)); perhaps the NY Flora Association http://www.nyflora.org/
- LI Botanical Society; http://libotanical.org/

- Tom O'Dell (Town of Westbrook) collecting data on coastal forest spp before and after treatment for invasive plant species
- JBarrett (CT Sea Grant) doing same in coastal forest in Fenwick with permanent transects
- Avalonia Land Conservancy (southeastern CT; coastal shrubland data) http://www.avalonialandconservancy.org/
- Connecticut Arboretum long term surveys (G. Dreyer - ConnCollege)
- Ken Metzler (CTDEP - retired) surveys at Bluff Point - Old Growth Natural Area at Bluff Point may be a place to establish/extend long-term monitoring.
- Tom Siccama (Yale) - had online a series of photostations starting with the George Nichols collection in the 1910's
- Plant community mapping by Ron Rozsa at West Rock Ridge - 1976 - digital copy available
- J. Barrett (CT Sea Grant) - Futures Fund grant 2011 to include descriptions of CT Coastal Forests

b. Group Discussion
- We need to follow up with some of these contacts to determine actual data availability
- We need to work on the description of the sentinel, as it currently includes phenology in addition to composition.
- **Decision: Yes (given caveats listed above)**

8. Areal extent and distribution of eelgrass

a. Sources:
- LISS-funded USFWS surveys 2002, 2006, 2009;
- 1915 survey at Inner Cold Spring Harbor - gives critical insight as to depth of distribution in western LIS with high tidal range http://www.cteco.uconn.edu/metadata/dep/document/eelgrass_beds_historic_points_FGDC_Plus.htm
- 1993-95 survey by Yarish and report is available on the LIS Resource Center website http://www.lisrc.uconn.edu/eelgrass/index.html
- Vaudrey and Kremer work; reports posted on the LIS Resource Center website http://www.lisrc.uconn.edu/eelgrass/index.html
- Restoration efforts coordinated by CCE http://counties.cce.cornell.edu/suffolk/habitat_restoration/seagrassli/restoration/current_projects.html While tracking restoration may not be appropriate here, it is important to note that this may increase acreage.
- Millstone Environmental Lab has a great current and historic record of eelgrass in the Niantic Area (2002-2003 data set on LIS Resource Center website; Lab Director/point of contact at Millstone is Don Landers)
- CT DEP OLISP has a report on historic distribution of eelgrass in LIS. Much of the same data are available in GIS format from Yarish et al. (both are available on the LISRC website). R. Rozsa (CT DEP - retired) still has a few historic data points to add. Rozsa has digital copies of all of the historic surveys – 1930's and 1940's.

- From Jamie Vaudrey (UConn): Fred Short (Univ of New Hampshire) is heading up a TNC funded project examining genetic diversity in eelgrass throughout New England. Jamie Vaudrey is CT collaborator and Chris Pickerell (Cornell Coop Ext) is the NY collaborator. While not distribution and areal extent, this project should yield information on eelgrass status.

b. Group Discussion

- These data sets, while extending back in time further than many of the other sentinels, appear to be less complete than some of the other sentinels. They are patchier in time; there are some data from the late 1800s/early 1900s and more recent, but not the continuous data sets that we see for some of the other sentinels.
- **Decision: No**

9. Areal extent, diversity and composition of brackish marshes

a. Sources:

- From Ron Rozsa (CT DEP - retired): CT marshes mapped from aerial photography (CTDEP OLISP); - need to use a consistent definition – none of the polygon data affix labels such as salt marsh complex (where polyhaline marshes are dominant versus oligo/mesohaline modifiers).
- Miller (1948) – plant community maps for impounded marshes at Barn Island – Imp IV was entirely brackish meadow; upper limits of Imp I were brackish; Upper limits of Imp V were brackish.
- Community vegetation mapping at Ragged Rock Creek – Barrett N. (NRCS) http://web2.uconn.edu/seagrant/publications/coastalres/raggedrock.pdf
- From C.Elphick (UConn) - data on broad cover types for some brackish marshes with GPS locations (CT marshes)
- NBarrett (NRCS) Master's thesis (UConn) documented extent, diversity and composition of brackish marshes along the CT River;
- CTDEP has done areal extent mapping: Nels Barrett (NRCS) used the 1980 (?) false color infrared aerial photography to map all of the coastal marshes using NWI classification – mylar overlays at CTDEP OLISP definitely hard copy Xerox there. [USFWS is redoing the NWI for CT although likely at lower resolution
- CT DEP has digitized the Coast and Geodetic Charts (called T-sheets) from the 1880's – and extracted the wetland polygons. Helpful with regard to areal extent of tidal wetlands then and now; assess marine transgression – not very helpful for differentiating between tidal wetland classes.
- 1915 (?) Mosquito control survey of Mill River in New Haven – generated a vegetation map that was georeferenced (CTDEP OLISP (R. Rozsa CTDEP retired)
- JBarrett (CT Sea Grant) and NBarrett (NRCS) have 4 permanent transects in brackish tidal marsh at mouth of CT River (Data collected from 2005 - 2008)
- Mark Hoover's Master's thesis (UConn 2009) on classification of coastal marshes and inundation projections - should be a good baseline for current conditions and benchmark conditions to compare future changes to.

b. Group Discussion

- Available data is primarily from Connecticut. At the pilot level we are interested in bi-state sentinels.

- **Decision: No**

10. Areal extent, diversity and composition of freshwater tidal marshes
    a. Sources:
    - RRozsa (CT DEP - retired) - see comments under brackish marshes
    - NBarrett (NRCS) Master's thesis (UConn) documented extent, diversity and composition of freshwater tidal marshes along the CT River

    b. Group Discussion
    - Available data is primarily from Connecticut and we are lacking specifics about much of it. At the pilot level we are interested in bi-state sentinels.
    - **Decision: No**

11. Areal extent, diversity and composition of salt marshes
    a. Sources:
    - SET's in CT (N.Barrett (NRCS) and S.Warren (retired - Conn College) set up SET's in Barn Island marsh, 2003) and CT DEP had 20 SET set ups to be installed in 2005 - H. Yamalis (CTDEP OLISP) is contact person; NY SET's not yet being monitored.
    - Aerial imagery (see #9 & 10 above);
    - USGS continuous tide-level monitoring at 4 NY embayments (3 sites from 12/07, one site from 5/09); one site with continuous QW (DO, Salinity, pH, turbidity, temp since 4/08) and two sites with temp and SC/sal, since 12/07. All sites are currently still in operation. (http://waterdata.usgs.gov/ny/nwis/current?type=tidal) This doesn't cover the areal extent, diversity, and composition, however.
    - K. Cochran (Stony Brook University SoMAS)- accretion rate data (210Pb chronologies) for the following marsh locations: New York City (3 cores), Jamaica Bay (3 cores), North Shore of Long Island (7 cores), Peconic Bay system (7 cores), South Shore of LI (4 cores); pore water geochemical data for many of the above sites.
    - C. Elphick (UConn) - data on broad cover types for some salt marshes with GPS locations
    - Mark Hoover thesis (UConn) on potential marine transgression of some CT salt marshes – R. Rozsa (CT DEP - retired) has a GIS coverages comparing 1880 to 1994 wetland polygons.
    - NWI mapped CT wetlands including salt marsh in 1980's; to be updated by Tiner (USFWS) using 2008 and 2004 imagery. http://www.fws.gov/northeast/wetlands/NWI%20Presentations%20for%20Web/Tiner_Updating%20NWI%20Data%20for%20Connecticut_for_R5-posting.pdf
    - From Ron Rozsa (CT DEP - retired): Plant community mapping at Barn Island (various students – I have the Masters reports), Great Meadows in Stratford mapped by Nels Barrett (NRCS) circa 1988 – in digital format with metadata
    - Some permanent transects - but no compilation of theses and locations of these transects; (a few available in GIS – such as Brucker Marsh from Masters Thesis; Scott Warren (Retired Connecticut College) transects in Barn Island, Stonington,CT

- Microrelief plots are recorded in a GIS coverage – 10 plots. Scott Warren (Retired Connecticut College) has note book. Several have been resurveyed twice. Two new plots established at Barn Island in 1997.
- R. Tiner (USFWS) Six western LIS embayments – trend analysis using summer aerial photography from 1974 to 2004 using NWI classification. http://library.fws.gov/wetlands/saltmarsh_ct06.pdf
- From Andrew MacLachlan (USFWS): CT DEP mapped tidal wetlands in the 1990's. This documentation includes: "This coverage shows all mapped tidal wetlands across the state of CT. The mapping has been compiled from two sources: the 1994 Ramsar Tidal Wetlands Mapping and the 1995 OLISP Tidal Wetland Mapping, both produced by CT DEP OLISP. The tidal wetland boundaries are not regulatory boundaries but should be interpreted as a guide to the location of tidal wetlands throughout the state."
- EPA-funded project currently under way to map marshes in LIS and Peconic Estuary of NY.

b. Group Discussion

- Lots of data available, from multiple sources, in both states.
- **Group Decision: Yes; note, combine with #12 below but for salt marshes specifically.**

12. Changes in distribution and marine transgression of marshes

a. Sources:

- See #11 above

b. Group Discussion

- This is encompassed in the salt marsh sentinel #11
- **Decision: Yes but combined with #11 above for salt marshes specifically**

13. Extent and distribution of barrier beaches/islands

a. Sources:

- Barrier beaches in NY include Port Jefferson, Mt Sinai, Long Beach, Nissequoque/Sunken Meadow,Caumsett, Target rock, Cold Spring Inner Harbor (vegetation transect in 1915 across barrier into lagoon, Mattituck, Inlet Pond, Goldsmith, etc. (R. Rozsa) but no ongoing monitoring in NY
- CT DEP has done some mapping of barrier beaches (H. Yamalis - CTDEP OLISP)
- Frank Bohlen's students (UConn) have permanent (?) transects at Bushy Point Beach; USACOE surveys of the 1950's established transects – can they be reoccupied? Masters Report for Hammo in OLISP library
- Ron Rozsa (CT DEP - retired) digital shorelines for Morse Beach in New Haven (CTDEP OLISP)
- Ron Rozsa (CT DEP - retired) plant community descriptions for Long Beach, Pleasure Beach, Lordship Beach (CTDEP OLISP)
- From Ron Rozsa (CT DEP - retired): 1880 T-sheets can be used to reconstruct historic barrier beach location (has been done for a few sites like Bluff Point)

b. Group Discussion

- Available data is primarily from Connecticut. At the pilot level we are interested in bi-state sentinels.
- **Decision: No**

14. Extent and distribution of coastal forests, shrublands and grasslands
    a. Sources:
    - Larger (50 to 100 acres) cool season grasslands in CT mapped in 2009 by UConn CLEAR - data with CTDEP Wildlife) CTDEP Wildlife has maps of large warm season grasslands (Kate Moran - CTDEP)
    - Coastal woodlands/shrublands in CT mapped by Ken Metzler (CTDEP - retired), data listed on CT ECO http://www.cteco.uconn.edu/
    - From Andrew MacLachlan (USFWS): CT forests were extensively assessed by a group including Patrick Comins (Audubon) – may have delineated coastal forests – need to ask Comins
    - Ron Rozsa (CTDEP - retired) and J. Dowhan (USFWS -retired) mapped plant communities at West Rock Ridge (1977) – available in digital format

    b. Group Discussion
    - Available data is primarily from Connecticut. At the pilot level we are interested in bi-state sentinels.
    - **Decision: No**

15. Extent and distribution of habitats associated with coastal embayments (e.g. fringe marsh, shorelines and tidal creeks)
    a. Sources:
    - Few have been surveyed – Alewife done by Roman Zajac (University of New Haven); Mumford Cove survey – since restoration it would be great to resurvey (these are in OLISP library/Harry/ Coves files for Alewife).
    - Mumford/Wequetequock/Quiambog Surveys by Patton et al – critical examination of sediments; reports at LIS Resource Center and published in peer review literature.
    - From Ron Rozsa (CTDEP - retired): Various grey literature reports such as Pellagrino should be at UConn Avery Point library.

    b. Group Discussion
    - Limited available data is primarily from Connecticut. At the pilot level we are interested in bi-state sentinels.
    - **Decision: No**

16. Extent and distribution of sea cliffs/bluff and escarpments
    a. Sources:
    - From Ron Rozsa (CTDEP - retired): Mapped as linear features in CT – part of the Coastal Resources map of 1979. (CT DEP OLISP) Most are modified by seawalls and so we devised the mapping term modified bluff and escarpment. These are still functionally bluffs. Mapping at http://ctecoapp1.uconn.edu/advancedviewer/

    b. Group Discussion

- Limited available data is primarily from Connecticut. At the pilot level we are interested in bi-state sentinels.
- **Decision: No**

17. Extent and distribution of unvegetated nearshore (submerged and intertidal) habitats, e.g. mudflats, sandflats, rocky intertidal

a. Sources:
   - T.Getchis (CTSG) working with CT shellfishers to use GIS to map beds
   - NWI – most detailed is the circa 1980's mapping by Nels Barrett (NRCS). CT Maps housed at CTDEP
   - CT Coastal Environmental Sensitivity Index maps (2002 - Kevin O'Brian contact CTDEP OLISP)

b. Group Discussion
   - Not enough data available relative to other sentinels
   - **Decision: No**