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

Volume 2 (2018)

Volume 2 Authors
Dr. Juliana Barrett, University of Connecticut/Connecticut Sea Grant
Cassie Bauer, NYS Department of Environmental Conservation
Penny Howell, retired, CT Department of Energy & Environmental Protection
Dr. James O'Donnell, University of Connecticut
Mark Parker, CT Department of Energy & Environmental Protection
Ron Rozsa, retired, CT Department of Energy & Environmental Protection

Long Island Sound Study
A Partnership to Restore and Protect the Sound

TABLE OF CONTENTS

BACKGROUND

I. Mission, Goals, and Objectives

Mission of the Sentinel Monitoring for Climate Change in Long Island Sound Program
The Sentinel Monitoring for Climate Change Program in Long Island Sound (SMCCP) is a multidisciplinary scientific approach to provide early warnings of climate change impacts to Long Island Sound (LIS) estuarine and coastal ecosystems, species, and processes to facilitate appropriate and timely management decisions and adaptation responses. These warnings will be based on assessments of climate-related changes to the indicators/sentinels recommended in the strategy presented here. The strategy is a dynamic document which will evolve as data becomes available and are analyzed. The 2011 strategy (Volume 1) was reviewed and updated in 2017 and, as a result, Volume 2 of the strategy (this document) was created.

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, on 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 long range priorities for sentinel monitoring of climate change in Long Island Sound. Additionally, data gaps for sentinels 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 an adaptive monitoring program based on past and present monitoring and including the results of the pilot-scale project work completed under Volume 1 of the SMCCP Strategy (2011-2016) 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 projects 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 (that do not already exist), foster needed technological advancements, and implement long term monitoring and modeling.

5. Utilize the data citation clearinghouse, developed under Volume 1, to 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 monitoring program to provide regular assessments of indicators and determine if changes should be made in parameters measured. The data citation clearinghouse is a key tool to identify new monitoring, monitoring gaps and identify potential monitoring linkages to build a more robust network.

7. Provide data and predictions 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 term "indicator" as used here is consistent with EPA's Climate Ready Estuaries program.

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 temperate range (fringe) or in a habitat that is limited by geomorphic barriers
- 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).

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 2015, nearly 9 million people live in the LIS watershed, with the Sound contributing approximately $9.4 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. Recognizing the need to incorporate scientific and technological advances and address new challenges, the LISS revised its CCMP in 2015. The 2015 CCMP is organized around four themes (waters and watersheds; habitats and wildlife;

sustainable and resilient communities; and science and management) and integrative principles that have emerged as key challenges and environmental priorities, such as climate change and sustainability, are incorporated throughout each of the four themes. For more information on the LISS, visit the LISS website.

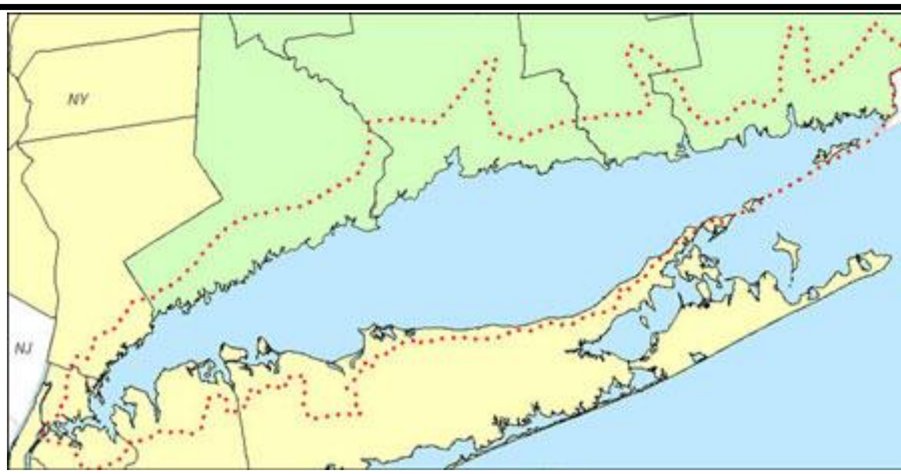

Figure 1. Map of coastal boundary established by LISS, prepared by the Southern New England Coastal Program Office, United States Fish and Wildlife Service

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

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, including the Long Island Sound Study, 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. 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)."

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. 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.

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 vetted through an RFP (request for proposals) process and that the awardee would be the best entity for an initial 'pilot' 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. The

Sound's estuarine and coastal habitats can be divided into beaches, tidal wetlands, tidal flats, sub-tidal 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.

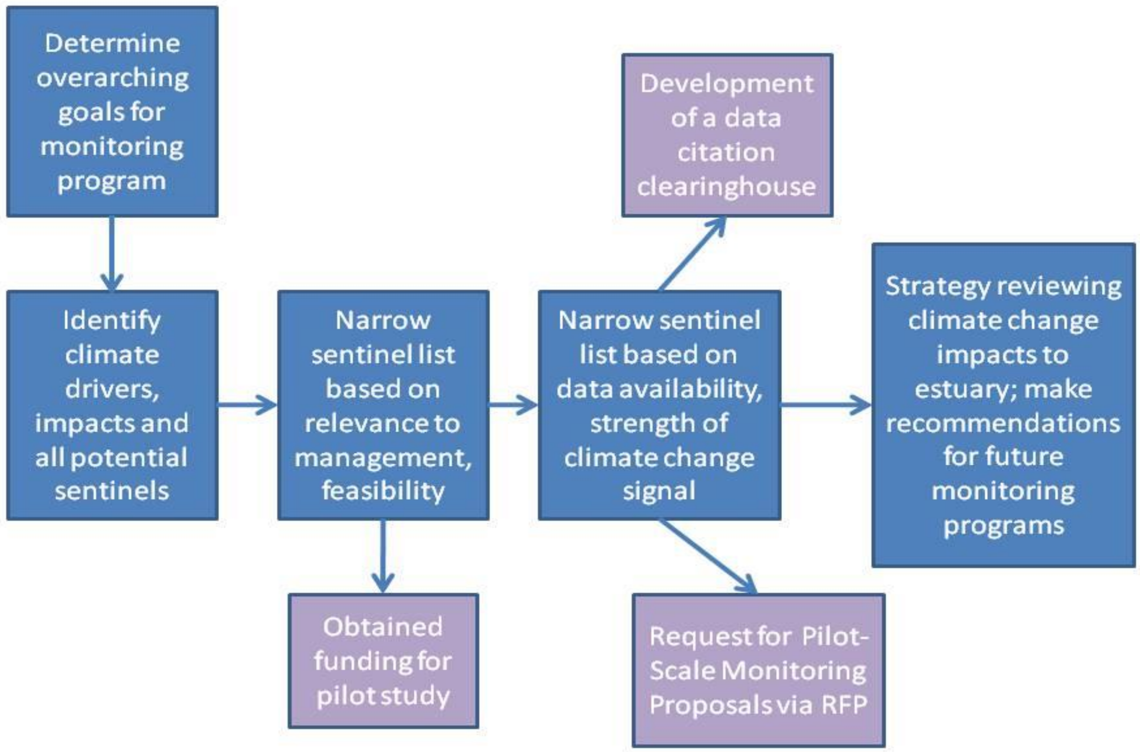

Chart 1. This flow chart describes the sequential approach applied by the SMCCP work groups to create a comprehensive strategy for climate change monitoring in Long Island Sound (blue boxes). The purple boxes are additional projects undertaken by the bi-state work group, which developed out of steps 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.

Sentinel Monitoring for Climate Change in Long Island Sound Pilot Program

Since the development of the Sentinel Monitoring for Climate Change program and the 2011 Strategy, three Long Island Sound Study funded pilot projects have been completed. These projects are:

1) *Sentinels of Climate Change: Coastal Indicators of Wildlife and Ecosystem Change in Long Island Sound*; Investigators: Chris Field, University of Connecticut and Chris Elphick, University of Connecticut; Final Report Submitted in September 2014.

2) *Sentinels of Change- Are Salt Marshes in LIS Keeping Pace with Sea Level Rise;* Investigator: Robinson Fulweiler, Boston University Laboratory of Coastal Ecology and Biogeochemistry; Final Report Submitted in January 2016.
3) *Detecting Climate Change Impacts in Long Island Sound;* Investigators: Jennifer E.D. O'Donnell, Coastal Ocean Analytics, James O'Donnell, Coastal Ocean Analytics, and Todd Fake, Coastal Ocean Analytics. Final Report Submitted in April 2016.

IV. Sentinel Monitoring Matrix and Core Parameters

The 2011 Sentinel Monitoring Strategy document included a matrix of recommended sentinels and sentinel indices to be measured. The matrix features four tables:

(1) Water Quality/Quantity,
(2) Pelagic/Benthic Systems and Associated Species,
(3) Fish Communities 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), what data have been collected to date, and what are the data gaps. In addition, the following question is asked for each sentinel: Can climate change effects be distinguished from other stressors?

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 the vertical density stratification that tends to restrict the vertical transport of oxygen to the bottom water where respiration rates are very high. The degree of stratification is controlled by surface heating and the transport of brackish water from the East River over the surface of the western Sound. As air and water temperatures rise, and river flow in the Hudson and Connecticut Rivers increase, it is expected that both respiration rates and stratification may increase exacerbating hypoxia. 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, CTDEEP 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. Fish Communities 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.

A set of core parameters was also included in the 2011 Sentinel Monitoring Strategy Document. The 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 were not included in the sentinel matrix, but the work group recommended that the availability of these core parameters from other monitoring programs be a factor when selecting monitoring sites. The core parameters include, but not limited to:

- precipitation
- stream flow (runoff and baseflow)
- sea level
- air/water temperature
- salinity
- wind (speed and direction)
- relative humidity
- groundwater levels
- pH

V. Climate Change Work Groups

As a result of the new LISS CCMP, a new Climate Change and Sentinel Monitoring (CCSM) work group was formed in 2016 (Appendix C). The purpose of the CCSM work group is to assist the Long Island Sound Study Management Conference in developing, maintaining, and enhancing a dynamic climate change monitoring program for the ecosystems of the Long Island Sound and its coastal ecoregions. One of the priorities for this work group was to carry out CCMP Implementation Action WW-30: Conduct periodic (five year) review and revision of the Sentinel Monitoring Strategy document. The CCSM work group decided the best way to revise the document would be to reconvene the technical work groups that developed the 2011 Sentinel Monitoring Matrix of sentinels and sentinel indices. As a result, the co-chairs invited the Connecticut and New York technical work group members (Appendix B) to a kickoff webinar in January 2017. The Connecticut and New York work groups were then broken up into four technical work teams, each assigned to review and update one of the four tables in the Sentinel Monitoring Matrix. The revised Sentinel Monitoring Matrix (Appendix D) consists of 33 sentinels.

VI. Priority Sentinels for Long Term Sentinel Monitoring

After revising the matrix of candidate sentinels for monitoring in Long Island Sound and its coastal ecoregions (see Sentinel Indices Matrix, Appendix D), the list of sentinels were prioritized for potential inclusion into a long-term Long Island Sound Sentinel Monitoring Program. In order to determine priority sentinels, an online survey was designed and distributed to the technical work teams in 2017. The work team members were asked to rate each sentinel based upon one of the main attributes of a sentinel: 1) 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 team 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 team members were given approximately one month to respond to the survey and reminders were periodically sent.

Overall, fourteen work group members responded to the survey. For a complete list of survey results, please see Appendix E. 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. The average rating for each attribute was generated for each of the 36 candidate sentinels. An average rating above 3.0 was considered general agreement by work group members of a sentinel’s potential value. Sentinels were included as a priority if their average rating was greater than 3.0. Of the 36 original candidates, this left 20 priority sentinels. These 20 priority sentinels were as follows:

Water /Quality/Quality

1. Hypoxia areal extent/severity/duration/timing of onset (LIS and embayments)
2. Acidification

3. Harmful Algal Bloom frequency/severity/etc.

Pelagic/Benthic Systems and Associated Species

4. Zooplankton biomass, species composition and abundance
5. **Finfish distribution and abundance**
6. Benthic Macroalgae (distribution and abundance)

Fish Communities of Long Island Sound and Associated River Systems

7. Lobster abundance (based on fishery-independent measurements)
8. Increased incidence of calcinosis or paramoebiasis in lobster
9. **Acidification impacts on shellfish**
10. **Changes in finfish community structure**
11. **Changes in diadromous fish run timing**

Coastal Habitats of Long Island Sound and Associated Species/Systems

12. **Areal extent, diversity, and composition of tidal wetlands**
13. Areal extent, diversity and composition of freshwater wetlands
14. **Changes in distribution, composition, and marine transgression of marshes**
15. Extent and distribution of coastal forests, shrublands, and grasslands
16. **Species composition within coastal forests, shrublands and grasslands**
17. Extent and distribution of unvegetated nearshore (submerged and intertidal), habitats, e.g. submerged and intertidal habitats (mudflats, sandflats, rocky intertidal)
18. Extent and distribution of barrier beaches/islands
19. Distribution, abundance and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl
20. Areal extent and distribution of eelgrass

Seven sentinels received an average score that was equal to or greater than 3.5. These seven sentinels are considered high priority and are bolded in the above list. The 2017 priority sentinel list was compared to the 2011 priority sentinel list (see Appendix F). Overall, 13 sentinels remained priorities for both 2011 and 2017; 7 priority sentinels in 2017 were not considered priorities in the 2011 survey; and 4 priority sentinels in 2011 were not considered priorities in the 2017 survey.

These research priorities 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.

VII. Data Citation Clearinghouse, data rescue, and modeling

In 2008, the Coastal Management Program of the Connecticut Department of Environmental Protection worked with the Marine Sciences Department of the University of Connecticut to create an online database to capture information about existing monitoring programs and data that would be used to identify a sentinel monitoring network to help understand the role of climate change in the coastal ecoregions and estuarine waters of the Sound. The database would serve several purposes:

- Identify existing monitoring programs (active or inactive) and data that could be used in support of monitoring to detect the contribution from climate change;
- Identify similar types of monitoring or data that could serve as a network of observations across subregions;
- Avoid redundancies such as recreating existing programs;
- Identify spatial or temporal gaps in data; and
- Identify priority data rescue priorities.

The database entries are metadata about monitoring programs, research and data. The entries may provide links to the monitoring programs and data sources wherever known.

The initial database was enhanced and became known as the 'citation clearinghouse database'. Enhancements include the addition of a geospatial component and search capabilities. This database was adopted by the Northeast Regional Ocean Council to serve as a regional database and added additional fields. It was envisioned that the LIS data would be drawn directly from the LIS database but instead, the LIS data were incorporated into the regional database. The regional database is housed on a server at Avery Point and purchased with LISS funds for the purpose of housing the clearinghouse database. This server also contains the LIS Sentinel Monitoring Website.

Data Rescue and Access

Critical data associated with long-term monitoring are lost but in some cases, an individual recognizes the value of the data and the data are rescued and made available. An example of this is the long-term temperature data records from the Noank marine laboratory was rescued by Dr. Peter Auster and these data were digitized and made available through Dr. James O'Donnell. Other data sets were not so fortunate such as the vegetation and tidal marsh studies of Dr. Michael Lefor and Dr. William Kennard. While they used the vegetation and microrelief plot technique developed by Drs. Niering and Warren, the location of the plots are unknown (not described in the reports or publications). Absent the location of those plots it is impossible to revisit those plots and establish long term trends.

Connecticut College scientists established microrelief plots in 1973 as a means to assess long-term tidal marsh changes. Copies of the original mylar maps overlays were copied by the Connecticut Department of Environmental Protection's Coastal Management Program. Some of the plots were resurveyed in 1988 and 1998. Those data are currently being rescued from disk formats that are not widely in use today. There are Connecticut College student studies of the marshes of Barn Island such as transects and vegetation maps that have been rediscovered and are in the process of being made available in digital format. These data will be made available through the Barn Island Sentinel Monitoring website.

Through the participation in the Connecticut College Arboretum Assessment of Barn Island, a review of Dr. Niering's Barn Island files located critical wetland data. Most of the photos of the photo stations created by Dr. Frank Egler in 1947 were in this collection of folders as were field notes of four new transects established in 1987 on the Palmer Neck Marsh section of Barn Island. These data were transformed into GIS line files and bridge the gap between the 1976 vegetation maps of Blake-Coleman and current vegetation which contribute to our understanding of the long-term role of marsh change caused by mosquito ditching.

The sentinel database is a key tool to identifying existing datasets and identifying sets that need to be rescued. The challenge is to identify what datasets exist and then generate a metadata record. Some researchers have entered information about datasets and many others have not. Obtaining this information may require calling or emailing scientists to determine what data exists that may support an understanding of climate change and assisting them in completing a metadata record.

Modeling

Models can be used to make forecasts and to integrate diverse data (e.g. from buoys and ship surveys) in a manner that is consistent with the model assumptions. There have been several models of the flow and water properties in Long Island Sound. The SWEM model (https://swem.uconn.edu) has been used extensively to inform water quality management decisions. Recently, UConn (LISICOS) has developed a model to describe salinity, temperature and bottom stress distributions for ecosystem mapping and sediment stability assessment (https://lisicos.uconn.edu/lis_mapping/). Models like these can be used to forecast changes to the habitats and species of the estuaries and coastal ecoregions. Models also help to identify key parameters to monitor which can then enhance forecasting accuracy. In addition to monitoring, it is important for the plan to identify important modeling efforts.

VIII. Continue Existing Monitoring Strategies

Given sufficient funding, existing monitoring programs such as NOAA and USGS tide and river gauges, meteorological measurements, LISICOS, and various CTDEEP and NYSDEC surveys will continue. In addition, CTDEEP's Long Island Sound Ambient Water Quality Monitoring Program will continue to incorporate and monitor climate change sentinels for water temperature, pH, and salinity and CTDEEP's Long Island Sound Trawl Surveys will continue to sample and document finfish warm water and cold water species abundance.

IX. Next Steps and Recommendations

Given this strategy is intended to be a dynamic document, the 2015 CCMP identified Implementation Action WW-30, to conduct a review and revision of the SMCCP Strategy every five year. 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. It is anticipated that funding for long-term monitoring will need to come from a combination of LISS funding and outside sources. 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.

The CCSM work group recommends the following next steps:

1) Hold workshops: Organize LISS sentinel monitoring workshops to help identify additional data, centralize all the available data, and develop a monitoring network.
2) Promote citizen science: use citizen science to help collect sentinel data, such as marsh trends.
3) Identify existing data sources to be added to the database and prioritize data rescue efforts on data gaps.
4) Keep the LIS sentinel monitoring website on the LISICOS website with a link to the regional NERACOOS sentinel monitoring database and update the sentinel monitoring webpage on the LISS website.
5) In order to promote the use of the database, request that a link to the database be included in future LISS research RFPs.
6) Develop a sentinel monitoring network.

Developing a Sentinel Monitoring Network

One recommendation for the SMCCP is to establish a network of monitoring sites. At the 2007 Connecticut sentinel monitoring meeting hosted by the University of Connecticut – Marine Sciences Department and the Department of Environmental Programs – Coastal Management Program the following suggestions for elements of a network were identified:

- there should be a cluster of sites (e.g., rocky intertidal, tidal wetlands, submerged habitats) for each major sub-region (i.e., eastern, central and western);
- it is important to compile basic information about long-term monitoring sites for an initial screening of potential sites for the Sentinel Site network; and
- early in the evaluation process it is important to solicit suggestions about new sampling sites.

While this meeting focused upon the estuarine environment, it is important to include the coastal upland habitats. To that end, the moderating effects of the Sound upon near-shore vegetation were used to identify the eastern and western coastal ecoregions. Inland there are long-term monitoring that are important to the understanding of climate changes in the Sound such as stream flow gauges and meteorological stations.

It is recommended that an appendix to the Monitoring Plan be developed that details the approach to developing the sentinel monitoring network. The appendix would also evaluate mechanisms for reviewing and approving additions to the network, compatibility of different methodology and identification of gaps. The database entries can be reviewed and assessed for their value to the network. One needs to assess the integrity of the data, the value of the data for monitoring climate changes, and the existence of a quality control plan. Other questions enter into this assessment such as the compatibility of measurements or whether there are statistical ways to use data collected with dissimilar sampling methods.

One approach to launching a network is to match existing QA/QC monitoring programs to the list of revised sentinels, giving consideration to providing regional coverage and then approve that list as the incipient network. The LISS should consider a hands on workshop event to seek input from partners regarding an approach to advance the development of a network.

X. References and Related Documents

Auster, P.J., R. Kurth, L.C. Wahle and T. Robben. 2017. A Century of Change in the Avifauna of Three Large Northeast U.S. Estuaries. Poster presentation. Connecticut Conference on Natural Resources 2017. Storrs, Connecticut. 13 March 2017. DOI: 10.13140/RG.2.2.17855.51365. Available at: https://www.researchgate.net/publication/315066293.

Bulkley, S., A.Al-Haj, and R. Fulweiler. 2016. Sentinels of change - are salt marshes in LIS keeping pace with sea level rise? Final Report to the U.S. EPA. 99 p.

Ellis, D., J. Vokoun, 2009. Earlier Spring Warming of Coastal Streams and Implications for Alewife Migration Timing. No. American Journal of Fisheries Management 29:1584-1589.

Field, C., C. Elphick. 2014. Sentinel of climate change: coastal indicators of wildlife and ecosystem change in Long Island Sound. Final Report to the U.S. EPA. 53 p.

G. Basso, K. O’Brien, M. Albino Hegeman and V. O’Neill. 2015. Status and trends of wetlands in the Long Island Sound Area: 130 year assessment. U.S. Department of the Interior, Fish and Wildlife Service. (37 p.)

Georgas, N., P. Howell, V. Saba, A. Blumberg, and P. Orton, J. Schute, 2016. Analyzing history to project and manage the future: Simulating the effects of climate on Long Island Sound's physical environment and living marine resources. NYSG Completion Report R/CE-33-NYCT.

Georgas, N., L. Yin , Y. Jiang , Y. Wang , P. Howell, V. Saba , J. Schulte , P. Orton and B. Wen, 2016. An open access, multidecadal, three-dimensional hydrodynamic hindcast dataset for Long Island Sound and New York/ New Jersey Harbor estuaries. *Journal of Marine Science and Engineering*, 4, 48 (22pp).

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.

Howell, P., J. Perreira, E. Schultz, and P. Auster, 2016. Habitat use in a depleted population of Winter Flounder: Insights into impediments to population recovery. *Transactions of the American Fisheries Society*, 145:1208-1222.

Howell, P. and P. Auster, 2012. Phase shift in an estuarine finfish community associated with warming temperatures. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, 4(1): 481-495.

Li et al. 2009, Particle removal by Northern bay scallops *A. irradians irradians* in a semi-natural settings: application of a flow-cytometric technique, Aquaculture 296: 237-245

NYSDEC. 2010. Distribution, Movement and Health of American Lobster (Homarus Americanus) in New York Waters with Emphasis on Western Long Island Sound. Semi-Annual Report for Grant Number NA16FW1327. (93 pgs).

NYSDEC. 2016 Fishery Monitoring of the Crustacean, Horseshoe Crab and Whelk Resources in the Marine District of Long Island, NY. Semi-Annual Report for Grant Number NA15NMF4070085. (10pgs)

Pederson, J. et al. 2003. Marine Invaders in the Northeast: Rapid assessment survey of non-native and native marine species of floating dock communities, August 2003. MIT Sea Gran College Program Publication No. 05-3. 46pp.

Rhoads, D. and J. Germano. 1982. Characterization of Organism-Sediment Relations Using Sediment Profile Imaging: An Efficient Method of Remote Ecological Monitoring of the Seafloor (REMOTS System). Marine Ecology – Progress Series. Vol. 8: 115-128.

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/

Rozsa, R., K. Metzler. 2013. Habitat Management Plan for Long Beach, Stratford, Connecticut with emphasis on invasive species control. Prepared for the Town of Stratford, Parks Department. 35p.

Stefaniak, L.M., P. Auster and I. Babb. 2014. Loss of an erect sponge on a rock reed in Long Island Sound (north-west Atlantic). Journal of the Marine Biological Association of the United Kingdom. Vol.7; e115. 6pp.

Vaudrey, J.M.P., J. Eddings, C. Pickerell, L. Brousseau, C. Yarish. (2013). Development and application of a GIS-based Long Island Sound Eelgrass Habitat Suitability Index Model, Final report submitted to the NEIWPCC and the Long Island Sound Study. 171 p. + appendices. http://digitalcommons.uconn.edu/

Whitlatch, R. and R. Zajac. 2011. Development of a Long Island Sound (LIS) Benthic Index for Assessing Environmental Conditions. Connecticut Sea Grant Final Report. 27pp.

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.

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.

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.

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.

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).

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

CCE	Cornell Cooperative Extension [Suffolk County, NY]
CCMP	Comprehensive Conservation and Management Plan
Chl a	Chlorophyll *a*
CO_2	Carbon Dioxide
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
CTDEEP	Connecticut Department of Energy and 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
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
LISS	Long Island Sound Study
MADL	Marine Animal Disease Laboratory [Stony Brook University]

NEIWPCC	New England Interstate Water Pollution Control Commission
NMFS	National Marine Fisheries Service [NOAA]
NOAA	National Oceanic and Atmospheric Administration
NY	New York (referring to the state)
NYC	New York City
NYS	New York State
NYSDEC	New York State Department of Environmental Conservation
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
SUNY	State University of New York
UConn	University of Connecticut
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

B. Technical Workgroup Participants

Name	Organization	Work Team*
Peter Auster	University of Connecticut	PB
Juliana Barrett	CT Sea Grant	CH
Cassie Bauer, lead	NYS Department of Environmental Conservation	WQ, PB, F, CH
Charles deQuillfeldt	NYS Department of Environmental Conservation	PB
Kristin DeRosia-Banick	CT Department of Energy and Environmental Protection	WQ, F
Carol DiPaolo	Coalition to Save Hempstead Harbor	WQ
Chris Elphick	University of Connecticut	CH
Peter Francis	CT Department of Energy and Environmental Protection	WQ, CH
Lorraine Holdridge	NYS Department of Environmental Conservation	WQ
Jesse Hornstein	NYS Department of Environmental Conservation	F
Penny Howell	Retired, CT Department of Energy and Environmental Protection	F
Mark Lowery	NYS Department of Environmental Conservation	CH
Matthew Lyman	CT Department of Energy and Environmental Protection	WQ
Peter Murdoch	U.S. Geological Survey	WQ, CH
Katie O'Brien-Clayton	CT Department of Energy and Environmental Protection	WQ, F
James O'Donnell	University of Connecticut	WQ
Vicky O'Neill	NYS Department of Environmental Conservation	F, CH
Mark Parker, lead	CT Department of Energy and Environmental Protection	WQ, PB, F, CH
Suzanne Paton	U.S. Fish and Wildlife Service	CH
Dylan Redman	NOAA Fisheries	WQ
Ron Rozsa	Retired, CT Department of Energy and Environmental Protection	CH
Emily Runnells	NYS Department of Environmental Conservation	PB, F, CH
Camilo Salazar	Suffolk County Dept. of Environmental and Energy	CH
Chris Schubert	U.S. Geological Survey	WQ, CH
William Wise	NY Sea Grant	PB, F
Harry Yamalis	CT Department of Energy and Environmental Protection	PB, F, CH

*WQ= Water Quality/Quantity; PB= Pelagic/Benthic Systems; F=Fish Communities of LIS; CH= Coastal Habitats of LIS

C. LISS Climate Change and Sentinel Monitoring Work Group

Dr. Juliana Barrett, CT State Co-Lead, University of Connecticut/Connecticut Sea Grant
Cassie Bauer, NY Lead, NYS Department of Environmental Conservation
Robert Burg, New England Interstate Water Pollution Control Commission
Penny Howell, retired, CT Department of Environmental Protection
James O'Donnell, University of Connecticut
Mark Parker, CT Lead, CT Department of Environmental Protection
Ron Rozsa, retired, CT Department of Environmental Protection

D. Long Island Sound Matrix of Climate Change Sentinels

Thirty-three 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, Fish Communities 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 effects 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 Indices**	**Data Availability[2]**
Is there a decreasing trend in Dissolved Oxygen (DO) in LIS? Are DO levels falling below the threshold level needed to support aquatic life (DO>1.4ml/l) due to climate related changes?	Hypoxia in LIS and embayments	• Water temperature • Wind (change in speed and direction) • Dissolved CO2 (pH related)	The combination of increases in water temperature and decomposition of excess algae reduces DO and leads to hypoxia; wind factors too (change in speed and direction = change in stratification)	Unknown at this time. (How do we tease out what is driving DO improvements (or worsening)? Is it temperature related, pH related, salinity, eutrophication related, STP discharge reductions?)	• DO in LIS and embayments (intensity, area, frequency, and duration) • Intervals of uncertainty of discharge vs. area of hypoxia • Wind speed and direction • Stratification trends	• CTDEEP LIS Monitoring Program (1991-present) • IEC WLIS monitoring (1991-present) • LISICOS buoy data **Embayment groups with approved EPA QAPPs:** • Save the Bay Westerly- Pawcatuck River and Little Narragansett Bay (Dave Prescott) • RI DEM Pawcatuck monitors • CUSH- Mystic/Stonington harbors (Sally Cognan and Fran Pijar) • Harbor Watch River Watch (Sarah Crosby) • Copps Island Oyster (Dick Harris) • CFE/STS- Bryam River, Greenwich, Mamaroneck area • USGS (CT River at Essex and Old Lyme, Flax Pond, Orient) • Millstone (John Swenarton) • Maritime Aquarium, Norwalk - MYSound • Williams College- Mystic, CT • U.S. Coast Guard • SCSU (Vin Breslin) • UNH (Carmela Cuomo) • Yale- Mill River and West River tidegate studies (Gabe Benoit) • Hempstead Harbor (1992 to present)- CSHH (Carol DiPaolo) • Oyster Bay (2006-present) – Friends of the Bay (Paul D’Orsay) • Cedar Island Marina – Clinton Harbor • Other embayments participating in Save the Sound’s Unified Water Study

[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 Indices**	**Data Availability[2]**
Is there an increasing trend in the salinity of groundwater? Is the depth to water declining? What are the trends of aquifer outflow (discharge) and its drivers? What are the freshwater ecosystem needs?	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 the amount of groundwater recharge; reduced precipitation and recharge reduce the amount of groundwater. Or, if precipitation increases groundwater levels could rise leading to a shallower depth to water and failure of on-site wastewater treatment systems. Groundwater acidity could change if the soil is unable to buffer CO_2.	Groundwater quantity- yes Groundwater quality – unknown at this time	• Salinity • Water temperature • Water table elevation	• 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 • Ground water sustainability projects (new project) • USGS(CT) modeling groundwater – Dave Bjerklie **Data needs** • Core network of regional continuous monitoring sites • More groundwater modeling
Is there an increasing trend in the abundance of human pathogens in LIS (as	Human related pathogens	• Increased precipitation • Streamflow • Groundwater level	Increases in precipitation, runoff, and groundwater level leading to failures in on-site wastewater	Maybe	• Abundance of a specific pathogen (i.e., enterococci, fecal coliform)	• LISS indicators program gets beach closure data annually from CTDEEP, CTDPH and NYDOH. However, many beach closures are preemptive closures based on rainfall.

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 Indices**	**Data Availability[2]**
evidenced by abundance of specific indicator organisms?			systems, WPCF exceedances, and storm water can cause increases in bacterial levels harmful to human health			
Is there an increasing trend in the abundance of naturally occurring pathogens in LIS?	Naturally occurring pathogens such as vibrio spp.	• Water temperature • Chlorophyll • pH • Turbidity • Salinity • Virulence of strains	Increases in the level of naturally occurring pathogens can cause a rise in human illnesses related to shellfish consumption (Gastrointestinal illness or systemic illness) and environmental (wound and ear) exposures	Maybe	• Abundance of indicator organism (monitored by CT DA/BA as Total vibrio parahaemolyticus (tlh) and virulence indicators trh + and tdh+ • Number of human illnesses related to Vibrio spp. • Spatial and temporal distribution of illnesses	• CT DA/BA monitors shellfish growing areas for shellfish tissue concentration of Total Vp, tdh+ and trh+ indicator using PCR (DeRosia-Banick) • CT DPH Epidemiology and Emerging Infections Vibrio illness surveillance data (Quyen Phan) • CT DA/BA tracks illnesses related to shellfish consumption (DeRosia-Banick)
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); Shellfish bed water quality classification	• Increased precipitation • Increased runoff • Increased bacterial levels	Increases in precipitation and runoff can cause increases in bacterial levels harmful to human health Precautionary closures Event closures	Maybe: increases in stormwater to CSOs can be directly linked with shellfish bed closures	• shellfish bed closures, number and duration • Change in acreage of shellfish growing area classified for direct harvest	• CT DA/BA Database (2003 to present) • NYSDEC
Is there an increase in the	Acidification	CO_2 more soluble in colder waters.	Aqueous CO_2 concentrations tend to	Maybe	• pH	• USGS continuously monitors pH at flax pond (2008-present) and Orient Point (2012 to present)

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 Indices**	**Data Availability**[2]
hydrogen ion concentration (pH) of sea water in LIS?		pH decreases (i.e., acidification increases) Ammonia levels	increase and carbonate ion concentrations CO_3^{2-} would tend to decrease. These new conditions would affect the ability of marine calcifying organisms to form biogenic calcium carbonate ($CaCO_3$). Some species would develop thinner shells (oysters, clams, mussels), others would develop thicker shells (crabs, shrimps, lobsters).		• Thickness of crustaceans shells	• CTDEEP 2010 to present • Embayment monitoring of pH: Oyster Bay (Friends of the Bay, 2008-present) and Hempstead Harbor (Coalition to Save Hempstead Harbor) • Millstone Power Station data • SoMAS data – Chris Gobler • UConn - Deployed pH sensors **Potential data sources** • CT DA/BA potential new project to monitor oyster beds for pH • NOAA's long-term dataset should include pH by 2018
Is there a change in suspended particle concentrations in the surface waters of LIS?	Turbidity of the 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 - Flax Pond (2008 to present) Orient Point (2012 to present) • UConn, SBU, ACOE • CTDEEP (1991 to present) ship surveys do TSS and PAR • Embayment monitoring of turbidity: Hempstead Harbor (2008 to present)

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 Indices**	**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 • Remote sensor sites	• Chris Gobler (SUNY Stony Brook) monitors for Alexandrium. • NYSDEC has to monitor for the shellfish sanitation program (2006-present) • CT DA/BA has a Biotoxin Contingency Plan which includes plankton monitoring stations throughout LIS and embayments; stations are sampled by vertical plankton tow on rotating schedules between March and October and additionally as necessary to evaluate CT growing areas during potential and actual HAB events. • CT DA/BA also analyzes shellfish tissue samples for PSP and ASP in response to HAB events and for routine screening of commercial shellfish production areas. • 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 experience elevated levels of PSP toxin in recent history. • PSP monitoring data is available from 1990 to present. General plankton data is available from 1997 to present. • UConn (Heidi Dearson) HAB data • 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)

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 (retired) • Nancy Balcom, CTSG • NYSDEC PRISMS • trawl surveys/ embayment seine surveys- CTDEEP/Milstone • Sandy Shumway (UConn) –algae; • data from other research projects • iMAPinvasives online database. (marine species should be added in the future) • MIT Sea Grant's Marine invader tracking and information system (MITIS) • Rapid assessment survey (Pederson et al., 2003)
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 • Remote Ecological Monitoring of the Seafloor (REMOTS) Benthic camera	• Long Island Sound Benthic Index (Whitlatch and Zajac, 2011) • REMOTs system (Rhoads and Germano, 1982) • 80 stations in LIS (per ICF document) • Cable fund seafloor mapping work (reference sites) • National coastal assessment – CT collects samples for main body of LIS (mostly looking at contaminants) • Chapter 5 of the Seafloor Mapping of LIS Phase 1 Final Report: http://longislandsoundstudy.net/wp-content/uploads/2010/02/LISCF_Pil

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**
						otMappingProject_Report_Final_June2015-reduced-file-size.pdf
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)	• CTDEEP collects Chlorophyll a monthly at 17 stations (more in summer): 1994-present • CTDEEP collects monthly phytoplankton and zooplankton (annual reports available) • CTSG working with NOAA on the Phytoplankton Monitoring Network for LIS • CTDA/BA have been and are currently monitoring phytoplankton • SeaWiFS, MODIS Aqua and Terra, SNPP VIIRS Red Proxy Chlorophyll a – Derived from NASA Rrs (Dierssen) • NOAA east coast remote sensing node. • Monthly chlorophyll a samples from 1992-1995 (Capruilo et al. 2002) • Chorophyll a data collected in Milford Harbor in 2006 (Li et al. 2009)
Are there any trends in annual zooplankton biomass? Is there evidence of changes	Zooplankton species composition and abundance	• Water temperature • pH	• Increases in water temp will affect the species • composition and abundance of planktonic orgs depending on	Maybe	• Annual biomass (George McManus and Hans Dam, UConn) • species composition • species identification analysis	• Hans Dam UCONN doing monthly zooplankton analysis for CTDEEP from at least 2002-present; 6 stations in LIS **Data gap**

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**
in zooplankton species composition?			thermal tolerances (and new species) • Introduction of new zooplanktivorous species • Shifts to jellyfish from crustacean plankton			• No one is looking at demersal zooplankton
Have there been long-term declines in cold-water species in LIS and increases in warm-water species? If so, are these trends continuing and is the shift becoming more apparent? Is there any evidence that nearshore habitat is being harmed by changes related to sea level rise?	Finfish (Distribution and Abundance)	• Water temperature • SLR • Runoff & precipitation • Stream Flow	Increasing water temperature is leading to a shift in the fish 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 (manageme nt 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	• NYS DEC Western Long Island Seine Survey (1984-present) • NYS DEC has a long-term juvenile survey for the Peconic estuary (good link to see if changes are local or regional) • CTDEEP seine survey- 8 sites sampled in September • Howell and Auster, 2012 • Howell et al., 2016
Are there changes in the distribution and abundance of benthic algae species that are associated with	Benthic Macroalgae (e.g. seagrasses, kelp)	• Precipitation • Increased turbidity • Water temperature	Some marine species could decrease locally if freshwater overwhelms current habitat	Likely	• Specific species studies	• There is published work on light levels and temperature requirements. • Monitoring by Millstone Environmental Lab • Kelp aquaculture • Charlie Yarish and Jamie Vaudrey (UConn) research

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**
climate-related factors?			Increased turbidity could decrease available light necessary for photosynthesis and reproduction. 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 data and image sets from Peter Auster (UConn & Mystic Aquarium), collected at various times and locations, could provide general patterns (see Stefaniak et al. 2014 for example of severe change in sponge fauna) • Foram data: 1996/97 E. Thomas et al.(Yale) (soft substrate communities); M. Buzas (1965/66, 1969); 1948 F. Parker

TABLE 3. FISH COMMUNITIES 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 temperatures 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 for larval; Yes for adults	• Adult and larval lobster abundance from fisheries independent monitoring • Catch per unit effort	• CT DEEP LIS Trawl Survey adult abundance indices (1984-present) http://www.ct.gov/deep/cwp/view.asp?a=2696&q=322660&deepNav_GID=1647 • CT DEEP larval annual indices at 7 stations in LIS (1984-2012) • CTDEEP commercial sampling (1983-2014) • CT Lobster Population Studies (2005-2010) Final Report http://www.ct.gov/deep/lib/deep/fishing/commercial/2005_2010_ct_lobster_population_study_report.pdf • CT Lobstermen's Volunteer Temperature Survey http://www.ct.gov/deep/lib/deep/fishing/fisheries_management/022609_lobster_volunteer_termperature_survey.pdf • Millstone larval entrainment index (Dominion Nuclear CT 1984-present) • Millstone monitoring adult lobsters through research traps (DNC 1976-present) • NYSDEC young-of-year lobster survey from 2002-2009 and an adult trap line survey in WLIS from 2003-2007 (NYSDEC, 2010) • Cornell Cooperative Extension under contract with NYSDEC conducts port and market sampling for lobster (NYSDEC, 2016)

TABLE 3. FISH COMMUNITIES 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 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	• NYSDEC does disease monitoring opportunistically
			Paramoebiasis (*Neoparamoeba pemaquidensis*) (a parasite that attacks the nervous system of lobsters)	Maybe	• Distribution in the water column; also invaded soft tissue, however, this infection is most likely secondary	• Limited data collection occurred in CT 2001-2002, 2007. Pathogen not currently monitored. Molecular test was developed and is available.
Have water temperatures 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	• CT DEEP Water Quality Survey and LIS Trawl Survey (1991 – present) • No current assay work • CT DEEP sponsored in situ water temperature monitoring in the traps of volunteer lobstermen in LIS (2006-present)
Is there evidence of changes in abundance in shellfish associated with increased acidification in LIS?	All Shellfish (clams, mussels, oysters, scallops)	• pH	Shellfish are stressed and their decline is exacerbated locally by nutrient loading, acidification, and temperature.	Yes	• pH • alkalinity • CO_2 concentration	• Current shellfish research by Chris Gobler, Bassem Allam, and others at SUNY Stony Brook

TABLE 3. FISH COMMUNITIES 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**
Are there increasing trends in one or more oyster diseases? Is there any association of oyster declines with increases in parasites that are linked to increases in salinity and water temperature?	Eastern Oyster	• Water temperature (primary factor) • Salinity (secondary factor) for both Dermo and MSX.	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 disease Dermo, and *Haplosporidium nelsoni*, and *Haplosporidium costale* which cause MSX and SSO respectively. The incidence of both diseases has been linked to increases in water temperature and salinity (Ford, 1996). Monitoring trends for all three organisms have shown a decreasing trend due to development of resistance.	Probably not; many factors other than climate change are responsible for disease	• % oyster infected per square area (need to take into account disease prevalence AND intensity)	• MADL performs 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) **Data gap** • For LIS, there is no monitoring by any public agency in NY.

TABLE 3. FISH COMMUNITIES 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**
Are there trends in Eastern oyster landings associated with climate related factors?		• Water temperature • Salinity • pH • Precipitation • Runoff and turbidity • Phytoplankton community structure • HABs	pH effects on calcification (Table 1) Climate-related habitat changes Increases of invasive species that are predatory or compete for resources Shifts in phytoplankton community structure Shellfish-toxic HABs	Maybe; many factors can drive landings trends	• Eastern oyster landings • Distribution and abundance of Eastern Oyster • Oyster recruitment in natural beds • Mortality events	• CT DABA maintains landings data from 1990 through 2007 • CT DABA is currently seeking to establish daily landings reporting for commercial shellfish harvest via ACCSP SAFIS system • Species distribution and abundance is not monitored at the state level in CT • CT DA/BA has recruitment data from 1997 to present. • CTDA/BA have been and are currently monitoring phytoplankton for HAB detection
Are there changes in disease prevalence and parasites in Northern Quahogs?	Northern Quahog	• Water temperature (primary) • Salinity (secondary)	QPX (Quahog Parasite Unknown)	Probably not; many factors other than climate are responsible for disease	• % 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. • Bassem Allam (SUNY Stony Brook) monitors QPX in New York State waters, see: http://you.stonybrook.edu/madl/diagnostic/qpx-monitoring/

TABLE 3. FISH COMMUNITIES 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**
Are there trends in Northern Quahog landings associated with climate related factors?		• Water temperature • Salinity • pH • Precipitation • Turbidity • Phytoplankton ecology • HABs	pH effects on calcification (Table 1) Climate-related habitat changes Increases of invasive species that are predatory or compete for resources Shifts in phytoplankton community structure Shellfish-toxic HABs	Maybe; many factors can drive landings trends	• Northern Quahog landings from industry reporting • Distribution and abundance of Northern Quahog • Northern quahog recruitment • HAB events • Mortality event	• CT DABA maintains landings data from 1990 through 2007 • CT DABA is currently seeking to establish daily landings reporting for commercial shellfish harvest via ACCSP SAFIS system • Species distribution and abundance is not monitored at the state level in CT • Northern quahog recruitment is not monitored at state level in CT • CT DA/BA have been and are currently monitoring phytoplankton for HAB detection

TABLE 3. FISH COMMUNITIES 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**
Are there changes in bay scallop population abundance?	Bay Scallops	• Increased precipitation • Decreased salinity • Further loss of habitat (eelgrass) • Increased nutrients leading to degraded water quality	Increased/ decreased pH effects on calcification/shell formation? Increases of invasive species that are predatory or compete for resources	Maybe; more variable over time	• Distribution and abundance of Bay Scallops and habitat (eelgrass)	• LISS through USFWS conducted eelgrass surveys in 2006, 2009, and 2012. The next survey is scheduled for the summer of 2017. • NOAA NMFS Milford Laboratory conducts periodic sampling in eastern LIS, as does Millstone Lab • UCONN and Cornell have information on eelgrass abundance
Are changes in seasonal water temperatures affecting finfish community structure?	Finfish	• Temperature (primary) • Increased precipitation • Salinity	Finfish community is divided into 4 temperature guilds (cold-adapted, warm-adapted, subtropical, and tropical). The warm-adapted group has increased in abundance and diversity while the cold-adapted group has decreased in abundance. Subtropical has increased in diversity.	Yes	• Abundance and diversity of finfish in the 4 temperature guilds.	• LIS Trawl Survey catch analysis (Howell & Auster, 2012) • LIS Climate Model- Temperature History and Projection (See NY Sea Grant Completion Report (Georgas et al., 2016) • Winter Flounder population data and work done at the Milford Lab (Howell et al., 2016) • Harbor Watch Trawl Surveys in Norwalk Harbor, Five Mile Harbor and Saugatuck Harbor
Is there a change in finfish pathogen			Pathogens (i.e., Mycobacteria):	Maybe	• Proportion of population infected with the pathogen or	• MADL has some baseline data • NYSDEC contracted MADL to do monitoring for this in LIS and Hudson

TABLE 3. FISH COMMUNITIES 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**
abundance and occurrence? (secondary question)			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).		annual index of mortalities directly attributable to this disease (difficult) • Parasite prevalence, abundance, seasonality, location, pathology: including but not limited to: Lironeca, Lernanthropus, Lernaeenichus	River in 2007-09. No current funding, but there is a pending proposal with NYSDEC to re-start monitoring.
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. Thermal gradients may limit movement and habitat availability.	Yes, demonstrated for Alewife; probably for Blueback and Shad.	Trend analyses (similarity coefficient /regression) of survey catch data; correlation of adaptation group abundance and individual species, with LIS temperature data	• LISS indicators program gets information from Steve Gephardt, CTDEEP, on Anadromous fish runs at Mianus Pond Fishway, Bride Brook, and Latimers Brook. (http://longislandsoundstudy.net/indicator/index-of-anadromous-fish-runs/) • CT Diadromous Fish Report (2014) http://www.ct.gov/deep/lib/deep/fishing/publications/F50D35.pdf • Hindcast model for river temperature available for 1979-2013. (Georgas et al., 2016) • See Ellis paper (Ellis, 2009)

TABLE 4. COASTAL HABITATS OF LONG ISLAND SOUND and ASSOCIATED SPECIES/SYSTEMS						
Monitoring Question	**Sentinel**	**Ecological Drivers**	**Responses to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors**	**Sentinel Indices**	**Data Availability**
Is there evidence of loss of marsh or change in marsh plant and animal communities? 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?	Tidal wetlands and associated species	• Sea level rise • Salinity • Precipitation • Stream flow • Runoff • Groundwater flow • Wind • Grid ditching • Loss of coastal barrier beaches	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; cannot tell the role of SLR from long-term impacts of grid ditching; do not understand the role of aggrading ditches in sequestering sediment availability to marsh surface- need sediment budgets	• Change in low:high marsh ratio • Elevation (Surface elevation tables - SET's); m², by veg type; transects; • Accretion rate- feldspar markers • Chronology of marsh elevation and accretion (SETs & Pb210) • Extent of plant species such as: Phragmites, Spartina alterniflora, Spartina patens, Juncus gerardii • Change in timing and duration of spring freshet on CTR (affects the natural impoundment effect to waterfowl migration in spring) • Pathogens (sudden vegetation dieback)	• SET's and feldspar markers 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 tidal marshes with GPS locations • UCONN- Remote sensing vegetation lab that classifies low marsh vs. high marsh • Sentinel Monitoring pilot study on salt marshes (Bulkley, 2016) • NY Tidal Wetlands Trends Analysis http://www.dec.ny.gov/lands/5113.html • Long Island Sound Trends Assessment (G. Basso et al., 2015). • Shimon Anisfeld's research, Yale school of Forestry & environmental studies (http://environment.yale.edu/profile/anisfeld/pubs) • Long-term vegetation data at Barn Island (transects, photostations) • Vegetation mapping (Barn Island, Great Meadows, Ragged Rock Creek, Mamacoke Marsh • Tide gauges

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

Monitoring Question	Sentinel	Ecological Drivers	Responses to Climate Related Factors	Climate Change Effects can be Distinguished from other Stressors	Sentinel Indices	Data Availability
						• Connecticut College microrelief and vegetation plots (12) • SLAMM data for NY and CT
Is sea level rise inundating freshwater wetlands? Is the natural vegetation of these wetlands being replaced by salt-tolerant plants?	Freshwater wetlands and associated species	• Sea level rise • Grid ditching • Increased precipitation • Air temperature • Increased runoff • Changes in groundwater • Salinity • Waves • Timing of spring freshet	Inundation and changes in salinity due to sea level rise (salt wedge) alter distribution and abundance; wetlands may convert to salt marsh if unable to 'Keep pace' and migrate landward; changes in spring freshet may impact marshes and position of the salt wedge on the rivers; changes in groundwater supply could affect plant species composition	Maybe; changing salt wedge position on CT River will reduce the amount of freshwater tidal marsh and favor an increase in salt marsh at the mouth of the river	• percent and area of different vegetation types • timing and duration of spring freshet (measure freshwater inflow) • salinity	• CT marshes mapped from aerial photography; some transects for CT River marshes • Nels Barrett (NRCS) set up permanent transects in CT River freshwater tidal marshes (1995) • LISS indicator on spring freshet from USGS data. • Old surveys from Bob Craig • Ragged Rock vegetation mapping • USGS real-time salinity gauges at Essex (to monitor changes in salt wedge) • USGS CT River gauges are useful for detecting change to center mass • USFWS Nyssa forest and marsh transgression plots at Barn Island (Raph Tiner)
Is there evidence of changes in the composition or abundance of coastal upland vegetation communities?	Coastal forests, shrublands, and 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 (ie. presence of saltmarsh plants in the forest understory or plant species expanding their range);	• Permanent plots in just a few sites • Bloom timing: Historical info (100y) from horticultural societies (Bronx) & arboretums LI Botanical Society; Perhaps migratory beekeepers. • USA National Phenology Network data • Sentinel Monitoring Pilot Project – forest transects adjacent to tidal marsh (Field, 2014)

TABLE 4. COASTAL HABITATS OF LONG ISLAND SOUND and ASSOCIATED SPECIES/SYSTEMS						
Monitoring Question	**Sentinel**	**Ecological Drivers**	**Responses to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors**	**Sentinel Indices**	**Data Availability**
					• Changes in timing of plant blooms, leaf out • Tree mortality at the boundary between marsh and upland • Vegetation mapping	• Long-term vegetation and bird monitoring at Connecticut College Arboretum (1953- every 10 years to present) • Barn Island upland vegetation plots (2012, C. Jones) • Bluff Point Vegetation plots – planned for 2018 (C. Jones) • Vegetation mapping and community analysis at West Rock Ridge • Bluff Point Vegetation transects (1996 Niering) • NYC DPR Ecological Assessments (Entitation) Reports https://www.nycgovparks.org/greening/natural-resources-group/publication
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 change effects)	• m^2 lost	• Potential to count m^2 lost by using aerial imagery • Topographic sheet (historic shoreline change analysis)- UConn/CT DEEP/Sea Grant • 1979 mapping of coastal resources including bluffs (mostly modified bluffs – bluff behind seawall)
Is the area of tidal flats declining in association with increased inundation from sea level rise?	Nearshore Subtidal/ Intertidal Flats and Rocky Intertidal Zones	• 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	Yes	• m^2 • Shorebird abundance • Number/species of high tide roosts • Sample benthic invertebrates to determine prey	• International Shorebird Survey • eBird data • WLIS Citizen science project by NYC Audubon • Aerial images from eelgrass surveys. Only available for eastern portion of LIS

TABLE 4. COASTAL HABITATS OF LONG ISLAND SOUND and ASSOCIATED SPECIES/SYSTEMS						
Monitoring Question	**Sentinel**	**Ecological Drivers**	**Responses to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors**	**Sentinel Indices**	**Data Availability**
Are shorebirds and other species (ie. bivalves) dependent on tidal flats declining?			tidal flat fauna, and rocky intertidal fauna		availability and depletion rate	• Baseline information for invertebrates (Roman Zajac) • Topographic sheet analysis • Submergence of former tidal marshes in central and western LIS- OLISP has digitized the 1880's wetland boundaries high marsh and low marsh- use with aerial photography to visualize wetland submergence. NY DEC has mapped the loss of wetland and increase in flats.
Is there evidence of increased erosion or deposition of barriers related to increases in sea level rise or storm surges? Is there an overall loss of barriers due to sea level rise? Are there changes in the plant and animal communities?	Barrier beaches/islands	• Sea level rise • Changing wind patterns • Changes in wave energy • Changes in sediment supply from eroding headlands	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 • Acreage (vegetation, dune, and beach habitats) • State listed plants • Rates of shoreline change	• USGS Coastal Vulnerability Index (CVI) • Historic shoreline data from sources like T-sheets and aerial photography • Natural diversity database • Long Beach management plan (Rozsa and Metzler, 2013) – habitat mapping in 2012 reveals foredune losses from Hurricane Irene and can be overlain on NOAA post-Sandy images to identify overwash fans.
Are there changes in coastal bird populations?	Changes to marsh birds (e.g. salt marsh sparrow), 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	• Marsh bird counts • Colonial waterbird counts • Shorebird counts • Winter waterfowl counts • Coastal upland bird counts	• CTDEEP and NYSDEC have limited data; CTDEEP has good winter waterfowl data; both CTDEEP and NYSDEC have data on colonial water birds (but no reason to believe it is climate change related) • NYC Audubon Harbor Herons Survey http://www.nycaudubon.org/issues-of-concern/harbor-herons

TABLE 4. COASTAL HABITATS OF LONG ISLAND SOUND and ASSOCIATED SPECIES/SYSTEMS						
Monitoring Question	**Sentinel**	**Ecological Drivers**	**Responses to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors**	**Sentinel Indices**	**Data Availability**
			• Distribution and abundance of forage fish could impact nesting terns		• Data from Great Gull Island and Falkner Island	• Chris Elphick (UConn) has detailed data for all coastal marsh birds • Other bird data sets include: International shorebird Survey, eBird data • NYS parks has winter waterfowl data • Audubon has nesting wading bird data • American Museum of Natural History has Great Gull Island data • USFWS for Stewart B. McKinney Falkner Island data • Analysis of Audubon Christmas Bird Count for shorebirds (Auster, et al. 2017) Available at: https://www.researchgate.net/publication/315066293 • Decadal surveys of breeding birds at the Connecticut College Arboretum (1953 to the present) - Askins
Are there shifts in insect species due to climate change? Are there changes in the distribution and the phenology of these species? Are issues with mosquitoes (and associated diseases) increasing with more standing water on the marshes?	Insects (e.g.. hairy-necked tiger beetle; southern pine beetle; mosquitoes)	• 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 • Tree swallow roosts	• Invasive species that are doing damage are being monitored. (USDA, USFS) • National Phenology Network • CT Butterfly Association • USDA, NYSDEC, USFW will have data on species moving up from the South • NY and CT track mosquitoes. The CT Agricultural Experiment Station (CAES) has data and sets out traps each year. • Long-term studies at Barn Island reveal how the marsh has been changing from both mosquito ditching and sea level rise. As the marsh reverts

TABLE 4. COASTAL HABITATS OF LONG ISLAND SOUND and ASSOCIATED SPECIES/SYSTEMS						
Monitoring Question	**Sentinel**	**Ecological Drivers**	**Responses to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors**	**Sentinel Indices**	**Data Availability**
						to the pre-ditching condition, salt pannes are increasing and creating new breeding habitat for salt marsh mosquitoes.
Is there evidence of declines in eelgrass 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 • Snow pack and its role with regard to the position of salt wedge on major rivers	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	• Eelgrass distribution • Secchi depth (light penetration) • Salinity • Precipitation • Temperature	• USFWS completed eelgrass surveys in 2002, 2006, 2009, 2012, and 2017 (scheduled) • Jamie Vaudrey (UConn) and Jim Kremer (UConn) research • Eelgrass suitability index model (Vaudrey et al., 2013) • Chris Pickerell (CCE) has habitat restoration data in NY (http://www.seagrassli.org/) • Historic distribution data (GIS and Rozsa report)

TABLE 4. COASTAL HABITATS OF LONG ISLAND SOUND and ASSOCIATED SPECIES/SYSTEMS						
Monitoring Question	**Sentinel**	**Ecological Drivers**	**Responses to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors**	**Sentinel Indices**	**Data Availability**
Is there evidence of declines in species of SAV or species dependent on SAV that is associated with climate-related factors specific to the tidal portions of the rivers? 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	• SAV abundance and distribution • Secchi depth (light penetration • Salinity • Water temperature • pH	• CT River Study (1995-97) Juliana Barrett (CTSG). The Roger Tory Peterson Institute is talking about updating the study. There is a 1945 survey report of this river.
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)? Will the rate of cold-stunning in sea turtles change?	Marine Mammals, Sea Turtles, and Diamondback Terrapins	• Sea level rise • Temperature • Runoff • Prey availability	Observable changes in distribution and range, relative abundance, changes in preferences for nearshore nursery waters, availability and preferences in haul out sites and rookeries, incidence of disease (due to toxic blooms), changes in overall survival associated with potential changes in available food sources; changes in T could decrease the incidence of cold-stunning;	Maybe; this is important to the public	• Distribution Data	• Riverhead Foundation/Atlantic Marine Conservation Society • CRESLI • Woods Hole Institute • Norwalk Aquarium • Mystic Aquarium • Russell Burke (Hofstra University)- Diamondback terrapins

TABLE 4. COASTAL HABITATS OF LONG ISLAND SOUND and ASSOCIATED SPECIES/SYSTEMS						
Monitoring Question	**Sentinel**	**Ecological Drivers**	**Responses to Climate Related Factors**	**Climate Change Effects can be Distinguished from other Stressors**	**Sentinel Indices**	**Data Availability**
			Runoff linked to increased pathogen occurrence			

E. 2017 Survey results used to prioritize sentinels for long-term monitoring

Question: A climate change signal could in theory be distinguished from natural variations or anthropogenic stressors with the appropriate sampling resolution	**Strongly Disagree**	**Disagree**	**Agree**	**Strongly Agree**	**Unsure**	**Total**
Hypoxia areal extent/severity/duration/timing of onset (LIS and embayments)	0	2	4	5	3	14
Groundwater quantity and quality within coastal areas	0	2	5	2	4	13
Abundance of human related pathogen indicator species	1	3	2	0	8	14
Abundance of naturally occurring pathogens	1	2	4	0	6	13
Amount and duration of shellfish bed closures	1	3	3	0	6	13
Acidification	1	1	5	6	1	14
Turbidity of the water column	2	5	2	1	3	13
Harmful Algal Bloom frequency/severity/etc.	1	0	4	4	4	13
Distribution, occurrence and abundance of aquatic invasive species	2	1	5	4	2	14
Composition and abundance of benthic (shallow and deep) fauna	2	3	2	4	3	14
Phytoplankton biomass, species composition and timing of blooms	1	0	6	2	5	14
Zooplankton biomass, species composition and abundance	0	1	6	2	5	14
Finfish distribution and abundance	0	0	7	6	2	15
Benthic Macroalgae (distribution and abundance)	0	2	3	3	6	14
Changes in hard substrate communities	0	3	4	2	4	13

Lobster abundance (based on fishery-independent measurements)	0	1	4	5	3	13
Increased incidence of calcinosis or parmoebiasis in lobster	0	0	5	2	6	13
Acidification impacts on shellfish	0	0	3	6	3	12
Disease occurrence in mollusks (e.g. Eastern Oyster, Northern quahog, Bay scallops)	0	1	5	1	5	12
Abundance of mollusks (e.g. Eastern Oyster, Northern quahog, Bay scallops)	0	1	5	1	5	12
Changes in finfish community structure	0	0	6	6	1	13
Disease occurrence in finfish	0	3	2	1	6	12
Changes in diadromous fish run timing	0	0	4	7	2	13
Areal extent, diversity, and composition of tidal wetlands	0	0	3	8	2	13
Areal extent, diversity and composition of freshwater wetlands	0	0	6	3	3	12
Changes in distribution, composition, and marine transgression of marshes	0	0	4	8	1	13
Extent and distribution of coastal forests, shrublands, and grasslands	0	1	4	5	2	12
Species composition within coastal forests, shrublands, grasslands	0	0	4	5	3	12
Extent and distribution of sea cliffs/bluffs and escarpments	1	3	2	3	3	12
Extent and distribution of unvegetated nearshore (submerged and intertidal), habitats, e.g submerged and intertidal habitats (mudflats, sandflats, rocky intertidal)	0	3	5	4	1	13
Extent and distribution of barrier beaches/islands	0	1	5	5	2	13

Distribution, abundance and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl	0	1	4	5	3	13
Distribution, composition and abundance of insect species associated with coastal habitats	0	1	4	1	6	12
Areal extent and distribution of eelgrass	1	0	7	4	2	14
Areal extent, composition and distribution of submerged aquatic vegetation other than eelgrass	1	0	5	2	5	13
Marine Mammals, sea turtles, and diamondback Terrapin distribution and incidence of cold-stunning	1	3	4	1	4	13

F. Comparison of 2017 priority sentinels with 2011 priority sentinels

2011 Priority Sentinels	2017 Priority Sentinels
Distribution, composition, and abundance of terrestrial invasive species	Hypoxia areal extent/severity/duration/timing of onset (LIS and embayments)
Extent and distribution of sea cliffs/bluff and escarpments	Acidification
	Harmful Algal Bloom frequency/severity/etc.
Phytoplankton biomass, species composition, and timing of blooms	Zooplankton biomass, species composition and abundance
Finfish biomass, species composition, and abundance	Finfish distribution and abundance
Extent and distribution of habitats associated with coastal embayments (e.g., fringe marsh, shorelines and tidal creeks)	Benthic Macroalgae (distribution and abundance)
Lobster abundance (based on fishery-independent measurements)	Lobster abundance (based on fishery-independent measurements)
Areal extent, diversity, and composition of brackish marshes	Increased incidence of calcinosis or paramoebiasis in lobster
Changes in diadromous fish run timing	Acidification impacts on shellfish
Areal extent, diversity, and composition of salt marshes	Changes in finfish community structure
Areal extent, diversity, and composition of freshwater tidal marshes	Changes in diadromous fish run timing
Changes in distribution and marine transgression of marshes	Areal extent, diversity, and composition of tidal wetlands

Extent and distribution of coastal forests, shrublands and grasslands	Areal extent, diversity and composition of freshwater wetlands
Species composition within coastal forests, shrublands, and grasslands	Changes in distribution, composition, and marine transgression of marshes
Extent and distribution of unvegetated nearshore (submerged and intertidal) habitats (e.g., mudflats, sandflats, rocky intertidal)	Extent and distribution of coastal forests, shrublands, and grasslands
Extent and distribution of barrier beaches/islands	Species composition within coastal forests, shrublands and grasslands
Distribution, abundance, and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl	Extent and distribution of unvegetated nearshore (submerged and intertidal) habitats, (e.g. mudflats, sandflats, rocky intertidal)
Areal extent and distribution of eelgrass	Extent and distribution of barrier beaches/islands
	Distribution, abundance and species composition of marsh birds, colonial nesting birds, shorebirds, waterfowl
	Areal extent and distribution of eelgrass

The highlighted sentinels in the above table represent priority sentinels that were different from 2011 to 2017.