

# Integrated Sentinel Monitoring Network for Change in Northeast U.S. Ocean and Coastal Ecosystems

## *Science and Implementation Plan: Ed. I*



### ABSTRACT

The Northeast U.S. region spans a range of ocean and coastal environments from Long Island Sound to the Canadian border in the eastern Gulf of Maine, and includes ecologically and economically rich ecosystems. Climate change, living resource harvesting, and increasing human populations are altering the structure and function of these ecosystems. Ecosystem changes are not only threatening the sustainability of marine and human communities, but also challenging managers to make decisions about marine resources under novel conditions with high degrees of uncertainty. In response to these changes and challenges, this document describes a plan to sustain an adaptive sentinel monitoring program that leverages and enhances existing monitoring efforts to detect key changes, informs researchers, managers, and the public about ecosystem status and vulnerabilities; and supports an integrated, ecosystem-based management framework for adaptive responses to changes in ecosystem states.

*A project of the joint Northeast Regional Ocean Council (NROC) and Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) Ocean and Coastal Ecosystem Health Committee*

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## Executive Summary

### *The need for an Integrated Sentinel Monitoring Network*

There is clear evidence of recent change in the coastal environment of the Northeast United States. Sea level and coastal ocean temperatures are presently rising at rates far greater than the global average. Precipitation patterns have changed, with the consequence of increased stormwater and freshwater discharge from local rivers. The relative contribution of oceanic water transported onto the coastal shelf has decreased, resulting in lower salinity and changes to stratification of surface waters. Observations of dramatic local fluctuations in pH and low buffering capacity in the region's coastal waters have elicited concerns about ocean acidification. Changes are observed at seasonal, interannual, and longer time scales and may be associated with greenhouse gas emissions and global warming. They compound long-standing stresses caused by human activities such as fishing and coastal development.

The collective impact of these environmental pressures have and will continue to affect marine ecosystems and the services they provide in the Northeast region. Already, warmer seawater temperatures have contributed to the decline of the southern New England lobster fishery and likely the northern shrimp and Atlantic cod fishery in the Gulf of Maine. Other fish and invertebrate species are also experiencing range shifts with consequences for fisheries management. Changes in the magnitude and timing of plankton production cycles are expected, with consequences for the productivity of forage fish such as herring and sand lance that are fundamental to the region's marine food web. Sea level rise will impact the region's tidal wetlands and other shoreline ecosystems. Ocean acidification will affect the region's shellfish industries and may have other yet unknown impacts on coastal ecosystems. Estuarine ecosystems and near-coastal waters are also subject to the pressures and impacts caused by land-use practices, toxic pollution, habitat destruction and especially nutrient enrichment and eutrophication among others.

These changes will affect the region's ecosystem services. It is imperative that they be observed and reported in order to inform marine resource decision-making, whether in regard to fisheries, aquaculture, tourism, industrial impacts, coastal land development or any other activities that use or impact Northeast ecosystems. The information must come from a coordinated system for data collection, access, analysis and interpretation. To be sure about the status and health of the region's ecosystems, a systematic and integrated observing program that focuses on sentinel indicators is needed. In the context here, a sentinel indicator refers to a measureable variable representing a system, process, or key component of the ecosystem that is sensitive to environmental pressures and that can be quantitatively measured and monitored.

While there are numerous and diverse environmental and ecosystem observing activities presently conducted in the Northeast region, a broad consensus of scientists and managers from state and federal agencies, universities, and other non-governmental organizations recognizes that present monitoring activities are fragmented and moreover leave important gaps in coverage of key ecosystem properties. A series of regional

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workshops and strategic planning sessions within the Northeast region over the past two decades has identified the need for an integrated sentinel monitoring network to improve our understanding of how the region's ocean and coastal ecosystems are changing. The need for a sentinel monitoring network has been further reinforced by the U.S. National Ocean Policy and its call for regional ocean plans and better monitoring and observing to support more informed ecosystem-based management of ocean and coastal resources.

### *Development of the Science and Implementation Plan*

To address this need, the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) and the Northeast Region Ocean Council (NROC) established a joint regional Ocean and Coastal Ecosystems Health Committee in 2012. The committee was tasked with developing a Science and Implementation (S&I) Plan for an Integrated Sentinel Monitoring Network (ISMN) for the Northeast U.S. The formulation of the S&I Plan was overseen by a 16-member steering committee, which convened a series of workshops open to the marine research and management communities over a two-year period between June 2013 and June 2015. The S&I Plan represents the collective efforts of over 60 experts from 45 state and federal agencies, universities, and non-governmental organizations, as well as from Fisheries and Oceans Canada, that oversees Canadian observing activities in the coastal ocean waters of the Bay of Fundy and Scotian Shelf.

This S&I Plan is the first step in the establishment of the ISMN. It builds on active ecosystem indicator programs such as the NOAA Sentinel Monitoring Program, the Gulf of Maine EcoSystem Indicator Partnership (ESIP), the Long Island Sound Sentinel Monitoring for Climate Change Program, and the Atlantic Zone Monitoring Program (AZMP, in Canada). It is intended to be a dynamic working document, carried forward and adapted by an ISMN infrastructure and communicated to the community through an active website.

The S&I Plan covers the Northeast U.S. region, defined as the coastal and ocean waters from the Eastern New York Bight to the Scotian Shelf, including Long Island Sound, Gulf of Maine, and Bay of Fundy. The plan contains seven chapters. Chapter 1 identifies the need for and purpose of the ISMN, the objectives of the plan, and the intended audience. Chapter 2 discusses major characteristics and properties of environments and ecosystems in the Northeast region, as well as the major drivers and pressures of ecosystem change. In order to organize and marshal expertise to determine sentinel indicators, the environments of the Northeast region were classified as pelagic, benthic, or coastal and estuarine. Chapter 3 summarizes an inventory, available online at [www.neracoos.org/sentinelmonitoring/database](http://www.neracoos.org/sentinelmonitoring/database) of present monitoring activities conducted by U.S. and Canadian federal agencies, state agencies, academic research institutions, and non-governmental organizations. Chapter 4 lays out the criteria for sentinel indicators of ecosystem change and identifies sentinel questions and indicators determined by expert working groups for each of the three environments. Chapter 5 recommends enhancements to present observing activities to fill gaps in coverage of sentinel indicators. Chapter 6 discusses needs, challenges, and recommendations for data management and dissemination, a primary role for the ISMN. Finally, Chapter 7 discusses implementation of the ISMN, including needs for new infrastructure.



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### *Functions of the ISMN*

The ISMN will be a regional “network of networks” with infrastructure to support effective and coordinated ecosystem monitoring across the numerous existing and new observing activities. The ISMN will:

- Provide coordination support for existing observing activities,
- Further develop, integrate, and coordinate regional capacity for data management and distribution, quality control, and integrated analysis,
- Enhance and expand current monitoring efforts by supporting needed supplemental measurements, either within existing monitoring programs or as new monitoring activities to fill gaps as necessary,
- Create and sustain data management system and communication strategy that informs researchers, managers and the public about ecosystem status, change, and vulnerabilities. This includes support for analysis, interpretation and prediction that integrates across regional observing activities,
- Support an integrated, ecosystem-based management framework for adaptive responses to drivers of change and resulting ecosystem pressures, such as that being developed in support of the Northeast Regional Ocean Plan.

### *Implementation of the ISMN*

To sustain a successful Integrated Sentinel Monitoring Network, a collaborative mechanism for providing coordination support and maintaining data collection, management, and synthesis activities will need to be established. Ad-hoc partnerships that lack stable funding or mission objectives have seldom continued for longer than a few years, and often result in further fragmentation of the data and a reduction in synthesis potential. An operational structure managed by a team dedicated to sustaining the network is therefore essential as the “glue” for the ISMN, providing oversight at a number of levels in order to achieve integration across data sets and disciplines. Within a selected host institution, the ISMN coordination and support function will require an internal framework that ensures the key components of the network are fully operational and sustained over time. The key elements of this infrastructure are the ISMN Director, the Oversight Committee, and the Center for Analysis, Prediction and Evaluation.

An ISMN Director will have the overall responsibility for integration and operation of the ISMN. The ISMN directorship could be a renewable, fixed-term position that may be accomplished by a combination of funds from the host agency, the ISMN Director’s home institution, and participating agencies in the ISMN. Duties of the ISMN Director will also include supervision of contracts for website services, data management, and information products, while making use of existing regional and host agency resources where possible. The ISMN Director will also chair an ISMN Oversight Committee, comprising experts from the regional research and management community with

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representation from both major subregions (Long Island Sound/Southern New England and the Gulf of Maine) and from the pelagic, benthic, and coastal and estuarine habitats. The Oversight Committee will advise the ISMN Director on the implementation and integration of ISMN activities. It will determine priorities for enhancement of present observing activities, guided by the community consensus provided in the S&I Plan. It will also establish and recruit participants in technical science committees to integrate and facilitate effectiveness of data collection, management, and analysis across ISMN activities. An important role of the Oversight Committee will be to guide the ISMN Director in awarding grants for data synthesis through the Center for Analysis, Prediction and Evaluation (CAPE). The CAPE will involve the participating institutions in the ISMN and will focus on enabling integrated analysis across datasets, generating information products about the status of the Northeast region ecosystems, and assuring the utility of this information in addressing identified needs of federal and state agencies and other stakeholders.

To accomplish these functions, the ISMN directorship will be provided with an annual budget through the host agency, but generated through contributions of a range of participating federal, state, and non-governmental funding sources.

#### *Sentinel indicators*

A diverse, multidisciplinary group of scientists and managers with expertise in pelagic, benthic and coastal and estuarine systems of the Northeast region convened in working groups over the two year period between June 2013 and June 2015 to identify sentinel indicators for ecosystem change. The selection process involved matching each sentinel indicator with a question formulated from either: (1) hypothesis-based predictions of responses to environmental pressures, or (2) identification of key ecosystem properties that are known to be fundamental to ecosystem structure and function, without explicit understanding of the mechanisms for change (i.e., covering for the unexpected). It is anticipated that indicators will be used in novel analyses to answer new questions as they arise. Sentinel questions and their respective indicators are summarized in Tables 4.2.1 (pelagic environment), 4.3.1 (benthic environment) and 4.4.1 (coastal and estuarine environment).

The working groups conducted a gap analysis to identify necessary enhancements to the present regional observing system. This analysis was based on the expert knowledge within each working group of existing observing activities and the scientific needs for effective sentinel monitoring. Enhancements include supplemental measurements added to existing monitoring activities and provision of sustained funding for new or recently established time series that measure sentinel indicators. A summary of recommended enhancements is provided in Sections 5.2 (pelagic environment), 5.3 (benthic environment) and 5.4 (coastal and estuarine environment).

The working groups' expert recommendations will provide guidance to the ISMN Director and Oversight Committee for the development of the regional integrated sentinel monitoring network.

#### *Relation to other regional collection and analysis of observing data*

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The focus of the ISMN is facilitation of integrated collection and analysis of observing data about ecosystem change in the Northeast region. Integrated analysis of ecosystem change requires information on all aspects of the ecosystem, including physical, chemical and biological components. Coordination with federal and state agencies (e.g. NOAA, USGS), regional organizations (e.g., NERACOOS, the Northeast Coastal Acidification Network, the Northeast Regional [Ocean] Planning Body) and other university and non-governmental observing programs will be needed in order to ensure that necessary data are collected and accessible. Similarly, coordination and collaboration with Canadian federal and provincial programs, for example the AZMP in the analysis and interpretation of data will be an important role for the ISMN.

The need for a comprehensive, centralized, and easy to use data management system cannot be understated. Such a system must enable the discovery of all relevant data and provide access to data in formats that meet the needs of the varied users in the region. Efforts to make regional data discoverable and accessible have been underway in this region for over a decade, under various names such as the Northeast Coastal Ocean Data Partnership and, most recently, under the NERACOOS Data Management and Communications subsystem (DMAC). Similar efforts have been underway in the Long Island Sound region (Long Island Sound Study), for U.S. federally funded university research (National Science Foundation's Biological and Chemical Oceanography Data Management Office-BCO-DMO), Canadian observing data (ISDM – Integrated Science Data Management) and for biological data (Ocean Biogeographic Information System-OBIS). A successful ISMN data management system will leverage, enhance, and integrate existing systems, including standards, methodologies, and people involved.

One of the functions of the ISMN CAPE will be the contribution of regional expertise to advance analysis of indicators and model development to serve the needs of the NOAA Integrated Ecosystem Assessment for the Northeast, which incorporates multidisciplinary ecosystem analysis for use in fisheries management and for the Ecosystem Advisories issued by the Northeast Fisheries Science Center. The ISMN will coordinate these efforts with the Cooperative Institute for the North Atlantic Region (CINAR) and its successor. Similarly, CAPE participants will collaborate with scientists involved in the AZMP, administered by Fisheries and Oceans Canada, to interpret and predict marine ecosystem change in the Northwest Atlantic. The Northeast Regional Planning Body is planning to incorporate the ISMN into its Northeast Regional Ocean Plan as one of the tools to ensure ecosystem change is accounted for in regulatory and management decisions that are guided and informed by the plan. The CAPE and ISMN technical committees will share analysis and information with the Gulf of Maine Council ESIP, which reports on U.S. and Canadian observing data collected in the Gulf of Maine, to provide integrated ecosystem analysis and prediction of ecosystem change in the estuaries and coastal habitats of the Northeast region.

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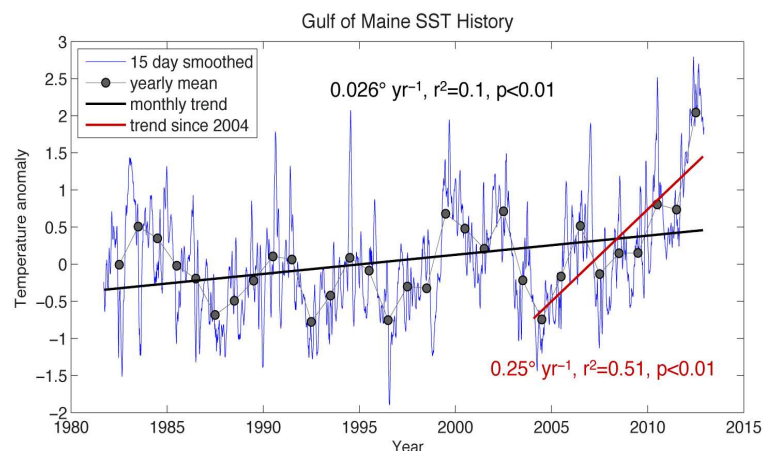
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## 1. Introduction

### 1.1 The Need for Sentinel Monitoring

The ocean and coastal ecosystems of the Northeast U.S. holds fundamental economic, societal, cultural, and spiritual importance for the 20 million people living within the coastal watershed. Even more individuals rely on the products extracted from the region's marine system. These same ecosystems are under pressure from numerous local and global system drivers, including climate change, resource exploitation, invasive species, and human population growth and its associated development. Managers and communities need accurate, objective, and accessible information of quantified ecosystem changes in response to these system drivers. This will allow timely and informed decisions to adapt to future changes. While many efforts have been recently made to assess ecosystem change, the region's existing monitoring programs remain largely stand-alone and tenuous due to resource constraints, which limits the region's ability to effectively understand shifts in ecosystem properties, including changes in physical structure, biodiversity, and ecosystem function. Moreover, gaps in current monitoring efforts leave important ecosystem characteristics either unmonitored or insufficiently assessed over appropriate spatial and temporal scales. Ultimately, these shortcomings hamper the ability of decision makers to respond to existing and emerging



**Figure 1.1.1. Pressures on Northeast U.S. Region Ocean and Coastal Ecosystems**

The need to observe effects of short- and long-term climate and ocean variability on marine ecosystems is especially acute in the Northeast U.S. region. Analysis of satellite sea surface temperature observations have shown water column temperatures have been rising at the rate of 0.1-0.3°C yr<sup>-1</sup> over the past decade (Mills et al. 2013, above), more than ten times the trend over the past century (Shearman and Lentz 2010). Long-term sea surface temperature increases are driven by the steady increase in concentrations of CO<sub>2</sub> and other greenhouse gases that result in atmospheric warming. On shorter time scales, temperature increases may be also be influenced by natural climate cycles (e.g., the North Atlantic Oscillation, the Atlantic Multidecadal Oscillation), shifts in the position of the Gulf Stream, or changes in circulation patterns, which can bring warmer or colder water into the region. Alarm about the effects of rising temperatures on the Gulf of Maine ecosystem has been raised in numerous media reports. Nevertheless, scientific observing and analysis of the biological effects of increasing temperature remain poorly sampled, fragmented and sometimes contradictory. *To what extent are the region's ecosystems really changing? What are the impacts and implications for management of the region's ecosystem services?* Regional coordination is needed to ensure timely collection, analysis, and interpretation of the states and responses of marine ecosystems to increasing temperature and other pressures.

threats, making it more difficult to foster resilient ocean and coastal ecosystems and the goods and services they provide.

A series of regional workshops and strategic planning sessions, including the New York Bight Sea Grant Regional Ocean Science Council Workshop in June 2010 and the New England-Canadian Maritime Collaboration and Planning Initiative in May-October 2010, led to a consensus on the need for an integrated sentinel monitoring network to improve our understanding of how the Northeast region's ocean and coastal ecosystems are changing. The need for a sentinel monitoring network was further reinforced by the National Ocean Policy and its call for coordinated and integrated monitoring and observing to support more informed ecosystem-based management of ocean and coastal resources, and for the development of regional ocean plans. To help address this need, the Northeast Regional Ocean Council (NROC) and Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) have partnered through a joint Ocean and Coastal Ecosystem Health Committee to develop this Science and Implementation (S&I) Plan for the development of an Integrated Sentinel Monitoring Network (ISMN) for Northeast ocean and coastal ecosystems. The plan represents the culmination of the multidisciplinary efforts of a large number of collaborators and contributors. It lays the groundwork for an improved, cost-effective monitoring collaboration that builds on and adapts existing monitoring capacities through coordination, integration, and targeted enhancement.

Northeast U.S. ocean and coastal ecosystems comprise a complex mosaic of pelagic, benthic, and coastal and estuarine environments. Comprehensive monitoring of all chemical, physical, and biological variables across these environments is not feasible. However, within and across these environments, there are sentinel indicators (Box 1.1) that can broadly inform decision makers about corresponding changes in ecosystem state, and provide direction for management actions. Over the course of two years, the contributing authors to this S&I Plan identified a suite of representative indicators across the region that can consistently and effectively represent changes in ecosystem properties. The result integrates pelagic, benthic, and coastal and estuarine environment monitoring, observing, and data

### **Box 1.1. What is a sentinel?**

The American Heritage dictionary defines a sentinel as “one that keeps guard; a sentry.” In the context of the ISMN, different conceptions of a “sentinel” emerged during the course of development of this plan. For some, the monitoring programs are the sentinels watching for change in ecosystems. To others, the habitats, species, or ecosystem properties sensitive to change are the sentinels. In either case, the connotation of “sentinel” is the sense of “warning” to coastal managers and the public of changes in the ecosystem and its services in response to climate and other drivers. For the purposes of this plan, sentinel is best used as an adjective. To detect change, the ISMN has identified a number of sentinel questions. The answers to these sentinel questions will be routinely evaluated by the measurement and analysis of sentinel indicators, which refer to measureable variables (whether abiotic or biotic) representing a system, process, or key component of the ecosystem that are sensitive to environmental pressures. The discussion of sentinel questions and indicators that were identified for inclusion in the ISMN is found in Chapter 4.

management efforts (by regulatory bodies, scientific academia/groups and citizen-scientist groups) from across the region, and was developed by consensus among a wide range of scientists and managers representing federal and state government agencies, universities, and non-governmental organizations (NGOs).

The planning process made it clear that the representative suite of sentinel indicators either are not currently monitored or not assessed at the appropriate temporal or spatial scales necessary to track changes. Integrated monitoring on a regional scale requires a flexible and adaptive structure that can accommodate strategic enhancements and technological and modeling advances, ultimately increasing the region's ability to monitor, understand, and respond to ecosystem changes.

### **Box 1.2. Need for Sentinel Monitoring: The case of the American lobster**

Recent warming trends across the Northeast U.S. region are affecting coastal habitats and organisms, including the American lobster (*Homarus americanus*), one of the Gulf of Maine's most valuable marine resources. Warming temperatures may be benefiting American lobster populations and the lobster fishery by making much of the Gulf of Maine seabed more favorable for lobster production. However, warming temperatures may also be causing unwanted and detrimental effects on the lobster fishery. For instance, during 2012 the lobster molt cycle occurred 2-4 months earlier than normal, likely the consequence of exceptionally warm bottom water temperatures (Mills et al. 2013). This early molting contributed to an unexpected influx of lobsters on the market, creating a temporary economic crisis in the Gulf of Maine coastal fisheries (Dicolo and Friedman 2012). Yet, managers and fisherman only have to look to southern New England and Long Island Sound, where summer temperatures have been exceeding lobster physiological limits with greater frequency, for a reminder of how these changes can have more permanent consequences. In southern New England and Long Island Sound, the lobster fishery has all but vanished because of a combination of factors, including warming water temperatures and increased incidence of shell disease (Wahle et al. 2009). Warming waters and other changes are undoubtedly impacting the coastal ecosystem in additional significant ways, but the region does not have an integrated, collaborative plan in place to observe these changes. The *American Lobster Settlement Index* is an example of a long-term, region-wide monitoring program that keeps a finger on the pulse of young-of-year lobsters entering the population each year. Fluctuations in year class strength are proving to be a useful predictor of lobster landings 5-9 years later. As these early-warning models are developed, it is critical to integrate their results with observations from other monitoring programs, such as state and federal trawl surveys and ocean observing systems, to provide information on the physical and biological factors that may cause changes in the population dynamics of this iconic species.



**Figure 1.1.2. American lobster.**

The American lobster is a critical species supporting the coastal communities in the Northeast U.S. region. © GoM Research Institute.



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## 1.2 Functions of an Integrated Sentinel Monitoring Network

Coordinating and maintaining consistent and effective monitoring, and interpreting changes in sentinel indicators are significant challenges for the Northeast region. Multiple political jurisdictions, academic and research institutions, and citizen monitoring groups are already operating and generating important datasets. However, these efforts are not systematically coordinated. A regional Integrated Sentinel Monitoring Network (ISMN) will address the need for more effective and integrated ecosystem monitoring. The vision for the ISMN is a regional entity with infrastructure that will sustain an adaptive sentinel monitoring network with the following major functions:

- Provide coordination support for existing observing activities.
- Further develop, integrate, and coordinate regional capacity for data management and distribution, quality control, and integrated analysis.
- Enhance and expand current monitoring efforts by supporting needed supplemental measurements, either within existing monitoring programs or as new monitoring activities to fill gaps as necessary.
- Create and sustain data management system and communication strategy that informs researchers, managers and the public about ecosystem status, change, and vulnerabilities. This includes support for analysis, interpretation and prediction that integrates across regional observing activities.
- Support an integrated, ecosystem-based management framework for adaptive responses to drivers of change and resulting ecosystem pressures, such as that being developed in support of the Northeast Regional Ocean Plan.

With the ISMN in place, the region will benefit from coordinated monitoring and integrated insight into ecosystem change in an extensive geographic area that spans political boundaries and a range of environments. The ISMN will improve our ability to detect and understand the causes of long-term change in the composition, structure, and function of the Northeast U.S. region's ocean and coastal ecosystems in an efficient and cost-effective way.

## 1.3 Scope of the Science and Implementation Plan

### 1.3.1 Objectives

To realize this vision, the objectives of this regional ISMN S&I Plan are:

1. To promote integrated sentinel monitoring of ecosystem change in the region,
2. To initiate a metadata database that includes information on historical and ongoing research projects to facilitate standardized implementation study designs, foster project integration, and encourage data interoperability across the region,

3. To recommend sentinel indicators and associated observing questions for detecting ecosystem changes in pelagic, benthic, and coastal and estuarine environments across the region,
4. To complete a general gap analysis of current monitoring efforts,
5. To advance, promote, and outline an operational structure for implementing an Integrated Sentinel Monitoring Network (ISMN) and associated data analysis and prediction center that will inform and meet the needs of resource managers, communities, and decision makers,
6. To advance application of a regional data management system for compilation and dissemination of observing data, and visualization of data products and information on the region's ecosystem status to facilitate more effective and timely policy actions, and
7. To provide funding agencies the necessary information to guide future requests for proposals that would help facilitate meeting sentinel monitoring needs for ecosystem change in the region.

### 1.3.2 Audience

This plan provides information to decision makers at multiple levels about the state of the science in the Northeast U.S., examples include:

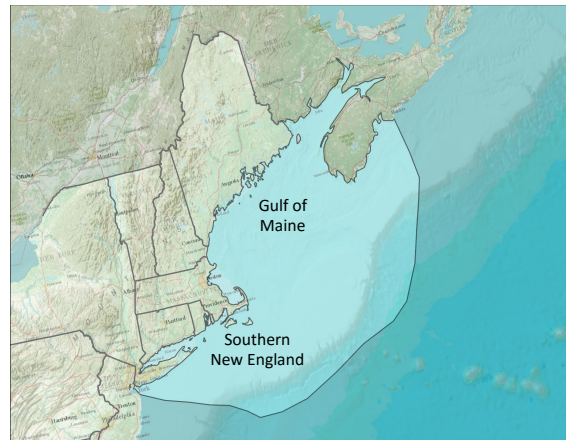
- Regional planning bodies responsible for setting research and monitoring priorities, and developing regional ocean management plans.
- Resource managers seeking information about existing monitoring programs.
- Researchers planning new research and monitoring projects.
- Graduate students seeking research questions relevant to emerging ecosystem change.
- Nonprofit organizations and citizen scientist groups designing their own programs, or hoping to share their own data sets.
- Government agencies developing policies and guidance grounded in local and regional conditions.

Implementation of the ISMN is intended to increase capacity to detect, attribute, and report on ecosystem change in the Northeast U.S. region with great power and at a lower cost than multiple, uncoordinated approaches. A coordinated monitoring network and data management system will enable researchers and managers to rapidly access the data required to inform decision in a time of rapid ecosystem change.

## 2. Northeast U.S. Region Ocean and Coastal Ecosystems in the Context of Climate Change

### 2.1 Overview

The Northeast U.S. region comprises ecosystems in the coastal and ocean waters from the Eastern New York Bight to the Scotian Shelf, including Long Island Sound, Georges Bank, Southern New England, Gulf of Maine, and the Bay of Fundy (Fig. 2.1.1.). These ecosystems are located within the Northeast U.S. Continental Shelf Large Marine Ecosystem (NE LME) spanning national and state lines. These large (>200,000 km<sup>2</sup>) marine ecosystems were defined by ecological characteristics, including bathymetric features, hydrographic regimes, productivity patterns and trophic relationships. Within the NE LME, four subregions were delineated because of unique ecosystem structure and function: the Gulf of Maine, Georges Bank, Southern New England and mid-Atlantic Bight (Shearman and Hempel 2009).



**Figure 2.1.1. The Northeast U.S. region.**

The Northeast U.S. region stretches from the Eastern New York Bight to the Scotian Shelf. It includes two distinct subregions, the Gulf of Maine and Southern New England, and spans international boundaries as it encompasses and is directly influenced by eastern Canadian Maritime waters. © NERACOOS

This chapter first introduces a general overview of the dominant ocean and coastal ecosystem drivers and pressures in the Northeast U.S. region. Subregions are then identified and discussed in more detail. Finally, an environment-based approach, focusing on the physical structure, biodiversity, and ecosystem function of pelagic, benthic, and coastal and estuarine environments, is applied to each subregion. Biodiversity and ecosystem function are two ecosystem properties key to understanding the region's ocean and coastal ecosystems. **Biodiversity**, including genetic, species, and functional diversity, is fundamental to the characteristics and productivity of the region's ecosystems. The genetic and species diversity in each subregion characterize the living organisms that can survive and reproduce in, or immigrate into, each subregion. A region's biodiversity is further shaped by biotic interactions among these organisms, including interactions with human activities, such as fishing. **Ecosystem function** characterizes the interactions among these species and with their physical and chemical environment that determine the productivity and services that each ecosystem provides, as well as the responses of species and communities to abiotic or biotic change.

## 2.2 Northeast U.S. Region Ocean and Coastal Ecosystems: Drivers and Pressures

### 2.2.1 Drivers of change

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The ocean and coastal ecosystems in the Northeast U.S. region are subject to driving changes in the physical environment. This can be associated with bottom-up forcing of ecosystem state such as changes in wind or temperature (Pershing et al. 2015), as well as top-down effects from direct forcing by human activities, notably fishing and other resource extraction activities.

A dominant driving force in the physical environment is climate change. Increases in atmospheric carbon dioxide (CO<sub>2</sub>) and other greenhouse gases are identified as fundamental sources of long-term climate change. The 2013 Intergovernmental Panel on Climate Change (IPCC) report unequivocally attributes the increase in greenhouse gases to human activities (IPCC 2013). For purposes of observing how climate change is affecting ecosystems, the relevant factor is not so much the ultimate cause of increased CO<sub>2</sub>, but rather, that the levels are increasing.

Increasing atmospheric CO<sub>2</sub> concentrations result in a number of pressures on ecosystems globally. In addition to warming temperatures (Fig. 1.1.1.), long-term climate change may contribute to large-scale shifts in coastal ocean circulation and wind patterns, stratification of surface waters, changes in local precipitation and, riverine discharge, sea level rise, increased storm frequency and surge, as well as ocean and coastal acidification.

Other potential physical drivers including basin-scale atmospheric oscillations, such as the North Atlantic Oscillation and the Atlantic Multidecadal Oscillation, and concomitant changes in the position of the Gulf Stream are not directly linked, but are increasingly influenced by rising atmospheric CO<sub>2</sub> concentrations. These physical alterations may dampen or enhance the effects of the long-term climate drivers exerting pressures on the environment. Some of the ecosystem effects of these pressures have already been identified for this region, including lower primary production with increased precipitation (Balch et al. 2012), shifts in nutrient loading to deep waters of the Gulf of Maine affecting primary production and phytoplankton diversity (Townsend et al. in review), changes in stratification of surface waters affecting the structure of higher trophic levels (Pershing et al. 2015), shifts in zooplankton diversity affecting energy available to fish predators (Johnson et al. 2011; Reygondeau and Beaugrand 2011), and local acidification events affecting shellfish production (State of Maine 2015).

Along with the anthropogenic and natural system effects related to climate change discussed above, change in population density, land use, and land cover are important drivers leading to pressures such as food production, resource extraction, and fishing are important forces causing ecosystem changes. Integrated and simultaneous monitoring of top-down system drivers caused by human activities and natural forces will be critical for successful resource management, which conserves coastal resources while sustaining coastal communities.

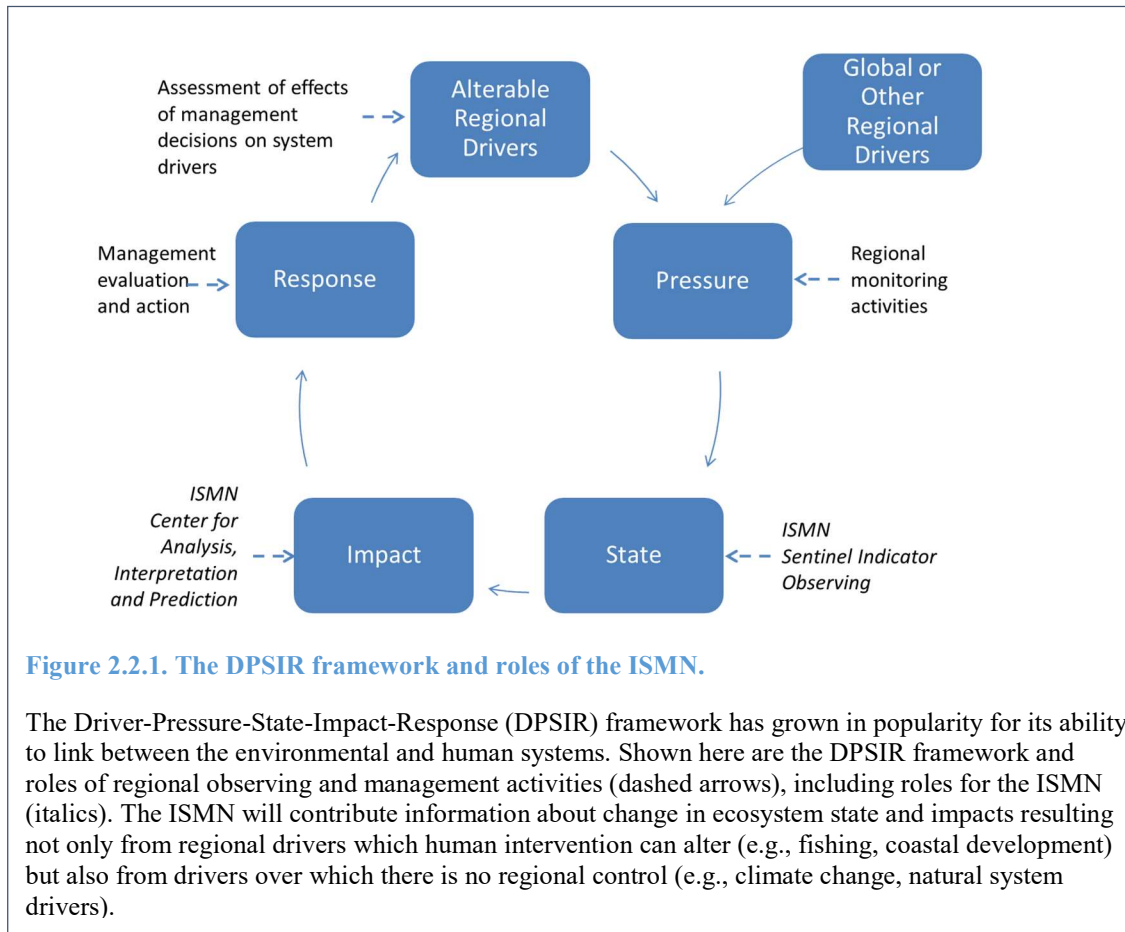
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### 2.2.2 The DPSIR framework applied to Northeast U.S. region ocean and coastal ecosystems

Linking change in marine ecosystems to human intervention is one of the many challenges in managing ecosystem services. One tool that has helped researchers, managers, and communities understand and discuss connections among drivers, ecosystem change, and management of socioeconomic impacts since its inception in the early 1990s is the Driver-Pressures-States-Impacts-Response (DPSIR) framework. DPSIR (Fig. 2.2.1.) provides a link between the environmental system and the human system through systems analysis pathways (e.g., Fogarty et al. 2012; Walmsley 2012). Broadly, external **driving forces** exert **pressures** on ecosystems. As a result of these pressures, there may be changes in **state** (i.e., structure and function) of the ecosystem. In turn, these state changes may result in **impacts** to ecosystem services, which warrant **responses** to address, mitigate or adapt to the observed impacts. In turn, responses could influence driving forces and impacts through feedback mechanisms (Smeets and Weterings 1999; Gabrielsen and Bosch 2003; Maxim et al. 2009).

While this conceptual framework is applicable to anthropogenic drivers (e.g., coastal land development), it does not capture the total dynamics of the system, as some of the most important drivers (climate change, natural ocean variability) operate either outside of the human capabilities for intervention (e.g., North Atlantic Multidecadal Oscillation and change in the position of the Gulf Stream) or the response is global rather than regional in scale (e.g., reduction of CO<sub>2</sub> emissions). Additionally, complex interactions of multiple stressors from multiple drivers confound interpretation. These drivers may exert pressures whose effects on ecosystems could either exacerbate, moderate, or result in unexpected changes in ecosystem states and services from those expected from human interventions. The ISMN will provide timely information not only on changes in ecosystem state as influenced by the cumulative impact of drivers, but also analysis and prediction to provide the best information possible for managers and communities to understand the nature of change and to develop alternative strategies to adapt to ecosystem conditions that may be beyond capabilities for human intervention.

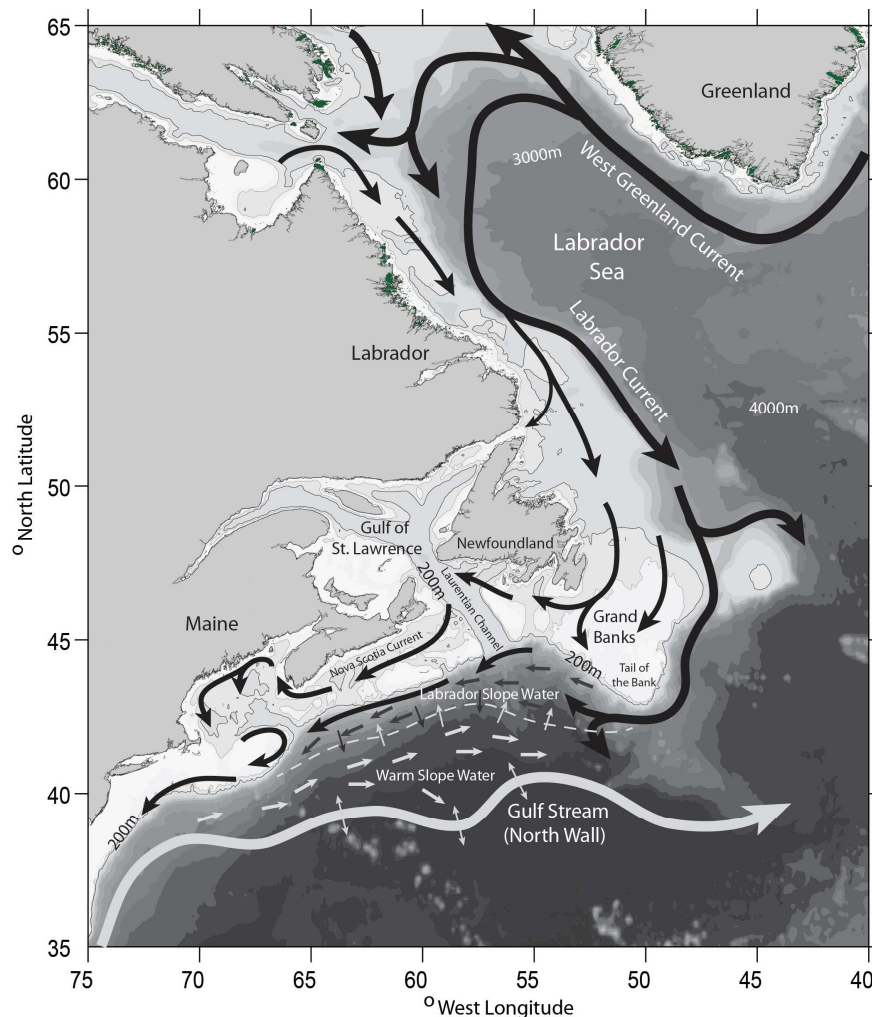




## 2.3 Northeast U.S. Region Ocean and Coastal Ecosystems Subregions

### 2.3.1 Overview

The boundary between the Gulf of Maine (including Georges Bank, hereafter GoM) and Southern New England (including Long Island Sound, hereafter SNE-LIS) subregions could be drawn loosely based on geographic locations. However, the two subregions are separated by a more pronounced physiographic break. This significant change occurs just south of the Great South Channel off of Cape Cod. The colder and fresher water transported in the Nova Scotia and Labrador Currents prominently influences waters to the north in the GoM subregion. Contrastingly, waters to the south and west in the SNE-LIS subregion are associated with the warmer and saltier waters of the Mid-Atlantic Bight, influenced by cross shelf mixing of warm slope water adjacent to the Gulf Stream (Fig. 2.3.1.).



**Figure 2.3.1. Circulation patterns of the Northeast U.S. region and associated waters**

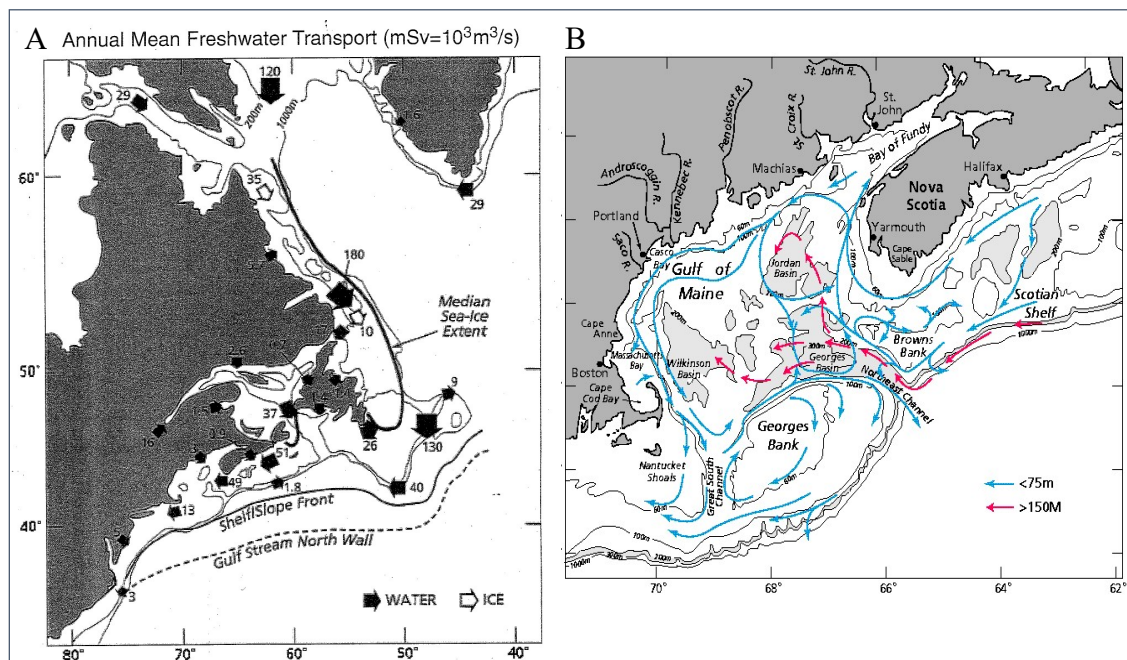
Bathymetric map showing the position of the North Wall of the Gulf Stream, and major features of the Labrador Current with its offshore, slope, and continental shelf components, which crosses the Grand Banks and the Laurentian Channel, joining the Nova Scotia Current (after Chapman and Beardsley 1989). The subsurface (~200 m) distributions of the two types of Slope Water, Warm Slope Water and Labrador Slope Water, are shown schematically, separated by the dashed line, along with their presumed residual flows (short arrows); mixing of the water masses is also indicated by short arrows (after Gatién 1976). Image reprinted from Townsend et al. (in review) with permission.

### 2.3.2 Gulf of Maine

The GoM is an international, semi-enclosed marginal sea that includes waters from the high tide mark to the edge of the continental shelf, and stretches from Nantucket Shoals off Cape Cod, Massachusetts to the Bay of Fundy. Traced along this route, the shoreline is roughly 12,000 km; when enclosed by its seaward boundary, the subregion spans over 90,700 km<sup>2</sup> (Kelley et al. 1995).

The GoM can be considered a continuation of an advective estuarine system coupled to the Gulf of St. Lawrence. Freshwater inflow to the Gulf of St. Lawrence from the St. Lawrence River and from Labrador Current inflow through the Strait of Belle Isle (Fig.2.3.2, left) are delivered into the Bay of Fundy and eastern GoM by the surface flowing Nova Scotia Current. Just south of these surface currents, saltier slope water with either Labrador Sea or temperate Atlantic Slope Water origin also enters the GoM through the Northeast Channel. Local river discharge into the GoM also makes a significant freshwater contribution.

The relative balance between these inflows contributes importantly to the water temperature, salinity and nutrient characteristics of the GoM (Townsend et al. in review). Once in the GoM system, a buoyancy-driven coastal current then flows predominantly in a southwesterly direction in spring and summer, with major offshore departures in the vicinity of Penobscot Bay where the coastal current is pushed offshore and recirculates in a counter-clockwise direction back into the eastern GoM (Fig. 2.3.2, right). After flowing past Massachusetts Bay, the western Maine Coastal Current splits, entering either the clockwise Georges Bank gyre or exiting the GoM over Nantucket Shoals through the Great South Channel.



**Figure 2.3.2. Gulf of Maine transport and circulation patterns.**

The left figure (A) shows the estimated magnitude of freshwater volume transport in the coastal northwest Atlantic System, showing contributions of freshwater into the Gulf of St. Lawrence from the St. Lawrence River and Labrador Current (through the Strait of Belle Isle) and into the Gulf of Maine from the Nova Scotia Current and local river discharge. The right figure (B) shows surface (< 75 m) and deep water (> 150 m) flows once waters have entered the Gulf of Maine and the characteristic counter-clockwise circulation pattern. Images reprinted from Beardsley et al. (1997) with permission.

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GoM habitats support productive coastal and ocean ecosystems, boasting a rich blend of ecological, economic, recreational, and environmental resources (Sherman and Skjodal 2002). The diverse pelagic, benthic, and coastal and estuarine environments support a range of biological communities, including a number of state and federally threatened or endangered marine birds (e.g., razorbills, Arctic terns, Atlantic puffins, roseate terns and piping plovers) and marine mammals (e.g., North Atlantic right whales, humpback whales, and fin whales). Meanwhile, benthic ecosystems provide key habitat for species like the American lobster, a dominant contributor to local economies. When combined with other shellfish and finfish landings, the nutrient rich waters of the coastal GoM yield an annual harvest valued at nearly 650 million dollars and employ over 20,000 commercial fishermen. Commercial fishermen are not the only resource users and the area is estimated to draw over 10 million tourists annually, who contribute a substantial amount of money to local communities.

### **2.3.3 Southern New England-Long Island Sound**

The SNE-LIS subregion begins at the southern edge of the Great South Channel near the southeastern tip of Cape Cod, Massachusetts and extends down the Rhode Island and Connecticut shoreline, finally ending at the southwestern shore of Long Island.

The circulation pattern in the SNE-LIS subregion is characteristic of an eastern boundary along-shore equatorial current system. Waters exiting the GoM over the shallow Nantucket Shoals area form the southward flowing nearshore current, while waters exiting through the Great South Channel drive a parallel current in deeper waters farther from shore. While moving south, there is considerable cross-shelf mixing with Gulf Stream waters as a result of the decreased width of the continental shelf with decreasing latitude (Townsend et al. 2006).

Long Island Sound is a large urban estuary that separates Long Island from Connecticut. There are two connections to the Atlantic Ocean, The Race to the east and the East River to the west. Several major rivers, including the Connecticut, Housatonic, and Thames Rivers, comprise eighty percent of the freshwater flowing into the Sound. The coastal and nearshore habitat provides critical feeding, nesting, breeding, and nursery habitat for many plant and animal species (Latimer et al. 2014). Changes in precipitation as a result of climate change can alter the amount of freshwater input into Long Island Sound.

A recent and comprehensive estimation of the total economic value of Long Island Sound is not available. However, Altobello (1992) calculated that Long Island Sound contributes \$8 billion (adjusted for inflation) to the regional economy through commercial and recreational activities. Pomeroy et al. (2013) conducted a more limited analysis of just Connecticut's maritime industry, and found that in 2010 the total impact was nearly \$7 billion. The maritime industry was defined as: commercial fishing, seafood product preparation and packaging, ship building and repairing, boat building, transport by water, scenic and sightseeing transportation and support activities for transportation, and amusement and recreation activities.



## 2.4 Northeast U.S. Region Ocean and Coastal Environments and Ecosystem Properties

### 2.4.1 Pelagic environment

#### *Physical characteristics*

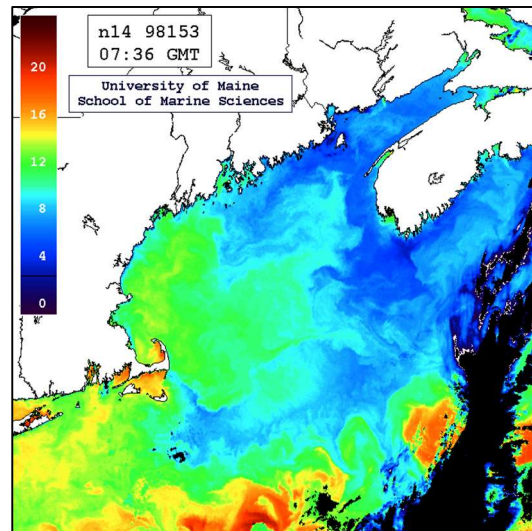
The physical pelagic habitat of the GoM is characterized by a strong seasonal cycle of temperature, wind and convective mixing and stratification, transport of cold, subarctic water (containing plankton) from eastern Canada, a marked temperature gradient in summer between the eastern and western GoM (e.g., Fig. 2.4.1.), areas of strong tidal mixing and a varied topography that includes relatively shallow (25-50 m) embayments, ledges and banks as well as three relatively deep (200-350 m) offshore basins.

The physical pelagic habitat of the SNE-LIS coastal shelf is indicative of an Atlantic coastal plain system. Here, there is much less depth diversity than the GoM subregion because the SNE-LIS subregion lacks the banks, ledges and basins scattered throughout the GoM. Instead, the SNE-LIS subregion contains a number of large bays, including Buzzards Bay and Narragansett Bay, as well as six large sounds, including Nantucket Sound, Martha's Vineyard Sound, Rhode Island Sound, Block Island Sound, Fishers Island Sound and Long Island Sound. Additionally, overall the SNE-LIS subregion has warmer water temperatures.

#### *Biodiversity*

##### *Microbial and microalgal communities*

In the GoM, biodiversity patterns of microbial and microalgal communities in pelagic habitats were recently reviewed by Li et al. (2011), providing the first assessment for the region. Genomic sequencing indicates that viruses are clearly abundant, representing about 3% of total predicted proteins. Microbial cell inventories of bacteria suggest the total mass of bacteria cells in the GoM is  $7.6 \times 10^{24}$ , estimated as  $1.8 \times 10^5$  tons of dry weight. For the microalgae, 665 taxa have been named. The vast majority by number of the phytoplankton in the GoM are small autotrophs, the most abundant being the cyanobacterium, *Synechococcus*, estimated to make up about 75% of the number of phytoplankton in the GoM (Li et al. 2011). However, the larger microalgae make an



**Figure 2.4.1. Gulf of Maine temperature gradient.**

This figure shows an AVHRR satellite image of sea surface temperature in the Gulf of Maine in June 1998, exhibiting cold temperatures due to tidal mixing off SW Nova Scotia and in the Bay of Fundy, extending west along the coast of Maine in the eastern Maine Coastal Current. Image from University of Maine Physical Oceanography Group and Satellite Oceanography Lab ([http://wavy.umeoce.maine.edu/sat\\_ims.htm](http://wavy.umeoce.maine.edu/sat_ims.htm)).



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important contribution to ecosystem function. About 60% are diatoms, which are predominant components of spring phytoplankton blooms. Autotrophic and heterotrophic dinoflagellates also figure prominently in ecosystem function, and their relative abundance in the pelagic ecosystem is related to the state of the nutrient regime (Townsend et al. in review). Blooms of the toxic dinoflagellate, *Alexandrium fundyense*, are a common feature in the GoM, potentially resulting in Paralytic Shellfish Poisoning when humans consume contaminated shellfish. The species richness of heterotrophic protists in the GoM appears to be low. Overall, nine species of aloricate ciliates, 24 species of loricate ciliates, and one species of heterotrophic dinoflagellate have been identified. Abundance estimates range from about ten to many thousand cells ml<sup>-1</sup> (Li et al. 2011).

Up to 45 phytoplankton species were recorded in SNE-LIS in the 1990s (Capriulo et al. 2002). During the last decade, the Connecticut Department of Energy and Environmental Protection (CT DEEP) phytoplankton monitoring program found that diatoms contributed 61% of the species richness and dinoflagellates accounted for 26% (Lopez et al. 2013). *Synechococcus* spp., are present, especially in summer (Campbell 1985), but contribute less than 10% of the total phytoplankton biomass (Lopez et al. 2013). In eutrophic inner bays of the Sound, harmful dinoflagellates such as *Prorocentrum minimum*, *Akashiwo sanguinea* and *Alexandrium fundyense* bloom seasonally. For example, *A. fundyense* has formed blooms in Huntington Bay, New York, causing Paralytic Shellfish Poisoning outbreaks since 2006 (Hattenrath et al. 2010). Brown tides consisting of high concentrations of *Aureococcus anophagefferens* occur in some Long Island Sound bays, contributing to the loss of the bay scallop industry. There is little information in LIS-SNE on the biodiversity and distribution of heterotrophic protists. In a recent review of heterotrophic protists in Long Island Sound (Lopez et al. 2013), 71 species of ciliates were reported (Capriulo et al. 2002). Heterotrophic nanoflagellates in SNE-LIS are two-orders of magnitude more abundant than ciliates (McManus 1986; Capriulo et al. 2002).

### Zooplankton

Among the net-captured zooplankton in the GoM, 533 metazoan species, including 247 ichthyoplankton and 237 crustacean species have been identified (Johnson et al. 2011). This however, does not include all of the meroplankton originating from benthic invertebrates, of which there are over 2,000 named species. Despite the total number of zooplankton species recorded, only a very small number of species dominate the zooplankton community. Species accumulation studies show that only 15 species are typically found among 10,000 captured individuals. In Canadian waters to the north of the GoM, three copepod species, *Oithona similis*, *Pseudocalanus* spp. (likely a combination of two morphologically very similar species) and *Calanus finmarchicus*, make up over 60% of the abundance of zooplankton captured with a 200 µm mesh net (Johnson et al. in prep). In the GoM, analysis of thousands of samples taken with a larger mesh net between 1977-1999 by the National Oceanic and Atmospheric Administration (NOAA) Marine Resources Monitoring, Assessment, & Prediction Program (MARMAP) indicate that three species, *Centropages typicus*, *C. finmarchicus* and *Pseudocalanus* spp. made up about 70% of the total number of zooplankton captured with a 333 µm mesh net.

The pelagic habitat of the GoM contributes to the structure of diversity of the plankton and thereby its ecosystem function (as discussed below). This is illustrated by the

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remarkable abundance of *C. finmarchicus* where it resides at the southern edge of its biogeographic range. Although its life cycle is adapted to the environmental conditions of the deep and colder subarctic North Atlantic Ocean, the species is as abundant in the GoM as anywhere across its range (Melle et al. 2014). *C. finmarchicus* is sustained in the GoM by a combination of transport from the *Calanus*-rich waters of eastern Canada and its capacity to grow quickly in the cool and food-rich waters of the Maine Coastal Current, which then deposits the species in large numbers to overwinter in Wilkinson Basin in the western GoM (Runge et al. 2015). Residence in Wilkinson Basin, which is deep enough to allow the species to avoid high mortality from pelagic fish and other visual predators, allows the species to reproduce and complete its life cycle in the following spring. The extent to which this spring replenishment is successful depends on the match between the exit of the species from dormancy and the timing and duration of the spring phytoplankton bloom.

Unlike the GoM, the zooplankton assemblage of SNE-LIS is typical of estuarine environments, with relatively poor diversity but high abundance. 20 species of calanoid copepods and seven species of cladocera were identified in central LIS in 1952-54 (Deevey 1956). Other zooplankton groups were not, however, identified to species, but pooled into taxa: cyclopoid copepods (one subgroup), harpacticoid copepods (one subgroup), crustacean larvae (22 subgroups), other larval forms (five subgroups), polychaetes (three subgroups), coelenterates (three subgroups), and other forms (seven subgroups). Altogether, 66 taxa were recognized. The CT DEEP zooplankton monitoring program recognizes 49 taxa (Dam and McManus 2012). The zooplankton abundance in SNE-LIS is overwhelmingly dominated by calanoid copepods. The winter-spring assemblage is dominated by *Acartia hudsonica* and *Temora longicornis*, whereas the summer-fall assemblage is dominated by *Acartia tonsa* and *Parvocalanus parvus* (Dam and McManus 2012). The most striking changes in the zooplankton community of SNE-LIS since the study of Deevey (1956) is the reduction in body size the copepod *Acartia tonsa*, and the almost disappearance of the large-sized copepods *Calanus finmarchicus* and *Tortanus discaudatus*, presumably as the Sound has warmed (Rice et al. 2014).

### Marine fish

Based on the Census of Marine Life Report, a total of 252 fish species have been identified in the GoM (Fautin et al. 2010). There are 87 resident species, of which 55 are shallow-water species, 23 are deeper-water species, and nine are pelagic species (Collette and Klein-MacPhee 2002). A total of 95 finfish species, 37 of which are pelagic and 58 are primarily benthic have been identified in the Long Island Sound Trawl Survey (Gottschall and Pacileo 2010). Of the Long Island Sound fish species, 33 species are considered cold-adapted (i.e., they are more abundant north of Cape Cod), 34 species are warm-adapted (more abundant south of New York), and 28 species are subtropical or tropical species rarely found north of Chesapeake Bay (Howell and Auster 2012; Lopez et al. 2013).

### Marine birds and mammals

The productive marine ecosystems in the region also host a diverse community of marine birds and mammals. This includes species that breed within the region and those that spend their non-breeding season here. Additionally, the region serves as a unique transition zone for these marine birds and mammals as it is the northern edge of the

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biogeographic range for some species and the southern edge of the biogeographic range for others. Finally, there are species that are relatively common as well as rare species with only incidental observations, which is rather common given the ability of these species to travel great distances. Thus, depending on the criteria used, the number of different species varies.

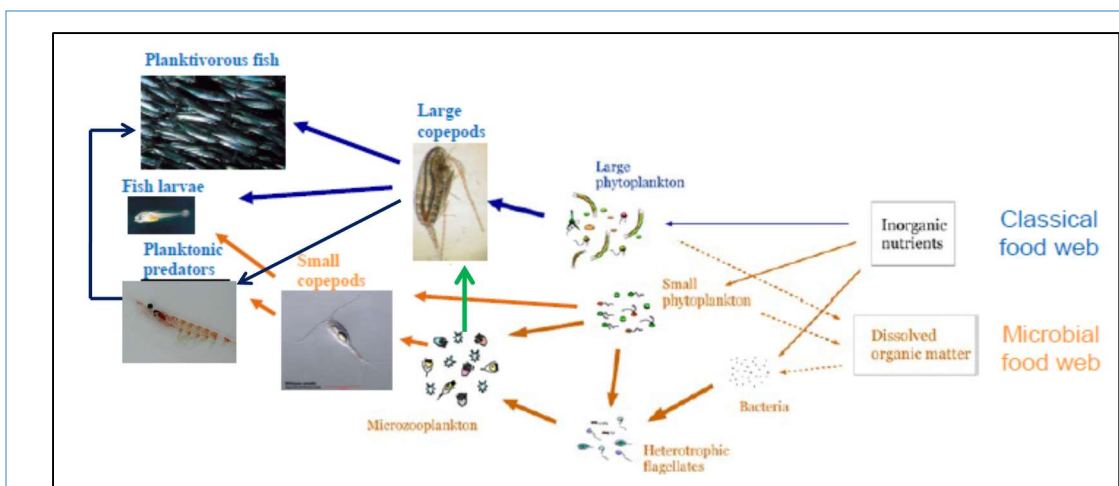
Recently there have been attempts to quantify the marine bird and marine mammal biodiversity in the region. One of the most extensive efforts, the Census for Marine Life, lists 184 bird species and 32 mammal species in the GoM subregion. Focusing explicitly on seabirds, which are defined as a subset of marine birds that are colonial and nest in saltwater, Nisbet et al. (2013) documented 80 different species that to some extent used a region extending from the Bay of Fundy down to Chesapeake Bay. Modifying a field guide species list from Proctor and Lynch 2005, the New England Coastal Wildlife Association (NECWA) lists 68 marine bird species, including seabirds, sea ducks, and shorebirds (NECWA 2007). The NECWA lists five seal species, seven large baleen whale species, ten large-toothed whale species, and ten species of dolphin and porpoises. Among the large baleen whales is the North Atlantic right whale, arguably one of the most endangered marine species in the region with a population of only ~ 500 individuals (NOAA North Atlantic right whales 2015).

### *Ecosystem function*

The Northeast U.S. continental shelf is known to be highly productive (Townsend et al. 2006). Offshore areas are characterized by pronounced spring and fall algal blooms that can vary in timing from year to year (Durbin et al. 2003; Tian et al. 2015). Primary production is highest along the coastal shelf, banks (including Georges Bank), and ledges of the GoM, where tidal pumping and mixing sustain nutrient supply and primary and secondary production from late winter through autumn (Davis 1987; Runge et al. 2015; Tian et al. 2015).

In the GoM pelagic environment, the classical food web shunting primary production to large zooplankton, notably *C. finmarchicus*, is prominent (Fig. 2.4.2.). In its older stages, this species is exceptionally rich in fatty acids, which provides energy in packets abundant enough to meet the needs of fish and large planktivorous consumers such as North Atlantic right whales. This lipid-rich food web pathway is the result of the advective connection between the GoM and the colder, subarctic waters of eastern Canada. In the relatively warm and shallow estuaries and bays of SNE-LIS, the pathway shunting primary production and dissolved organic matter to ecosystem services moves through the small copepod and heterotrophic grazers.

This simplified food web model of course does not capture all of the ecosystem function relevant to ecosystem services. There are, for example, a number of “underknown” species, such as species of gelatinous zooplankton, euphausiids, and mysids, which are not well sampled in present observing programs (Johnson et al. 2011). Nevertheless, they may have high functional importance in the pelagic ecosystem, serving either as high quality prey for fish (euphausiids, mysids, gelatinous zooplankton) or consumers of primary and secondary production (gelatinous zooplankton).



**Figure 2.4.2. A simplified food web model for the Northeast U.S. region pelagic environment.**

The food web shows the classical and microbial pathways for transforming sunlight and dissolved organic matter into ecosystem services, in this case production of planktivorous fish such as herring, sand lance, and mackerel. The planktivorous fish in turn supply piscivores such as groundfish, tuna, lobsters, and, ultimately, humans.

To inform users about the effects of major drivers on ecosystem services in the Northeast U.S. region pelagic environment, it will be necessary to integrate understanding of species responses and linkages with observing system data on biological and environmental change. This will likely involve a synthesis among a wide range of modeling approaches, including population, integrative ecosystem, and food web modeling (Johnson et al. 2011).

## 2.4.2 Benthic environment

### *Physical characteristics*

The benthic habitat includes the seafloor and all organisms living on or beneath the seafloor from the high tide mark, not including vascular plants, out to and including the canyons (2,100 m). There are a number of different schemes used to classify the physical benthic habitats that are found in the region. Although each is slightly different, most include dominant benthic habitat types characterized as either sedimentary bottoms, rocky bottoms, kelp beds, eelgrass beds, or epifaunal shellfish beds (e.g., Tyrell 2005; Stevenson et al. 2014). Salt marsh benthic habitats are sometimes also included; however, given their proximity to the shoreline and water depths commonly less than mean low low water, this habitat type is covered in the discussion of the coastal and estuarine environment (see section 2.4.3).

An application of the Coastal and Marine Ecological Classification System (CMECS) has recently been completed for the Northeast shelf, and various data can be viewed online (<http://tinyurl.com/mdhhqrs>). The seafloor environment in the Northeast U.S. region comprises a patchwork of habitat types, with similar habitats dominating across relatively broad spatial scales. In particular, Maine benthic habitats are mostly hard substrates (e.g., ledge, boulders, cobble, and gravel). In contrast, Atlantic Maritime Canada, and specifically the Bay of Fundy Basin, is dominated by soft substrates (e.g., sand and clay). These soft substrate habitats are also common south of Maine along the coast of New

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Hampshire, and Massachusetts to Race Point. Likewise, sedimentary habitats dominate the seafloor south of Cape Cod into Nantucket Sound and across to Georges Bank, and west into Buzzards Bay, Block Island Sound, and Narragansett Bay and into Long Island Sound. These sedimentary environments range from muds to sands to gravels and mixtures of each, with some areas of hard substrates dispersed throughout such as rocky shoals and outcrops (e.g., Poppe et al. 2000; Kostylev et al. 2001; Valentine et al. 2005; Greene et al. 2010 and references therein; LaFrance et al. 2010).

### *Biodiversity*

Substrate type, grain-size, depth, levels of organic matter, and seafloor roughness play a key role in shaping the diversity of biological communities in benthic habitats. Benthic communities include both infaunal (living in the seafloor sediments) and epifaunal (living on or attached to the seafloor) organisms. Infaunal organisms are commonly found in soft sediments because these benthic habitats are easier to burrow into. Epifaunal organisms are found inhabiting both soft and hard substrates. On soft sediments they are generally mobile, including various species of crustaceans, echinoderms, and mollusks. On rocky bottom habitats, as well as in kelp beds, eelgrass, and shellfish beds, they are often attached or sessile and include sponges, cnidarians, bryozoans, barnacles, polychaetes, and tunicates. Benthic habitats with high topographic roughness increase the surface area and provide more space for attachment and larval settlement. The increased roughness or rugosity also provides protection from predators. Consequently, species richness and biomass levels are generally higher in these benthic habitats with high seafloor roughness index values (Snelgrove 2001; Gladstone 2007).

Given the sharp physiographic break between the GoM and SNE-LIS subregions, and related environmental gradients/hydrodynamic regimes, the benthic community types in each region are fairly distinct. In the GoM, macroinvertebrates, including the commercially important American lobster, rock crab and sea scallop, are major contributors to the benthic community. As a result of the relatively narrow coastal plain and greater depths in the GoM, overall benthic biomass is generally lower here than in the SNE-LIS subregion because of the inverse relationship between benthic biomass and depth. The high benthic biomass levels in the SNE-LIS subregion are mainly due to high abundance of epibenthic suspension feeders (e.g. sea scallops and tunicates), infaunal suspension feeders (e.g., clams) and deposit feeders (e.g. sea cucumbers and brittle stars). These species thrive in the SNE-LIS subregion because shallow waters and decreased wave energy result in a greater amount of organic matter (e.g. marine snow) finding its way to the benthic habitats, providing food for suspension and deposit feeders (Gallager et al. 2011). Although these are fairly consistent benthic community patterns between the two subregions, seasonally forming warm and cool pockets of water allow species to extend their ranges to the north or south (e.g., Bousfield and Laubitz 1972; Campbell 1987; Larsen 2004).

### *Ecosystem function*

Primary productivity produces detrital and marine snow that falls to the benthic substrate. The benthic inhabitants feed on this material and produce animal protein that forms the basis of the marine food chain. This linkage and cycling of nutrients is critical to sustaining the species harvested for human consumption. The faunal community associated with benthic substrates feed as filter feeders, deposit feeders, and predators,



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creating a complex community of inter-related trophic niches. As prey and forage species become increasingly larger, humans engage in harvest of the benthic species. Cogan and Noji (2007) discuss that program drivers such as climate change (temperature increases) and habitat degradation (physical impacts and eutrophication) can be measured as changes in compositional diversity, structural diversity, and functional diversity. This approach to benthic ecosystem community complexity allows sentinel monitoring opportunities to measure and monitor diversity of species, habitat structure, and feeding types.

### 2.4.3 Coastal and estuarine environment

#### *Physical characteristics*

The diversity of habitats in the coastal and estuarine environment (defined for the purpose of this document as waters from the high tide mark to a depth of 10 m) lining the Northeast U.S. region shoreline is considerably greater than that found along the U.S. eastern seaboard running from the southern shores of Long Island to the Florida coastline and into the Gulf of Mexico. Beginning in the northeast GoM, these coastal and estuarine habitats are composed mainly of rocky coasts with relatively few tidal inlets, some of which are macrotidal but are generally smaller than their southern counterparts (Duffy et al. 1989). Habitat composition changes moving south, and larger, broader embayments created by a combination of variable erosion rates and major river outflow systems become more common along the central GoM coasts of New Hampshire and Massachusetts. The physical habitat in the SNE-LIS subregion comprises bedrock-dominated sections, with extensive beaches (outwash plains) and drowned river valleys. In this region, the shoreline is less jagged and interspersed with a few dominant drowned-river valley (e.g., Narragansett Bay) or drowned-basin (e.g., Long Island Sound) estuaries. Many of the embayments, especially those in southern New England, such as Plum Island Sound and Cape Cod (e.g. Pleasant Bay), are bordered by significant sandy barrier beaches that are very dynamic and constantly changed by coastal processes, such as erosion, overwash and inlet formation and migration.

Across the region, habitats in the coastal and estuarine environment can be broadly classified as: rocky, cobble, gravel, and sandy shores; tidal mudflats and tidal wetlands; or salt marshes. Overall, salt marshes are relatively small in spatial extent compared to those found along the southern Atlantic coastline because of the limited available area of flat coastal plain habitat. There are some exceptions to this, including Scarborough Marsh (ME), Plum Island/Parker River Marsh (MA), and Barnstable Marsh (MA). However, the other habitat types are still much more common throughout the region.

In addition to the north-south gradation of habitat types, there are also north-south gradients in tidal ranges and wave energy. The highest tidal ranges are in the northeast GoM, boasting some of the largest tide ranges in the world (e.g., 16 m in the Bay of Fundy). From north to south tidal ranges decrease and wave energy trends follow a similar pattern (Fitzgerald 2002). As a result of these patterns, the only tide-dominated coastal and estuarine habitats are found northeast from the Kennebec River (ME) to the Bay of Fundy. Wave-dominated (e.g., open coasts of Cape Cod and Rhode Island) and mixed-energy-dominated (e.g., southern GoM and much of SNE) systems cover a larger area in the region (Fitzgerald et al. 1999).

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### *Biodiversity*

The Northeast region coastal and estuarine ecosystems are highly productive because of their unique physical conditions and geographic locations. Because of their shallow waters, sunlight is able to penetrate through most of the water column. Coastal oceanographic processes, e.g. the Maine Coastal Current, in combination with periodic upwelling, deliver nutrients to the coastal and estuarine environment. These shallow depths also support warmer water temperatures in summer and fall than offshore coastal waters. Additionally, given their proximity to the coasts and river systems, there is usually an abundance of nutrients, providing the final key ingredient to support a diversity of phytoplankton, macroalgae and salt marsh grasses and shrubs. These high levels of primary productivity found in coastal and estuarine systems as well as the diversity of habitat types support a variety of biological organisms. Salt marshes and tidal flats provide critical habitats for a number of invertebrate species such as polychaete worms, amphipods, horseshoe crabs, and bivalves (some of which are commercially important to local harvesters). This, in turn, fuels higher trophic levels such as waterfowl, shorebirds, saltmarsh-specialist nesting species, and predatory fish species. Submerged Aquatic Vegetation (SAV), such as eelgrass and kelp (*Saccharina latissimi*), provide very diverse and essential habitats for a range of aquatic species at different life stages. Rocky shores are preferred habitat for commercially valuable species (mussels, periwinkles, rockweed) and for juvenile stages of other species (pollock, lobster, cod). The marine component provides key nursery areas for juvenile commercially and recreationally valued species, including Atlantic cod and other groundfish species, and offers shelter and protection to a number of marine transient organisms.

### *Ecosystem function*

Estuaries are productive systems that perform a number of services for coastal communities. Embayments and estuaries are connected to upstream tributaries, which provide sediment, nutrients and organic matter to downstream habitats. This connection is especially important for sustaining populations of anadromous (e.g. herring) and other forage fish. *Rocky shores* fortress coasts, buffering against erosion and storm surge while providing critical habitat for marine birds and seals. *Salt marshes* help to filter stormwater and runoff of pollutants coming from highly developed uplands that border the region's estuaries. They help to recycle nutrients back into the food web, protect communities from storm surges and wave action and provide critical habitat for shellfish, birds, invertebrates, and juvenile marine and diadromous fish species. *Coastal Wetlands* represent the largest component of the terrestrial biological carbon pool and thus play an important role in global carbon cycles (Chimura et al. 2003). *Coastal beaches and dunes* provide protection against storm surges and wave action while providing nesting habitat for shore birds and recreational activities for beach goers in the summer months. Beaches are a major draw for many tourists in the region and provide an economic boost to these seasonal communities. Coastal systems such as tidal bays and inlets, saltmarshes, rocky shores, and beaches also offer a wide variety of recreational uses to the public such as fishing, boating, and swimming. These activities make an important contribution to the economy of local communities and businesses.

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## 3. The Present Monitoring System in the Northeast U.S. Region Ocean and Coastal Ecosystem

### 3.1 Overview

This chapter summarizes the present monitoring activities for the Northeast U.S. ocean and coastal ecosystem. Because the region naturally extends into Canada, monitoring activities in coastal waters of the Bay of Fundy and Scotian Shelf are also included. The summary of current observing activities is based on a comprehensive inventory of monitoring programs developed by the ISMN is available online (Appendix I). While it is not possible to include every observing activity here, monitoring programs coordinated by major regional organizations, federal, state and provincial agencies (U.S. and Canada), academia, and NGO-managed activities and regional collaboratives are discussed in successive sections. Ultimately, this inventory of existing monitoring efforts serves as the foundation for the general gap analysis identifying needs for enhancement of current observing system (Chapter 5).

### 3.2 Historical Context

Early ecosystem observing in the region was motivated by some of the most legendary and valuable fisheries resources in the world. A fishing journal entry from the 1600s describes “fishes abounding therein, the consideration whereof is readie to wallow up and drown my senses not being able to comprehend or express the riches thereof” (Bolster, 2012). Anecdotal concerns about the lack of fish had led to better measurements of indicators of ecosystem productivity in the 1850s and 1860s (Bolster 2012). In the early twentieth century, Henry Bigelow, the first Director of the Woods Hole Oceanographic Institution, and colleagues conducted oceanographic surveys to understand circulation and the ecosystem supporting fisheries in the GoM. Long-term monitoring of landings, and more recently, of fisheries-independent surveys conducted by the U.S. and Canadian government fishing agencies show that the populations of Atlantic cod might be about 1% of historic levels, leading government regulators to severely restrict Atlantic cod fishing in some parts of the GoM, due to the dwindling resource.

Long-term monitoring in other marine ecosystems in the Northeast region has not been established until relatively recently, even though these ecosystems are also important for ecosystem services. In the mid twentieth century, Gordon Riley, while at Yale University, characterized the physical and chemical oceanography of Long Island Sound. His work was critical to understanding the effects of nutrient enrichment on dissolved oxygen in Long Island Sound:

*The region poses a vast number of ecological questions, and the answers, many of which are perceived dimly if at all at the present time, are of general interest because the region is similar in its broad oceanographic aspect to many other temperate coastal waters... The answers to such questions can only be obtained by a long term program of broad scope (Riley 1956).*

Howard Sanders, also while at Yale University, characterized the benthic ecology of soft sediments of Long Island Sound. His work informed Don Rhoads and colleagues and is

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now the foundation for modern sampling technologies such as Sediment Profile Imaging, which is currently used for evaluation of sediments for dredged material management as well as other ecological assessments. Critical studies for understanding energy and nutrient flow in salt marshes were conducted by John Teal and colleagues from the WHOI. The region has an important tradition of observing by natural historians who have provided a record of diversity and abundance of plants and animals that occupy the salt marshes, mudflats, rocky intertidal zones, and pelagic habitats along the coast of New England.

These are just a few examples of the history of monitoring the coastal ocean in New England. Current monitoring efforts described below build on the conceptual models of ecosystem functioning derived from these activities. Documentation and understanding of the biological changes, such as expansion in range of endemic or invasive species, could not be conducted without these historic observations.

### **3.3 Regional Organizations**

#### **3.3.1 Gulf of Maine Council on the Marine Environment**

The Gulf of Maine Council on the Marine Environment (GoMC), created in 1989 by the governments of Maine, Massachusetts, New Brunswick, New Hampshire, and Nova Scotia, works to foster environmental health and community well-being throughout the Gulf watershed. The GoMC's mission is to maintain and enhance environmental quality in the GoM to allow for sustainable resource use by existing and future generations. The GoMC maintains several projects including the EcoSystem Indicator Partnership (ESIP), the State of the Gulf Reporting, and the Climate Network.

ESIP identifies 22 indicators for the GoM and integrates regional data into a web-based reporting system for marine ecosystem monitoring. Activities of ESIP center on convening more than 150 regional practitioners in seven indicator areas: coastal development, contaminants and pathogens, eutrophication, aquatic habitat, fisheries, aquaculture, and climate change. The GoM regional indicators and reporting initiative include web-based interactive tools in the form of a Monitoring Map and an Indicator Reporting Tool.

#### **3.3.2 Northeast Regional Ocean Council**

The Northeast Regional Ocean Council (NROC) is a state and federal partnership that facilitates the New England states, federal agencies, regional organizations, and other interested groups in addressing ocean and coastal issues that benefit from a regional response. NROC provides a voluntary forum for New England states and federal partners to coordinate and collaborate on regional approaches to support balanced uses and conservation of the Northeast region's ocean and coastal resources.

NROC was formed in 2005 by the Governors of the New England states — Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut — to serve as a forum for the development of goals and priorities and address regional coastal and ocean management challenges with creative solutions. Recognizing the importance of the national role in these regional issues, NROC was expanded to include federal agencies as members of the Council. In addition to its members, NROC works with bordering states and countries as needed.

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### 3.3.3 Northeastern Regional Association of Coastal Ocean Observing Systems

The Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) mission is to produce, integrate, and communicate high quality information that helps ensure safety, economic and environmental resilience, and sustainable use of the coastal ocean. NERACOOS is one of 11 regional associations of the U.S. Integrated Ocean Observing System (IOOS), a partnership between 17 federal agencies and 11 coastal regions. IOOS has a program office housed within NOAA and was authorized by the Integrated Coastal and Ocean Observing System Act of 2009. NERACOOS was established as an independent, nonprofit organization in 2008 and built on the successes of a number of subregional efforts with continuous observations going back to 2001. The governance of NERACOOS includes state, federal, academic, industry, and nonprofit organizations.

NERACOOS supports continuous real-time observations with moorings and shore-stations, as well as model forecasts on marine and meteorological conditions. Ocean observations and model results are integrated through a regional Data Management Framework, which makes the information accessible and useful to the diverse communities that depend on ocean and coastal information.

### 3.3.4 Northeast Regional Planning Body

The Northeast Regional Planning Body (RPB) was established in November 2012 in response to the National Ocean Policy directive to develop regional ocean management plans, and also to support other goals and objectives of the policy, including improving monitoring and observing capabilities and promoting ecosystem-based management. The charge of the RPB is to develop and implement a regional ocean plan for Northeast U.S. ocean and coastal ecosystems that advances three overarching goals- healthy ocean and coastal ecosystems, effective decision making, and compatibility among uses- by guiding and informing agency regulatory and management decisions and support related science and monitoring activities.

The Northeast RPB drafted a plan for public comment and subsequently submitted a final plan to the National Ocean Council for its approval in 2016. The plan has a monitoring and evaluation section that includes the ISMN as a potential tool for measuring ecosystem change to help determine whether regulatory and management decisions informed by the ocean plan are contributing to any changes, positive or negative.

### 3.3.5 The Call for an Integrated Sentinel Monitoring Network

The 2011-2016 Strategic Plan for NERACOOS called for establishing 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 Coastal Ecosystem Health Committees (OCEH) of NERACOOS and NROC merged together and started the process of building an integrated sentinel monitoring network as one of its first actions.



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### 3.4 Federal observing efforts

#### *U.S. Waters*

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 to build a truly regional observing system, which includes estuarine monitoring, buoy observations, and extensive offshore oceanographic, fishery, and protected resource surveys. An excellent example is the integration of the data from the NOAA National Data Buoy Center (NDBC) buoys and the NERACOOS buoys. To the user, all the data are accessible from multiple sources and not dependent on the organization that is collecting the data. ISMN will build on these successes and complement the ongoing programs (described below and summarized in Table 3.4.1.) in the region.

#### NOAA Northeast Fisheries Science Center Resource and Ecosystem Surveys

The NEFSC collects fishery-independent data during standardized research vessel surveys from Cape Hatteras to the Scotian shelf. NEFSC gathers data on abundance, distribution, feeding ecology, size and age composition of stocks of economically and ecologically important species, e.g. fish, whales, and seabirds. The data is vital for assessment, management and a wide variety of research programs (<http://www.nefsc.noaa.gov/femad/ecosurvey/mainpage/>). The survey of fish species began in 1964 and represents the longest, continuous record of fish species diversity in the GoM. In addition, shelf-wide plankton and hydrographic surveys are conducted six times per year over the continental shelf from Cape Hatteras, North Carolina to Cape Sable, Nova Scotia. Two surveys are performed jointly with the bottom trawl surveys in the spring and autumn. An additional four cruises, conducted in winter, late spring, late summer and late autumn, are dedicated to plankton and hydrographic data collection. Zooplankton and ichthyoplankton are collected and include over 300 plankton taxa (<http://www.nefsc.noaa.gov/epd/ocean/MainPage/shelfwide.html>). To supplement these surveys, NEFSC began the Environmental Monitors on Lobster Traps (eMOLT) Program in 2001 and continues today with approximately 70 fishermen collecting hourly time series of parameters (e.g. temperature) throughout the fishing year and, in some places, year-round by installing low-cost sensors on their traps at fixed locations throughout the region. NEFSC also maintains a few multi-decade dockside temperature series. The one in Woods Hole dates back to the 1880s. More recently, series were established in Milford, CT and Narragansett, RI.

#### NOAA Stellwagen Bank National Marine Sanctuary

Stellwagen Bank National Marine Sanctuary (SBNMS) represents a microcosm of the GoM. It is a highly productive, federally protected area established in 1992 that encompasses a complex mosaic of seafloor habitats and depths from shallows (40 m), to rocky assemblages with interstitial voids providing excellent habitat for juvenile and adult fish, to sandy plains and gravelly pavement, to steep rocky slopes, to deep planes (150 m) consisting of soft mud and cerianthid/anemone aggregations. The diversity of fish and invertebrate communities and pelagic habitats support abundant marine mammal, seabird, and fish populations. The goal of the SBNMS is to conserve, protect and enhance the biological diversity, ecological integrity and cultural legacy of the sanctuary while facilitating compatible use. The 2010 management plan uses a DPSIR

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framework to document the condition of resources and recommends management strategies for restoring sanctuary resources (<http://stellwagen.noaa.gov/management/fmp/fmp2010.html>). Fishing of various kinds is allowed throughout SBNMS as are most other activities except sand and gravel mining, oil and gas exploration, and mariculture. Activities such as fishing with trawls and dredges as well as industrial activities like cable installations have demonstrable disturbance effects on seafloor communities and patterns of biological diversity. About 22% of the SBNMS has been closed to bottom trawling and gillnetting since May 1998 providing a defacto reference area for discerning the effects of bottom-tending fishing gear (trawls and gillnets) on biological diversity and habitat.

The Seafloor Habitat Recovery Monitoring Program (SHRMP) (<http://stellwagen.noaa.gov/science/shrmp.html>) was established in 1998 for the purpose of monitoring the recovery of seafloor habitats and biodiversity. Other monitoring activities address seabirds, whale sightings, whale calls, whale behavior, fish spawning sounds, ship traffic, habitat surveys, cod movements, forage fish (sand lance) habitat mapping, water quality, sediment chemistry, and plankton. Many of these monitoring programs can be found on the NERACOOS metadata site (Appendix I) or at <http://stellwagen.noaa.gov>.

#### NOAA National Estuarine Research Reserve System

The National Estuarine Research Reserve System (NERRS) has 28 sites around the country, with reserves in Wells, ME, Great Bay, NH, Waquoit Bay, MA, and Narragansett Bay, RI in the Northeast. At each of these reserves, continuous monitoring data are collected via the System Wide Monitoring Program (SWMP), a national program within the NERRS system that aims to identify and track short-term variability and long-term changes in the integrity and biodiversity of estuarine ecosystems. The program monitors in three arenas: abiotic monitoring (meteorological, water quality, and nutrients); biological monitoring (habitat change and biodiversity); and watershed and land use classification. At the majority of the reserves, the following parameters are collected year-round in 15-minute intervals at four long term stations: water and air temperature, pH, turbidity (or suspended particles in the water column), conductivity (salinity), dissolved oxygen, wind speed and direction, relative humidity, barometric pressure, photosynthetic active radiation (PAR), and precipitation. Nutrients are also monitored monthly at all sites. Orthophosphates, ammonia, nitrogen, silicates, and chlorophyll a are monitored within the estuary. Due to winter ice conditions in some of the New England reserves, it is often not possible to collect water quality data from December to March. More information as well as access to data (both historical and real time) are available at [www.nerrsdata.org](http://www.nerrsdata.org). In addition to SWMP, many visiting and resident scientists and investigators use these protected sites to study estuarine ecosystems and processes.

#### U.S. EPA National Coastal Condition Assessment

Section 305(b) of the Clean Water Act requires that the states report to the U.S. Environmental Protection Agency (EPA), and that the EPA report to Congress on the condition of the nation's waters, including coastal waters every two years. In response to this mandate every five years EPA conducts a survey of U.S. coastal waters and the Great Lakes. The National Coastal Condition Assessment (NCCA) uses nationally consistent

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monitoring protocols to assess and report on coastal conditions. The results of these assessments are compiled into NCCA reports. This series of reports contain one of the most comprehensive ecological assessments of the condition of our nation's coastal bays and estuaries. These surveys began in the 1990s as part of the Environmental Monitoring and Assessment Program (EMAP), evolved into the Coastal 2000, and now are part of the National Aquatic Resource Surveys.

The NCCA 2010 reports on data collected from 1,104 sites in estuarine and Great Lakes nearshore waters, representing 35,400 square miles of U.S. coastal waters. The report examines four indices as indicators of coastal conditions: a benthic index, a water quality index, sediment, quality index, and an ecological fish tissue contaminant index. The resulting ratings for each index are then used to calculate the overall condition ratings for each region (including the Northeast Coast), as well as the index and overall condition ratings for the nation. The next NCCR will report on data collected in 2015 and on trends observed since 2010.

In 2007 EPA published the National Estuary Program (NEP) Coastal Condition Report. Using results compiled from the NCCA reports (I and II) EPA conducted an assessment of estuarine condition within the 28 National Estuary Programs. Data were used for four primary indices of estuarine condition (water quality index, sediment quality index, benthic index, and fish tissue contaminant index) by assigning a good, fair, or poor rating for each NEP estuary. The ratings were then used to create overall condition ratings for the NEP estuaries of each coastal region, including the Northeast Coast. The most recent NCCA was conducted in 2015, and reports will be available in 1-2 years.

#### U.S. EPA National Estuary Program

The EPA NEP was established by Congress under Section 320 of the Clean Water Act. The program consists of a network of 28 NEPs that work to improve the waters, habitats and living resources of estuaries in the U.S. There are six NEPs in the U.S. Northeast region: Casco Bay Estuary Partnership, Piscataqua Region Estuaries Partnership, Massachusetts Bays National Estuary Program, Buzzards Bay National Estuary Program, Narragansett Bay Estuary Program, and Long Island Sound Study. NEPs' work is guided by a Comprehensive Conservation and Management Plan and most programs have various mechanisms to implement, coordinate or oversee monitoring efforts in the respective estuary. For example, the Buzzards Bay NEP coordinates closely with the volunteer-based Buzzards Bay Coalition to conduct periodic monitoring of water quality in Buzzards Bay. The monitoring programs conducted by the Massachusetts Water Resources Authority and the Center for Coastal Science provide the Massachusetts Bays NEP with data on the state of coastal and estuarine waters. The data from these programs are used regularly to report on conditions in the estuaries and to help managers in their work and inform decision making. Besides water quality programs, some NEPs are also involved with species-specific monitoring, for example eelgrass, herring counts, and horseshoe crabs.

#### U.S. Army Corps of Engineers

Since 1977, the U.S. Army Corps of Engineers (USACE) has consistently monitored dredged material disposal areas in New England under the Dredged Area Monitoring System (DAMOS) program. DAMOS is an interagency, interdisciplinary effort that

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documents composition, function, and condition of benthic fauna. For each disposal area, the program identifies one to three nearby reference sites for comparison sampling. The six EPA designated dredged material disposal sites in New England waters are the focus of the most regular monitoring, while more than 20 additional limited-use sites receive less frequent monitoring. This large body of data, collected consistently at reference sites over decades, is an incomparable source of baseline imaging information and correlated taxonomic analyses for New England benthic fauna and ecosystems. These data are of high value to the USACE as comparisons for evaluating the effects of dredge material disposal. Beyond that mission, these rich reference data have not been analyzed as a complete dataset to reveal patterns over the broad spatial and temporal scales at which data were collected. In addition, USACE benthic studies in Buzzards Bay are documented and available through their New England District Offices.

#### U.S. Fish and Wildlife Service National Wildlife Refuge Marine Bird Monitoring Programs

The USFWS National Wildlife Refuge System is a complex of federally owned lands and waters acquired to help conserve, manage, and restore fish, wildlife and plant populations and habitats. Within the Northeast U.S. region, there are over 20 National Wildlife Refuges that include coastal lands and coastal islands. Among these, the Maine Coastal Islands National Wildlife Refuge and the Monomoy National Wildlife Refuge both have long-standing marine bird monitoring programs that provide productivity, survival, and behavior data for colonial nesting marine birds dating back to the 1980s. These data include information on the federally endangered roseate tern (*Sterna dougalli*) and species threatened or endangered at the state level, such as the Arctic tern (*Sterna paradisaea*) and Atlantic puffin (*Fratercula arctica*). In combination, these time series data provide insights not only into aspects of the ecology for a specific species, but also to the broader marine ecosystem, as marine birds rely on marine resources throughout their lives and have long been recognized as potential indicators of marine ecosystem productivity.

#### U.S. National Park Service Northeast Temperate Inventory Network

In 2007, the National Park Service established the Northeast Temperate Inventory Network to monitor the condition of key habitats under their jurisdiction. The program monitors “Vital Signs” which, like sentinel indicators, are selected to “represent the overall health or conditions of park resources, known or hypothesized effects of stressors, or elements that have important human values.” Coastal habitats monitored include rocky intertidal shores and coastal breeding bird status. In the Northeast region, rocky intertidal monitoring is conducted at Acadia National Park, Maine Coastal Islands (which is actually a National Wildlife Refuge), and the Boston Harbor Islands National Recreation Area (NRA). At Boston Harbor Islands NRA, one of the goals of the Vital Signs project is to determine annual changes and long-term trends in abundance of high priority coastal breeding bird species, such as least terns, common terns, and American oystercatchers. Protocols have been piloted and established for both of these Vital Signs. For more information visit: <http://science.nature.nps.gov/im/units/netn/index.cfm>.

#### U.S. Geological Survey

The U.S. Geological Survey (USGS) has collected and archived an extensive variety of marine-related data with much of the work conducted out of their Woods Hole Coastal and Marine Science Center. The results of their work which includes extensive mapping

of seafloor geology in the Northeast U.S. region are available on the USGS website. Also available are a variety of datasets (e.g. oceanographic moored time series, sediment, maps) along with various tools to visualize the data such as ESRI ArcInfo and GoogleEarth utilities.

#### Bureau of Ocean Energy Management

The Bureau of Ocean Energy Management (BOEM), formerly the Minerals Management Service, oversees the exploration and development of oil, natural gas, and other minerals and renewable energy on the U.S. Outer Continental Shelf (OCS). The program not only supports decisions made within the DOI, but also provides coastal states, tribes and local governments with the information necessary to ensure that all stages of offshore energy and mineral activities are conducted in a manner to protect both human and natural environments. BOEM has been coordinating OCS renewable energy activities offshore in the Northeast, specifically with Massachusetts and Rhode Island since 2011. As part of this effort BOEM has funded numerous studies to collect information about the marine environment to support decisions concerning offshore energy development, including: abundance and distribution of marine mammals (e.g. North Atlantic right whale), sea turtles, birds and other species as well as select human uses. Since 2013 BOEM has also conducted studies on wind resources and ocean conditions. More information is available at <http://www.boem.gov/Commercial-Wind-Lease-Rhode-Island-and-Massachusetts/>.

#### Other federal agencies

Several other federal agencies also have marine-related studies in the Northeast region. While the extent of their efforts is not detailed here, these agencies should nevertheless be considered significant partners in both past, present, and future efforts in coordination. While they are not usually involved in ongoing long-term monitoring, their efforts should not be lost. For example, the U.S. Coast Guard has more permanent moorings in the region's coastal waters than any other agency and could potentially provide permanent platforms for moored instrumentation.

**Table 3.4.1. Federal Northeast Region Observing Programs Relevant to Sentinel Ecosystem Monitoring**

<i>Program Name</i>	<i>Agency</i>	<i>Monitoring</i>
NOAA Northeast Fisheries Science Center Resource and Ecosystem Surveys	NOAA, Fisheries and Oceans Canada	Physical, chemical, and biological properties in Bay of Fundy and Scotian Shelf.
Stellwagen Bank National Marine Sanctuary (SBNMS)	NOAA	Comprehensive studies on habitat, marine birds and mammals, human uses, and noise
NERRS System Wide Monitoring Program: Narragansett Bay, RI, Waquoit Bay, MA, Great Bay, NH, and Wells, ME	NOAA	Physical, chemical, biological monitoring, watershed, habitat land change
Forecasting	NOAA- National Weather Service	Meteorological variables



Long Term Ecological Research (LTER)	National Science Foundation: Plum Island Ecosystems LTER	Organic and inorganic biogeochemistry, estuarine food webs
National Coastal Condition Assessment Project  (Previously Ecosystem Monitoring and Assessment Program)	EPA	Physical, chemical, biological ecosystem characteristics  National Aquatic Resource Surveys
Disposal Area Monitoring System (DAMOS)	USACE	Benthic fauna composition, function and condition at disposal areas
Stream Gauging and Water Quality Network	USGS	Streamflow information, water quality data and water information
USFWS Wildlife Refuge Marine Bird Monitoring Program	USFWS	Productivity, survival and behavior data for colonial nesting marine birds
Renewable Energy Intergovernmental Task Force	BOEM	Abundance and distribution of marine mammals and human uses, ocean and wind conditions.

### *Canadian Waters*

Fisheries and Oceans Canada (DFO) Maritimes Region conducts monitoring surveys used in assessments for groundfish on the Scotian Shelf and Georges Bank, lobster in Southwest Nova Scotia, and scallops in the Bay of Fundy. Industry-funded surveys are used in assessments for snow crab on the Scotian Shelf, halibut on the Scotian Shelf and Bay of Fundy, shrimp in Eastern Nova Scotia, herring in the Bay of Fundy and southern shore coastal areas, and scallop on the western Scotian Shelf, southwest Nova Scotia, and eastern Gulf of Maine. Grey seal abundance and pup production are monitored on Sable Island. DFO also assesses the stock status of harvested populations using data from industry on landings and other population metrics. Wild Atlantic salmon abundance and returns are monitored in several rivers, including the St. John River and Mactaquac dam where striped bass and gaspereau are also monitored. Many fishing vessels carry observers, and the observer program provides information about some non-commercial and threatened species such as leatherback turtles, coral, and sponges. DFO also measures temperature and sea level at long-term coastal monitoring stations in locations in the Maritimes and other Atlantic regions. Environment Canada (EC) monitors pulp and paper effluents and their influence on biological communities, as well as monitoring water quality for fecal contamination of shellfish areas and other point and non-point sources of pollution. The Canadian Shellfish Sanitation Program is run jointly by the Canadian Food Inspection Agency, EC and DFO.

### *Atlantic Zone Monitoring Program*

DFO has monitored the physical, chemical, and biological properties of the Bay of Fundy and Scotian Shelf since 1998, under the Atlantic Zone Monitoring Program (AZMP:

<http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/index-eng.html>). The program was initiated in response to the need to inform fisheries management decisions about environmental change and its effects on fish stocks, in the wake of the collapse of the northern cod stock in the early 1990s. The program focuses on variability at annual and longer time scales. Time series stations are sampled in the Bay of Fundy (monthly), on the coastal central Scotian Shelf (semi-monthly), and in the Bedford Basin (weekly), and sections across the Scotian Shelf and Cabot Strait are sampled semi-annually in spring and autumn. In addition, environmental sampling using the AZMP protocols is performed on ecosystem trawl surveys on Georges Bank, the Bay of Fundy, the eastern GoM, and Scotian Shelf. Analogous AZMP sampling is performed in the Gulf of St. Lawrence and on the Newfoundland and Labrador Shelves by DFO's Quebec and Newfoundland regions.

#### Marine Environmental Observation Prediction and Response Network

Since early 2012, a large team of Canadian researchers from a variety of organizations including government, academia, and industry have been preparing for the future with a particular focus on responding to marine hazards and emergencies. A comprehensive plan is in place to develop the Marine Environmental Observation Prediction and Response Network (MEOPAR) over the next few decades. The plan includes testing new technologies, setting up ocean observing systems in strategic locations, understanding the effect of changes in the marine environment at multiple time scales, and training the next generation of “highly qualified personnel.”

#### Canadian Maritime Waters Observing Programs Relevant to Sentinel Ecosystem Monitoring:

<i>Program Name</i>	<i>Agency</i>	<i>Monitoring</i>
Fisheries and Oceans Canada Monitoring Surveys and Assessment	Fisheries and Oceans Canada	Physical and biological properties in the Maritimes Region
Atlantic Zone Monitoring Program	Fisheries and Oceans Canada	Physical, chemical, and biological properties in Bay of Fundy and Scotian Shelf
Marine Environmental Observation Prediction and Response Network	Canadian researchers	Chemical, physical and biological characteristics of the marine environment, testing new technologies

### 3.5 State, provincial, academic, private sector, and NGO observing activities

#### Overview

A number of past and present non-federal observing activities across the entire Northeast region are also relevant to sentinel monitoring of its coastal ecosystems. Partial lists of past and present observing of ecosystem variables have been published elsewhere and we have attempted here to compile a comprehensive inventory. Elements of sentinel monitoring are already in place in subregions but there has been no formal plan to

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coordinate these efforts under an overarching umbrella. Described below are some of the existing activities.

### NERACOOS

The collaborative observing activities supported by NERACOOS span coastal waters from Long Island Sound to the Canadian Maritime Provinces of New Brunswick and Nova Scotia. NERACOOS operations are carried out by a group of dedicated scientists from academic organizations within the region. Multipurpose marine buoys form the cornerstone of the program. NERACOOS helps support 13 data buoys in the Northeast, which provide over 50% of the continuous real-time weather observations and over 90% of the continuous sub-surface, real-time measurements in the region. The data are used daily by a variety of groups including the United States Coast Guard, ship captains, meteorologists, emergency response managers, fishermen, and ecosystem scientists.

### Canadian Waters

The Nova Scotia Department of Fisheries and Aquaculture and the Province of New Brunswick monitor finfish aquaculture impacts, including sediment sulfide and other impacts on the sediment environment and community. Water quality in coastal population centers is monitored by many municipalities, including Halifax Regional Municipality. NGOs or collaborative groups monitor a variety of environmental and ecological properties, including lobster recruitment (Fishermen and Scientists Research Society, Bay of Fundy), lobster quality (LFA 27 Management Board, Cape Breton), sediment pollutants (Eastern Charlotte Waterways/Gulf of Maine Council– ECW/GoMC, Bay of Fundy estuaries), and water quality and eutrophication in the Annapolis River (Clean Annapolis River Project), southwest New Brunswick estuaries (ECW/GoMC) and Musquash Estuary Marine Protected Area (ECW/DFO). A variety of community groups make observations at a local scale across the Maritime Provinces (e.g. CURA H<sub>2</sub>O, run by the Community-Based Environmental Monitoring Network at Saint Mary's University).

### Maine Waters

Given the extent of the Maine coastline and the number of islands and estuaries, it is not possible here to describe all efforts to monitor the health of coastal waters.

Several observing activities are supported at the state and federal level. The Maine Department of Marine Resources (DMR) maintains a Marine Biotoxin Monitoring Program to detect the presence of Harmful Algal Bloom (HAB) toxins in shellfish. DMR also supports a Lobster Research, Monitoring, and Assessment Program. The American Lobster Settlement Index (ALSI: <http://umaine.edu/wahlelab/american-lobster-settlement-index-alsi/american-lobster-settlement-index/>) with funding from several U.S. and Canada state, province and federal sources, is an annual monitoring program that quantifies the repopulation of rocky coastal nursery grounds in New England and Atlantic Canada by newly settled lobsters. Finally, since 1967 (or earlier for some systems) DMR has been monitoring seven river systems across the state for abundance of Atlantic salmon and river herring.

Academia and research institutions involved in coastal observing in Maine waters include Bowdoin College, Bigelow Laboratory for Ocean Sciences, the College of the Atlantic, the Gulf of Maine Research Institute, St. Joseph's College, the University of New England, and the University of Maine. NGO's include the Gulf of Maine Lobster Foundation, the Island Institute, and the Marine Environmental Research Institute. There are numerous groups of concerned citizens who are often involved in voluntary data collection programs such as the Friends of Casco Bay, the Friends of Merry Meeting Bay, the Maine Coastal Observing Alliance (comprising a number of land and river trusts), the Lobster Conservancy, and Marine Science for Maine Citizens. All these efforts have set up monitoring efforts of their own and many, such as the dockside temperature series at Boothbay Harbor, have been around for many decades.

Of particular relevance to the ISMN is the development of a mid-coast node of observing activity, involving the University of Maine (Darling Marine Center), Bigelow Laboratory for Ocean Sciences, and St. Joseph's College. These activities include measurement of zooplankton and microplankton diversity at the Coastal Maine Time Series Station (CMTS) several miles east of Monhegan Island and a times series station in the Damariscotta Estuary, monitoring of phytoplankton diversity in Harspswell Sound (with detailed phytoplankton taxonomy from scope counts), and observing changes in microbial diversity in Boothbay Harbor. Bigelow Laboratory for Ocean Sciences also has run an annual transect across the GoM between 1998 and 2006. This dataset, known as the Gulf of Maine North Atlantic Time Series (GNATS), contains valuable information on hydrography, and apparent and inherent water column properties (e.g., Balch et al. 2004, 2008). In addition, the Gulf of Maine Research Institute maintains an observing program (CBASS: Casco Bay Aquatic Systems Survey) to monitor ecosystem properties of Casco Bay, where Maine's largest city, Portland, is located. Fish, benthic crustacean and plankton abundance and diversity are assessed in the Presumscot River and inner and outer bays.

Also of relevance to the ISMN is a developing network of small Gulf of Maine field stations, currently supported by an NSF planning grant to Bates College and the Hurricane Island Center for Science and Leadership. The goals of the network are to coordinate monitoring, data management and training programs in order to contribute to larger efforts and data sets, and to enhance the relevance of fine-scale data collected across the GoM. To date, the network includes 12 stations and has reached consensus on coordinating inter-tidal transects, phenological studies, and basic abiotic measures. With respect to ISMN, the NeCSA represents a model for a nested organizational structure dedicated to tracking climate changes at a regional scale.

#### **Maine Waters Observing Programs Relevant to Sentinel Ecosystem Monitoring:**

<i>Program Name</i>	<i>Agency</i>	<i>Monitoring</i>
DMR Marine Biotoxin Monitoring	Maine DMR	Presence of HAB toxins in shellfish
ME/NH Inshore Trawl Survey	Maine DMR	Distribution and abundance of marine fishes

American Lobster Settlement Index	Maine DMR, with other U.S. states and Canadian Provinces	Lobster settlement in rocky coastal shore habitats
Mid-coast node of observing activity	University of Maine (Darling Marine Center), Bigelow Laboratory for Ocean Sciences, and St. Joseph's College	Chlorophyll biomass and seasonal cycles Microplankton diversity, Mesozooplankton abundance and diversity, Ichthyoplankton abundance and diversity
Water Quality	Maine Department of Environmental Protection	Nutrients, point source nutrient loadings, contaminants in shellfish (mussels, clams, lobsters)
Gulf of Maine North Atlantic Time Series (GNATS)	Bigelow Laboratory for Ocean Sciences	Primary production, carbon chemistry
Penobscot Estuarine Fish Community Survey	NOAA National Marine Fisheries Service	Diadromous and estuarine fish community, and salinity, temperature, turbidity, dissolved oxygen, and chlorophyll
Casco Bay Aquatic Systems Survey (CBASS)	Gulf of Maine Research Institute	Fish abundance and diversity (by seines, traps, and hook), Chlorophyll concentration Zooplankton abundance and diversity Acoustic surveys

### New Hampshire Waters

There are numerous observing system assets in New Hampshire waters and further offshore have been developed and supported by the University of New Hampshire (UNH) since the early 2000s. In particular, the UNH Ocean Process Analysis Laboratory (OPAL) has been active within IOOS and NERACOOS conducting GoM ecosystem, biophysical, and ocean carbon and carbonate chemistry measurements since 2004. OPAL has maintained seasonal data collection at several time series stations for carbon chemistry, primary production, and zooplankton diversity along an east-west transect extending from Portsmouth to Wilkinson Basin. Recently in collaboration with the University of Maine, OPAL has maintained sampling at less frequent intervals at a fixed station (WB-7, also known as the Wilkinson Basin Time Series station) in Wilkinson Basin. Their NH CO<sub>2</sub> monitoring buoy, located northwest of Appledore Island since 2006, is the longest continuous ocean CO<sub>2</sub> sampling station within NOAA's coastal ocean acidification sampling network. OPAL also operates two ecosystem and water-quality monitoring sites inshore, one in Great Bay and another at the mouth of Portsmouth Harbor as complement to the NOAA NERRS network. They've also maintained a full-time offshore wave measurement buoy on Jeffrey's Ledge since 2009. There are also ongoing UNH activities involved with offshore renewable engineering demonstration projects, aquaculture research, and supporting inundation issues in Hampton harbor.

There is a growing consortium of coastal and intertidal observing efforts being fostered by the UNH/Cornell Shoals Marine Laboratory located on the Isles of Shoals, as well as by the non-profit Seacoast Science Center. The NH Department of Environmental



Services (NH DES) has a strong marine science and monitoring component, including seasonal sampling for Paralytic Shellfish Poisoning levels used to inform red tide shellfish closures. NH DES has been actively involved in compiling water quality databases and constructing a data framework for metadata archives to support early phase of development of a regional sentinel monitoring program.

### **New Hampshire Waters Observing Programs Relevant to Sentinel Ecosystem Monitoring:**

<i>Program Name</i>	<i>Agency</i>	<i>Monitoring</i>
UNH OPAL	UNH Ocean Process Analysis Laboratory (OPAL), with the University of Maine	Biophysical, ocean carbon and carbonate chemistry
NH-DES Shellfish Monitoring and Water Quality Programs	NH Dept. of Environmental Services	Paralytic shellfish poisoning levels, water quality variables

### **Massachusetts Waters**

In Massachusetts waters, there are several non-federal efforts related to sentinel monitoring. The Massachusetts Water Resources Authority (MWRA) has been conducting water quality and sediment toxicity monitoring in recent decades primarily in connection with the development of the Deer Island sewage treatment plant in Boston Harbor and outfall pipe. Monitoring is conducted in Boston Harbor and in Massachusetts Bay in the vicinity of the outfall which is located about nine miles outside of Boston Harbor. MWRA receives assistance from the Center for Coastal Studies to conduct water quality monitoring in Cape Cod Bay as well as conducting monitoring focused on whales and their habitat. The Center for Coastal Studies also conducts extensive monitoring along the south shore of Cape Cod and in Nantucket Sound.

The Buzzards Bay Coalition conducts extensive water quality monitoring in Buzzards Bay and generates reports on the state of the bay. Woods Hole Oceanographic Institution in partnership with the Cape Cod Cooperative Extension have been collecting data on ocean acidification from four nearshore buoys deployed in Cape Cod Bay (near Wellfleet) and along the southern shore of Cape Cod for the last ten years. Mass. Audubon conducts various studies of the health of the ecosystem around the state, each with its own focus. The century-old Christmas bird count is one example of Mass. Audubon's efforts.

The state agency most involved in marine-related observation programs is the Massachusetts Division of Marine Fisheries, which has been conducting both near-shore and coastal (<3 km) surveys for decades. These include a trawl resource assessment survey in May and September each year since 1978, as well as monitoring of specific species such as American lobster, Atlantic cod and winter flounder. Massachusetts Department of Environmental Protection conducts aerial assessments of eelgrass extent in Massachusetts waters. These surveys have been conducted since the 1950s but more frequently since 1995, the most recent survey was conducted in 2012

The Massachusetts Department of Conservation and Recreation is also involved with monitoring the environment and has active programs in both Boston Harbor and Waquoit Bay.

Several universities and research laboratories around the state, most notably those connected with the University of Massachusetts (UMass), Massachusetts Institute of Technology (MIT) and the Woods Hole Oceanographic Institution (WHOI), have led the way in many aspects of marine science research and monitoring. WHOI has initiated a set of observation systems including the Martha's Vineyard Coastal Observatory (MVCO) and, more recently, the NSF-funded Ocean Observatories Initiative (OOI) in offshore waters. WHOI has also established the Northeast Benthic-Pelagic Observatory (NEBO) focusing on the benthos with extensive datasets collected by the Habitat Camera (HabCam) system.

UMass Dartmouth's School of Marine Science and Technology (SMAST) and the School for the Environment at UMass Boston each have a variety of programs in place. The Department of Biology at UMass Boston hosts the Gulf of Maine Kelp Ecosystem Ecology Network monitoring rocky reefs along the Massachusetts coast. Boston University and Northeastern University have marine science investigators and field stations, with many years of benthic observations.

#### **Massachusetts Waters Observing Programs Relevant to Sentinel Ecosystem Monitoring:**

<i>Program Name</i>	<i>Agency</i>	<i>Monitoring</i>
Martha's Vineyard Coastal Observatory (MVCO)	Woods Hole Oceanographic Institution	Cabled monitoring system with multiple locations on inner shelf/beach that collects ocean and meteorological data and beach images
Northeast Benthic Observatory (NEBO)	Woods Hole Oceanographic Institution	Ecosystem assessments and community responses
Mass Bay Project	Massachusetts Water Research Authority	Ecosystem assessment, marine mammals
Christmas Bird Count	Massachusetts Audubon	Bird distribution and abundance
Coastal trawl survey	MA Division of Marine Fisheries	Distribution and abundance of marine fishes

#### **Rhode Island Waters**

Rhode Island supports many marine monitoring efforts of various levels of effort and duration. Most of these monitoring programs are affiliated with either the Rhode Island Department of Environmental Management (RIDEM) or through the University of Rhode Island (URI).

RIDEM has land use and historic (to 1939) aerial photographs, fisheries landing data, bacteria data, and phytoplankton data and trend reports for RI shellfishing areas. RIDEM Fish and Wildlife has a long-term fish trawl survey data with 30 years' worth of data. RIDEM Office of Water Resources (OWR) is the lead agency for the Narragansett Bay Fixed Site Monitoring Network (NBFSMN). For over ten years this network has monitored 15-minute time scale of physical water quality parameters throughout the bay with an emphasis on monitoring for low oxygen. This network consists of the Narragansett Bay Commission, Narragansett Bay NERR, University of Rhode Island (URI), and RIDEM-OWR, with real-time data accessible through NERACOOS. Other notable active projects in the state include RI GIS, Narragansett Bay NERR Long Term Monitoring Program, the Rhode Island Special Area Management Plan, and RI Sea Grant. These programs supply data on a variety of research topics including bird nesting sites, wetland maps, ecological community classifications, submerged aquatic vegetation, forest coverage, invasive species distribution maps, salt marsh vegetation studies and commercial fisheries research.

URI's Graduate School of (GSO) Oceanography maintains several long-term time series monitoring programs that will be fundamental to the regional estuarine sentinel monitoring effort. URI/GSO surveys throughout Narragansett Bay include: water quality, benthos, phytoplankton/zooplankton, meteorology, nutrients, and fish trawl surveys. Many of these surveys have datasets with over 30 years of data. Most of these data and other state program information are available through [www.narrbay.org](http://www.narrbay.org).

Other universities and local groups have ongoing marine monitoring programs in Rhode Island waters. UMass Dartmouth, Salve Regina University, and Roger Williams University conduct research in the Mt. Hope Bay and Newport areas focusing on aquaculture, plankton, water quality, nearshore fish, macroinvertebrates, and shore birds. Local groups such as the Rhode Island Bristol County Observing Network, Prudence Island Conservancy Citizens Monitoring Program, the Jamestown Bird Survey, and several projects by local land trusts and citizen groups monitor the health of particular coastal areas or rivers. There is a recent effort to coordinate all observing of RI waters under the Ocean State Coastal Observatory (OSCO) including several partners, but primarily based at URI and Brown University, with potential funding from NSF.

While RI marine monitoring efforts comprise multiple programs across many agencies and local groups, these efforts collectively contribute to the overall objective of sentinel monitoring.

### **Rhode Island Waters Observing Programs Relevant to Sentinel Ecosystem Monitoring:**

<i>Program Name</i>	<i>Agency</i>	<i>Monitoring</i>
Narragansett Bay Fixed-Site Monitoring Program	RI DEM-OWR, URI/GSO, NBC, NBNERR	Physical water quality parameters within Narragansett Bay, including changes in hypoxia and primary production.
NB NERR Long Term Monitoring Program	NB NERR	Eelgrass, salt marsh, benthic, physical, chemical, and biological monitoring

Rhode Island Ocean Special Area Management Plan, or Ocean SAMP	RI CRMC, URI/GSO, URI	Coastal and water bird distribution, abundance and productivity, primary production, nutrients, fisheries, marine mammals
Plankton of Narragansett Bay	URI/GSO	Physical ocean data, plankton distribution and abundance
Inshore trawl survey	RI DFW	Marine finfish and shellfish distribution and abundance

### Connecticut Waters

The Connecticut Department of Energy and Environmental Protection (CT DEEP) conducts monthly water quality monitoring program in the open waters of Long Island Sound. This program includes physical, chemical, and biological parameters. Several local monitoring programs are focused on the nearshore embayments of the Sound, including: Hempstead Harbor, the Mystic/Stonington area, and Norwalk/Westport area. CT DEEP also has conducted a LIS Trawl Survey since 1984 and a nearshore standardized beach seine survey since 1988. The Millstone Environmental Lab has a dataset of physical, chemical, and biological variables collected from the Niantic River estuary since the mid-1970s. The University of Connecticut, Stony Brook University, Yale University, Sacred Heart University, Connecticut State University system, City University of New York system, Connecticut College, University of Rhode Island, Columbia University, University of New Haven, University of Massachusetts, Wesleyan, and Cornell University all have researchers who have existing or past projects based in LIS.

The Long Island Sound Study (LISS), a NEP collaboration between the 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 (Barrett et al. 2011). The mission of the SMCCP is to provide early warnings of climate change impacts to LIS estuarine and coastal ecosystems, species, and processes to facilitate management decisions and adaptation responses. Warnings are based on multidisciplinary assessments of a suite of indicators/sentinel variables. Six of the 17 prioritized variables were selected for a pilot scale sentinel monitoring program and implementation began in 2012. Topics being studied include coastal birds and associated habitats, salt marsh migration, and a trend analysis of abiotic sentinels of climate in LIS.

Other LIS SMCCP products include documents which have been used to advise this regional process, such as a Matrix of Climate Change Sentinels, and a comprehensive strategy for Sentinel Monitoring, all available for download online. In addition, a data citation clearinghouse created in 2013 contains all known research and monitoring related to LIS and its coastal ecoregions. While direct records exist for monitoring related to climate change, additional research is contained in a references section of the clearinghouse. The spatial and tabular clearinghouse is searchable by researcher, monitoring type, and location. The template for this clearinghouse was shared with ISMN for use in this project. The current LIS Data Citation Clearinghouse is an on-line interactive database of historic, current, and emerging research.

## Connecticut Waters Observing Programs Relevant to Sentinel Ecosystem Monitoring:

<i>Program Name</i>	<i>Agency</i>	<i>Monitoring</i>
Water Quality Monitoring	Connecticut Department of Energy and CT DEEP	Chemical, physical, and biological data
The Long Island Sound Sentinel Monitoring Program	EPA LISS, CT, NY	Ecosystem assessment of chemical, physical and biological sentinel variables

### Other observing activities: NGO, Private Industry and Citizen Science

Other smaller scale observing and monitoring activities occur at more local levels. For example, private industries often have monitoring programs as part of compliance with National Pollutant Discharge Elimination System (NPDES) permits issued by the EPA. Consulting firms such as Normandeau and Battelle provide these monitoring services with data sets that go back many years. Many citizen science programs also exist in the region and have been cataloged in the metadata database.

With the event of phone based computing power, new citizen science applications are being developed. One such crowd sourced project is Jellywatch, which records environmental observations on a phone application as well as at <http://www.jellywatch.org/>. About 600 observations have been recorded for eight species of jellies (e.g. salps. ctenophores, jellyfish).

Many organizations (e.g. Sacred Heart University, Mass Audubon, and Damariscotta River Association) have engaged volunteers in monitoring distribution and abundance of horseshoe crabs.

## 3.6 Collaborative regional efforts

### *Gulfwatch: A Gulf Wide Contaminants Monitoring Program*

Gulfwatch, a GoM and Bay of Fundy toxic chemicals (contaminants) monitoring program, was initiated in 1991 by the GoMC. The program which involves collection of the intertidal-shallow, sub-tidal bivalve mollusk, the blue mussel *Mytilus edulis* from 56 stations permits detailed spatial and temporal analysis of bioaccumulated toxic substances in GoM coastal waters, and an evaluation of risk to both human and ecosystem health. Given the value of the shellfish industry to both Canada and the U.S., the program contributes data vital for assessing shellfish safety. The samples are analyzed for toxic substances, including metals, pesticides, PCBs and polycyclic aromatic hydrocarbons. The program was conducted in coordination with the NOAA Mussel Watch program, and samples for Gulfwatch were collected from Mussel Watch stations for comparison of data. Funded by various U.S. and Canadian federal agencies, the program has produced about 20 reports ([www.gulfofmaine.org/gulfwatch](http://www.gulfofmaine.org/gulfwatch)) and 161 papers, technical reports, presentations, and fact sheets (Chamberlain 2014). Unfortunately, despite its economic and ecological importance, the Gulfwatch program is currently on hold due to lack of



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financial support. A program assessment was conducted in 2012 resulting in a revised sampling design that would allow for measurement of emerging contaminants if and when funding becomes available.

#### *Northeastern Coastal Stations Alliance*

The Northeastern Coastal Stations Alliance (NeCSA) is a newly formed consortium of coastal field stations and research institutions with a shared goal of coordinating research activities monitoring efforts across the GoM. They are in the midst of drafting a strategic plan and developing a shared monitoring program across their respective field station locations.

#### *Northeast Coastal Acidification Network*

Public awareness and concern about Ocean Acidification (OA) is growing at the same time as the science is still maturing. In addition to the trend in global OA, near-coastal areas experience Coastal Acidification that is highly dependent on factors such as freshwater and nutrient delivery which are beyond the general increase in atmospheric CO<sub>2</sub>, but may be influenced by other human use and climate trends. Understanding these processes, predicting the consequences for marine resources, and devising local adaptation strategies are critical to enabling local communities and dependent industries to better prepare and adapt to such changes. Formed in 2013, the Northeast Coastal Acidification Network (NECAN) is the leading organization for the synthesis and dissemination of regional OCA data and information. NECAN's mission is to provide rigorous and balanced scientific information to decision makers and user groups regarding the current state of knowledge of OCA and its potential environmental and socio-economic impacts to the Northeast region. Efforts to date have included a webinar series, state-of-the-science meeting and publications, web-based translation materials and face-to-face interactive stakeholder engagement workshops. The ultimate goal is to develop and implement a regional implementation plan in 2016 that will outline the information needed by stakeholders, including managers, policymakers, and industry, as well as the required observations, research, and communication mechanisms to address OCA. More information may be found at [www.necan.org](http://www.necan.org).

#### *Saltmarsh Habitat and Avian Research Program*

Since 2011, the Saltmarsh Habitat and Avian Research Program (SHARP), a partnership of academic, governmental, and non-profit collaborators including the University of Connecticut and the University of Maine, has surveyed tidal marsh vegetation and birds at ~1700 points from Virginia to Maine. SHARP has conducted detailed demographic studies of tidal marsh birds at >20 5-20 ha plots in seven states across this region. For more information visit [www.tidalmarshbirds.org](http://www.tidalmarshbirds.org).

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## 4. Sentinel Indicators

### 4.1 What is a sentinel indicator?

In the context here, the ISMN serves to warn coastal managers, and the broader public, of changes in the ecosystem in response to climate or other ecosystem drivers. Using sentinel indicators (see Box 1.1.), the ISMN provides information to enable society to understand, acknowledge, and respond to the consequences for ecosystem services. Responses may include specific management decisions, such as adjustments to harvesting quotas, or broader, community-based strategies to adapt to changes that are seen to be inevitable.

Sentinel indicators for the Northeast region ecosystems have been identified for the purpose of informing the ISMN and its user communities about ecosystem change. A **sentinel indicator** refers to a variable (whether abiotic or biotic) representing a system, process, or key component of the ecosystem that is sensitive to environmental pressures and that can be quantitatively measured and monitored. Sentinel indicators may be based on predictions from conceptual or quantitative models of ecosystem responses to climate forcing and other pressures. Recognizing that not all change can be predicted, indicators are also needed to reveal unexpected ecosystem changes. Each sentinel indicator is therefore matched with a question formulated from either (1) hypothesis-based predictions of responses to environmental pressures or (2) identification of key ecosystem properties that are known to be fundamental to ecosystem structure and function, without necessarily understanding the mechanisms for change (i.e., covering for the unexpected). It is anticipated that indicators will be used in novel analyses to answer new questions as they arise.

Two approaches were taken to organize the presentation of the sentinel questions. For the pelagic and benthic environments, working groups organized sentinel questions by three types of ecosystem properties. *Biodiversity* questions address species (or higher level taxon) richness, composition, and genetic diversity. Questions about *key species or taxa* groups recognize organisms that have known significant ecosystem impacts. Questions about *ecosystem function* address ecosystem-level characteristics and processes that determine ecosystem services. These questions direct quantitative monitoring activities that subsequently inform evaluation of the nature and extent of ecosystem change, a primary sentinel activity. The working group for the habitat-rich coastal and estuarine environment organized sentinel questions by each specific habitat. For example, there are three sentinel questions posed for communities found on rocky shores (Table 4.4.4.).

The criteria for selecting sentinel indicators were developed by a subcommittee of the OCEH and approved by the ISMN Steering Committee. The criteria were adapted from documents associated with the LISS Monitoring project, GoM ESIP, NOAA Sentinel Sites, Working Group on the Northwest Atlantic Regional Sea (WGNARS) and NOAA Climate Assessments. Criteria for selection of sentinel indicators included that the indicator:

(1) is consistently measureable at multiple sites, so that comparison among sites can be made,

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(2) has an existing or forthcoming data record (or time series) that would allow comparison of historic, current, and future conditions to identify long term trends,

(3) can be measured and studied feasibly with respect to cost and available technology, and

(4) is easily explained and relevant to managers, decision makers, and other stakeholders. Sentinel indicators may include representatives of regional biological communities and/or a species at the edge of its range or in a habitat that is limited.

#### 4.1.1 Core Abiotic Parameters

The focus of this plan is primarily on response of species, community, and ecosystem properties to climate and ecosystem change stressors. For example, we propose that the zooplankton community be monitored routinely in response to changes in temperature in the Gulf of Maine; that the salt marsh vegetation community be monitored in response to sea level rise, or attached benthic communities be monitored in response to expected changes in ocean and coastal acidification, temperature, or invasive species. For virtually all of these sentinel indicators, however, core abiotic variables are drivers of ecosystem or climate change. Many core abiotic variables are routinely monitored and are fundamental to better understanding and predicting ecosystem and climate change. These variables are integrative and cross-cutting, in that they apply to pelagic, benthic and coastal and estuarine habitats. The LISS Monitoring project proposed a list of core, abiotic variables. These include: precipitation; stream flow (runoff and baseflow); sea level; water temperature; salinity; wind (speed and direction); relative humidity; groundwater levels; and pH.

This plan recognizes that specific abiotic parameters for each type of sentinel indicator be collected and is dependent on the questions asked or the type of habitat.

For pelagic habitats, appropriate parameters include: water temperature, salinity, pH and other carbonate parameters, dissolved oxygen, and oceanographic measurements including wind speed and direction (using buoy-based continuous monitoring) that influence key water column properties such as stratification and heat flux.

For benthic habitats, appropriate parameters may also include sediment properties such as total organic carbon, bottom types, grain size, or habitat classification.

For sentinel indicators related to eutrophication or acidification we suggest that dissolved oxygen, pH, partial pressure of CO<sub>2</sub>, nutrient concentrations (e.g. dissolved inorganic nitrogen or total nitrogen), light availability (e.g. light attenuation using PAR sensors), color dissolved organic matter or other optical properties be monitored.

For coastal vegetation sentinels, we recommend air temperature and other meteorological parameters, including sea level rise and sediment elevation. It is recommended to install a meteorological station as is conducted by the National Estuarine Research Reserves for their System Wide Monitoring Program if feasible.

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The one major exception to the focus on biological sentinel indicators is consideration of sentinel indicators for better understanding changes to the physical structure, sediment rates, and nutrient loadings of estuaries and embayments (Table 4.4.1.). These are system wide observations that rely on a suite of abiotic parameters such as river flow and nutrient discharges to estuaries.

## 4.2 Pelagic Sentinel Indicators

The sentinel observing questions and indicators for the pelagic ecosystem in the Northeast region (Table 4.2.) address the need for an observing system that not only will monitor key pelagic ecosystem properties and species for which responses to climate forcing are expected, but also will provide indications of change that are unforeseen based on current knowledge.

### 4.2.1 Biodiversity

Biodiversity is an ecosystem property that will undergo change in response to drivers and pressures (Duffy et al. 2013). Sentinel variables to be used as indicators of biodiversity include species (or higher level taxon) fitness, species (or higher level taxon) composition and genetic diversity (Table 4.2.). These sentinel variables can be measured across trophic levels in the pelagic ecosystem, including microbes, phytoplankton, zooplankton and fish. The target taxa in Table 4.2. are based on analyses conducted as part of the GoM Census program (Johnson et al. 2011; Li et al. 2011). An example of the presentation of species richness and composition are the rank abundance and rank biomass plots for planktonic copepods in Canadian waters, based on Canadian AZMP data. The biodiversity sentinel variables fit criteria 1-4 discussed in section 4.1. While biodiversity of fishes has direct relevance to inform fisheries management, biodiversity at other trophic levels will also inform users and communities about change, perhaps unforeseen, at lower ecosystem levels that ultimately support fisheries production. Much of the data used to measure species richness and composition is also used to answer hypothesis-driven sentinel questions discussed below.

### 4.2.2 Key species, taxa or functional groups

#### *Overview*

Several species or higher-level taxonomic groupings of species fit the criteria outlined in section 4.1 for focus in sentinel observing. These particular taxa represent organisms with recognized significant impacts on the pelagic ecosystem and its services. Some, for example harmful algae, would be detrimental to ecosystem services if they were to increase under future environmental pressures. Others, such as the planktonic copepod, *Calanus finmarchicus*, and energy-rich zooplanktivorous fish like herring, are critical foundational species in the ecosystem. Disappearance of these key taxa would likely result in profound changes to the structure of pelagic ecosystems.

#### *Harmful algal blooms*

The GoM region experiences annually recurrent blooms of *Alexandrium fundyense*, the toxic dinoflagellate that causes Paralytic Shellfish Poisoning (Anderson 1997; Townsend et al. 2001, 2005). These annual blooms commence in areas of tidal mixing and pumping of naturally occurring deep water nutrients into surface waters (McGillicuddy et al. 2014;

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Townsend et al. 2014) and are advected throughout the region (Pettigrew et al. 2005). While these blooms vary among years in their cell densities and areal coverage (McGillicuddy et al. 2005a, 2014), they normally commence when benthic resting cysts (Anderson et al. 2005b; Matrai et al. 2005), as well as suspended cysts (Kirn et al. 2005), germinate in the spring and inoculate surface waters with vegetative cells. The initial appearance of *A. fundyense* cells generally follows the annual spring phytoplankton bloom, which is dominated by diatoms (Bigelow 1926; Bigelow et al. 1940). As *A. fundyense* cells multiply they are transported throughout the region in the residual near-surface currents (McGillicuddy et al. 2003, 2005a,b, 2011, 2014). Their rates of photosynthesis and population growth are potentially limited by a number of factors, including light and nutrients (Townsend et al. 2001; McGillicuddy et al. 2005b), zooplankton grazing (Turner and Borkman 2005), and possibly by competitive interactions with other phytoplankton taxa, particularly diatoms (Townsend et al. 2005; Gettings 2010; Gettings et al. 2013).

In addition to bloom dependence on the initial stock size of benthic resting cysts each year (McGillicuddy et al. 2005a, b), interannual variability in the distributions and cell densities of *A. fundyense* blooms may be controlled by the availability of dissolved inorganic nutrients (Townsend et al. 2001, 2005; McGillicuddy et al. 2011), concentrations and proportions of which (e.g., proportions of nitrate and silicate) may in turn be undergoing climate change-related alterations in the GoM region (Townsend et al. 2010; Rebeck 2011). The importance of the nutrient field to interannual variability in the magnitude of *A. fundyense* blooms in the GoM was shown by McGillicuddy et al. (2011) and Townsend et al. (2014).

Each state in the Northeast region maintains a program to test shellfish for Paralytic Shellfish Poisoning. A multiagency federal research program (ECOHAB: <http://coastalscience.noaa.gov/about/centers/escor>) has sponsored long-term observing and process-oriented research on *A. fundyense* blooms in the GoM. Given the health and economic implications of Harmful Algal Blooms, measurement of the abundance and distribution of *A. fundyense* is identified as a sentinel indicator.

#### *Phytoplankton functional groups*

As primary producers fueling the base of the food web, phytoplankton play essential roles in structuring the rest of plankton community, with implications for the flows of energy and materials through the food web and the efficiency of transfer to higher trophic levels. While species level detail is important for some aspects sentinel observing questions, other questions are best addressed with sentinel indicators that reflect phytoplankton functional groups. These functional groups represent collections of species that serve similar ecosystem roles or have specialist adaptations or requirements that differentiate them (see review by Sathyendranath et al. 2014). Groups of species that mediate particular biogeochemical transformations are important, including silicifiers (principally diatoms), calcifiers (principally coccolithophorids), nitrogen fixers, and dimethyl sulfide producers. Each of these functional types has been shown to be important at different times and locations in the GoM and surrounding shelf regions (e.g., Balch et al. 1991; Townsend et al. 1996; Kane 2011; Mulholland et al. 2012). Furthermore, they may be expected to respond to on-going climate change impacts including warming,



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acidification, and shifts in patterns of stratification and mixing. For this reason, functional characteristics of phytoplankton communities are important sentinel indicators.

#### *Energy-rich zooplankton species*

The planktonic copepod, *Calanus finmarchicus*, is the biomass dominant mesozooplankton species in the deep GoM and often along its coastal shelf (Bigelow 1926; Johnson et al. 2011; Runge et al. 2015). Euphausiids, particularly *Meganyctiphanes norvegica*, are also dominant, energy-rich zooplankton known to be abundant in the GoM, although they are not well sampled. Recent statistical-based modeling of *C. finmarchicus* habitat characteristics, especially sea surface temperature, predicts that ocean warming will drive the distribution of *C. finmarchicus* northward out of the GoM over the next several decades (Reygondeau and Beaugrand 2011). There is no similar study of *M. norvegica* or other euphausiid species, but since it also resides at the southern edge of its subarctic range in the GoM, its distribution is also likely to be sensitive to warming. By storing energy derived from spring and summer primary production, *C. finmarchicus* and euphausiids sustain a high biomass of energy-rich forage fish species, notably Atlantic herring, silver hake and sand lance, which is discussed in the next section. As there is no known functional substitute for these energy-rich zooplankton in the GoM system, substantial reduction in their abundance could trigger a regional ecosystem shift. These components of the GoM ecosystems are therefore hypothesized to be sensitive to future bottom-up pressures and are candidates for enhanced observing in the ISMN.

#### *Forage fish species*

Forage fishes, small pelagic fishes that often form dense schools, form a crucial trophic link between primary producers and secondary consumers. Forage fishes feed on zooplankton and become the primary diet for larger, predatory fish species, some marine mammals, and sea birds. They support commercially valuable species including cod, hake, and tuna. The presence of humpback, fin, and other whales off the coast of Massachusetts is closely linked to forage fishes, a primary food source for these endangered cetaceans (Payne 1990).

The forage species present in the Northeast include sand lances (two species), river herrings (blueback, alewife, and shad), Atlantic herring, menhaden, and butterfish, as well as young mackerel and a host of other juvenile fishes. Among these, Atlantic herring, whose distribution is constrained to cold-temperate and boreal waters on both sides of the North Atlantic (Collette and Klein-MacPhee 2002) and the river herrings (Lynch et al. 2015) are the most susceptible to reduction in suitable habitat with predicted warming in the Northeast region. On the other hand the more temperate menhaden and butterfish may expand northward into the GoM, as was seen with butterfish in 2012.

Many species of forage fish also use estuaries during their early life stages for refuge, feeding, and growth, linking bays and tidal wetlands to nearshore and offshore populations. Juvenile stages of these species also support the recreational fisheries for game fish, such as striped bass and bluefish, which can play important roles in the local economy.

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With several species of forage fishes present in the Northeast, consumers can substitute prey if one or more species decline. For example, whales can feed on herring when available but seek out sand lance in their absence. However, the accessibility and quality of the forage is different. Herring are highly mobile, while sand lance are tied to nocturnal resting areas in sandy bottom, venturing only periodically to upwelling areas and oceanographic fronts to feed. Herring have a much higher fat content than sand lance, making them a preferred energy source. The distribution of alternate forage species may not be compatible. For example, the historic loss of river herring runs and inshore fish populations generally greatly diminished the production of fisheries and other forage fish-based ecosystem services along the coastal GoM. The available forage species may not be the right size or shape. Adult puffins had to rely on butterfish to feed their young when juvenile herring were not available in 2012, leading to high chick mortality.

Before the 1950s, forage fishes made up only a small share of the global marine fisheries catch, perhaps as low as 8% (Macer 1974). But during the last half of the twentieth century, the depletion of top predators and new fishing technologies motivated a more focused and efficient extraction of these smaller fishes. As a result, in 2002, forage fishes accounted for 37% of global marine fish landings (Pikitch, 2014). While healthy populations and natural assemblages of forage fishes preserve ecosystem integrity and support important economic activities, namely commercial fishing and whale watching, the fact that these fish too are commercially viable poses additional challenges for management and stewardship. These species, in particular Atlantic herring and the river herrings are therefore nominated as sentinel indicators.

#### *Harvested fish and invertebrates at the northern or southern edge of their biogeographic range*

Surveys of harvested fish and invertebrates lie in the domain of federal and state fisheries agencies. Analysis of extensive survey data has already shown impacts of climate-related change on distribution and recruitment of fish and invertebrates on the Northeast continental shelf. Species assemblages of fish are shifting toward species that prefer warmer water (Lucey and Nye 2010). Statistically significant distributional shifts, either poleward or deeper to colder depths, are associated with warming of the continental shelf waters (Nye et al. 2011; Pinsky et al. 2013). The recent warming has been implicated in the collapse of fisheries for Atlantic cod and northern shrimp (Richards et al. 2012), two subarctic species residing at the southern margin of their range in the GoM.

The effects of climate change on Northeast region ecosystems present a new dimension of challenges for fisheries management. If climate forcing is driving not only change in abiotic habitat but also in productivity of lower trophic levels, stock assessments and subsequent management advice may be inaccurate, potentially leading to ineffective and costly actions by the fishing industry. A promising tool that includes information about ecosystem change is ecological risk assessment, in which the sensitivity of species and communities to observed and predicted change can be assessed (Gaichas et al. 2013). A number of the ISMN sentinel indicators will contribute directly to inform development of these risk assessments.

### *Endangered or protected marine fish, birds and mammals*

The nutrient-rich Northeast U.S. coastal and ocean ecosystems support a number of state and federally threatened and endangered fish species that are experiencing changes in distribution, abundance, and vital rates, increasing their conservation concern. Among fish species, cusk (*Brosme brosme*) is a candidate for the Endangered Species List and has received much attention recently because of the influence climate change might have on cusk important habitat. Specifically, cusk habitat is restricted to relatively small areas boasting distinctive seafloor characteristic, confined by specific ocean temperatures. Given these habitat requirements, increased ocean temperatures predicted with climate change may cause cusk habitat to shrink and be more fragmented, which will likely impact population vital rates and, ultimately, declines in abundance (Hare et al. 2012). Other examples of key threatened and endangered fish species experiencing changes in the Northeast U.S. region include Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) and Atlantic salmon (*Salmo salar*). With Atlantic sturgeon, endangered populations in the New York Bight and threatened GoM populations are under increased pressure from human activities, such as dams limiting upriver movements and continued water quality degradation effecting fecundity, growth, and survival (NOAA NMFS Atlantic sturgeon 2014). These changes are also likely to influence Atlantic salmon, another anadromous species; however, recent findings also point to marine survival as an important population-limiting factor. In particular, decreases in Atlantic salmon marine survival appear to be correlated with broad-scale climate driver impacts affecting survival rates by shifting prey distribution and abundance (Mills et al. 2013).

Along with threatened and endangered fish species, Northeast U.S. ecosystems also provide habitat for threatened and endangered marine mammals and marine bird species. These species include one of the rarest species in the region, the North Atlantic right whale (*Eubalaena glacialis*). In addition to human-caused mortalities, the North Atlantic right whale population is also subject to the effects of climate change and shifts in natural conditions. The link between right whales and climate change arise because of climate change altering the distribution and abundance of their key prey species, the nutrient-rich zooplankton, *Calanus finmarchicus*. In turn, limited prey availability appears to be tied to declines in female calving rates (Greene and Pershing 2004). Similar connections among natural drivers, the availability of prey, and threatened or endangered species populations also appear evident in marine bird species, such as the Arctic tern (*Sterna paradisaea*), a state of Maine threatened species (Maine DIFW 2003). Recent investigations into long-term colony monitoring datasets suggest Arctic tern reproductive parameters (e.g. number of chicks per nest, chick growth rates) and population sizes have been declining despite considerable management efforts, especially since ~ 2004 (L. Welch, unpubl. data). Interestingly, the timing of these declines seems to overlap with a shift in GoM ocean currents and circulation patterns (Smith et al. 2012), which are characteristics sensitive to climate change and natural ecosystem drivers.

### **4.2.3 Ecosystem properties and function**

#### *Nutrient loading and primary production the pelagic environment*

The overall biological productivity of the continental shelf waters of the Northwest Atlantic is founded on the level of primary production that is sustained in the region by fluxes of dissolved inorganic nutrient loads carried onto the shelf from the adjacent Atlantic basin and from the continental shelf "upstream" (e.g., Fournier et al. 1977;

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Townsend et al. 2006). In the GoM, interannual variations in resident nutrient loads can be attributed to the relative fluxes into the interior Gulf of different water masses, including the Warm Slope Water (WSW), Labrador Slope Water (LSW; e.g., Houghton and Fairbanks 2001; Smith et al. 2001), and Shelf Water dominated by Scotian Shelf Water (SSW) from the Nova Scotian Shelf. The GoM receives negligible anthropogenic fluxes of dissolved inorganic nitrogen (so far, with the possible exceptions of urban harbors). While deep water intrusions of slope waters from off the continental shelf are the principal source of nutrients that drive the high rates of primary production in the interior GoM and on Georges Bank (Townsend 1991, 1998; Townsend and Pettigrew 1997; Hu et al. 2008), the type of slope water – WSW versus LSW – is important in that the two differ significantly in their nutrient loads (Townsend et al. 2006; Townsend and Ellis 2010).

Recent climate change-related shifts in oceanographic processes off the east coast of North America have altered water mass fluxes, nutrient fields, primary production, and phytoplankton communities in the GoM region (e.g. Townsend et al. 2010; McGillicuddy et al. 2011; Rebeck, 2011; Balch et al. 2012; Rebeck and Townsend 2014; Townsend et al. 2014). Analyses of hydrographic data collected on moorings in the Gulf over the past decade are showing highly variable fluxes of different water masses, on time scales of months to several years (Townsend et al. 2014), which along with the concomitant nutrient loads, forewarn continued variability in water temperatures and in plankton productivity. This water mass variability is believed to be the result of far-field processes associated with changes in the Arctic (Townsend et al. 2014). Episodes of low-nitrate Shelf Waters have been shown to result in lowered primary production during the spring bloom and changes in the subsequent phytoplankton species succession (e.g. McGillicuddy et al. 2011; Townsend et al. 2014). Changes in primary production in the GoM have also been associated with climate-forced shifts in precipitation patterns altering discharge from rivers in the GoM watershed (Balch et al. 2012).

It is probable that this variable flow of Shelf and Slope Waters is similarly affecting shelf waters farther downstream in the New York and Mid-Atlantic Bights. Moreover, as precipitation patterns and source waters and their nutrient loads vary, commensurate changes in primary production and species composition can be expected. Together these phenomena are likely to influence the species composition of higher trophic levels, including commercially exploited fish stocks. Connections between and among these variable water mass fluxes, plankton productivity and community structure, and stocks of commercially exploited species are unknown and are in immediate need of more detailed observations and research.

#### *Shifts in plankton community composition in the pelagic environment: functional traits*

As discussed in sections above, bottom-up pressures may result in changes to plankton community composition. While biodiversity indicators will provide information about species and taxa needed to interpret change, ecosystem models also require information about changes to functional traits within the plankton communities. Functional traits are characteristics that reflect growth and life history strategies of functionally similar groups of individuals in the community, regardless of species. Models of ecosystem structure and services can be simplified to focus on how change in functional traits alter biogeochemical cycles and pathways of production to harvested fish and invertebrates.

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Body size is a fundamental functional trait. Cell size is typically used as a proxy for phytoplankton function, especially in regard to predicting impacts of food web structure. Phytoplankton communities dominated by relatively small-sized cells (pico- and nano-phytoplankton) are expected to produce high levels of recycled production and relatively low transfer to higher trophic levels, as compared to communities dominated by microphytoplankton, such as diatoms and other groups that are effectively grazed by copepods and fish larvae (e.g. Cullen et al. 2002). Body size is an important structuring trait in zooplankton communities, with a shift toward smaller body size predicted in a warmer ocean (Barton et al. 2013).

Other key functional traits in the Northeast region include the abundance relative to other zooplankton of gelatinous zooplankton, which have a disproportionately large body size relative to mass or energy content, and the relative contribution of energy-rich, diapausing copepods to the zooplankton community. There is considerable uncertainty about the extent to which these traits will change in the northern ocean in the future (e.g., Johnson et al. 2011; Gibbons and Richardson 2013), hence the need to track them in an observing system.

Many of these functional traits are either presently measured in existing observing activities or can be feasibly added as enhancements. Since they are keys to understanding change in the properties and function of the region's ecosystem, functional traits satisfy the criteria for sentinel indicators.

#### *Phenology: seasonal timing of cycles in the pelagic environments*

Phenology refers to the study of cyclic and seasonal natural phenomena, especially in reference to the oceans, and the relationships between climate driven pressures and seasonality of phytoplankton, zooplankton, and higher trophic level seasonal cycles. Climate forcing is predicted to result in timing mismatches between organisms and the physical environment, and across trophic interconnections (Ji et al. 2010). Examples of trophic linkage include the timing of the spring bloom and emergence from diapause of *Calanus finmarchicus*, which is hypothesized to be critical for future resilience of this species in the GoM (Runge et al. 2015). Timing of the coastal winter-spring phytoplankton and zooplankton bloom providing food for northern shrimp larvae after winter hatching is an essential component for recruitment success in this species (Richards et al. 2012). Shifts in the timing of seasonal phytoplankton cycles can be measured by satellite and on moored sensors but need ground truthing. Shifts in the timing of seasonal zooplankton and ichthyoplankton cycles can be feasibly measured at designated fixed time series stations for which the frequency of collection is at least monthly (Ji et al. 2010). A number of seasonal time series exist in the Northeast region for historical analysis.



#### Box 4 Sentinel Indicators of Biodiversity and Tracking Invasive Species

The ISMN, with an emphasis on observing the variability of organisms from genes to taxa through targeted biodiversity sentinel indicator monitoring, will strengthen our ability to track invasive species throughout the Northeast U.S. region. Invasive species can negatively affect commercial shellfish and finfish aquaculture, impact native communities through competition and predation, and may represent up to 40% of the biomass in some fouling communities (Ruiz et al. 2000; Dijkstra and Nolan 2010; J. Pederson, unpubl. data). Unfortunately, the threats posed by invasive species are only expected to intensify as both the rate of invasive species introductions and the range of established invasive species populations are likely to increase with warming sea temperatures (Sorte et al. 2011).

In the pelagic environment, increases in gelatinous zooplankton (e.g., ctenophores) have been observed across the Northeast U.S. Continental Shelf, with potential impacts to fisheries (Link and Ford 2006). Record temperatures in 2012 (Mills et al. 2013) underscored this threat with multiple anecdotal reports of gelatinous plankton blooms, followed by massive blooms of lion's mane (*Cyanea capillata*) and moon (*Aurelia aurita*) jellyfish along the coast in 2014. While these species have been occasional visitors to the GoM or coastal waters, or present in low numbers, the threat of increases in magnitude and frequency of gelatinous plankton blooms echo similar increases in other parts of the ocean (Kideys 2002).

Within the benthic environment, there are a number of invasive species with established populations in the Northeast U.S. region. *Didemnum vexillum* is a sea squirt that has spread up and down the East Coast (and elsewhere) and is one of the few invertebrates that have become established offshore. Two shellfish predators, *Carcinus maenas* (green crabs) and *Hemigrapsus sanguineus* (Asian shore crab), are found in estuaries and along the coast where they are the focus of monitoring programs in the East Coast U.S. and Canada. Concern that these populations will increase with warming sea temperatures and exert greater predation to native shellfish populations supports including them as sentinels that can be incorporated into ongoing monitoring programs. Other species that are observed during the summer populations are the lion fish (*Pterois miles/volitans*) that has been observed in Long Island Sound, and two summer migrants, a bryozoan *Zoobotryon verticillatum* that forms colonies of 1-2 m and has been observed in Connecticut and Massachusetts, and *Amphibalanus amphitrite*, a red-striped barnacle often seen in the summer in New England.

In coastal and estuarine environments, oyster parasites such as *Perkinsus marinus*, *P. chesapeaki*, and *Haplosporidium nelsoni* appear to be spreading northward with warming climate or increasing trade (Ford and Chintala 2006; Marquis et al. in press). The ranges of these parasites have extended across much of coastal Maine in recent years. Oyster parasites can cause population crashes and in some cases can impact human health. The spread of these species has potential consequences for a growing aquaculture industry.

**Table 4.2.** Pelagic environment sentinel observing questions and sentinel indicators.

Sentinel Observing Question	Sentinel Indicators
<b>4.2.1 – Biodiversity (same numbering as text sections)</b>	
1) Is microbial diversity changing?	<ul style="list-style-type: none"> <li>Genetic diversity</li> <li>Distribution, abundance and size characteristics of bacteria</li> </ul>
2) Is phytoplankton diversity changing?	<ul style="list-style-type: none"> <li>Genetic diversity</li> <li>Taxa seasonal and annual rank abundance</li> </ul>
3) Is zooplankton diversity changing?	<ul style="list-style-type: none"> <li>Genetic diversity</li> <li>Taxa seasonal and annual rank abundance, focusing on: <ul style="list-style-type: none"> <li>Copepods</li> <li>Meroplankton</li> <li>Gelatinous zooplankton</li> <li>Euphausiids</li> <li>Mysids</li> </ul> </li> </ul>
4) Is fish diversity changing	<ul style="list-style-type: none"> <li>Species richness and community composition of marine fishes</li> <li>Species richness and community composition of ichthyoplankton</li> </ul>
5) Are marine bird and mammal diversity changing?	<ul style="list-style-type: none"> <li>Species richness and community composition of marine birds and mammals</li> </ul>
<b>4.2.2 – Key species, taxa or functional groups</b>	
1) Are harmful algal blooms (HABs) occurring with greater frequency, severity or across greater spatial extents?	<ul style="list-style-type: none"> <li><i>A. fundyense</i> distribution and abundance</li> <li>Algal pigments</li> </ul>
2) Is the relative biomass of phytoplankton functional groups (e.g., picoplankton and large diatoms), which influence ecosystem structure and energy pathways, changing?	<ul style="list-style-type: none"> <li>Phytoplankton taxa distribution and abundance</li> <li>Phytoplankton size spectra</li> <li>Algal pigments</li> </ul>
3) Is the abundance of <i>Calanus finmarchicus</i> or euphausiid species decreasing or becoming more variable?	<ul style="list-style-type: none"> <li><i>Calanus finmarchicus</i> and euphausiid spp. distribution and abundance</li> </ul>
4) Is the abundance of key forage fish (e.g., herring and sandlance) declining?	<ul style="list-style-type: none"> <li>Forage fish distribution and abundance</li> </ul>
5) Are the abundance and landings of key harvested fish species at the edge of their biogeographic ranges changing?	<ul style="list-style-type: none"> <li>Landings and trawl survey data for Atlantic cod, American lobster and Northern shrimp</li> </ul>
6) Are the distribution or abundance of endangered or protected marine fish, birds or mammals changing?	<ul style="list-style-type: none"> <li>Atlantic salmon and shortnose sturgeon and baleen whales distribution and abundance</li> <li>Marine bird community composition</li> </ul>

4.2.3 – Ecosystem Properties and Function	
1) How are conditions for primary productivity and trophic transfer changing?	<ul style="list-style-type: none"> <li>• Nutrient and chlorophyll concentrations</li> <li>• Seasonal and annual ratios of key functional groups (e.g., diatoms vs. dinoflagellates)</li> <li>• Commercial fish landings in relation to primary production</li> </ul>
2) Are there shifts in plankton functional traits?	<ul style="list-style-type: none"> <li>• Phytoplankton cell size</li> <li>• Zooplankton size frequency distributions, biovolume, and biomass</li> <li>• Ratios of crustacean/gelatinous zooplankton; large-bodied lipid-rich to small, lipid-poor copepod taxa</li> </ul>
3) Are there changes in phenologies and match/mismatch of seasonal biological processes influencing trophic linkage?	<ul style="list-style-type: none"> <li>• Chlorophyll a seasonal cycle</li> <li>• Seasonal and annual shifts in phytoplankton and zooplankton species composition and functional traits</li> <li>• Shifts in fish and invertebrate phenological cycles</li> </ul>

## 4.3 Benthic Sentinel Indicators

The seafloor landscapes of the Northeast U.S. ocean and coastal waters comprise a diverse set of environments with a multitude of habitat types. Community level metrics focusing on biodiversity and species and functional group level indicators (Table 4.3.1.) across these varied environments are being recommended as sentinels. These metrics would be used to assess the extent to which the ecological characteristics of the benthic realms of the region may be changing over different spatial and temporal scales.

### 4.3.1 Biodiversity

Benthic communities are integral and important components of coastal ecosystems via high secondary production, food web dynamics, contributions to biogeochemical cycles, and as a human resource. Research is increasingly revealing that these functions and services are dependent on the biotic diversity found in benthic communities, and that loss of diversity or changes in composition may affect such functions and the overall dynamics of benthic communities (Bolam et al. 2002; Covich et al. 2004; Solan et al. 2004, 2008; Harley 2011). Diversity patterns over space and time provide indications of how benthic communities respond to seafloor habitat characteristics and environmental conditions (Gray 1997; Snelgrove 1998; Hewitt et al. 2008; Weissberger et al. 2008; Josefsen 2009; Zajac et al. 2013). As such it is not surprising that the sensitivity of benthos to climate change related phenomena is also becoming more evident (Smith et al. 2006; Thrush et al. 2006; Jones et al. 2013; Birchenough et al. 2015). The biodiversity of the benthos can be a very effective indicator of climate change and disturbances to the seafloor and can be linked/related to pelagic and nearshore indicators. For the ISMN, the spatial and temporal patterns of biodiversity in infaunal communities inhabiting soft sediment habitats and hard bottom attached fauna and flora would be critical to measure and monitor as community level indicators of any changes occurring in northeast coastal

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environments. Due to limited or lack of mobility, organisms in these communities integrate environmental conditions over multiple spatial and temporal scales and have been extensively used as indicators of impacts to benthic habitats and coastal and estuarine environments in general.

Going forward with the ISMN, it is important to have historical data and related analyses focusing on biodiversity as a framework to assess long-term changes in diversity and trends identified by a sentinel system. For both soft-sediment and hard bottom communities, a number of studies are components. Alpha diversity is the diversity at a single site and can be further divided into species richness and evenness, also called equitability; the more species and more even their abundances, the higher the alpha diversity. Beta diversity is the change in species composition in space or time attributable to habitat discontinuities. Beta diversity can be quantified with a variety of community similarity or dissimilarity indices, such as Orloci's chord distance, Grassle and Smith's (1976), NESS, Gallagher's CNESS (Trueblood et al. 1994) or Bray Curtis similarity. Gamma diversity represents the overall diversity at a region, representing the combined effects of alpha and beta diversity.

Benthic community structure and related biodiversity components are sensitive to changes in the environment and should reveal the effects of ecosystem change caused by a variety of pressures, including those related to climate change. For example, Gallagher et al. have shown that alpha diversity measured with Fisher's log-series alpha is strongly correlated with the Atlantic Multidecadal Oscillation (AMO) which can be used to develop such a framework. A number of studies have assessed biodiversity/community structure characteristics of benthic communities in the geographic areas of the northeast sentinel region. For sedimentary habitats these include studies in the GoM by Hilbig and Blake (2000), Maciolek and Smith (2009), Evgenidou (2012); in Block Island Sound by LaFrance et al. 2010; and in Long Island Sound by Zajac (1998 and references therein) and Zajac et al. (2000, 2013). There are larger-scale biogeographical analyses as well (Hale 2010; Hale et al. 2013). For hard substrate communities these include studies in the GoM by Vadas and Steneck (1988), Patricio and Dearborn (1989), Witman and Sebens (1990), Lechter and Witman (1997), Miller and Etter (2008, 2011), Incze et al. (2010), and Kelly et al. (2010), Fuller (2011), and in LIS by Liebman et al. (2010). There are also studies of the diversity of demersal fauna in the region (e.g., Oviatt and Nixon 1973; Ojeda and Dearborn 1990; Auster 2002; Collie et al. 2008; Howell and Auster 2012).

As has been noted by Maciolek and Smith (2009) and others, conducting analyses of biodiversity trends can be difficult due to differences in sampling and sample processing methodologies and taxonomic biases. Identifying data sets that are as consistent as possible with respect to these issues will be critical in order to apply a variety of multivariate and diversity-focused analyses (see below). While direct analyses will likely not be possible across all historical data sets, meta-analyses (e.g., Côté et al. 2005; Batáry et al. 2011; Trott 2015) of the overall set of previous findings can be conducted to provide insights as to biodiversity trends and causes across the region.

The biodiversity data collected in the sentinel network can be analyzed in a variety of ways (Magarrum et al. 2010; Veech and Crist 2010; Gotelli and Colwell 2011) in order to assess trends within and among regions. Biodiversity can be partitioned into alpha, beta,

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and gamma AMO, an index derived from average North Atlantic temperature. They also found that alpha diversity was affected by the massive MWRA sewage effluent outfall that began discharging most of the Boston area's secondarily treated sewage effluent into a site in Massachusetts Bay 15 km from the mouth of Boston Harbor. However, the coupling between diversity and climate-driven stressors may not be direct and/or may be difficult to identify due to autocorrelation or community drift over time (Hubbell 2001) that is uncoupled from climate change. Similarly, there is considerable spatial pattern in benthic communities due to spatial autocorrelation; pattern that is potentially uncoupled to measured, spatially patterned external drivers such as mixed models; and multivariate statistics such as Legendre and Legendre's (2012) variation partitioning (and as described in references given above) that permit the statistical evaluation of drivers of change in community structure and associated biodiversity characteristics. Such methods and approaches can be applied for assessing biodiversity monitoring metrics in both soft and hard bottom habitats, and also for the demersal fauna that are found in those habitats.

#### 4.3.2 Key species, taxa or functional groups

Whereas biodiversity metrics provide critical community-level sentinel indicators, individual taxa that are key components of benthic environments can be valuable sentinels. These may include species that have well defined biogeographic boundaries, may be particularly sensitive to environmental changes, provide critical habitat and/or have critical functions, have been identified as invasive, or are commercially important species. It may be particularly important to monitor all life cycle stages of commercially important species such as lobsters and ocean scallops. Several potential candidates in this class of sentinels are discussed below.

##### *American lobster*

The American lobster (*Homarus americanus*) is a key sentinel indicator species for the region because it is a cultural icon as one of the most commercially valuable species to the U.S. Northeast and Atlantic Canada with a combined landed value in the two countries on the order of \$1 billion. It is also an important and conspicuous mid-level consumer in the region's coastal ecosystem. Several monitoring programs quantify lobsters at different stages in their life history and meet the criteria of sentinel ecosystem indicator in that they are feasibly measured at multiple sites, include species that are relevant to stakeholders, are fundamental to ecosystem structure, exist at the northern and southern extreme their range within the monitoring domain, manifest long-term trends in abundance, and are responsive to climate change.

The American Lobster Settlement Index (ALSI) quantifies newly settled young-of-year and older juveniles in their coastal nursery habitats. Initiated in 1989 in Maine, the time series has expanded to include over 100 fixed sites currently sampled annually by U.S. and Canadian marine resource agencies and universities from Rhode Island to Newfoundland. The ALSI partnership now comprises Rhode Island Division of Fish and Wildlife, Massachusetts Division of Marine Fisheries, New Hampshire Fish & Game, Maine Department of Marine Resources, Fisheries and Oceans Canada (at St. Andrews and Moncton, New Brunswick, and Bedford, Nova Scotia), the University of Maine, University of New Brunswick, Memorial University, Prince Edward Island Fishermen's Association, and Guysborough County Inshore Fishermen's Association in Nova Scotia. ALSI sampling is conducted once at the end of the summer larval settlement period by



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two methods: (1) diver-based airlift suction sampling in natural cobble nursery habitat, and (2) vessel deployed, cobble-filled passive collectors which enable sampling in locations that are unsafe or impractical for divers. The ALSI program stands out for several reasons. First, while sampling includes all sizes of lobsters present in the nursery habitat, it is the only monitoring program that quantifies the young-of-year lobsters, thereby giving the best indication of lobster year-class strength at the beginning of its benthic life. Second, it is the only monitoring program with completely standardized methodology across all collaborators in the U.S. and Canada. Finally, ALSI monitoring can be used as a biodiversity indicator in that it also includes early stages of commercially important and invasive crabs such as Jonah crab (*Cancer borealis*), rock crab (*C. irroratus*), green crab (*Carcinus maenas*), and Asian shore crab (*Hemigrapsus sanguineus*). Passive collectors have proven to be especially effective at sampling juvenile stages of demersal fish. The University of Maine compiles ALSI data annually and maintains a database and a password-protected participants' web portal hosted by the Atlantic Coastal Cooperative Statistics Program. Results of the survey are used as an indicator of the health of the lobster fishery in period stock assessments by the Atlantic State Marine Fisheries Commission and the National Marine Fisheries Service. ALSI data have been used in more than 35 peer reviewed scientific publications and technical reports. Annual updates of the status of settlement have been disseminated to stakeholders and media since 2001. The GoMC ESIP also maintains an online reporting tool at <http://www2.gulfofmaine.org/esip/reporting/gmap2.php?new=true> where users can graph ALSI time series for selected study areas.

ALSI monitoring complements other long-standing fishery-independent monitoring programs that include older juveniles and adult lobsters in their collections. NOAA's groundfish trawl surveys began in 1963 and cover federal waters out to the continental shelf break in a random stratified sampling design. Surveys are conducted annually in the spring and fall. New England state marine resource agencies initiated complementary groundfish trawl surveys within 3-miles of shore in 1978-79, in NY waters of LIS in 1984 and in Maine in 2000. In addition, Rhode Island Division of Fish and Wildlife has conducted research trawls since 1990 at 13 fixed stations in Narragansett Bay, and URI's Graduate School of Oceanography has conducted year-round weekly research trawls at two sites in Narragansett Bay since 1959. Fishery-dependent surveys of lobsters conducted by each state include at-sea sampling and port sampling of the commercial catch. In addition, in 2005 state agencies have collaborated with volunteer harvesters to begin ventless trap surveys, whereby standard commercial traps have been modified to prevent the escape of sublegal lobsters to give an index pre-recruit abundance. Databases are maintained for these monitoring programs by the respective agencies.

### *Infaunal taxa*

Several species of infaunal taxa may also potentially be effective sentinel indicators. Gene Gallagher at UMass Boston has found interesting large-scale spatial patterns in the distribution of two species of the polychaete genus *Mediomastus*. Based on several studies spanning Massachusetts Bay and waters south of Cape Cod, it appears that *Mediomastus ambiseta* is found primarily south of Cape Cod, whereas *M. californiensis* is found almost exclusively north of Cape Cod. Gallagher's reanalysis of the EPA's EMAP-E data indicates that *Mediomastus ambiseta* is nearly ubiquitous south of Cape Cod, being found in 63% of samples. No *M. ambiseta* individuals were found in an

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extensive sampling effort in Massachusetts Bay. It is not yet clear what are the determinants of the difference in distribution of these two congeners across the well-known Cape Cod biogeographic transition. However, factors such as water temperature and food supply to the benthos may play a role, and as such a shift in the distribution of *M. ambiseta* northward of Cape Cod could indicate changes in coastal environmental conditions affecting benthic communities. The use of this set of congeners should be accompanied by genetic analyses to confirm taxonomic identifications and also to determine if there are changes in the population genetic makeup of the species.

#### *Kelp beds and selected hard bottom taxa*

Kelp beds are noted in section 4.4.5. It is suggested that subtidal macroalgal communities be surveyed in a number of areas in the GoM, across the Cape Cod biogeographic transition, and in southern New England waters, in particular Vineyard Sound, Buzzards Bay, Block Island Sound, and LIS. Dominant macroalgal taxa should be identified in these habitats as shifts in their relative dominance and presence/absence may be effective indicators of changes in nearshore subtidal environmental conditions.

In addition to macroalgae, hard bottom invertebrate taxa (apart from lobsters which are discussed above) may also be effective sentinels and provide ecosystem level indications of environmental change. Key among these may be sea urchins, which numerous studies have shown to play important roles in the structuring of hard bottom communities and be sensitive to changes in food web structure and dynamics (e.g., Witman 1987; Harris and Tyrrell 2001; Steneck et al. 2004, 2013). Their population dynamics have been greatly affected by such changes and they may provide insights on environmental changes and how they may be interacting with human impacts on these food webs.

#### *Invasive species*

Invasive species can negatively affect commercial shellfish and finfish aquaculture, impact native communities through competition and predation, and may represent up to 40% of the biomass in some fouling communities (Ruiz et al. 2000; Dijkstra and Nolan 2010; J. Pederson, unpubl. data). Invasive species are good sentinels and should be, at a minimum, integrated into ongoing programs. Established invasive species populations are expanding their ranges with warming sea temperatures (Sorte et al. 2011) and the rate of introduction is likely to increase. This section briefly describes current efforts to document the invasive species presence and impacts and offer ways to incorporate them into ongoing monitoring programs.

The Massachusetts Office of Coastal Zone Management (CZM) leads marine invasive species (MIS) detection and monitoring efforts through the Marine Invader Monitoring and Information Collaborative (MIMIC), a network of community groups and citizens. CZM trains interested groups to use a standardized monitoring protocol, and partners throughout the region coordinate monitoring by citizen scientists. The data and information collected by MIMIC are available through MA CZM by request and at the Massachusetts Ocean Resource Information System (MORIS, [http://maps.massgis.state.ma.us/map\\_ol/moris.php](http://maps.massgis.state.ma.us/map_ol/moris.php)).

Since 2000, six rapid assessment surveys by taxonomic experts have been conducted to record native and non-native macroinvertebrates and macroalgae on floating pontoons in

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the Northeast (Pederson et al. 2005; McIntyre et al. 2013; Wells et al. 2014). Data from these surveys are available through published reports on the MA CZM and MIT Sea Grant websites and through the Massachusetts Invader Tracking and Information System (MITIS; [http://mit.sea-grant.net/mitis/mitis\\_map](http://mit.sea-grant.net/mitis/mitis_map)). The results show a trend of increasing non-native species over time, and increased numbers of summer migrants in the last two surveys than were present in the early surveys.

The following species are potential sentinel candidates that have established northern ranges, have demonstrated ecological and economic impacts, and can be monitored with other ongoing programs. *Didemnum vexillum* is a sea squirt that has spread up and down the East Coast (and elsewhere) and is one of the few invertebrates that have become established offshore. The monitoring of *Didemnum vexillum* in Georges Bank using the Habitat Characterization Camera System (HabCam) is now under the management of NOAA and data are available at <http://habcam.whoi.edu/>. Ongoing monitoring of *Zostera marina*, as part of the coastal and estuarine monitoring activities, could offer an opportunity to monitor *D. vexillum* that are found on the blades. Two shellfish predators, *Carcinus maenas* (green crabs) and *Hemigrapsus sanguineus* (Asian shore crab), are found in estuaries and along the coast where they are the focus of monitoring programs in the East Coast U.S. and Canada. Concern that these populations will increase with warming sea temperatures and exert greater predation to native shellfish populations supports including them as sentinels that can be incorporated into ongoing monitoring programs. Other species that are observed during the summer populations are the lion fish (*Pterois miles/volitans*) that has been observed in LIS, and two summer migrants, a bryozoan *Zoobotryon verticillatum* that forms colonies of 1-2 m and has been observed in Connecticut and Massachusetts, and *Amphibalanus amphitrite*, a red-striped barnacle often seen in the summer in New England.

#### 4.3.3 Ecosystem properties and function

##### *Critical functions of soft-sediment benthic ecosystems*

Benthic ecosystem functions are vital to the local, regional, and global processes that sustain the environment and benefit human interests. Functions related to cycling of materials include processing of organic matter and nutrients, sediment mixing, and metabolism/sequestration of pollutants (Herringshaw and Solan 2008). Trophic ecosystem functions include secondary production, trophic transfer, and production of food for human needs (Diaz and Schaffner 1990).

##### *Benthic ecosystem functions as sentinels*

Measures of benthic function have been used as indicators of stressed communities for decades (Pearson and Rosenberg 1976) and are valuable sentinels for the cumulative effects of multiple stressors, particularly low oxygen levels. Many benthic functions are affected by higher temperatures that speed up rates of chemical processes, or exacerbate oxygen stress. In one hypothesis related to climate change, higher temperatures may increase oxygen stress in susceptible areas such as estuaries with low flushing rates, and functional sentinels may detect these effects. These sentinels are also sensitive to changes in food quality and quantity (Rosenberg 1995), and hypothesized climate-related changes in plankton size distributions (section 4.2.2 above) may then shift benthic functions in measurable ways, e.g., shifts from larger suspension feeders to smaller deposit feeders. However, benthic functions generally involve many species, and sentinels will likely not

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detect climate-related range shifts of individual species. Further, responses of functional metrics to climate changes have not been investigated. Nonetheless, analyses of benthic function do reveal larger patterns and trends, can be measured directly or through proxies, and may be cheaper and easier to apply than other benthic measures.

#### *Promising measures and proxies*

*Infaunal successional stage* describes differences in biotic communities as related to levels of stress, and related to recovery of a community following cessation of a stressor (Pearson and Rosenberg 1978). Communities dominated by small, surface dwelling forms are associated with high stress, whether due to high physical energy, low dissolved oxygen, toxicity, high sediment deposition, or other factors. At the other end of the spectrum, communities dominated by large, deep burrowing forms take time to develop, are associated with low levels of stress, and the large abundant fauna provide feeding opportunities for larger predators. This functional attribute is of particular sentinel value in that it detects the effects of many stressors, including dissolved oxygen, food supply, and sediment toxicity.

*Functional group measures* evaluate the morphologies, activities, and life histories of fauna to provide insight into benthic functioning and response to stressors. Functional groups can be defined as feeding groups, often combined with mobility modes, reviewed in Rosenberg 2001. Feeding group diversity is related to food availability, stress, and ecological status (Gamito and Furtado 2009) and has been evaluated both with taxonomic species identifications and with sediment profile imaging. Functional groups can also be defined as biological traits. Trait analyses consider feeding and mobility as well as size, living depth, larval development, many other organism features, and can lead to more resolved inferences on pollution gradients, sediment reworking, and material cycling (Oug et al. 2012). Trait analyses rely on taxonomic identification of species. Functional group measures are a proxy for biodiversity (section 4.3.1 above), and feeding group analyses (e.g., suspension feeders vs. deposit feeders, Rosenberg 1995) may be sensitive to changes in food supply driven by climate related shifts in primary production.

*Bioturbation depth* reflects the extent to which fauna mix the top layers of soft sediments through burrowing, feeding, and irrigation activities. Bioturbation depth, though affected by sediment context, is a proxy for benthic ecosystem stress, process, and function, particularly those functions related to material cycling (Teal et al. 2010). Deeper bioturbation introduces more oxygen into the top layers of the sediment, enhances rates of organic matter decomposition and nutrient regeneration, and indicates higher biodiversity and biomass of fauna (Solan et al. 2004). This parameter can be measured using microelectrodes, sediment profile imagery, or visual inspection of sediment cores. Bioturbation depth is an excellent measure of benthic function, but variability due to sediment grain size and composition may require additional site information to allow detection of subtle effects related to climate change.

#### *Databases*

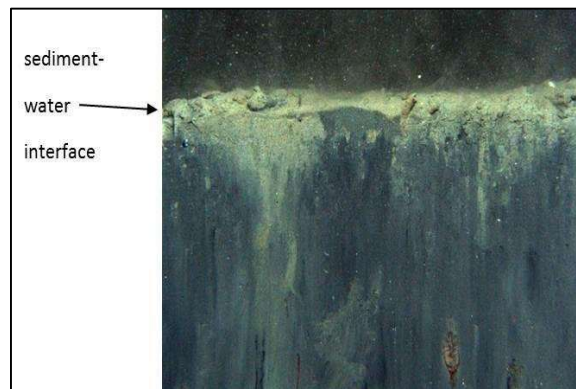
Infaunal successional stage, feeding group diversity, and bioturbation depth can be measured in various ways, including retrieval and analysis of sediments and fauna, use of microelectrodes to measure bioturbation depth, sediment profile imaging, and surface imaging. Imaging methods have the longest history of consistent use, and several large

databases of surface and sediment profile images and image analyses exist, some dating back almost 40 years.

Most significantly, the USACE maintains a large database of information from dredged material disposal areas in New England, including adjacent reference sites. Data have been consistently collected and analyzed since 1977 and include sediment profile images (Figure 4.3.1.), taxonomic analyses, water quality parameters (including temperature), and other measures to document composition, function, and condition of benthic fauna. The reference site dataset is an invaluable source of baseline imaging information and correlated taxonomic analyses for New England, but has not been analyzed to reveal patterns over the broad spatial and temporal scales at which data were collected. Data will continue to be collected, and this database may be the most compelling reason to incorporate imaging and functional analyses into a sentinel monitoring effort.

Also of special interest for baseline image data, Narragansett Bay was the subject of intensive sediment profile imaging surveys in 1988 and again (at the same 55 stations) in 2008. Other areas in the Northeast region that have previously been sampled with imagery should also be considered in identifying baseline data and change for a regional approach, e.g., BOEM studies, and other projects in areas of special interest.

Functional measures can serve as effective sentinels for change, and meet the four criteria for indicator selection as described in section 4.1 above: consistently measurable; historic data exist; feasibly measured; and easily explained/relevant.



**Figure 4.3.1.** Sediment profile image, taken in an Atlantic U.S. estuary. The image shows epifaunal tubes (brown oblong features protruding from the sediment surface), small worms (red vertical streaks at bottom left) and larger infauna (red-brown segmented structure at bottom right). The apparent area of oxidized sediments (aRPD) or Mixing Depth is visible as the light tan-colored zone in the upper part of the sediment column. Scene is 15 cm wide. The location of the sediment-water interface is shown.



**Table 4.3** Benthic environment sentinel observing questions and sentinel indicators.

Sentinel Observing Question	Sentinel Indicators
<b>4.3.1 - Biodiversity</b>	
1) Are community composition and diversity of soft bottom infaunal communities changing?	<ul style="list-style-type: none"> <li>Soft bottom infaunal community composition and diversity components (<math>\alpha</math>, <math>\beta</math>, <math>\gamma</math> diversity)</li> </ul>
2) Are community composition and diversity of hard bottom communities changing?	<ul style="list-style-type: none"> <li>Hard bottom community composition and diversity components (<math>\alpha</math>, <math>\beta</math>, <math>\gamma</math> diversity)</li> </ul>
3) Are demersal communities in soft and hard bottom habitats changing?	<ul style="list-style-type: none"> <li>Soft and hard bottom demersal community composition and diversity components (<math>\alpha</math>, <math>\beta</math>, <math>\gamma</math> diversity), focusing on: <ul style="list-style-type: none"> <li>American lobster</li> <li>Ocean scallops</li> <li>Crabs</li> <li>Mysid spp.</li> </ul> </li> </ul>
<b>4.3.2 – Key species, taxa or functional groups</b>	
1) Are the distribution, abundance and population dynamics of American lobster changing?	<ul style="list-style-type: none"> <li>Distribution, abundance, size-age structure and health of American lobster</li> <li>Recruitment of American lobster</li> <li>eMolt samples</li> </ul>
2) Is the abundance of <i>Mediomastus</i> spp. changing?	<ul style="list-style-type: none"> <li>Distribution and abundance of <i>Mediomastus</i> spp.</li> </ul>
3) Is the functional diversity of infaunal communities changing?	<ul style="list-style-type: none"> <li>Temporal and spatial patterns of abundance of infaunal communities, focusing on: <ul style="list-style-type: none"> <li>Tube building spp.</li> <li>Burrowing spp.</li> </ul> </li> </ul>
4) Are the distribution, abundance and population dynamics of benthic resource species changing? Does this include invasives?	<ul style="list-style-type: none"> <li>Distribution, abundance, size-age structure and health of benthic resource species</li> <li>Recruitment of benthic resource species</li> </ul>
5) Are the abundance of key forage for benthic fauna changing?	<ul style="list-style-type: none"> <li>Distribution and abundance of key forage for benthic fauna</li> </ul>
6) Are the abundance of focal cold-water species decreasing and the abundance of warm-water species increasing?	<ul style="list-style-type: none"> <li>Distribution and abundance of focal cold-water and warm-water species</li> </ul>
<b>4.3.3 – Ecosystem Properties and Function</b>	
1) Are functional properties of benthic ecosystems changing?	<ul style="list-style-type: none"> <li>Successional stage of infaunal communities</li> <li>Functional group elements of benthic fauna, focusing on feeding groups or biological traits</li> <li>Bioturbation depth in soft substrate habitats</li> </ul>



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## 4.4 Coastal and Estuarine Sentinel Indicators

The coastal and estuarine environment spans a wide range of physical, chemical, and biological habitats. As such, this environment is influenced to varying degrees by the delivery of water, material, and energy across the terrestrial/aquatic boundary and the saltwater/freshwater interface. Under most climate change scenarios, the Northeast is predicted to experience increased inflows of freshwater and nutrient inputs to estuarine and nearshore ecosystems (e.g., Rabalais et al. 2009; Howarth et al. 2012). While climate models differ on anticipated trends in precipitation (i.e., the amount, timing and spatial distribution), there is agreement on higher maximum flows and earlier snow-melt-dominated flows (Adams et al. 2009).

Because of the heterogeneity in this environment, sentinel questions and indicators are discussed by habitat rather than ecosystem property. Tables 4.4.1 - 4.4.7 summarize sentinel questions and indicators for seven habitats identified within the coastal and estuarine environment: 1) estuaries and embayments, 2) tidal wetlands, 3) eelgrass and submerged aquatic vegetation, 4) rocky shores, 5) *Saccharina latissima* kelp beds, 6) coastal barriers, and 7) coastal forests.

The key rationale for inclusion of these sentinel indicators based on the criteria provided in section 4.1 are described, especially how the sentinel might respond to climate change and current and anticipated feasibility of measurement.

### 4.4.1 Estuaries and embayments

#### *Physical changes*

Estuaries and embayments from large (e.g., LIS, CT/NY) to small (e.g., Pleasant Bay, MA) are whole geographic areas with system-wide emergent ecosystem properties. These properties are often responsive to changes in watershed and atmospheric inputs, such as water flow, sediment, nutrients, alkalinity and major ions, organic matter, and contaminants (dissolved and particulate) from riverine, groundwater, and runoff sources. Howarth et al. (2012) suggest that nitrogen is exported at a higher rate in rivers from watersheds that have higher freshwater discharge. Changes in freshwater flow are also likely to affect sedimentation and stratification patterns within estuaries and embayments. Higher temperatures are expected to promote stronger stratification, which decreases the mixing depth and improves the light regime for algal production.

#### *Nutrient and sediment loading*

Measuring and modeling annual or seasonal loading rates of nutrients (nitrogen and phosphorus) and suspended sediments are key to understanding changes in system-wide biological responses. River monitoring stations provide a valuable baseline of long-term flow measurements, and stations with historical records have provided estimates for coastal rivers when applied to existing watershed loading models. The U.S. Geological Survey (USGS) National Water Quality Assessment Program (NAWQA) offers a principal source of flow, sediment, and chemistry data for a number of rivers and coastal streams. NAWQA allows an ongoing regional assessment of potential nutrient loads to coastal waters of the Northeast (Robinson et al. 2004); statistical models (e.g., the Spatially Referenced Regressions on Watershed Attributes (SPARROW) models or the Narragansett Bay Coastal Hypoxia Research Program (CHRP) models) (Moore et al.

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2004); and a number of explicit watershed models allow loading assessments of some ungauged or insufficiently gauged watersheds.

#### *Biological production and lowered dissolved oxygen (eutrophication responses)*

Direct and indirect eutrophication responses, such as nuisance and harmful algal blooms, increased light attenuation, and lowered dissolved oxygen (Cloern 2001) are linked to both long-term loading (e.g., Dettmann LIS study) and short-term nutrient pulses (Patricio et al. 2004) which may increase in future climate scenarios. Rabalais et al. (2009) suggest that higher water temperatures, stronger stratification, and increased inflows and material loads to coastal waters will lead to increases in primary production and algal biomass and more frequent and severe occurrences of hypoxia from decomposition of organic material (e.g., Scavia and Bricker 2006). Hypoxic and anoxic zones have increased markedly worldwide in the last 50 years (Diaz and Rosenberg 2008), including in parts of LIS and Narragansett Bay (Codiga et al. 2009).

#### *Pathogens and Human Health Risks*

Nearshore ecosystems, characterized by inflows of urban runoff, high population densities, water-based recreational activity, and shallow, nutrient-rich habitats, expose humans to disease-causing organisms including bacteria, viruses, and protozoa (Wu 1999; Stewart et al. 2008). Resultant illnesses include gastroenteritis, acute respiratory disease, and eye, ear, and skin infections which can result in a cumulative public health cost to coastal communities (Griffin et al. 2003; Dwight et al. 2005). In addition, concentrations of marine biotoxins and toxigenic phytoplankton can have both direct and indirect impacts to humans through water contact and contamination of seafood. Anticipated climate-related changes in precipitation patterns and resultant increases in river flows, changing inundation due to sea level rise, and the impacts of burgeoning coastal populations will potentially exacerbate current pathogen-related public health concerns.

#### *Fish and Invertebrate Populations*

Increasing water temperature is leading to a shift in the fish fauna with movement of species distribution to the north; warm-adapted species are replacing cold-adapted species. Fish community monitoring has been discussed in the pelagic habitat (see section 4.2), but also applies on an estuarine basis as well. Changes in water temperature can also cause shifts in the timing and success of spawning events which can have implications to other trophic levels. Horseshoe crabs (*Limulus polychemus*) for example, spawn on sandy beaches in New England in the spring and respond to local temperatures; their eggs are a major food source for migrating birds. Eutrophication is another factor affecting fish and invertebrate populations in our nation's estuaries. Direct and indirect eutrophication responses, such as nuisance and harmful algal blooms, lowered light attenuation, and lowered dissolved oxygen (Cloern 2001) are linked to both long-term loading (e.g., Dettmann LISS) and short-term nutrient pulses (Patricio et al. 2004). Excess nutrient loading to a system can contribute to large blooms of algae which can reduce dissolved oxygen levels to hypoxic/anoxic conditions, and in extreme cases, lead to fish kills. Certain species of harmful algae (e.g. *Alexandrium fundyense*, and *Pseudo-nitzschia sp.*) also pose risks to human health (and marine mammals) and occur more locally in small embayments (e.g. Nauset Bay on Cape Cod). Increases in macroalgae can also lead to loss of habitat for spawning and foraging. Certain species of invertebrates such as grass

shrimp and other calcifying organisms will be adversely affected by increases in pH and, more specifically, increases in associated concentrations of aragonite which shellfish and crustaceans use to create their shells. Many of these small crustacean species (such as amphipods, horseshoe crabs, copepods, and mysid shrimp) are important part of the estuarine food web supporting higher trophic levels of fish, birds, and in some case even mammals.

The sentinel questions below focus on watershed inputs to estuaries and embayments that specifically change whole system ecosystem properties. Because they are so important to understanding the nature of change in these systems, the key abiotic indicators are also identified.

**Table 4.4.1.** Sentinel questions and indicators for estuaries and embayments

Sentinel observing questions	Sentinel indicators
Is the physical structure of the estuary changing?	<ul style="list-style-type: none"> <li>• Salinity and temperature</li> <li>• Groundwater and stormwater inputs</li> <li>• Stratification</li> <li>• Depth</li> <li>• Sediment and substrate types</li> <li>• Distribution and extent of vegetated and unvegetated areas</li> </ul>
Are sedimentation rates changing?	<ul style="list-style-type: none"> <li>• Riverine discharge</li> <li>• Sediment loads,</li> <li>• Sedimentation/sediment distribution</li> </ul>
Are nutrient delivery/loadings changing?	<ul style="list-style-type: none"> <li>• Riverine discharge and nutrient concentrations</li> <li>• Point and nonpoint sources</li> </ul>
Are plant biomass and production rates changing?	<ul style="list-style-type: none"> <li>• Phytoplankton chlorophyll concentrations</li> <li>• Total organic carbon</li> <li>• Primary productivity</li> <li>• Water clarity (Secchi or turbidity)</li> <li>• Macroalgal and macrophyte biomass</li> </ul>
Are harmful algal blooms (HAB) occurring with greater frequency and severity?	<ul style="list-style-type: none"> <li>• Speciation/density</li> <li>• Areal extent</li> <li>• Duration, frequency, and timing</li> </ul>
Are dissolved oxygen (DO) deficit patterns changing? (Note that supersaturation is sometimes of interest)	<ul style="list-style-type: none"> <li>• Dissolved oxygen (DO) concentrations</li> <li>• DO area or volume days (reporting indicator)</li> <li>• Need to relate to weather patterns because of mixing, precipitation patterns</li> </ul>
Are the abundance of human pathogens and health risks from swimming and seafood consumption changing?	<ul style="list-style-type: none"> <li>• Levels of indicator bacteria (enterococcus and/or E. coli) and viruses in water column and sand</li> <li>• Concentrations of marine biotoxins (in shellfish) and toxigenic phytoplankton</li> <li>• Presence and concentrations of antibiotic-resistant bacteria</li> </ul>
Is the distribution and abundance of key invertebrate species changing?	<ul style="list-style-type: none"> <li>• Abundance and timing of spawning of horseshoe crab populations</li> </ul>
Is the fish community structure changing?	<ul style="list-style-type: none"> <li>• See section 4.2 for fish community indicator metrics</li> </ul>



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#### 4.4.2 Tidal wetlands

Tidal wetlands are flooded by tides associated with fresh, estuarine and marine waters. These include the salt marshes (polyhaline soils), brackish marshes, and freshwater tidal marshes. The upland border seepage/groundwater communities such as *Panicum/Cladium* fens and *Nyssa* Forested Wetlands, which are the primary habitats in the marsh migration process, are also included. Tidal wetlands are the second most productive ecosystem on the planet (after tropical forests) and provide key ecosystem services – habitat, food for forage fish, flood control, and carbon storage. Understanding how marshes change under accelerating sea level rise may help to identify adaptive management strategies (e.g., identifying strategic lands for marsh migration) to protect marsh habitat and the species that depend upon them.

Tidal wetlands change in response to various processes including but not limited to groundwater, sediment input from waves or tides, sea level rise, the metonic cycle, temperature (air and water), deposition of wrack, salinity, and catastrophic events such as surge. Nearly seven decades of observations at Barn Island (Stonington, CT) suggest that tidal marshes are still adapting to the high density drainage created by mosquito ditches. There are also almost no studies that examine marsh response to the metonic cycle. Therefore, while there is concern that accelerated sea level rise will lead to marsh loss, there are many causes of marsh change and loss.

The following are examples of hypothesized changes from anticipated changes association with climate change:

- Tidal wetlands as known today (expansive) will likely drown (be converted to flats) under various sea level rise projections and then transform into narrow belts of vegetation along the shore. Vulnerable plant and animal species will decline or go extinct. While marsh migration will occur on uplands, New England lacks the flat coastal plain of the Mid-Atlantic States; therefore marsh migration will likely not create expansive marshes without intervention by humans.
- The Connecticut River supports the largest fresh and brackish tidal wetlands in the Northeast. In addition to anticipated changes due to sea level rise, these marshes will change as the salt wedge moves upstream (sea level rise and changes in river discharge from declining winter snow pack in northern New England).
- Under forecast warmer temperatures vegetation losses on the high marsh such as those caused by flotsam will create shallow pool habitat that may not re-vegetate.
- Increased nutrient loading has been shown to promote slumping and erosion at creek banks. Some creek bank slumping is caused by the formation of levees but this does not change wetland area.
- Increased wave energy from stronger storms may promote accelerated erosion and loss of marsh habitat.
- Vulnerable and sensitive plant and animal species may be lost and some extinctions are anticipated (e.g., marsh sparrows)
- Rare habitat such as *Panicum/Cladium* sea level fens decrease as the pre-colonial *Nyssa* forest returns to the upland edge.

In the Northeast, both abiotic and biological variables are measured in tidal wetlands:

- vegetation using plots, transects and plant community mapping
- elevation by direct measurement with transits or permanent benchmarks (sediment elevation table)
- sediment accumulation rates using marker horizons and dating techniques
- temperature and precipitation at meteorological stations
- salinity
- tides
- marsh bird nesting populations
- river flow

**Table 4.4.2.** Sentinel questions and indicators for tidal wetlands

Sentinel questions	Sentinel indicators
Are biophysical properties of tidal wetland ecosystems changing?	<ul style="list-style-type: none"> <li>• Surface elevation measurements and sediment accumulation rates (marker horizons)</li> <li>• Salinity and changing position of salt wedge on large rivers</li> <li>• Changes in center mass volumes especially for the large river systems</li> <li>• Changes in snowpack (as it affects center mass volumes)</li> <li>• Water table position and elevation</li> <li>• Wetland area</li> <li>• Vegetation</li> <li>• Marsh birds</li> </ul>

#### 4.4.3 Submerged aquatic vegetation habitats

Rooted submerged aquatic vegetation (SAV) are important sentinel indicators because of their role in stabilizing sediments, their biomass, and their ecological services including providing nursery habitat for fish and shellfish (Orth et al. 2006). In estuarine waters the primary species are eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*) but in the large tidal rivers like the Connecticut River over 25 species reside in tidal fresh and brackish waters.

Submerged aquatic vegetation distribution and abundance respond to the following parameters:

- nutrients (nitrogen in estuaries and phosphorus in tidal fresh waters)
- light availability
- sediment organic matter
- tidal range
- salinity/temperature
- chlorophyll a
- diseases such as wasting disease (*Labyrinthula zosterae*)

The following are hypothesized changes anticipated from climate change:

- seaward boundaries of SAV shift as sea level rises and beds will move landward
- increased water temperatures will make some SAV more vulnerable to nutrient enrichment

- brackish and fresh tidal beds on major tidal rivers will shift upstream in response to changes in salt wedge position, which shifts due to sea level rise and changes in center mass of river flow
- increased rainfall and increased storm frequency may cause loss of SAV to erosion and increased turbidity

Parameters measured in the northeast include:

- vegetation (mapping, transects)
- biomass and density measurements
- species composition
- depth
- nutrients
- light availability
- water temperature
- sediment grain size and carbon content

**Table 4.4.3.** Sentinel questions and indicators for SAV communities

Sentinel questions	Sentinel indicators
Is there evidence of changes in eelgrass or submerged aquatic vegetation (SAV) populations?	<ul style="list-style-type: none"> <li>• Occurrence and extent of SAV habitat</li> <li>• Relative species abundance within and among SAV beds</li> <li>• Secchi depth (light penetration)</li> <li>• Total suspended solids (TSS)</li> <li>• Eelgrass cover, density and biomass</li> <li>• Eelgrass growth (leaf length and density/m<sup>2</sup>)</li> <li>• Air and water temperature</li> <li>• Sediment grain size and carbon content</li> <li>• Chlorophyll a concentration</li> </ul>

#### 4.4.4 Rocky shore habitats

Rocky shores are a common feature along the Northeast coast. Their vulnerability, prevalence, measurable ecosystem services, and history of study make rocky shore communities important sentinel indicators for evaluating climate and ecosystem changes. Rocky intertidal environments are expected to be strongly influenced by sea level rise, atmospheric and ocean warming, and acidification (Helmuth et al. 2006). The zonation of plants and animals between tide marks is responsive to air temperature and duration of periods of exposure, and consequently warming atmospheric temperatures and sea level rise. Warmer- adapted plants and animals, both native and non-native, currently restricted to southerly locations may extend ranges into areas that warming ocean temperatures make favorable. In contrast, range contraction will occur for endemic inhabitants that find warming temperatures unfavorable. Rocky shore biodiversity and ecosystem function are vulnerable to acidification, since many inhabitants that depend on calcareous protection (i.e., shells, tubes, and crusts) play critical ecosystem roles and are susceptible to anticipated increased ocean acidification in coastal waters. Rocky shores likely contain the largest reservoir (both in diversity and abundance) of invasive species in the GoM, with negative consequences on the commercial value of other habitats when invasive species disperse into them. Fortunately, the deep history of rocky shore biological and

physical observations forms a reliable baseline for comparison to present day and future conditions (Trott 2015). Standard methods for monitoring rocky shores are well developed (Murray et al. 2006) and currently there are several programs that monitor and assess changes in rocky shore community structure.

**Table 4.4.4.** Sentinel questions and indicators for rocky shore biological communities

Sentinel questions	Sentinel indicators
Are rocky shore biological communities changing related to changes in air and water temperature?	<ul style="list-style-type: none"> <li>• Intertidal species assemblages</li> <li>• Tide pool species assemblages</li> <li>• Range extension and abundance of invasive Asian Shore Crabs and Green Crabs</li> <li>• Delayed die-off and earlier re-growth of <i>Didemnum vexillum</i></li> <li>• Distribution and abundance of sea stars</li> <li>• Change in species assemblages resulting from possible range extensions</li> <li>• Timing of spawning and settlement</li> <li>• Mussel survival (abundance and distribution)</li> <li>• Rough periwinkle <i>Littorina saxatilis</i> (abundance and distribution)</li> <li>• Fucoids (percent cover)</li> <li>• Barnacle survival</li> </ul>
Are rocky shore biological communities changing in response to sea level rise?	<ul style="list-style-type: none"> <li>• Vertical distribution and abundance of key intertidal species (i.e., mussels, barnacles, periwinkles, etc.)</li> <li>• Barnacle recruitment</li> <li>• Barnacle survival</li> <li>• Rough periwinkle <i>Littorina saxatilis</i> (abundance and distribution)</li> <li>• Fucoids (percent cover)</li> <li>• Intertidal species assemblages</li> <li>• Tide pool species assemblages, i.e., abundance and percent cover of animals and algae, respectively.</li> </ul>
Are rocky shore biological communities changing related to changes in pH and aragonite saturation (caused by changes in air and water temperature, pH and aragonite saturation)?	<ul style="list-style-type: none"> <li>• Coralline algae (<i>Corallina</i> sp., <i>Lithothamnium</i> sp., etc.)</li> <li>• Barnacle settlement</li> <li>• Bivalve spat settlement (Soft-shell clams, quahogs, mussels, bay scallops, oysters)</li> <li>• Gastropod settlement (whelks)</li> <li>• Mussel abundance</li> <li>• Sea star abundance</li> <li>• Sea urchin abundance</li> <li>• Calcite sponges (boring sponges and other species)</li> <li>• Bryozoans (encrusting and upright)</li> <li>• Serpulid worms (calcium tubes dwellers)</li> </ul>

#### 4.4.5 *Saccharina latissima* kelp bed habitats

Kelp beds provide key habitat for lobsters and fish, as well as food for urchins and other grazers. They also buffer shorelines from wave energy, reducing erosion. Kelp forest ecosystems have been subject to multiple biological invasions transforming underwater habitats with potential impacts on associated species. Although adapted to high wave environments, higher wave energy from climate change is expected to cause losses of kelp beds. Kelp bed community indicators (Table 4.4.5.) are conducted using divers and are straightforward, reliable, and accurate to measure. Observations have been made at a variety of sites around New England since the 1970s.

**Table 4.4.5.** Sentinel questions and indicators for *Saccharina latissima* kelp beds

Sentinel questions	Sentinel indicators
Will distribution and abundance of <i>Saccharina latissima</i> kelp beds change due to increasing wave energy?	<ul style="list-style-type: none"><li>• Distribution and abundance of kelp</li><li>• Distribution and abundance of associated benthic invertebrate and fish community composition.</li></ul>

#### 4.4.6 Coastal barriers

Coastal barriers are coastal deposition features composed of sand dunes and beach. The majority of coastal barriers are retrogressive features that migrate landward, and are able to avoid drowning from long-term sea level rise via processes such as inlet formation and over wash fan creation. The construction of breakwaters at inlets may create beaches that prograde seaward which in natural systems only occurs where sea levels are declining. In the low wave energy environment of the Sounds of southern New England, coastal barriers are low in elevation and narrow. Large ocean barriers such as Cape Cod and Fire Island National Seashore form adjacent to the high-energy wave environment of the Atlantic Ocean. Compared to other coastal habitats in the region, coastal barrier beaches have a very small footprint and their key species are rare and vulnerable.

Often coastal barrier beaches are formed through the erosion of headlands, and headland erosion provides a continuous supply of sediment to re-nourish these beaches. However, elevated headlands are prime real estate for development, and seawalls may be constructed to protect structures erected on these eroding lands. The resultant reduction in sandy supply can jeopardize a coastal barrier's ability to avoid drowning or erosion from coastal storms.

**Table 4.4.6.** Sentinel questions and indicators for coastal barrier habitats

Sentinel questions	Sentinel indicators
Are key physical forces that shape coastal barrier habitats changing in form, frequency, or magnitude?	<ul style="list-style-type: none"><li>• Alongshore transport direction and sediment volumes</li><li>• Onshore – offshore transport volumes</li><li>• Shoreline change – position of mean high water on ocean shoreline</li></ul>
Are the species composition and diversity of plant communities of coastal barrier habitats changing?	<ul style="list-style-type: none"><li>• Transect data and results of community mapping analyses at benchmarking sites</li></ul>



#### 4.4.7 Coastal forests

As temperature increases and length of growing season changes, species are expected to change their ranges. Some species (e.g., hemlock, due to insect pest increases) and communities (such as algific) may be lost from the coastal ecoregions and new species are expected to arrive. Changes will include shifts in species at their range limits. For example, Lianas and invasive Kudzu are projected to increase in southern New England under some climate change scenarios. Locations with increasing summer drought may favor more xeric vegetation and, perhaps in very dry sites, grasslands habitat might replace forest and shrubland. In addition, plant phenology changes will continue.

**Table 4.4.7.** Sentinel questions and indicators for coastal forests

Sentinel questions	Sentinel indicators
Are the physiognomy and floristic composition of the vegetation in coastal forests changing?	<ul style="list-style-type: none"><li>• Floristic composition of plant communities</li><li>• Liana abundance</li><li>• Invasive species – abundance and species</li><li>• Aerial and satellite interpretation of vegetation cover</li></ul>

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## 5. Gap Assessment: Enhancements to Present Observing Activities

### 5.1 Overview

To address priority sentinel questions outlined in Chapter 4, a number of enhancements to the present observing activities identified in Chapter 3 need to be implemented. In this chapter the present observing capabilities for measurement of sentinel variables are assessed, and gaps are identified for each habitat. Enhancements will require stable funding sources in order to sustain long-term measurement.

The gap assessment process involved evaluation by each working group of the suitability of the present observing activities for measurement of sentinel indicators identified in Chapter 4. For the pelagic and benthic environments, the range of expertise and the relatively small number of existing monitoring programs allowed for consensus agreement on needed enhancements. The focus here is on gaps in monitoring of ecosystem sentinel indicators and does not extend to needs for monitoring abiotic variables. The diversity of habitats and number of monitoring programs in the estuarine and coastal zone, however, exceeded the capacity of the working group to conduct a formal gap assessment taking into account all the monitoring activities in the coastal and estuarine environment. The recommendations from this working group nevertheless represent the considered judgments of a broad range of experts within the community. In this chapter the gaps are identified, but not prioritized, as this task will fall to the operational ISMN.

### 5.2 Enhancements to Observing the Pelagic Environment

Within the pelagic environment, nine enhancements to the present capabilities for observing were identified. Table 5.2.1. summarizes present observing activities and the enhancements needed to address the priority pelagic sentinel questions identified in Chapter 4 (Table 4.2.).

#### 5.2.1 Time series stations

The need for a small number of strategically located, regional time series stations to sample the pelagic ecosystem has been recognized for over a decade (e.g., RARGOM 2005). Samples collected by ship at monthly intervals or higher temporal resolution provide data to address questions about changes in seasonal patterns, population dynamics of key species, and matches and mismatches between trophic levels (Ji et al. 2010). These data are either not amenable at present to autonomous sensing (e.g., zooplankton and ichthyoplankton abundance and composition) or are necessary for ground truthing in situ instrumentation or remotely collected data (e.g., remote sensing of chlorophyll).

Fixed locations designated as sentinel time series stations in U.S. waters (Table 5.2.1.) represent LIS, a large southern New England estuary, the southern New England shelf, coastal and offshore GoM waters, and the Bay of Fundy. They are visited monthly or at higher frequency (semi-monthly or in some cases weekly during spring and summer).

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The long-time series collections at these stations need to continue and would benefit from enhancements to address a broader suite of sentinel questions (Table 5.2.1.). Standardization of protocols and long-term sources of funding are key issues for sustained contributions of sentinel fixed stations to the ISMN. Sustaining sentinel fixed stations is considered a priority for supplementary enhancement by the operational ISMN.

### 5.2.2 Acoustic measurements of key forage species

Euphausiid species and herring are typically heterogeneously distributed and their abundance is difficult to assess with traditional net systems. High-frequency acoustic systems allow sampling both vertically and horizontally over large areas. They can be deployed on ships involved in present survey activities (e.g., EcoMon) as well as small research or fishing vessels participating in coastal herring surveys (e.g., GMRI Casco Bay monitoring). Acoustic data can be interpreted with the aid of ground-truthing from samples taken with depth-stratified plankton nets and large mouth-opening trawls to provide abundance indices for swim bladdered fish such as herring and large crustaceans such as euphausiids.

### 5.2.3 Genetic analysis

For plankton in particular, biodiversity and patterns of change in taxonomic structure can be extremely difficult to quantify with conventional observational approaches such as microscopy. This is certainly true for pico- and nano-plankton, but even microplankton can be difficult to distinguish on the basis of size and shape alone. For example, the Narragansett Bay time series microscopy-based sampling catalogs 246 species of phyto- and microzoo-plankton, while high-throughput DNA sequencing revealed that >5000 microplankton species may inhabit the Bay (Amaral-Zettler et al. 2009). Evidently, there is far more diversity than the microscopy time series captures. For this reason, sentinel time series stations need to incorporate genetic analyses to fully evaluate biodiversity.

Bacteria, phytoplankton, and heterotrophic protists can be characterized with high throughput sequencing approaches targeting hypervariable regions of the 16S rRNA gene for prokaryotes and 18S rRNA gene for eukaryotes. These analyses require collection of filtered water samples from the time series or survey stations, and then access to sequencing facilities, and analysis pipelines coupled to databases supporting a growing knowledge base from which to interpret and assign taxonomic (or Operational Taxonomic Unit, OTU) designations.

Zooplankton and ichthyoplankton that are also difficult to distinguish morphologically can be similarly characterized by high throughput sequence analysis of hypervariable regions of 18S rRNA gene or cytochrome c oxidase subunit I gene. For these analyses, homogenized net tow samples can be used.

### 5.2.4 Optical measurements

Traditional sampling strategies for analysis of biodiversity and patterns of change in community structure suffer from limited ability to characterize spatial and temporal variability. This is principally due to the time- and labor-intensive nature of the analyses. The emergence of automated measurement and analysis approaches based on imaging and other optical observations provide a means to enhance sample throughput and

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overcome constraints that have hindered broad-scale taxonomic observations. Sentinel time series stations and survey programs should be enhanced to take advantage of these technologies. Both phytoplankton and zooplankton can be assessed with automatic imaging systems. For some application, proven in situ technologies exist, such as Imaging FlowCytobot (IFCB; McLane Research, Inc.) (Olson and Sosik 2007; Sosik and Olson 2007), the Video Plankton Recorder (VPR; Seascan, Inc.) (Davis et al. 1992, 2004), CPICS, the Continuous Plankton Imaging and Classification System (ocean.cubes.whoi.edu) and ZOOVIS, a visual imaging system for mesozooplankton and macrozooplankton (Benfield et al. 2003). Other systems such as the FlowCAM (Fluid Imaging Technologies) (Sieracki et al. 1998) and ZooScan (HYDROPTIC) (Gorsky et al. 2010) provide laboratory capability. When coupled with automated image processing and classification approaches (e.g., Hu and Davis 2005; Sosik and Olson 2007; Gorsky et al. 2010), these methods can be used at sentinel time series stations and during surveys to provide unprecedented spatial and temporal characterization of taxonomic groups and key species.

### 5.2.5 Gelatinous zooplankton monitoring

Anthropogenic effects, including climate change, overfishing, eutrophication, bottom trawling, translocation (invasives), and aquaculture may be driving increasing abundance of gelatinous zooplankton, including cnidarians, ctenophores, salps, and siphonophores (Richardson et al. 2009). The hypothesized global increase of gelatinous zooplankton is a source of debate due to poor historical sampling (Condon et al. 2012). The present observing activities are insufficient to detect change in gelatinous zooplankton abundance in the Northeast region for many of the most significant species. Enhancements to the observing system include enumeration of gelatinous zooplankton identified to the lowest taxonomic level possible. Methods for monitoring gelatinous zooplankton include not only net collection but also optical in situ enumeration, assessment from wash-up of gelatinous zooplankton on beaches, and genetic sequencing.

### 5.2.6 Functional traits

Understanding of biodiversity and its effects on ecosystem services has grown beyond studies of taxonomic richness and evenness to a perspective that includes both intra-specific variability and variability at the community and ecosystem organizational scales. A key component of the latter is the diversity of functional traits. The presence, values, and ranges of species traits are strong determinants of functioning at the ecosystem scale (Tilman et al. 1997; Díaz and Cabido 2001) and provide an ecologically meaningful framework for interpreting taxonomic information. Including important functional trait distributions is crucial to providing a comprehensive measurement of biodiversity.

In the pelagic ocean, most processes have strong allometric dependencies, leading many ocean ecologists to use size as a master trait (Barton et al. 2013). Strongly size-dependent processes include metabolism (Brown et al. 2004), prey selection and trophic role (Hansen et al. 1994; Banas 2011), light-dependent predation (Aksnes et al. 2004), sinking rates and flux (Alldredge and Gotschalk 1988), and energy and carbon flow through the food web (Pershing et al. 2010). Many theoretical approaches to marine ecology are built on a foundation of size structure (Baird and Suthers 2007; Follows et al. 2007; Zhou et al. 2010; Banas 2011; Record et al. 2013). Technology is available for rapid measurement of size across many scales (Stemmann and Boss 2012). By compiling flow cytometry,

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FlowCAM, CPICS, LOPC (Laser Optical Plankton Counter), ZoosScan, and size measurements from the trawl surveys, a size spectrum spanning from pelagic viruses to nekton can be constructed, providing a valuable dimension of insight into change in ecosystem properties. In addition, images can be archived and used to build taxonomic expertise. Some important functional traits of phytoplankton (e.g., size and morphological characters that impact sinking, grazing resistance, etc.) can be derived from the type of optical observations described in section 5.2.4. One functional trait, grazing, can be indirectly quantified using the color information derived from images of plankton using CPICS. The relative contribution of chlorophyll and b-carotene and other pigments can be extracted from CPICS images and followed over time to infer rates within populations and communities.

The same collection technology can also provide information on a suite of secondary functional traits. The prevalence of lipid storage, calcification, low carbon-to-volume (aka "jelly factor"), and mixotrophy, for example, can all be obtained as automated products of these measurements. Tracking the temporal dynamics and spatial heterogeneity in these functional traits offers a way to mechanistically link patterns of taxonomic diversity to important services such as biogeochemical fluxes and fisheries production.

### **5.2.7 Threatened or protected marine fish, birds and mammals**

Along with sustaining current monitoring activities for endangered or protected fish, marine birds, and marine mammals, a few targeted enhancements would provide critical information necessary to fill basic ecological knowledge gaps for these species. Among these enhancements are actions that could benefit all species groups, as well as those that are specific to individual species groups. One of the primary enhancements that would benefit all groups is increasing the spatial and temporal coverage of distribution and abundance surveys. Reaching this goal could be done in several ways. NOAA Federal surveys are presently used as ships of opportunity for marine bird and marine mammal observers. This approach requires relatively little investment with significant benefits. With additional funding, these surveys could be enhanced by increasing their frequency, for example by adding surveys during the summer that focus on more coastal and inshore waters. Spatial coverage could be expanded to target times and areas important for endangered or protected fish, marine birds or mammals. Additionally, adding aerial high definition photography surveys would also help fill these spatial and temporal survey coverage gaps. Overall, enhancing current surveys will contribute to understanding relationships among these species and the marine ecosystem, identifying critical habitat requirements, and evaluating how endangered and protected species may be affected by ecosystem changes that alter physical and biological habitat characteristics.

A second enhancement that would benefit all groups is supplementing current diet monitoring studies with more detailed studies on prey energetics. Although there is good understanding of key prey species for many endangered or protected fish, marine birds and mammals, the quality (i.e., energetic content) of prey species is just as important as prey availability to the survival and productivity of endangered or protected species. Enhancing diet studies to include prey energetics components would provide a better understanding of how these endangered or protected species are influenced by the quality of their prey. Such energetic studies may also offer insights into overall ecosystem status,



given the links between forage species quality and lower level productivity and physical marine ecosystem conditions.

Separate from the umbrella-type enhancements discussed above, there are also enhancements that would target specific species groups. For instance, there is need for understanding of how critical habitat, movement, and survival are related to physical and biological ecosystem characteristics for endangered and protected fish species (e.g., Atlantic salmon, Atlantic sturgeon and shortnose sturgeon). These knowledge gaps could be filled by enhancing the present Ocean Tracking Network (OTN) by adding receiving stations and increasing the number of tagged individuals. Similar tracking enhancements would also benefit endangered or protected marine birds. These activities may include deploying additional nanotag tags on marine birds and linking into pre-existing monitoring network or using satellite tags for species that are not easily monitored by fixed receiving locations. Finally, the passive acoustic monitoring network for marine mammals could be supplemented with additional station locations or increasing the frequency range monitored at these stations to detect odontocetes (i.e., toothed) species. These enhancements would help us better understand marine mammal distribution and movement patterns and behavior, all key components influencing population dynamics.

**Table 5.2.1.** Summary of enhanced pelagic sentinel observing network. First column: sampling activity (by program name and organization) in first column. Second column: specific sentinel questions addressed (refer to Table 4.2). Third column: sampling location and frequency. Last column: priority enhancements needed (see referenced subsections in chapter 5.2 for discussion of enhancements needed to present observing activities). Only programs needing enhancements are identified. Sentinel fixed stations shown in bold.

<b>Surveys</b>			
<b>Observing Activity (Organization)</b>	<b>Sentinel questions (Q) addressed (See table 4.2)</b>	<b>Location and Frequency</b>	<b>Enhancements</b>
EcoMon (NOAA/NMFS)	Biodiversity (Q2,3)Key species (Q4)Ecosystem Properties (Q1,2)	GoM and SNE Shelf Quarterly	5.2.2 5.2.4 5.2.5 5.2.6
Maritime Atlantic Zone Monitoring Program transects: (Canada DFO)	Biodiversity (Q2,30 Key species (Q3) Ecosystem Properties Q 1,2)	Scotian Shelf Spring and Fall	
NMFS and State Fish Trawl Surveys (NOAA and state agencies)	Biodiversity (Q4) Key species (Q4,5)	GoM and SNE Shelf	
DFO Fish Trawl Surveys	Biodiversity (Q4) Key species (Q4,5) Ecosystem Properties (Q1, 2)	Scotian shelf Georges Bank Bay of Fundy Eastern GoM	
Gulf of Maine North Atlantic Time Series	Biodiversity (Q1,2) Key species (Q1,2)	Eastern GoM, Western Maine Coastal Current	

(GNATS: Bigelow Laboratory)	Ecosystem Properties (Q1,3)		
American Lobster Settlement Index (Wahle)	Key species (Q5) Ecosystem Properties (Q3)	GOM	
Coastal herring and euphausiid survey (GMRI)	Key species (Q3,4)	Coastal GOM	
NEBO- the Northeast Benthopelagic Observatory WHOI-Gallager	Biodiversity (Q2,3) Key species (Q3) Ecosystem Properties (Q1)	Northeast Continental Shelf	
<b>Fixed Location Stations</b>			
Prince 5, AZMP (DFO, Canada)	Biodiversity (Q2,3) Key species (Q3) Ecosystem Properties (Q1,2,3)	Bay of Fundy Semi monthly to monthly	<b>5.2.1</b> 5.2.4,5.2.5, 5.2.6
Coastal Maine Time Series Station (Univ. of Maine)	Biodiversity (Q2,3) Key species (Q3) Ecosystem Properties (Q1,2,3)	Mid Coast Maine shelf (100 m) Semi monthly to monthly	<b>5.2.1</b> , 5.2.3,5.2.4, 5.2.5,5.2.6
Damariscotta Estuary Time Series Station (UMaine/BLOS)	Biodiversity (Q2,3) Key species (Q3) Ecosystem Properties (Q1,2,3)	Damariscotta Estuary, Maine Semi monthly to monthly	
Casco Bay Monitoring Stations (CBASS: GMRI)	Biodiversity (Q2,3) Key species (Q3) Ecosystem Properties (Q1,2,3)	Casco Bay, Maine Semi-monthly (spring and summer)	
Wilkinson Basin Time Series Station (U Maine/UNH)	Biodiversity (Q2,3) Key species (Q3) Ecosystem Properties (Q1,2,3)	Wilkinson Basin, Western GoM Semi monthly to monthly)	<b>5.2.1</b> , 5.2.3,5.2.4, 5.2.5,5.2.6
MWRA Fixed stations (Mass Water Resources Authority)	Biodiversity (Q2,3) Ecosystem Properties (Q1,2)	Massachusetts Bay 9 times per year	
Martha's Vineyard Coastal Observatory (WHOI)	Biodiversity (Q1,2) Key species (Q1,2) Ecosystem Properties (Q1,3)	Southern New England monthly	<b>5.2.1</b> , 5.2.3,5.2.4, 5.2.5,5.2.6
Narragansett Bay Time Series (URI)	Biodiversity (Q1,2) Key species (Q1,2) Ecosystem Properties (Q1,3)	Southern New England monthly	<b>5.2.1</b> , 5.2.3, 5.2.4, 5.2.5,5.2.6

Long Island Sound Time Series (UConn)	Biodiversity (Q2,3) Key species (Q3) Ecosystem Properties (Q1,2,3)	Long Island Sound Weekly to monthly	<b>5.2.1,</b> 5.2.3,5.2.4, 5.2.5,5.2.6
<b>Other Observing Activities</b>			
Ocean Tracking Network (OTN and NOAA)	Biodiversity (Q4) Key species (Q6) Ecosystem Properties (Q3)	Canadian Shelf, Gulf of Maine, select tributary rivers, and Massachusetts Bay	
Seabird Colony Monitoring (US FWS)	Biodiversity (Q4) Key species (Q6) Ecosystem Properties (Q3)	Maine Coast	

### 5.3 Enhancements to Observing the Benthic Environment

Within the benthic environment, the primary enhancement needed is the establishment of specific sentinel sites where consistent sets of time series data are collected and analyzed relative to the sentinel indicators provided in Table 4.3. The network of sites should be established along a longitudinal gradient representing the variety of benthic habitats found in the Northeast. Selection of the sites should be informed by their geographic location, whether they have been mapped, and by the history of research and monitoring that has occurred there. Advanced technologies can greatly enhance monitoring of benthic communities, particularly epibenthic organisms. The development of these new technologies should be encouraged.

#### 5.3.1 Time series stations

The selection of sites where benthic time series can be established should reflect the large-scale environmental gradient from southern New England into the northern waters of the GoM, and extending into the deeper water areas of the region. Ideally, sentinel sites should be located along this gradient so they capture the local species pool and ecosystem dynamics over a variety of sea floor habitats in each area. For example, a benthic sentinel system might include sites within each of the sounds of southern New England (LIS, Block Island Sound, Vineyard / Nantucket Sound), a site at the “elbow” of Cape Cod, and sites in the Gulf of Maine, including Stellwagen Bank, Jeffreys Ledge, as well sites in the deeper basins (e.g., Wilkinson and Jordan Basins). Sites should also be included across Georges Bank, including the Great South Channel and the Northeast Channel).

As noted in section 4.3, there have been a number of short- and longer-term benthic surveys and research studies focusing on infauna and epifauna conducted in the region’s waters. These provide information for the selection of sites, particularly for identifying locations where there have been or are on-going studies, so that these can serve as components of a benthic sentinel system. For example, these may include specific areas of Massachusetts Bay, Stellwagen Bank and Georges Bank where detailed studies have

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been conducted (e.g., <http://stellwagen.noaa.gov/science/shrmp.html>, <http://habcam.whoi.edu/>, <http://www.mwra.state.ma.us/harbor/enquad/trlist.html>). There are also locations in southern New England where detailed studies may provide the basis for establishing sites within the benthic sentinel system. For example, recent studies were conducted in the area around Block Island in the development of the Rhode Island Ocean Special Area Management Plan (Ocean SAMP) (<http://seagrant.gso.uri.edu/oceansamp/>) and also in LIS as part of the Seafloor Mapping of Long Island Sound Project (<http://longislandsoundstudy.net/research-monitoring/seafloor-mapping/>). Such sentinel sites would complement sites that are currently being studied with respect to other benthic sentinel indicators, such as for the lobster settlement studies (See section 4. 3.3). One key factor in selecting benthic sentinel sites may be the composition of seafloor habitats within a location. Habitat diversity is a key driver for biodiversity, and as such it will be important to having detailed seafloor maps derived from acoustic surveys and related ground-truthing efforts of candidate locations to assess habitat composition and diversity. Seafloor maps are available for number of the potential sites noted above (Shumchenia et al. 2014), as well as related habitat analyses and classifications. Ideally, each of the benthic sentinel sites would have a comparable collection of habitat types to the extent possible so that community level sentinel indicators (e.g. biodiversity) can be compared along the regional environmental gradient for specific habitat types (e.g. sand, muds, boulder fields).

### 5.3.2 Technology development for collecting data benthic environments and biota

Seafloor environments pose a suite of research challenges that are well known. For benthic communities, sample collection and processing may be especially costly and time consuming, especially in the case of infaunal communities. The development of various types of remotely operated vehicles, automated and tethered systems, and increasingly sophisticated imaging systems (e.g. (Undersea Imaging Workshop Report, 2014) <http://njseagrant.org/wp-content/uploads/2014/07/Undersea-Imaging-Workshop.pdf>) has greatly enhanced our abilities to collect data on mobile and attached epibenthic organisms, and to some extent some infaunal organisms that are exposed above the sediment-water interface. It is critical that these technologies continue to develop, including systems that can enhance species identification and obtain other types of biotic data, such as size and extent of patchiness (e.g. McGonigle et al. 2011).

## 5.4 Enhancements to Observing the Coastal and Estuarine Environment

The working group for coastal and estuarine habitats comprised experts from both subregions with specialties in one or more of the habitats identified below for sentinel monitoring. The group recognized that due to the magnitude and diversity of monitoring activities in this environment conducted by federal, state, university, NGO, and citizen monitoring groups, it was beyond the scope of available resources to conduct a formal gap analysis. Nevertheless, three general categories of enhancement needs clearly emerged:

1. Adding new sites, stations or more frequent measurements to existing monitoring sites and to link across existing monitoring programs;
2. Bringing into the network and sustaining incipient or inadequately funded monitoring programs; and
3. Supplementing existing monitoring programs with new technology or indicators.

The working group recommended that monitoring protocols should be standardized to the extent possible, recognizing the trade-off between consistency and innovation. Enhancements are listed below in the same order as in Chapter 4.

#### **5.4.1 A Estuaries and embayments: nutrient and sediment loadings**

##### *Adding new sites/measurements*

Major gaps are related to the water, nutrient, and sediment loadings that influence the physical pressures affecting estuaries and embayments. Although there are ongoing monitoring activities in many bays, especially those associated with NEPs (Casco Bay, Great Bay, Massachusetts Bay, Buzzards Bay, Narragansett Bay, Long Island Sound, and Peconic Bay), with few exceptions (Great Bay) most of the monitoring is not synoptic. In addition to the NEP sites, other major bays that could be supplemented include Cobscook Bay (ME), Penobscot Bay (ME), Sheepscot Bay (ME), Niantic Bay (CT), Salem Sound (MA), and Plum Island Sound (MA), where other local efforts provide a foundation on which to build, and for which ecosystem changes are occurring or expected to occur.

In general, monitoring of major rivers to these estuaries is insufficient to characterize changes in flow, nutrients (especially nitrogen), sediment or organic carbon loading and other variables associated with coastal acidification and eutrophication of coastal ecosystems. Additional sites or more frequent measurements are needed to improve loading estimates and validate loading models. New sites on rivers currently not monitored, as well as a greater frequency of data collection, especially during storm events, would markedly improve regional assessments of potential nutrient and sediment loads to Northeast coastal waters (e.g. Robinson et al. 2004).

##### *Bringing new groups into the network*

Regional-scale assessments of ecosystem change require data that are difficult and costly to collect. The majority of monitoring programs are driven by local issues, limited in spatial extent and lack a common set of sampling and analytical protocols that would insure data quality and comparability. Many of these programs are performed by citizen scientist organizations. While often limited in technical expertise and instrumentation, these organizations are capable of collecting selected physicochemical data and as well as samples for laboratory analyses. The ISMN will need to effectively engage these organizations, provide necessary technical and administrative assistance, support their fundraising activities, and encourage inter-organizational collaboration. As an example, the Maine Coastal Observing Alliance supports the collaborative estuary water quality monitoring efforts of several land trust and municipal organizations along the Maine coast from Casco Bay to Penobscot Bay. Also the nascent NeCSCA may provide a similar collaborative monitoring effort for the regions' Field Stations.





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#### *Adding new technology or indicators*

Recent advances in continuous monitoring technology for nutrients (e.g., Submersible Ultraviolet Nitrate Analyzer) offer new opportunities to obtain time-series data. These and yet to be developed sensors should be deployed in key tributaries to estuaries, including the Piscataqua River (Great Bay), Presumpscot River (Casco Bay), Charles River (Boston Harbor and Massachusetts Bay), as well as the major rivers which contribute loadings to the GoM (e.g., the Merrimack, Kennebec/Androscoggin and Penobscot Rivers).

Most monitoring programs do not include macroalgal abundance, which is a growing concern in some GoM embayments (e.g., Great Bay, Cobscook Bay), as well as Waquoit Bay, and Nahant Bay in southern New England. There are cost-effective remote sensing methods (Larsen, 2004) which, when applied in conjunction with standard protocols, provide a means for regional mapping and the identification and quantification of macroalgal extent and biomass.

Identifying and describing the extent of Harmful Algal Blooms is difficult and generally doesn't occur until the bloom is well established. New monitoring strategies that provide early detection and opportunities to assess causal mechanisms are required. Vila et al. (2001) suggest establishment of long-term monitoring sites that provide appropriate spatio-temporal scale and that target sites exhibiting characteristics thought to encourage blooms (e.g., reduced water exchange, high nutrient loadings, and/or engineered structures that reduce water movement or mixing).

#### **5.4.1.1 Estuaries and embayments: fish and invertebrate populations**

There are few examples of bay-wide population surveys for fish and invertebrate populations. The best current example is CBASS (see above), conducted by the Gulf of Maine Research Institute for Casco Bay. Periodic surveys of other embayments (e.g. the Saco River Estuary and Plum Island estuary) have also been conducted by local institutions, and by state marine resource agencies but there are few long term synoptic surveys of embayment fish communities.

A key sentinel invertebrate species identified is the horseshoe crab. Significant efforts to monitor distribution and abundance are underway spearheaded by Sacred Heart University for Connecticut populations, by Mass Audubon for Wellfleet Bay in Cape Cod, and by University of New Hampshire for Great Bay. These surveys can be complemented at other sites with a standard protocol.

#### **5.4.2 Tidal wetlands**

##### *Adding new sites, bringing new groups into the network and adding new technology or indicators*

Sentinel indicators for tidal wetlands are needed because of the diverse suite of ecological services provided not only to fish and wildlife populations, but also to adjacent coastal communities. Some significant tidal wetlands in the region have established long-term monitoring programs, especially at NERRS through the SWMP. SWMP includes vegetation transects, continuous data on water quality, meteorological parameters,

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sediment elevation tables and related indicators of community structure. More accurate instrumentation is needed to measure pH as the current probes being used in the SWMP program do not have the required resolution. Applying vertical control to all of the SWMP water quality stations should be a priority so changes in sea level can be observed along the estuarine gradient from coast to head of tide.

Other sites performing long-term monitoring efforts are maintained at USFWS refuges (Moosehorn, Maine Coastal Islands and Rachel Carson in Maine; Parker River and Monomoy in Massachusetts; Rhode Island Complex; and Stewart B. McKinney in Connecticut). Along with these National Wildlife Refuge (NWR) sites, the Plum Island Sound Long Term Ecological Research (LTER) station, colleges and universities stations, and National Park Service sites are part of the USFWS Salt Marsh Integrity sampling program. These sites, however, need to standardize and expand protocols for certain indicators, such as Surface Elevation Tables (<http://www.pwrc.usgs.gov/set/>) and for vegetation transects at the upland edge. There is a need to identify and gain access to the people and programs collecting monitoring data at colleges and universities in the region, such as the Bates Morse Mountain Conservation Area of Bates College which includes significant tidal wetlands and sediment elevation tables. In addition, the SHARP should be expanded to monitor key avian species at risk.

#### **5.4.3 Eelgrass (*Zostera marina*) communities and submerged aquatic vegetation**

##### *Adding new sites and adding new technology or indicators*

Submerged aquatic vegetation (SAV) is a key sentinel habitat. Enhancements needed include expansion of an established monitoring routine, called SeagrassNet (<http://seagrassnet.org/>). Current stations in New England are Duck Harbor, Cape Cod Bay, Hog Island, Pleasant Bay, and Salem Sound in Massachusetts; Fishing Island, Portsmouth Harbor, and Great Bay in New Hampshire; and Fort Getty and Prudence Island in Narragansett Bay in Rhode Island. Although establishing a SeagrassNet site is rigorous and time intensive, additional sites are recommended to document changes in Maine (e.g. Casco Bay, Long Island Sound, and Buzzards Bay).

Another important, but expensive, technique for mapping eelgrass beds is high resolution aerial photographs with ground-truthing using underwater videography. In many states, however, surveys are conducted on a ten year interval, and changes, such as those recently observed in Casco Bay can occur on a more rapid time scale. According to the Casco Bay Estuary Partnership State of the Bay Report 2015, the highest density eelgrass beds in Casco Bay (between 70-100% cover) declined by 55% (over 4,000 acres) between the 2001-2002 and 2013 aerial surveys. Much of the eelgrass decline apparently occurred in less than two years, between 2012 and 2013, when a population explosion of European green crabs were observed to clip eelgrass when foraging.

So, while aerial photographs are critical for making state-wide or bay-wide assessments, routine observations using a combination of boaters and divers to measure areal coverage, percent cover, shoot density, aboveground biomass or maximum depth limit of growth are recommended. A tiered monitoring approach is recommended. Monitoring groups could check for presence or absence based on simple boat (e.g. canoe, kayak, small boat) observations), or snorkeling. If suspected changes have occurred, more

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intensive sampling, with divers using standard quadrats to measure percent cover, shoot density, presence or absence of rhizome material, or changes in sediment type can be conducted. In addition, echosounders (“fish finders”) can also be conducted to assess the maximum depth limit.

#### 5.4.4 Rocky shore biological communities

##### *Adding new sites*

The working group proposed expansion of the Northeast Temperate Inventory and Monitoring Network (<http://science.nature.nps.gov/im/units/netn/>) established by the National Park Service. The sampling protocols need to be harmonized with other protocols, including the Massachusetts Sea Grant Rapid Assessment Survey for Non-native Species, Spat Collectors, Cobble filled collectors and Settlement plates. These data should be related to erosion and sedimentation measurements collected by USGS from the surge and wave network.

Current sites are located in Acadia National Park, Maine (Ship Harbor, Bass Harbor, Otter Point, Schoodic Point, Little Moose Island), two Maine Coastal Islands (Metinic Island, Petit Manan Island), and the Boston Harbor Islands (Green Island, Outer Brewster Island, Calf Island) in Massachusetts. Expansion of this network is proposed to other islands in Maine (West Quoddy Head, Great Wass Island, Isle Au Haut, Appledore Island and in Casco Bay). For data on invasive species, connect to the Marine Invader Monitoring Information Collaborative (MIMIC), part of the Massachusetts Sea Grant Rapid Assessment Survey.

##### *Bringing other groups into the network*

There is an incipient network of field station sites called the Northeastern Coastal Stations Alliance (NECSA). Stations include the Hurricane Island Center for Science and Leadership; the Bates College at Shortridge, Bowdoin Scientific Station on Kent’s Island, Shoals Marine Laboratory, and several others. To date, eleven stations are represented in the network with new linkages to larger institutions, including NERACOOS, Bigelow Laboratory, the Darling Marine Center, and the Gulf of Maine Research Institute. New stations should be connected to this network and can help to implement standardized methodologies.

#### 5.4.5 *Saccharina latissima* kelp beds

##### *Adding new sites*

Kelp bed community abundance metrics are conducted using divers and are straightforward, reliable and accurate. Monitoring programs in Southern California have provided a template for full community monitoring which will be implemented by the Gulf of Maine Kelp Ecosystem Ecology Network. These measurements can easily be coupled with benthic temperature loggers and modeled swell heights. Kelp abundance and the composition of species in subtidal kelp forests has been recorded at a variety of sites around New England since the 1970s and could be expanded. Some of the new locations could coincide with rocky shore locations.

#### 5.4.6 Coastal Barriers and Forests

The working group did not consider enhancements needed to monitor these habitats.

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## 6. Data and Product Management and Dissemination

### 6.1 Overview of Present State

The role of a comprehensive, centralized, and easy to use data management system cannot be understated for the ISMN. Such a system must enable the discovery of all relevant data and provide access to data in formats that meet the needs of the varied users in the region.

Initial efforts within the ISMN working group have started the process of identifying monitoring activities. This work has focused on the creation of a meta-database that holds upwards of 300 records describing monitoring programs. A custom meta-database developed for the LISS is being utilized as the initial source to document details of these data resources, including the temporal and geospatial bounds, agency or organization, and parameters being collected. From this work, the ISMN will have a better understanding of the current data available as well as data gaps.

A queryable meta-database is the necessary starting point to understanding the current state of monitoring activities in the region, identify the gaps in coverage and provide pathways to access data directly. The next objective is to continue organizing this information in a standardized accessible format and begin to serve the actual data in a variety of processed forms (raw, derived, products).

#### 6.1.1 Long history of collection of sentinel and supporting data in the Northeast U.S. region

Efforts to make regional data discoverable and accessible have been underway in this region for over a decade, under various names such as the Northeast Coastal Ocean Data Partnership and, most recently, under the NERACOOS data management and communications subsystem (DMAC). Similar efforts have been underway in the LIS region (LISS), for U.S. federally funded university research (BCO-DMO), Canadian observing data (MEDS: Marine Environmental Data Service), and for biological data (OBIS: Ocean Biogeographic Information System). A successful ISMN data management system will leverage the best of the existing systems, including standards, methodologies, and people involved.

For accessing ocean observing data, NERACOOS has served as the aggregator and disseminator of data for the region, though currently this data only includes the primarily physical data collected from continuous monitoring stations (land based and buoys), models, satellites, HF Radar, and automated underwater vehicles. The broader scope and breadth of data envisioned in the ISMN goes well beyond the physical to include chemical and biological monitoring data. By scaling up NERACOOS's data management capacity to include a wider array of sentinel monitoring data, the ISMN will provide a uniquely holistic view into the health of the system.

#### 6.1.2 Standards enable innovation – the NERACOOS data framework

Following the standards adopted by U.S. IOOS, the ideal system is one where data are accessible in a distributed format such that a single clearinghouse is not needed. This increases efficiency, reduces redundancy, and gives data providers control over quality of



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the data. By following standard protocols, it is possible for each data collector to archive and maintain datasets on their own local servers and make them accessible to the general public. Over the last few years, NERACOOS DMAC has implemented these practices, and has developed a robust, standards-based data framework (NDF) that has greatly improved the capacity of users in the region to discover and access data.

While currently focusing on the physical data, the system was designed to ingest diverse data types and formats including physical oceanographic and biological time series and sampling data that range from ongoing continuous monitoring to discrete sampling events over a specific window of time.

Through the data access interface, the metadata and data can be accessed through various web services which would make sentinel monitoring data available for use by scientists throughout the region in coupled physical-biological and ecosystem models. The NDF aims to improve the discoverability, access and aggregation of data from disparate sources and provide seamless integration into other systems and web-based products and services.

### *Discovery*

To fully enable the discovery and understand the capacity and limits of a dataset requires that metadata are available and that they are of as high quality as possible. Collection, creation, editing, and testing of metadata to meet the standard requirements is the first step in adding each new dataset to the NDF. Once added to the framework, the data conform to IOOS, GOOS, and GEOSS compliant data standards and metadata conventions for access and services. These standards include detailed information about the data provider, sampling methodology, temporal and geospatial bounds of the study, quality control parameters, naming conventions, and much more.

The metadata standards in place in the NDF are the ISO standardized metadata as recommended by IOOS for facilitating ESIP approved Attribute Conventions for Dataset Discovery (ACDD). The IOOS standards also include integrated support for use of the Marine Metadata Initiative (MMI) for storing CF compliant vocabularies and ontologies to ensure interoperability.

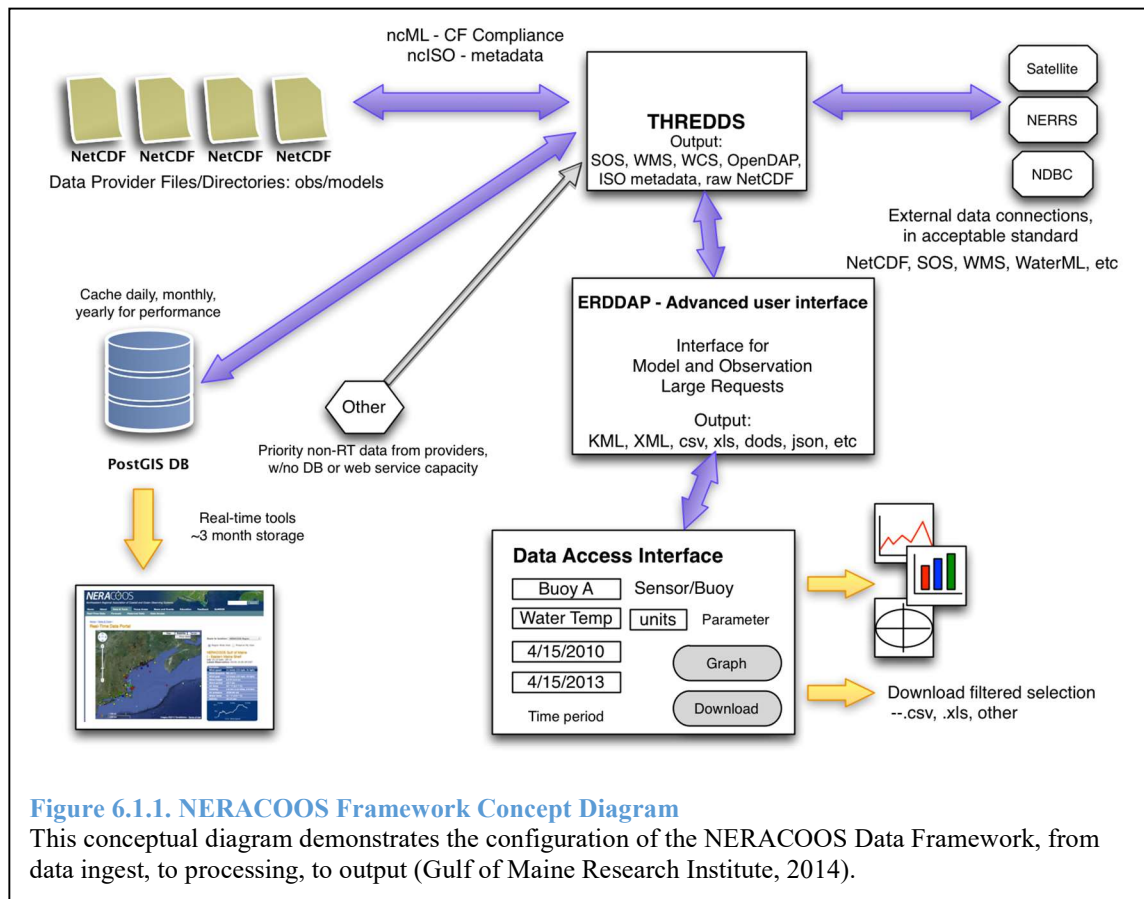
### *Accessibility and Integration*

The backbone of the NDF comprises two discrete toolkits with slightly different functions. The primary engine is the THematic Real-time Environmental Distributed Data Services (THREDDS). Primarily a machine-machine interface, the THREDDS Data Server (TDS) stores data files and make them available through standard web services.

The second component of the NDF is the front-end human readable interface known as ERDDAP. This engine supports data in a variety of formats, the ability to aggregate multiple files for the same location (e.g., repeat buoy deployments), and tools for accessing and editing metadata by the data manager. For the end-user, there is a user-friendly interface for querying and downloading subsets of data in common file formats (e.g., .csv, html, JSON, XML, NetCDF, RESTful APIs etc.). In addition, users can view the data online and produce charts and maps on the fly that can be exported as images or PDF files.

In addition to an improved discovery interface, the NDF exposes the data offerings through the World Wide Web, improving discoverability through standard search tools for users that may be unaware of the NDF. The NDF produces a metadata output that acts as a catalog for the system, and is available via Web Accessible Folders (WAFs). The WAFs are regularly crawled and indexed by various catalog, registry, and geospatial and keyword search tools such as: NOAA's IOOS Catalog and NGDC's EMMA system, GEOS geoportal, and standard search engines (e.g., Google, Bing, etc.).

The standards and tools that comprise the NDF are accepted by the National Ocean Data Center (NODC) archiving service, allowing all data and metadata in the system to be archived permanently by NOAA.



## 6.2 Our Vision

### 6.2.1 Overview

The ideal data management system for the ISMN effort addresses the basic needs of *Discovery*, *Access*, and *Integration*. The complete data holdings are visible through a comprehensive catalog that makes it easy to query and discover the most relevant data. The NDF meets these needs and will be leveraged to include the critical ISMN data.

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A requirement of the data for inclusion in the extended NDF will be the availability of highest quality metadata possible so users can evaluate the scope of coverage (temporally, spatially), the quality of the data, parameters measured, methods, etc. For accessibility, clear paths to directly access the data will be necessary as well so they may be integrated into the NDF.

The NDF provides access to the metadata and data via known standard web services making data available for developing innovative data, model and forecasting products to meet the needs identified through the efforts of CAPE.

### **6.2.2 Easing the burden of creating and updating metadata**

Too often in the past, large volumes of good data have been lost in file cabinets, unreadable disks, and undocumented ascii files. The primary task of the ISMN, before any more data is collected, is to compile and document existing archives for future generations of scientists. While basic metadata are simple to deduce, the discipline of adding to the records is often lacking. Also, fragmentation occurs when the metadata record becomes separated from the dataset. Efforts to ease the burden include the idea of providing the data owner (or data curator) a web form to enter their metadata. These forms will insure that the necessary details are provided to comply with ISO standards. Some organizations already have their data documented in particular formats as prescribed (e.g., Federal Geographic Data Committee and NASA's Global Change Master Directory) but these can be easily linked and/or converted for ISMN purposes. However, careful investigation into the current accuracy is warranted, as maintenance of metadata in external directories is often overlooked. It is important that each data provider submits the details of where, when, and how the data was collected. It is especially important in this case where we are planning a long-term data collections system that spans multiple decades and generations of investigators.

### **6.2.3 Easing the path to contributing data to the system**

While it has become relatively easy to integrate continuous monitoring data, typically the common format of these datasets lends itself more easily to integration in data sharing systems (NetCDF, XML, etc.). Many data providers working on discrete studies keep their data in a variety of formats (flat files, spreadsheets, relational databases) and do not make them available for a variety of reasons, though methods are available to serve this data in shared systems. These methods have evolved over the years and some of the examples include the Open Source Network Data Access Protocol (OPeNDAP), Environmental Research Division Data Access Protocol (ERDDAP), and Sensor Observations System (SOS). These methods are an integral part of the NDF and will make adding and sharing data from many disparate sources much easier than it has been in the past. Detailed guidelines and steps have been developed by the DMAC community for both observed and modeled data and will be utilized in the ISMN data process.

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## 6.3 Challenges

### 6.3.1 Interoperability – lack of uniformity of formats, units, naming convention and quality

The most challenging aspect of ISMN's data management is the variety of data types that arise with biogeochemical systems. Relative to physical parameters most often served through IOOS (temperature, salinity, current), complexity grows with species, habitat characteristics, and chemical compositions. Some effort is underway in the IOOS sphere to address these difficulties, which should be followed and eventually adopted. The IOOS Biological Observations Project, for example, have already developed various schemas and terminologies and, as noted previously, much of this work has been underway already in Long Island Sound data management projects. Other community-driven efforts to standardize water quality data (NEIEN, WaterML, etc.) should be leveraged as well.

The standards-enabled data framework aims to eliminate the usual obstacles that prevent data interoperability. By adopting standards-based protocols for metadata, vocabularies, quality control, and data access (file format, web services) the ISMN data management system will make disparate datasets interoperable, a necessity in the development of decision support and analysis tools.

### 6.3.2 Resources needed: data domain experts and cyber infrastructure experts

The initial challenge in acquiring and compiling the data sources to add to the ISMN Data System is an arduous process that will involve identifying the data resources, assessing the data readiness, and working with the data provider or custodian to produce any missing metadata.

The next step in this effort will be the prioritization of data sets and development of a process for readying the data to be included in the NDF. Once resources are made available, the data management group can begin integration of datasets into the NDF.

Given the abundance of new tools and standards already in place, the primary objective here is to implement them at each of the labs that either have historical data and/or are continuing to collect data. This requires human resources to follow the protocols in serving data, which can be a significant time burden. As noted in the previous chapter, there will need to be a ISMN “liaison” charged with this task of working with the regional data providers to document metadata and gather the information necessary to add to the system. Working with the data experts that support ISMN “Data Management Services,” the process of adding and updating data to the system will become straightforward. While initial setup of the system will take some effort, once in place, maintenance of the existing system and regular addition of new datasets will be a manageable task for the ISMN DMAC group.

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## 7. Implementation of an Integrated Sentinel Monitoring Network for the Northeast U.S. Region Ocean and Coastal Ecosystems

### 7.1 Overview

As presented in Chapter 1, the ISMN is envisioned as a regional entity with infrastructure that will sustain an adaptive sentinel monitoring network, with five major functions: 1) provide coordination support for existing observing activities; 2) further develop, integrate, and coordinate regional capacity for data management and distribution; 3) enhance and expand current monitoring efforts by supporting needed supplemental measurements; 4) create and sustain a data management, analysis and interpretation system and communication strategy to inform researchers, managers and the public; and 5) support an integrated, ecosystem-based management framework for adaptive responses to change. Implementation of this vision will be a dynamic process that will involve development of both coordination support and integration activities.

Federal, state, university research, and other non-government entities presently engaged in ecosystem observing will continue their activities, and may undertake enhancements to collect and interpret sentinel indicators on their own. New entities not previously engaged in observing may also become involved. Funding for these activities may originate from a variety of sources, including successful competition in nationally sponsored initiatives, for example the Long Term Ecological Research Program (LTER) at NSF, the multi-agency Marine Biodiversity Observation Network (MBON), the Northeast Coastal Acidification Network (NECAN), or various NOAA-sponsored climate initiatives facilitated through the Cooperative Institute for North Atlantic Research (CINAR) or through its support for Regional Ocean Partnerships like NROC. The duration of these observing activities will be variable depending on the funding cycles of the particular program. Efforts should be made to establish a set of core sentinel measurements within long-term stable monitoring programs to ensure continuity of record.

For these independent activities the ISMN will need basic infrastructure to provide coordination and data management support by:

- updating and disseminating this Science and Implementation plan as guidance on the region's need for sentinel indicators and enhancements that can be identified in proposals for funding;
- writing letters of support to proposals that directly address sentinel monitoring needs;
- providing guidance on collection protocols and other technical issues to promote standardization and accuracy of data and hence its utility for broader integrated and comparative analyses; and
- developing data management capacity and guidelines to ensure that data produced by these observing activities are conserved and entrained in integrated analysis

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Second, the ISMN will need infrastructure to carry out an active integration role across observing activities, involving support to:

- fill data collection gaps in present monitoring activities;
- facilitate data synthesis and use of statistical and modeling tools to provide integrated assessment of Northeast coastal ecosystem health and interpretation products directed to specific user needs; and
- help to bridge the data and processed information from these activities to managers and other users.

The following sections outline the operational infrastructure needed to carry out these functions.

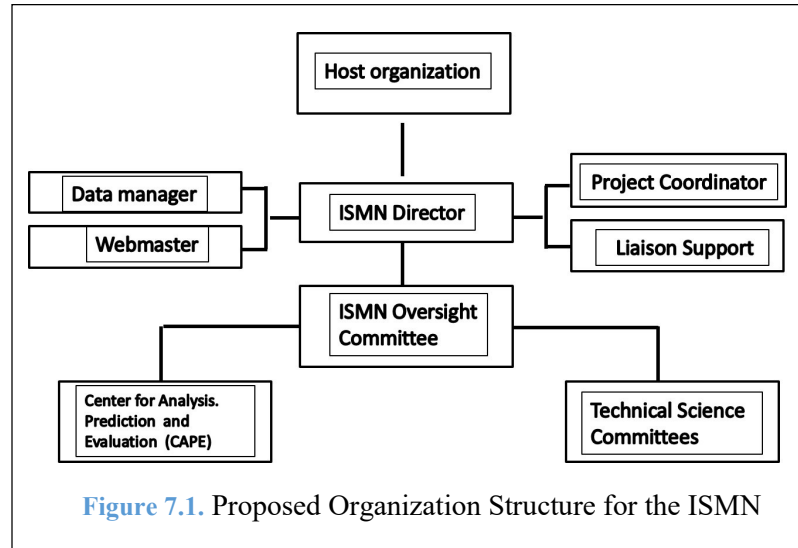
## **7.2 Operational structure: Establishing Coordination and Sustained Data Collection, Management, and Synthesis Capabilities**

To sustain a successful Integrated Sentinel Monitoring Network, a collaborative mechanism for providing coordination support and maintaining data collection, management, and synthesis activities will need to be established. Ad-hoc partnerships that lack stable funding or mission objectives have seldom continued for longer than a few years, and often result in further fragmentation of the data and a reduction in synthesis potential. An operational structure managed by a team dedicated to sustaining the network is therefore essential as the “glue” for the ISMN, providing oversight at a number of levels in order to achieve integration across data sets and disciplines. For example, an already established collaborative body such as NERACOOS with a governance structure that includes state and federal agencies, regional academic organizations, and stakeholders, and a federal mission to integrate ocean information on a regional scale could provide a home for the ISMN (ICOOS Act, 2009). Other collaborative monitoring programs such as the National Atmospheric Deposition Program (NADP) have established coordination offices within host universities (<http://nadp.sws.uiuc.edu/>).

Within the selected host institution, the ISMN coordination and support function will require an internal framework that ensures the key components of the network are fully operational and sustained over time (Figure 7.1.).



The ISMN Director will have the overall responsibility for integration and operation of the ISMN. The ISMN Director will in turn be supervised by an Executive Director of the chosen host agency. The ISMN directorship would be a renewable, fixed-term position that may be accomplished by a combination of funds from the host agency, the ISMN



Director's home institution, and the participating agencies of the ISMN. The duties of an ISMN director include chairmanship of the ISMN Oversight Committee (OC) comprising experts from the regional research and management community with representation from both sub-regions (Long Island Sound/Southern New England and the Gulf of Maine) and from the pelagic, benthic, and coastal and estuarine habitats. Guidance for the number, composition, and selection process, and term of the OC membership will be the next step of the NROC/NERACOOS Ocean and Coastal Ecosystem Health Committee (see section 7.5) with consideration of a mechanism that would ensure impartiality with regard to distribution of funding support for ISMN activities.

The OC will advise the ISMN Director on the implementation and integration of ISMN activities. The OC will determine priorities for enhancement of present observing activities guided by the community consensus provided in Chapters 4 and 5. The OC will also guide the ISMN director in awarding grants for data synthesis through the Center for Analysis, Prediction and Evaluation (CAPE). The CAPE, consisting of the participating institutions in the ISMN network, will focus on enabling integrated analysis across datasets, generating information products about the status of the Northeast region ecosystems, and assuring the utility of this information in addressing identified needs of federal and state agencies and other stakeholders. The OC will also establish and recruit participants on technical science committees to integrate and facilitate effectiveness of data collection, management, and analysis across ISMN activities. Technical science committees will have rotating membership made up of experts from ISMN participating programs. Technical science committees may set data collection and management standards and protocols, facilitate network-wide taxonomic identifications, and oversee and enable the ground-truthing of new instrumentation, enable periodic model skill analysis, encourage development of informatics for analysis of genetic data, and address specific data management issues. The OC will establish and, when appropriate, phase out a technical science committee according to the OC's assessment of needs for effective sentinel monitoring.

A dynamic and effective ISMN website will be necessary as a primary vehicle for dissemination of the work of the OC, CAPE, and technical science committees. The

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website will provide information on ISMN activities and regular updates and analysis of Northeast region ecosystems for stakeholders as well as the general public. It will have a section for technical reports about protocols for sample collection and data reporting, and it will provide a portal for access to the observing data. The primary purpose of the website is to facilitate the ISMN as a dynamic, collaborative observing network with the capability for continued refinement and improvement in (a) data collection and (b) analysis and assessment of ecosystem status. The OC will seek out and coordinate opportunities for collaboration and sharing of information and effort with ongoing coastal and ocean observing websites, such as the Gulf of Maine Council (GOMC) EcoSystem Indicator Partnership (ESIP), Long Island Sound Sentinel Monitoring for Climate Change Program, National Phenology Network, and the NOAA Sentinel Site Program and Ecosystem Status Reports.

Duties of the ISMN Director will include supervision of contracts for website services, data management, and information products, while making use of existing regional and host agency resources where possible. The ISMN Director will also supervise the activities of one or more “liaison support” or “network bridge” positions working in conjunction with the host agency’s stakeholder engagement systems. A liaison support person will have training in both marine resource management or policy and technical science disciplines. This position serves the role of “free electron” in the ISMN, connecting user needs with research expertise. The liaison will become familiar with federal and state agency and other user environmental needs for information and also of the capabilities in the research community, including ecosystem modeling and analysis. They will then work with the user and the scientific experts to make use of and tailor ISMN data, analysis and modeling tools to address specific problems (e.g. species response to sea level rise, contaminant release during flooding, spawning area fragmentation, etc.). Liaison duties may also involve identifying and working with citizen science groups, supporting them with information about protocols and data management and serving in other ways to bring citizen science groups into the network in consistent and meaningful ways.

To accomplish these functions, the ISMN directorship will be provided with an annual budget through the host agency, but generated through contributions from the range of participating funding sources including those described above.

### **7.3 The Center for Analysis, Prediction, and Evaluation (CAPE) of ISMN data**

Essential to the mission and vision of the ISMN is the management and analysis of observing data to provide integrated assessment and interpretation products that assess the health of the Northeast region marine ecosystems and address user needs about ecosystem change. Over the past three decades, a number of regional workshops have addressed the need to develop and coordinate regional analysis and modeling activities to support the detection and understanding of changes in the Gulf of Maine ecosystem (RARGOM 2005). The regional consensus identifies a critical need for regional infrastructure that would:

- facilitate regional model evaluation, including skill assessment, evaluation of uncertainty, and model ensemble approaches to predictions;
- serve to link data analyses, modeling and prediction capabilities to specific regional management needs;
- facilitate coordination among government agencies, research institutions, and universities; and
- develop and demonstrate environmental analysis and forecast products that could be implemented operationally.

The CAPE will be established and run by the ISMN Oversight Committee under the leadership of the ISMN director. The Center will comprise experts from organizations around and perhaps outside the region who will be based at their home institutions and work in teams, meeting periodically both virtually and at physical locations. Membership and themes for the CAPE may be sustained over several years or vary annually. Functions of the CAPE may include, for example, provisions of information and analysis of the NOAA Ecosystem Status Reports or Integrated Ecosystem Assessments; assessment of biodiversity shifts and invasive species status; development of coupled physical and biological models of key plankton species abundance, etc. The OC may invite participation of appropriate experts for each topic addressed, and compensate those experts by partial payment of annual salary. Data products, ecosystem assessments, and modeling tools will be distributed through the ISMN website and other media where appropriate. The liaison support personnel will also work within the CAPE to identify user needs and connect users with the observing system information.

## 7.4 The ISMN in Action: Meeting Regional Needs

*“It all starts with data and information. When you have agreement on the facts you can act and make decisions.”* Angus King, U.S Senator for Maine

This Science and Implementation Plan for the ISMN represents a way forward to overcome widely recognized deficiencies in the present ecosystem observing system in the Northeast region. While there are many and diverse monitoring programs in the pelagic, benthic, and coastal and estuarine environments (see Chapter 3), they are, for the most part, conducted in isolation, and there are identified gaps in coverage of sentinel questions needed to evaluate the extent and consequences of ecosystem change (Chapters 4 and 5). The ISMN will provide infrastructure needed to facilitate and sustain collection, analysis, and interpretation of data from observing activities and to convey information about ecosystem change and vulnerabilities to researchers, managers, and the public. In doing so, it develops and supports an integrated, ecosystem-based framework for adaptive responses to pressures on ecosystems resulting from climate change and other drivers.

The ISMN is conceived as an adaptive process, and a vision in this plan of its future role in the Northeast observing system cannot be prescriptive. Nevertheless, a number of

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functions and activities that improve effectiveness and add value to present investments in the observing system can be envisaged:

- The ISMN provides a dynamic inventory of the present ecosystem observing system. Liaison support personnel and managers use it to connect needs for information with observing activities. Researchers writing proposals use and reference this database to identify and justify needed enhancements to the present observing system, and to coordinate data collection and sharing with other observing activities.
- The ISMN serves as a central station for distribution of observing data and information about observing activities, analysis, and interpretation. The ISMN features a portal where users can access links to data and their metadata. The links may be served by any number of data archiving organizations. The ISMN website maintains a page devoted to CAPE activities, providing interpretive reports, model results, and links to publications.
- The ISMN supports a number of technical committees dealing with common issues related to collection and analysis of observing data (e.g., collection protocols; informatics solutions for analysis of genetic and other biological data; statistical methods; development and implementation of new technologies; taxonomic capacity building; data quality control; physical circulation model comparison, etc.). The activities and reports generated by the technical committees are available on the website for downloading and feedback from the user community.
- The ISMN holds an annual workshop and provides an annual report on ecosystem status and forecasts. As part of these CAPE activities, experts and managers will be invited to an annual workshop to report and synthesize information on indicator trends and predictions of ecosystem status. Each year may focus on a different aspect of ecosystem status. This activity will be coordinated with NOAA Integrated Ecological Assessment reports and reports from the GOMC ESIP.
- ISMN serves to facilitate and interface citizen science monitoring activities and data with federal, state, and other non-profit funded observing programs, making effective use of citizen science efforts. The public is engaged as participants and aware stakeholders in the long-term observing, bridging knowledge of ecosystem change directly to communities
- The CAPE supplies information to the regional NOAA Integrated Ecosystem Assessments and the Northeast Region Ecosystem Advisories issued by the Northeast Fisheries Science Center. In collaboration with CINAR, experts from the research and management communities are engaged to contribute to analysis and interpretation of enhanced observing system data conducted by NEFSC staff.
- The ISMN supports the Northeast Ocean Plan and other regional ocean planning and management initiatives by bringing to bear regional expertise on analyzing indicators to ensure ecosystem change is accounted for in regulatory and management decisions guided by the plan.

- The CAPE supports development of mechanistic, coupled physical biological models and other ecosystem models that can be used to diagnose and predict trends in ecosystem dynamics. Skilled liaison (bridge support) experts connect modeling expertise with users in the management community.
- A small core of ISMN staff link information and experts to specific state and federal management needs, citizen monitoring groups, etc.
- The ISMN website provides access to its activities and analyses to the general public. The ISMN serves as a regional contact for media presentations about the status of marine ecosystems and species and the role of climate change and other drivers.
- The ISMN is active in planning and promoting funding at federal and state levels to sustain essential sentinel monitoring activities

## 7.5 Next steps

The vision and plan for the ISMN, which evolved over three years of discussion in regional workshops and writing in expert working groups, has broad regional support. The ISMN is seen as an essential regional entity needed to organize data and provide integrated ecosystem information for actions and decisions about societal responses to climate drivers of change.

The vision is ambitious and implementation will by necessity proceed by stages. The coordination of the transition to implementation will be undertaken by a renewed NERACOOS/NROC Ocean and Coastal Ecosystem Health Committee. The OCEH Committee, under the guidance of a new Steering Committee, will be provided with a budget and charged with the next steps toward establishment of the ISMN, which include:

- providing coordination support for existing monitoring activities (Section 7.1), including marketing and support for ad hoc research groups proposing new or sustained regional observing activities to funding agencies;
- establishing and maintaining a preliminary ISMN website, which would make accessible this Science and Implementation Plan as a living document;
- maintaining the inventory of present observing activities;
- agreeing upon a host institution for the ISMN and establishing a fair procedure for determining the size and membership of the Oversight Committee;
- coordinating establishment of the ISMN and supporting its functions with the Northeast Regional Ocean Plan; and

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- seeking federal, state and non-governmental sources of support for implementation of the fully operational ISMN structure.



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## 10. Appendix I. ISMN Metadata Database

The ISMN regional metadata database can be found online at <http://www.neracoos.org/sentinelmonitoring/database>.



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## 11. Appendix II. Sidebar Text

### 11.1 Importance of reference areas

The ecological monitoring described in this document is concerned with detecting changes in abiotic and biotic variables over time through the analysis of long-term trends. Reference (control) areas are necessary when the purpose of the monitoring is to determine if the detected change is due to a particular cause or impact. It is important that the long-term monitoring for trends occurs in both the reference area and the impacted area for the same duration. The conditions in the reference area become the baseline conditions against which changes are measured. A reference area can be considered a sentinel site or be a subset of one.

There are currently no reference areas in the Gulf of Maine or southern New England. Consequently, we have no baseline condition against which we can gauge the effects of human activities. Additionally, we have no relatively undisturbed “natural” area from which we can better understand the capacity of a “natural” system for resilience.

The comparison of impacted to un-impacted sites is important for discerning the causes of detected changes. This is particularly useful in situations where a spatial management action has been implemented for the purpose of recovering or improving the condition or abundance of a species, community, or habitat. The accepted analytical approaches for detecting change are the BeforeAfterControlImpact (BACI) and ControlImpact (CI) design. The BACI method can be used when monitoring of the resource condition commences before the spatial management action goes into effect and continues after implementation in both control (e.g., reference areas) and impacted areas. The CI method can be used after a spatial management action has been implemented where comparisons are made between changes inside vs. outside the spatial management area. The Integrated Sentinel Monitoring Network discussed in this document contemplates the full range of monitoring methodologies; however, most of it is aimed at tracking the trends in a variable over time, such as sea surface temperature.

The New England Fishery Management Council has recommended establishing two Dedicated Habitat Research Areas (DHRA): one that overlaps the current Western Gulf of Maine Habitat Closed Area as well as the Stellwagen Bank National Marine Sanctuary (SBNMS) and one on the western end of Georges Bank. The DHRAs are proposed to be closed to bottom tending mobile gear; however, recreational and lobster fishing will continue to be allowed. DHRAs are not true reference areas due to the fishing that is allowed. If these DHRAs go into effect sometime in 2016 they should be incorporated into the ISMN to be used as defacto reference or control areas to not only answer questions related to the effectiveness of spatial management actions, but also to serve as baselines for the broader GoM to better discern signals of climate change and other human perturbations.



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## 11.2 Great Bay

Estuarine researchers and managers are challenged to understand the environmental consequences of drivers of ecosystem change, especially the “Big 5”: development; climate change; food and fiber production; resource harvest and extraction; and ecosystem instability caused by invasive species, extinctions, and pestilence. These drivers collectively contribute to a decline in ecosystem biodiversity and integrity, and lead to a loss of valued ecosystem services that have negative lifestyle and economic consequences for coastal communities. The goal of balancing ecosystem integrity with readily apparent (e.g., fish harvest) and hidden (e.g., pollution control) benefits of ecosystem services is complicated by often shortsighted political and economic forces that are difficult to control, and impacts of human presence that are increasingly intractable. Proactive management intervention is complicated by the lack of critical data coupled with accelerated ecosystem change with highly uncertain outcomes of condition for our nation’s estuaries. Fueled by the suite of drivers listed above and the inevitable changes in chemical, physical and biological state they cause, consequences are becoming more apparent and visibly impacting the health of estuarine waters. The predominant impacts include cultural eutrophication, pathogens, toxins from harmful algal blooms, habitat destruction, toxic contamination, loss of biodiversity, and loss of harvestable resources.

Great Bay and the New Hampshire (NH) Seacoast are not exempt from these problems. Of special concern are the effects of climate change – especially temperature, sea level rise, erosion and pH – and development – especially cultural eutrophication due to nutrient enrichment, but also pathogen contamination that restricts the harvest of shellfish in Great Bay and closes beaches for swimming. In many ways, management progress has been impeded by inadequate science, hampered by a shortage of monitoring data that would help researchers and managers understand the threats and vulnerabilities to Great Bay and the NH Seacoast and support effective management. The 2013 *State of Our Estuaries* report, a product of the Piscataqua Region Estuaries Partnership (PREP), identifies over 20 environmental indicators that the partnership tracks to better understand the impacts of drivers and stressors affecting Great Bay and the NH Seacoast (PREP, 2013). In every respect, these indicators are “sentinel indicators” of ecosystem change. The data resources and understanding provided by the regional ISMN would greatly contribute to our ability to understand and proactively meet management challenges.

A 2011 survey (Fleishman *et al.*, 2011) of public sector decision makers, nongovernmental and private sector science and policy specialists, public and private funders of research, and academic and other researchers set the tone for research and monitoring in their list of the *Top 40 Priorities for Science to Inform US Conservation and Management Policy*. Not surprisingly, one priority identified the need for “effective monitoring programs to detect ecosystem change at an early stage, permit statistical inference, and suggest mechanisms that may cause such changes.” They further noted, “methods to detect gradual as opposed to sudden ecosystem changes are poorly developed and long-term commitments to monitoring and adaptive management currently are difficult to secure and fund.” This explicitly states a critical problem facing our

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coastal waters, and implicitly identifies the growing need for sentinel monitoring that the ISMN serves up in this S&I Plan.

Primary monitoring partners in the Great Bay and NH Seacoast region, including PREP, the NH Department of Environmental Services (NH DES), the Great Bay National Estuarine Research Reserve (GBNERR), and the University of New Hampshire (UNH), have been holding *ad hoc* discussions over the past few years to define what a comprehensive monitoring program for the NH Seacoast region would look like and accomplish. In a joint statement, the partners identified the need for a comprehensive monitoring program to support scientific research, planning, permit compliance, and adaptive management. They recommended upgrading and modernizing monitoring programs to improve understanding and inform cost-effective management decisions. Further, to meet stakeholders' needs, adequate and stable resources are needed to ensure practices are updated and consistent with the latest scientific understanding. Of particular relevance to the ISMN, they recommended that data be quality assured and housed in a single repository. The efficient and collaborative framework detailed in the ISMN Plan, with unified methods and data protocols and capacity for data management and distribution, will provide more certain answers to key questions on ecosystem health and management options that the Great Bay and NH Seacoast partners seek. The partners concluded that a comprehensive monitoring program be developed, not unlike the ISMN structure, stating:

An effective program will set standards for consistent, high quality data that serves the broad array of researchers, managers, and the public. Monitoring and research that links air, land, and water pollutant sources with chemical, physical and biological conditions in state of the art computer models is essential to our understanding these ecosystems, and our skill in managing them.

Finally, a 2014 draft proposal for a Piscataqua region Monitoring Collaborative, shares a common goal and objectives with the ISMN. Its purpose, and goal, is:

...to allow communities, agencies, and organizations to combine their resources for the collaborative monitoring of the region. Dozens of communities surrounding the Piscataqua region estuaries have a common interest in understanding the health of their estuaries. These shared questions are best answered with a shared monitoring program.

Among the anticipated benefits of a collaborative monitoring framework are:

- Cost sharing between local, state, and federal agencies
- Collective decisions on monitoring priorities and methods
- An establish a baseline to assess progress
- Shared responsibility for solutions that protect and restore the estuaries

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### 11.3 Zooplankton diversity shifts in the Gulf of Maine

The Gulf of Maine zooplankton community is characterized by low species richness (Johnson et al. 2011). In the deep basins and on coastal shelves and ledges, one species, the subarctic planktonic copepod, *Calanus finmarchicus*, typically constitutes 40-80% by number of net-captured zooplankton in spring. Its lipid-rich preadult stages predominate in summer and fall. For this reason, Bigelow (1924) described the western Gulf of Maine as a “*Calanus* community,” stating that the “importance of *Calanus finmarchicus* to the general economy of the Gulf of Maine can hardly be overestimated.” Long-term surface warming in the Northwest Atlantic, exacerbated by the recent decade-long warming trend (Fig 1.1.1.) is predicted to result in a northward range shift of *C. finmarchicus* out of the Gulf of Maine within the next several decades (Reygondeau and Beaugrand 2011). However, this prediction does not take into account transport into the Gulf of Maine from *Calanus*-rich waters in eastern Canada. The uncertainty underscores the need for timely assessment of plankton diversity in the Gulf of Maine, as the consequences of shift in the zooplankton community from a large, *Calanus*-dominated assemblage to a smaller, and perhaps more diverse assemblage may have dramatic effects on the composition and structure of the higher trophic levels. Because there is no known functional equivalent to the lipid-rich stages of *C. finmarchicus*, this structural shift may have far-reaching consequences, including displacement of the northern right whale, herring, and perhaps other energy-rich forage fish that feed primarily on *C. finmarchicus* and in turn support tuna, groundfish, seabirds, and other species in the Gulf of Maine. For this reason, the abundance of *C. finmarchicus* is a sentinel indicator in the ISMN, providing resource managers with vital information to make complex decisions in the face of ecosystem change.

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## 11.4 Ocean acidification

Ocean acidification (OA) is a consequence of emissions of CO<sub>2</sub> to the atmosphere. The ocean has decreased in pH from an *estimated* 8.2 to 8.1 in the last 200 years -- an increase in acidity of 30%, and a rate perhaps unprecedented in hundreds of millions of years. Projections are that by the end of this century, when CO<sub>2</sub> is expected to increase from 400 ppm to 700 ppm, the surface waters of the oceans will reflect a pH of 7.8, or a doubling of acidity. Northeast waters, especially the Gulf of Maine, are more vulnerable to ocean acidification for two reasons. First, CO<sub>2</sub> is preferentially absorbed in colder waters; and second, northeast waters are typically not well buffered. Since the GoM is a semi-enclosed marginal sea, the changes may be more cumulative than in open Atlantic waters.

When CO<sub>2</sub> is absorbed in water, the concentration of calcium carbonate declines. This shell-forming material is vital for “marine calcifiers” such as mollusks (including pteropods), echinoderms, coralline algae and coccolithophores, an important group of planktonic algae in the Gulf of Maine. It is well documented that clam, bay scallop, and mussel larvae are susceptible to low pH, especially in sediments where they settle. Many of these species are important commercial species, so the impacts on fisheries are potentially large. In 2012, over 300,000 metric tons of finfish and shellfish were landed in New England, earning \$1.2 billion in revenue. Two thirds of the landings can be attributed to American lobster and sea scallops, both of which are potentially vulnerable to ocean acidification.

There is growing recognition that ocean acidification is exacerbated by many coastal processes, such as riverine discharge and eutrophication, hence the new term *ocean and coastal acidification (OCA)*. Coastal waters receive nutrients, especially nitrogen, which stimulate algal blooms that absorb additional CO<sub>2</sub> further lowering pH levels, especially during the summer when stratification of the water column occurs.

NERACOOS, NOAA’s Ocean Acidification Program, and the NSF Ocean Carbon Program have funded deployment of new sensitive ion selective sensors in Great Bay and the Gulf of Maine at the Isles of Shoals. Additional sensors are operating in Narragansett Bay (by EPA), and in Casco Bay (funded partly by the EPA Office of Water and the Casco Bay Estuary Partnership). In addition to pH, it is important to characterize the carbonate chemistry “weather” with a suite of other measurements, including CO<sub>2</sub>, total alkalinity, salinity, and temperature. To evaluate effects of OA on biological communities, this plan recommends monitoring rocky shore biological communities at a network of sites. Because these communities are dominated by calcifiers (e.g., mollusks, crustaceans, coralline algae, echinoderms, bryozoans, etc.), they are key sentinels of ecosystem change. Combined with chemical measurements of OA parameters and other potential stressors, such as freshwater runoff and nutrient concentrations, we may be able to better understand how the ecosystem changes in response to ocean and coastal acidification.

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## 11.5 Human Drivers of Coastal and Ocean Ecosystem Change in the GoM

Humans have been an integral part of the Gulf of Maine since the earliest native settlers in the region. The initial influx of people to the Gulf of Maine began approximately 12,000 years ago. It is only in the last 500 years, however, that the region has witnessed extensive coastal settlement and development, and exploitation of its fisheries and other resources. The historic and recent patterns of activity shed light onto the impacts of human activities on coastal and ocean ecosystems.

Human activities expanded from farming and fishing to industrial activities and maritime transport. This triggered rapid population growth with concomitant increase in coastal development and infrastructure. The increase in population is partly attributable to migration from rural to urban and suburban areas, and partly due to the aging population (GOMC date). It brings with it an increase in the pressures exerted by human activities and associated infrastructure on coastal and ocean ecosystems. The primary human driver is change in population and population density and consequent changes in land use and land cover as a result of coastal development and infrastructure. Human drivers exert pressures on the environment. With increase in population, expanding coastal development results in the need for increased infrastructure and industrial development (e.g., shipping facilities, wastewater treatment, power generation, offshore energy, desalination), increased resource extraction (e.g., fisheries, offshore mining), and increased recreational activities (e.g., whale watching, boating, tourism). These pressures exert changes in the condition of coastal and ocean waters (e.g. reduced water clarity from increased suspended solids; onset of eutrophic conditions from nutrients resulting from wastewater and stormwater discharge) that in turn impacts habitats and species (e.g., loss of seagrasses and nursery grounds, depletion of fish populations).

The human driver of growth in coastal population, with related development and land use change has contributed towards the increase in the discharge of pollutants into the coastal waters of the northeast from point sources (e.g., wastewater treatment plants, industrial plants, power plants) and from non-point sources (e.g., runoff). Contaminants include nutrients, suspended solids, pesticides, and industrial chemicals. In the GoM, there are just over 2000 point source facilities in the region, including 378 wastewater treatment plants and 93 power plants. Forty percent of these point sources are located in just two watersheds Massachusetts Bay (which includes the largest discharge from a wastewater treatment plant in the region) and the Merrimack River watershed.

## 12. Appendix III. Acronym Reference

Acronym	Definition
ACDD	Attribute Conventions for Dataset Discovery
ALSI	American Lobster Settlement Index
AMO	Atlantic Multidecadal Oscillation
AZMP	Atlantic Zone Monitoring Program
BCO-DMO	Biological and Chemical Oceanography Data Management Office
BLOS	Bigelow Laboratory for Ocean Science
BOEM	Bureau of Ocean Energy and Management
CAPE	Collaborative for Analysis, Prediction, and Evaluation
CBASS	Casco Bay Aquatic Systems Survey
CF	Climate and Forecast netCDF format
CHRP	Coastal Hypoxia Research Program
CINAR	Cooperative Institute for the North Atlantic Region
CMTS	Coastal Maine Time Series station
CNESS	Chord-Normalized Expected Species Shared Index
CPICS	Continuous Plankton Imaging and Classification System
CT DEEP	Connecticut Department of Energy and Environmental Protection
CZM	Coastal Zone Management
DAMOS	Dredged Area Monitoring System
DES	Department of Environmental Services
DFO	Department of Fisheries and Oceans (Canada)
DIFW	Department of Interior Fisheries and Wildlife
DMAC	Data Management And Communications subsystem
DMR	Department of Marine Resources
DNA	Deoxyribonucleic Acid
DO	Dissolved Oxygen
DOI	Department of Interior
DPSIR	Driver-Pressures-States-Impacts-Response Framework
EC	Environment and Climate Change Canada
ECOHAB	Ecology and Oceanography of Harmful Algal Blooms
EMAP	Environmental Monitoring and Assessment Program
EMAP - E	EPA's Environmental Monitoring and Assessment Program - Estuaries
EMMA	Enterprise Metadata Management Architecture
eMOLT	Environmental Monitors on Lobster Trap Program
EPA	United States Environmental Protection Agency
ERDDAP	Environmental Research Division Data Access Protocol
ESIP	Ecosystem Indicators Partnership
FlowCAM	Fluid Imaging Technologies
GEOSS	Global Earth Observation System of Systems
GEOS	Group on Earth Observations



<b>Acronym</b>	<b>Definition</b>
GIS	Geographic Information System
GMRI	Gulf of Maine Research Institute
GNATS	Gulf of Maine North Atlantic Time Series
GoM	Gulf of Maine
GoMC	Gulf of Maine Council on the Marine Environment
GOOS	Global Ocean Observing System
GSO	Graduate School of Oceanography
HAB	Harmful Algal Bloom
HabCam	Habitat Camera
HF	High Frequency
ICOOS	Integrated Coastal Ocean Observation System
IFCB	Imaging FlowCytobot
IOOS	Integrated Ocean Observing System
IPCC	Intergovernmental Panel on Climate Change
ISDM	Integrated Science Data Management
ISMN	Integrated Sentinel Monitoring Network
ISO	International Standards Organization
LISS	Long Island Sound Study
LOPC	Laser Optical Plankton Counter
LSW	Labrador Slope Water
LTER	Long Term Ecological Research
MARMAP	Marine Resources Monitoring, Assessment, and Prediction program
MBON	Marine Biodiversity Observation Network
MEDS	Marine Environmental Data Service
MEOPAR	Marine Environmental Observation, Prediction, and Response Network
MERL	University of Rhode Island Marine Ecosystems Research Laboratory
MIMIC	Marine Invader Monitoring and Information Collaborative
MIS	Marine Invasive Species
MIT	Massachusetts Institute of Technology
MITIS	Massachusetts Invader Tracker and Information System
MMI	Marine Metadata Initiative
MORIS	Massachusetts Ocean Resource Information System
MVCO	Martha's Vineyard Coastal Observatory
MWRA	Massachusetts Water Resources Authority
NADP	National Acidic Deposition Program
NAWQA	National Water Quality Assessment Program
NBC	Narragansett Bay Commission
NBFSMN	Narragansett Bay Fixed Site Monitoring Network
NCA	National Coastal Assessment
NCCR	National Coastal Condition Report

<b>Acronym</b>	<b>Definition</b>
NDBC	National Data Buoy Center
NDF	Standards-Based Data Framework
NGDC	NOAA's National Geophysical Data Center
NE LME	Northeastern U.S. Continental Shelf Large Marine Ecosystem
NEBO	Northeast Benthic-Pelagic Observatory
NECAN	Northeast Coastal Acidification Network
NECSA	Northeastern Coastal Stations Alliance
NECWA	New England Coastal Wildlife Association
NEFSC	NOAA's Northeast Fisheries Science Center
NEIEN	National Information Exchange Network
NEP	National Estuary Program
NERACOOS	Northeastern Regional Association of Coastal and Ocean Observing Systems
NERRS	National Estuarine Research Reserve System
NESS	Normalized Expected Species Shared
NGO	Non-Governmental Organization
NMFS	National Marine Fisheries Service (NOAA)
NOAA	National Oceanic and Atmospheric Administration
NODC	National Ocean Data Center
NRA	National Recreation Area
NROC	Northeast Region Ocean Council
NSF	National Science Foundation
NWR	National Wildlife Refuge
OBIS	Ocean Biogeographic Information System
OC	Oversight Committee
OCEH	Ocean and Coastal Ecosystem Health Committee
OPAL	UNH Ocean Process Analysis Laboratory
OPeNDAP	Open Source Network Data Access Protocol
OSAMP	Rhode Island Ocean Special Area Management Plan
OSCO	Ocean State Coastal Observatory
OTN	Ocean Tracking Network
OTU	Operational Taxonomic Unit
OWR	Office of Water Resources
PAR	Photosynthetic Active Radiation
RARGOM	Regional Association for Research in the Gulf of Maine
RI CRMC	Rhode Island Coastal Resources Management Council
RI DFW	Rhode Island Department of Fish and Wildlife
RIDEM	Rhode Island Department of Environmental Management
rRNA	Ribosomal Ribonucleic Acid
S&I	Science and Implementation
SAMP	Special Area Management Plan

<b>Acronym</b>	<b>Definition</b>
SAV	Submerged Aquatic Vegetation
SBNMS	Stellwagen Bank National Marine Sanctuary
SHARP	Saltmarsh Habitat and Avian Research Program
SHRMP	Seafloor Habitat Recovery Monitoring Program
SLR	Sea Level Rise
SMAST	UMASS Dartmouth's School of Marine Science and Technology
SMCCP	Sentinel Monitoring for Climate Change in Long Island Sound Program
SNE-LIS	Southern New England and Long Island Sound
SOS	Sensor Observation System
SPARROW	Spatially Referenced Regressions on Watershed Attributes
SWMP	System Wide Monitoring Program
TDS	THREDDS Data Server
THREDDS	Thematic Real-time Environmental Distributed Data Services
UMass	University of Massachusetts
UNH	University of New Hampshire
URI	University of Rhode Island
USACE	U.S. Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VPR	Video Plankton Recorder
WAF	Web Accessible Folders
WB-7	Wilkinson Basin Time Series station
WGNARS	Working Group on the Northwest Atlantic Regional Sea
WHOI	Woods Hole Oceanographic Institution
WSW	Warm Slope Water
ZOOVIS	Imaging System for Zooplankton