Review of current monitoring efforts in coastal ecosystems

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Science and Technical Advisory Committee

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Section I

Introduction

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

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

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

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

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

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

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

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

Section II

Monitoring programs

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

Global Earth Observing System of Systems (GEOSS)

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

Coastal Global Terrestrial Observing System (C-GTOS)

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

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

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

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

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

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

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

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

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

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

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

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

Global Ocean Observing System (GOOS)

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

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

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

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

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

Black SEA GOOS

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

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

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

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

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

North East Asian Regional (NEAR) GOOS

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

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

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

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

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

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

Coastal GOOS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

National Estuarine Research Reserve System (NERRS)

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

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

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

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

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

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

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

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

Chesapeake Bay Program (CBP)

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

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

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

Delaware Estuary (Climate Ready Estuaries program)

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

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

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

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

Albemarle-Pamlico Estuary (Climate Ready Estuaries Program)

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

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

Albermarle-Pamlico Estuary –Climate Ready Estuaries Program		
Driver	-Sea Level Rise -Storm intensity and frequency -Annual average precipitation -Temperature	
Responses	Physical Systems	- Increased rates of coastal erosion on ocean and estuarine shorelines - Possible disruption of continuous barrier island segments by formation of breaches and new inlets - General salinity increase in estuaries in response to drought, long-term sea-level rise and barrier changes - Possible rapid salinity increase in response to threshold collapse of barriers in response to major storm impacts - Alteration of estuarine circulation patterns due to changing salinity and temperature structure - Greater susceptibility to thermal stratification and hypoxic bottom waters, resulting in increased fish kills - Possible increase in tidal prism, accelerating estuarine

		shoreline erosion, modifying sediment transport and wetland communities, and increasing flooding of low-lying areas - Wetland migration and accretion, net losses in human modified areas resulting from bulkheads or other obstructions to migration - Reduced carbon storage in wetland soils due to flooding by saline water, increased sulfate reduction, increased organic matter degradation, increased erosion
Responses	Natural Biological Systems	- Cascading impacts on aquatic ecosystems (plankton, nekton, benthos, submerged aquatic vegetation (SAV), wetlands) via changes in salinity, temperature, circulation, stratification, hypoxia - Expected community change and migrations - Changes in SAV distribution (e.g., eel grass replaced by turtle grass) and emergent vegetation - increased number of threatened and endangered species with possible extinctions - Expansion of the range of exotic species (e.g., Lionfish, snakehead fish, Codium in mesohaline regions, *Phragmites*). Additionally, it will become necessary to identify exotics before they dominate and produce detrimental effects, and distinguish between them and the natural succession in response to global warming and barrier/estuarine changes

	Human Systems	-Changes to coastal development patterns with associated concerns regarding preservation of infrastructure, coastal hardening, water resources, drainage ditches, surface water impacts, and water management structures -Changes to social and economic structures of coastal communities; loss of fisheries, tourism, agriculture, silviculture, infrastructure, property and associated tax base; emigration -Increased introduction of toxins into coastal systems as coastal communities are increasingly flooded

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Section III

Current monitoring efforts on LIS

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

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

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

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

[1] Data could be disaggregated into components: Gleason's D diversity measure normalized by salinity, number of tubificids normalized by salinity, and abundance of spionid polychaetes.
[2] Data could be disaggregated into components: grain size, total organic carbon, sediment chemistry, benthic community structure, and sediment toxicity.

Section IV

Limitations of current indicators and non-linear changes

Limitations of current indicators

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

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

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

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

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

Thresholds and non-linear changes

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

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

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

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

Section V

Conclusions

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

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

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

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

Section VI

References

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