Integrated Sentinel Monitoring for the Northeast Region: Gap Assessment

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ABSTRACT

We address gaps in the Northeast Region's capability to observe key biotic and abiotic ecosystem variables that are likely impacted by climate forcing. The need to observe effects of shorter-term and longer term climate and ocean variability on coastal ecosystems is especially acute in the Northeast, where water column temperatures have been rising at the rate of 0.1- 0.3^{o}C yr^{-1} over the past decade. First, there is a need for coordination of sentinel monitoring for pelagic and benthic properties that makes use of regional capacity for data management and distribution, quality control and integrated analysis. The broad definition of a sentinel is a critical ecosystem variable (whether an abiotic factor, process, species or community index) that is measureable and likely to be affected by climate change. At present, a sentinel monitoring program has been initiated in parts of the Northeast Region, for Long Island Sound and adjacent Canadian waters, but there is no organized sentinel monitoring of other regional coastal ecosystems, for example in the Gulf of Maine. The NERACOOS Strategic Plan calls for development of an integrated sentinel monitoring program across the Northeast; here we discuss steps to make that happen. Second, there is a need for information about critical variables not presently sampled by the existing observing systems. We explore strategies for collection of data on sentinel variables that either cannot be measured autonomously with existing instrumentation or require validation with samples collected in the field. These strategies include establishment of sentinel, fixed time series stations and eventual introduction of new measurement technologies. We outline the way forward involving consultation with federal and non-federal users and experts to create a science and implementation plan and a vision for integration of data into physical-ecosystem models and dissemination of information to the user communities.

Key words: sentinel monitoring, climate change, benthic and water column properties, time series stations, modeling tools

1. INTRODUCTION AND HISTORY

This White Paper addresses gaps in observing system capabilities to detect, assess and interpret effects of climate and ocean change on the health of coastal ecosystems in the Northeast Region. This theme is particularly relevant to the Northeast Region, which is experiencing rapid change in water column temperature, on the order of 0.1-0.3^{o}C yr^{-1} since 2004[1]. Surface water temperatures in summer, 2012, are 2-4^{o}C warmer than normal in the region. These recent warming trends are affecting regional coastal ecosystems. For example, the molt cycle of the American lobster, New England's most valuable marine resource, is 2-4 months earlier in 2012, the likely consequence of exceptionally warm temperature of its bottom habitat. The early molting contributed to an unexpected glut of lobsters on the market, creating an economic crisis in Maine's coastal fisheries. The warming is undoubtedly impacting the coastal ecosystem in other significant ways, but the Northeast Region does not have an organized regional plan in place to observe these changes.

The gap assessment we provide here is likely also applicable to other regions under pressure from climate forcing. First, there is a need for a region-wide sentinel monitoring program for water column and benthic properties that takes advantage of regional capacity for integrated analysis and data management. Second, it is clear that a number of critical variables that may be changing cannot be observed by present capabilities in remote sensing and autonomous, in situ sampling platforms. The measurement of these variables will require collection and analysis of samples involving shipboard sampling where appropriate. Technological advances may allow autonomous measurement of some of these variables in the future, and resources may be well spent to develop this capability, but in the meantime "human-assisted" measurements at a limited number of shore or ship stations are needed to build essential time series.

1.1 Toward an integrated sentinel monitoring program in the Northeast Region: a brief history

The 2011-2016 Strategic Plan for the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS: www.neracoos.org) calls for establishment of an Integrated Regional Sentinel Monitoring Program in coastal waters from the Canadian Maritime provinces of Nova Scotia and New Brunswick to the New York Bight, including Long Island Sound. Elements of the monitoring program include measurement of critical physical and biological variables characterizing the water column and the benthos, as well as analysis and modeling for interpretation of changes observed and creation of data products. In 2012, the Ocean and Ecosystem Health Committee (OCEH) of NERACOOS and the OCEH of the Northeast Regional Ocean Council (NROC), merged together and started the process of building an integrated program as one of its first actions.

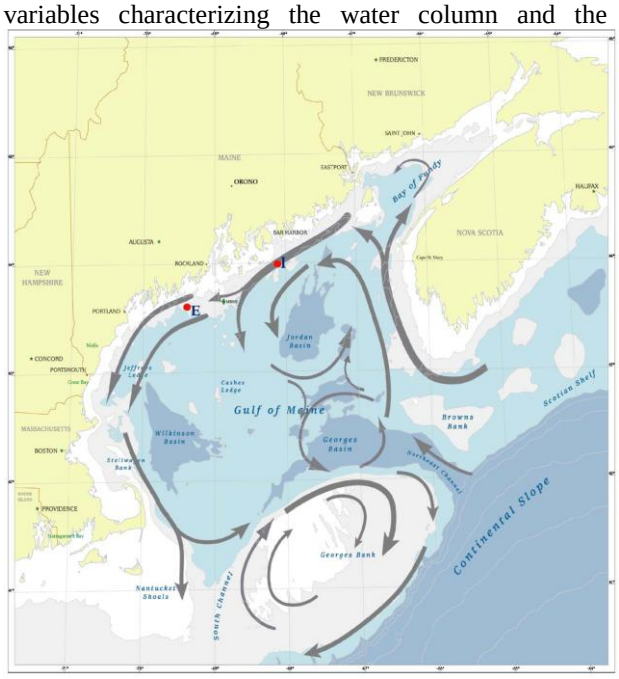

Fig. 1. The Northeast Region (Long Island Sound not shown), highlighting the Gulf of Maine circulation (from N.Pettigrew, Univ. Maine)

Fundamental challenges to the development and implementation of integrated sentinel monitoring are coordination with independently funded observing activities and the mismatch between regional political and ecosystem boundaries. The Northeast Region spans two countries (the U.S. and Canada), a marginal sea containing relatively deep basins (the Gulf of Maine: Fig. 1) and a nearshore complex of relatively shallow southern New England estuaries (Long Island Sound and Narragansett Bay). Integrated sentinel monitoring has been initiated in waters of the Canadian provinces and Long Island Sound, but not in U.S. coastal waters elsewhere.

1.2. Monitoring in Canadian waters: The Atlantic Zone Monitoring Program

Fisheries and Oceans Canada has monitored the physical, chemical, and biological environment of the Bay of Fundy and Scotian Shelf since 1998, under the Atlantic Zone Monitoring Program[2] (AZMP). The program focuses on variability at annual and longer time scales. Sampling is performed monthly or semi-monthly at fixed stations in the Bay of Fundy and on the central Scotian Shelf, and twice annually at stations along sections across the shelf and the Cabot Strait. In addition, environmental sampling using the AZMP protocols is performed on ecosystem trawl surveys in the on Georges Bank, the eastern Scotian Shelf, and eastern Gulf of Maine and Scotian Shelf. AZMP sampling in the Gulf of Maine and on the Scotian Shelf is conducted in coordination with analogous programs in the Gulf of Saint Lawrence and in Newfoundland and Labrador waters

1.3. The Sentinel Monitoring for Climate Change in Long Island Sound Program (SMCCP)

The Long Island Sound Study (LISS), a collaboration between the U.S. EPA and the states of Connecticut and New York, initiated the Sentinel Monitoring for Climate Change in Long Island Sound Program (SMCCP) in October, 2008[3]. The mission of the SMCCP is to provide early warnings of climate change impacts to Long Island Sound estuarine and coastal ecosystems, species and processes to facilitate management decisions and adaptation responses. The warnings will be based on multidisciplinary assessement of a suite of indicators/ sentinel variables. The identification of variables to observe involved collaboration between Connecticut and New York state-level working groups. An online survey was used to help prioritize 17 variables, from which six were selected for a pilot scale sentinel monitoring program. Implementation of the pilot scale sentinel monitoring is the next step for the SMCCP [3].

1.4. The Gulf of Maine

The Gulf of Maine (GoM: Fig. 1) is a semi-enclosed sea that is bathymetrically diverse, including three large deep basins and a number of coastal ledges. Primary and secondary production, in particular very high abundances of krill and lipid-rich copepods, support productive fisheries on the coastal shelf, ledges and banks. Coastal primary productivity is enhanced by tidal mixing and the relatively shallow coastal shelf captures considerable phytodetritus, making the benthos relatively productive for the region's lobsters, groundfish and other commercially important benthic species. The characteristics of hydrography and circulation, including inflows to the Gulf and local river discharge, are strongly under the influence of climate forcing. While a number of observing time series in the GoM have been initiated, some of which are still ongoing (see section 3), there is no systematic, organized observing of change that may be associated with variability in this physical forcing in its coastal ecosystems.

2. TECHNICAL AND USER REQUIREMENTS

2.1. User needs

Sentinel monitoring that records and interprets change in the Northeast coastal ecosystem will become an increasingly critical need for coastal zone management of the region's resources. Users of coastal ecosystem health information include state and federal managers tasked with management of coastal fisheries and environmental assessment of ecosystem effects of coastal development. Climate forced change in sentinel variables may lead to ecosystem shifts affecting many users. The SMCCP[3] has identified user needs in highly populated estuarine systems that are will be affected by climate change. Change in coastal ecosystems in the GoM may have great impact on fisheries and the regional economy. For example, the coastal fishery for American lobster is among the most valuable in the United States. With lobster abundance at historic highs and other fisheries depleted, the coastal economy of Maine is precariously dependent on this single fishery, which in southern New England has seen catastrophic declines as a result of physiologically stressful temperatures, hypoxia and shell disease[4]. The lipid-rich planktonic copepod, *Calanus finmarchicus*, the biomass dominant zooplanktion in spring and summer on the coastal Gulf of Maine shelf, is predicted to disappear from the Gulf of Maine over the next several decades due to surface layer warming[5]. Since *Calanus* production supports an abundance of planktivores, including herring, that in turn attract higher level consumers such as tuna and the endangered northern right whale, significant shifts in *Calanus* abundance may have profound effects on coastal ecosystem biodiversity[6]. A number of other important species (such as hering) find themselves at the southern edge of their biogeographic range.

2.2 Identification of critical variables

Detection of critical changes within an ecosystem requires long term, consistent sampling of the right properties. Given limited resources, identification of the "right" properties to observe at the appropriate temporal and spatial resolution is an important and challenging process. It must involve consultation among federal and non-federal regional experts and users and be dynamic, in that variables may be added (or deleted) over time as knowledge accumulates.

Criteria for selection include measurability, cost, user need and impact of change in the variable on ecosystem structure and function. Current autonomous technology is limited in its capacity to monitor the right properties. On the other hand, some current ship-based, monitoring efforts are low frequency, either stations along shelf transects twice yearly (AZMP) or broad scale random deep water locations six times per year (NOAA EcoMon). Infrequent observations in a highly variable system are insufficient to capture phenology[7] and decrease the capacity to rapidly detect change.

The SMCCP describes a process for determining sentinel variables in Long Island Sound[3], representative of the region's urban estuaries. It identifies 9 core physical parameters and 17 priority sentinels for detection of climate impacts that best meet user needs. The final list of 6 critical variable sets for the pilot monitoring project are: 1) distribution, abundance and species composition of marsh birds, nesting birds, shorebirds and waterfowl, 2) finfish biomass, species composition and abundance, 3) lobster abundance, 4) phytoplankton biomass, species composition and timing of blooms, 5) species composition within coastal forests, shrublands and grasslands and 6) areal extent, diversity composition and marine transgression of salt marshes. While many of the core physical parameters can be measure autonomously, many of the sentinel variables will require human-assisted sampling.

The process for identifying sentinel variables for water column and benthic properties in the coastal Gulf of Maine is ongoing. Candidates for biological water column properties include the core variables measured by the AZMP. Standard AZMP variables include temperature, salinity, oxygen, nutrients, chlorophyll, phytoplankton species abundance (fixed stations only) and zooplankton biomass and species abundance. Other variables are measured in ancillary programs utilizing the AZMP sampling platforms. Additional candidates are indices to measure key ecosystem taxa (harmful algal bloom species, *Calanus finmarchicus*, krill species and carbon cycle variables (e.g. particulate organic carbon). Core physical and chemical variables, in addition to standard hydrography, include nutrients, dissolved inorganic carbon, alkalinity and pH.

3. STATE OF THE OBSERVING SYSTEM AND TECHNOLOGY

3.1. The federal backbone

Numerous federal observing activities are conducted in freshwater, estuarine, coastal, shelf, and ocean systems (USGS, DOI, EPA, NOAA, USFWS, DFO). NERACOOS is working to integrate these activities, including estuarine monitoring (NERRs), buoy observations (NDBC) and extensive offshore oceanographic, fishery, and protected resource surveys (NMFS) with NERACOOS funded activities to build a truly regional observing system. An excellent example is the integration of the National Data Buoy Center buoys with the NERACOOS buoys. To the user, all the data is accessible and not dependent on the organization collecting the data. The Integrated Sentinel Monitoring for the Northeast Region will build on these successes and complement the ongoing programs in the region.

3.2 The state of observing

The NERACOOS/NROC OCEH committee is in the process of identifying present observing activities across the entire Northeast Region that are relevant to sentinel monitoring of its coastal ecosystems. Partial

lists of past and present observing of ecosystem variables have been published elsewhere[3,,8,9]. Elements of sentinel monitoring are already in place in two major U.S. subregions (Narragansett Bay and the Gulf of Maine) where there is no formal plan. In NB, these include the Fixed Site Water Quality Monitoring Network, the NB NERR Long Term Monitoring Program, and the Rhode Island Special Area Management Plan. In the GoM, they include the Martha's Vineyard Coastal Observatory (MVCO), Northeast Benthic Observatory (NEBO), Massachusetts Water Research Authority stations, Stellwagen Bank National Marine Sanctuary, the Wells NERR, UNH coastal carbon monitoring, a multi-institution observing node for microplankton, primary and secondary production and diversity in mid-coast Maine, marine seabird monitoring (US Fish and Wildlife Service and National Audubon Society), and state and federal fish and environmental surveys.

3.3 The state of technology

While some of the variables for sentinel monitoring are now measured autonomously, a number of others will require collection at shore- or ship-accessed stations. We envisage several, strategically placed fixed stations sampled at a frequency (semi-monthly to monthly) to capture change in phenology as well as annual trends. The selection and placement of stations for water column and benthic properties are likely to be decoupled in many cases, recognizing that multispecies ecosystem based management of the coastal benthic community will likely require assessment at local observing nodes.

The rapid evolution of sensor technologies provides increasing ability to monitor at high frequency important biotic and abiotic parameters. Optically based instruments that measure some chemical and biological parameters are already in use. New instruments/algorithms have become recently available and could be used as a part of the moored or ship based approach (e.g. ISUS based nitrogen measurements, optically based estimates of particulate organic carbon or organic dissolved carbon). The second generation Environmental Sample Processor (ESP) would allow for high temporal resolution of the microbial variability, harmful algal bloom events and changes in the dominant phytoplankton types[10]. Discrete datasets that will be collected on fixed stations can be used for development of in-situ or remote sensing based, regionally specific proxies, which can be incorporated into the monitoring strategy.

4. INTEGRATION WITHIN IOOS, MODELING, AND DMAC

NERACOOS Data Management and Communications can be leveraged to store and distribute data collected through these sentinel monitoring efforts. The DMAC team will help the sentinel monitoring group evaluate the data structure of planned sampling methodologies and help map these data to IOOS compliant data and metadata standards. NERACOOS is currently working on an effort to improve access to the highest QA/QC data from data providers distributed across the entire region (Canada to LIS) and improve discovery and access to these historical data sets through the integrated data portal. This effort will likely include the development of webservices, which could make sentinel monitoring data available for use in coupled physical-biological and ecosystem models by scientists throughout the region.

Where possible, these new data streams and associated metadata will be integrated into existing NERACOOS products and services. Existing products include the monitoring location stations mapping and data retrieval tool, model output visualizations and access of historical data.

Another important regional contribution to sentinel monitoring is data quality assurance, including intercalibration of methodologies (human based sampling and sample analysis) and instruments across the nodes and monitoring sites.

5. THE WAY FORWARD

The NERACOOS/NROC Ocean and Coastal Ecosystem Health committee is proceeding now with the development of an integrated sentinel monitoring program that includes measurement of critical biological as well as physical variables. A Steering Committee will be formed, tasked with setting up a working group with appropriate federal and non-federal user and expert representation to develop a regional sentinel monitoring strategy. This strategy will be expressed in a Science and Implementation Plan, recognizing that the suite of sentinel variables for the regional estuarine and coastal environments are likely to have differences. This Plan will be open for community review. It is anticipated that one or more proposals to implement the strategy will be submitted to relevant government agencies and private foundations on a continuing basis in order to leverage core IOOS funding.

It is possible that sentinel monitoring in the coastal Gulf of Maine and southern estuaries will build on geographic nodes (e.g. LIS, Martha's Vineyard Coastal Observatory, Massachusetts Bay/Stellwagen Bank and mid-coast Maine) at which there is already considerable observing activity, both autonomous and human-assisted. For some of these nodes, coastal research vessels are available for fixed station time series.

Additional needs for accessing and visualizing sentinel monitoring data through products beyond existing capacity will be evaluated and reviewed via user needs gathering process. The NERACOOS DMAC and Products teams can be leveraged for this effort. The interaction between the strategies for data collection and the development and needs for analytical interpretation and ecosystem modeling will be an important part of the process for data product development. Coupled multidisciplinary models serve to integrate multiple data

sets in the analysis and interpretation of physical and ecological processes, and can provide valuable insight and information for ecosystem approaches to management[11]. An important advance would be regional infrastructure that: (1) facilitates regional model evaluation, including skill assessment, evaluation of uncertainty, and model ensemble approaches to predictions; (2) serves to link data analyses, modeling and prediction capabilities to specific regional management needs; (3) facilitates coordination among government agencies, research institutions, and universities; and (4) develops and demonstrates environmental analysis and forecast products that could be implemented operationally. One possibility is establishment of a Regional Modeling Center, likely virtually distributed, involving a coordinating entity (NERACOOS) and distributed output of observations and modeling to desktop computers of researchers and resource managers via standards-based tools.

6. RECOMMENDATIONS

- There is immediate need for regional coordination to observe change in coastal ecosystems, underscored by recent rapid warming of water column temperatures in the Northeast Region.
- Sentinel variables are identified to characterize significant change in both pelagic and benthic coastal ecosystems across the region. The working set of sentinels established in the Long Island SMCC and Canadian AZMP can be used as a starting basis for GoM and NB habitats
- The joint NERACOOS/ NROC Ocean and Coastal Health Committee forms a Steering Committee tasked with setting up a working group with appropriate federal and non-federal representation to develop a regional sentinel monitoring strategy and prioritize variables for long term, consistent observation in a Science and Implementation Plan.
- It is not feasible at this time to measure all sentinel variables remotely or autonomously. Support for a limited number of fixed sites or geographic nodes of observing involving human assisted sampling (from shore or with the use of coastal vessels) is recommended. As technologies improve, measurement of sentinel variables can be replaced or enhanced with more autonomous methods
- Within the next 10 yr, establish a regional modeling and analysis center affiliated with NERACOOS. Data undergoing quality controlled are regionally stored and accessible. Using of modeling and analysis tools including coupled physical-biological and ecosystem models, the current status of the coastal ecosystem, target species and processes can be assessed in response to user need.
- A long term vision for the Integrated Sentinel Monitoring Program for the Northeast Region identifies an important role of NERACOOS as a regional clearinghouse of information to a multitude of users about the status of change in the region's coastal ecosystems.

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References

[1] Morrison, J.R., N. Pettigrew, J. O"Donnell & J. Runge (2012) Detecting variability in coastal oceans. IOOS Community White Paper.

[2] AZMP website: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/index-eng.html

[3] Barrett, J., J. Rose, S. Deonarine, A Clemetson, J. Pagach, M. Parker, & M. Tedesco (2011). Sentinel Monitoring for Climate Change in the Long Island Sound Estuarine and Coastal Ecosystems of New York and Connecticut. Volume 1. http://longislandsoundstudy.net/research-monitoring/sentinel-monitoring/, 136 pp.

[4] Steneck, R. S., T. P. Hughes, J.E. Cinner, W. N. Adger, et al. (2011). Creation of a gilded trap by the high economic value of the Maine lobster fishery. *Conservation Biology*, **25**, 904-912.

[5] Reygondeau, G. & G. Beaugrand. (201). Future climate-driven shifts in distribution of *Calanus finmarchicus*. *Global Change Biol.* **17**, 756-766.

[6] Johnson, C., J. Runge, A. Bucklin, K. A. Curtis et al. (2011). Biodiversity and ecosystem function in the Gulf of Maine: pattern and role of zooplankton and pelagic nekton. *PLoS One*. **6,** 1-18.

[7] Ji, R., M. Edwards, D. Mackas, J. Runge & A. Thomas (2010). Marine plankton phenology and life history in a changing climate: Current research and future directions. *J. Plankton Res*. **32**, 1355-1368.

[8] Raposa, K. B. & D. Durant (2011). Long-term Monitoring Program. *Narragansett Bay National Estuarine Research Reserve document*. www.nbnerr.org/Content/NBNERR_Monitoring_Plan_2011.pdf, 21pp.

[9] Johnson, C. L. & J. A. Hare (2012). Zooplankton Monitoring in the Gulf of Maine: Past, Present and Future. In R. Stephenson, J. Annala, M. Hall-Arber and J. Runge (eds.). *Advancing an Ecosystem Approach in the Gulf of Maine.* American Fisheries Society Symposium 79, 205-218.

[10] Scholin, C., G. Doucette, S. Jensen, B. Roman, et al. (2009). Remote detection of marine microbes, small invertebrates, harmful algae, and biotoxins using the Environmental Sample Processor. *Oceanography*, **22(2),** 158-167.

[11] Runge, J. A., A. Kovach, J. Churchill, L. Kerr, J. R. Morrison et al. (2010). Understanding climate impacts on recruitment and spatial dynamics of Atlantic cod in the Gulf of Maine: Integration of observations and modeling. *Prog. Oceanogr*. **87,** 251-26