



## Preliminary Build-out Plan for the Northeast Part one: Issues and Products

### 1. MARINE OPERATIONS

#### **Issue 1.1 Safe and efficient commercial shipping and recreational boating**

*The ocean and coastal waters of the Northeast are extensively used for commercial shipping, commercial fishing, cruise ships, and recreational boating. These maritime activities are important economic drivers for the region. The Northeast region includes several major shipping ports including: Halifax, Nova Scotia; Saint John and Saint Andrews, New Brunswick; Eastport, Searsport and Portland, ME; Portsmouth, NH; Boston, Chatham, Hyannis, New Bedford, Buzzards Bay and the Cape Cod Canal, MA; Providence, Narragansett Bay and Newport, RI; and New London, New Haven and Bridgeport, CT. The region also includes a great number of harbors and marinas for commercial fishing vessels and recreational boaters. The region is home to the US Coast Guard Sectors of Northern and Southern New England, and the Canadian Coast Guard. The safe and efficient operation of commercial shipping, commercial fishing, and recreational boating requires that mariners have access to reliable, accurate real-time observations of weather and ocean conditions through a variety communication technologies including web, mobile, and radio. While the consistent demand for accurate and accessible information is strong, the requirements for the commercial and recreational sectors vary. Key regional partners include the US and Canadian Coast Guard and Coast Guard Auxiliary, regional port safety forums, tug and pilot associations, NOAA, Port and Harbor authorities, state marine trade associations, and commercial and recreational fishing organizations.*

##### **1.1.1 PRODUCT AND SERVICES: Critical real time information for mariners**

Commercial and recreation mariners require access to reliable and accurate real-time observations of weather and sea state conditions, location of other vessels, and location of endangered whales through a variety of products and services including integrated web based portals, mobile applications, and NOAA weather radio. The National Weather Service (NWS) is the primary source for weather forecasts suitable to the marine industry. Improved NWS forecasts require an expanded data collection infrastructure. Existing programs, such as the NOAA National Data Buoy Center (NDBC) and the NOAA Physical Oceanographic Real Time System (PORTS) provide real-time data utilized by commercial shippers and the public. However, the PORTS infrastructure, in particular, is limited in the NERACOOS region (no PORTS exist north of Narragansett Bay).

Real-time data portals, both web and mobile, that provide the latest and recent history for weather and sea state conditions support short-term planning needs. Recreational boaters would particularly benefit from handheld electronic applications. Commercial shippers have more sophisticated computer systems through web-based data display portals, such as those in the PORTS network. Mariners also require products that integrate weather and ocean predictions with observations. Distribution of real-time data in ports and harbors via Automatic Identification Systems (AIS) also would be useful. Historical observations in both short and longer term data products would be useful, including climatology data products that document the range of conditions over time.

Site-specific real-time information improves the efficiency of marine commerce and is essential for safe navigation in restricted locations. Reducing light-loading operations and delays offshore waiting for suitable water depths can save valuable time and money.

#### **INFORMATION REQUIREMENTS:**

**REAL-TIME AND HISTORICAL OBSERVATIONS:** Weather and sea state conditions including air temperature, barometric pressure, wind speed, gusts and direction, visibility, rainfall, water temperature, wave height, period and direction, current speed and direction, water level, bridge clearances, and water density to calculate cargo displacement. Locations of other vessels and endangered marine mammals (e.g. Right whales). Spatial scales vary from short distances in ports and harbors (~100 m) to long distances (~100 km) for open ocean shipping. In the offshore areas mariners require sufficient geographical distribution of observations to accurately characterize the weather and sea state over the long distances they will be transiting. Delivery of the information should be as near real-time as possible. Data in more congested and confined waters of ports and harbors should be rapidly updated every 6 minutes. Offshore conditions should be updated every 30-60 minutes. Remote sensing products of winds and surface water temperature are also important information sources. Open ocean shipping and planning, information about regional weather patterns is crucial.

#### **1.1.2 PRODUCT AND SERVICES: Improved wind and ocean current forecasts**

Improved wind, wave and current forecasts can be used to help develop transit routes that improve efficiency and minimize risk. Accurate, high resolution forecasts would fill this need. Increasing the number of instrumented ports and harbors and the spatial density of instrumentation would contribute to increased forecast accuracy. The NWS has the responsibility of delivering official marine weather forecasts. NERACOOS can deliver “research” forecasts to the NWS to help improve their forecasts and supplement the weather forecasts with oceanographic forecasts.

#### **INFORMATION REQUIREMENTS:**

**MODEL INFORMATION:** Wind, wave and current forecasts for 24, 48 and 72 hours into the future are required. Within ports and harbors, water level (tide) and current data and forecasts are required at time intervals of less than 1 hour, particularly around changing tides. The spatial resolution of the forecast should vary and the forecasts should come with a measure of uncertainty that can be understood by mariners.

## **Issue 1.2: Search and Rescue**

*All mariners in the coastal waters of the United States Exclusive Economic Zone (EEZ) potentially need the services of the US Coast Guard's (USCG) office of Search and Rescue (SAR). In 2006, 28,316 search cases were conducted by the USCG and 5,260 lives were saved (Schafer et al., 2006). Unfortunately, there were also 786 deaths. Most of these SAR cases occurred within a few miles of shore where the currents are complicated as a consequence of coastal bathymetry and congested boat traffic. These cases are often resolved quickly and target drift is limited. The search target may be moved greater distances with limited visibility and farther from shore. Predicting this drift and its uncertainty allows searchers to be more effective by reducing the search area. Coastal High Frequency (HF) radar surface current observations, in concert with the USCG forecast and search management system has been demonstrated to reduce the search areas. High resolution circulation forecast models may also reduce search areas. Real-time information on water temperature is important for determining survival time and real-time, and forecast sea-state is critical for mission planning. Improving the probability of locating the object within the constraints of limited search resources is key to successful rescue efforts.*

### **1.2.1 PRODUCT AND SERVICES: Real-time and forecast conditions sent to the Coast Guard's Environmental Data Server**

SAR operations are both costly and dangerous, but have the potential to bring large human and economic benefits. Recently, the USCG implemented a new operational tool to manage searches, the Search and Rescue Operational Planning System (SAROPS). This tool requires wind, surface current, wave measurements, water and air temperature measurements, and exploits a wide range of environmental forecasts through an Environmental Data Server (EDS). The data processing and telemetry associated with HF radar results in a delay of 1 to 3 hours in the delivery of surface current observations, and search planners need short-term statistical forecasts to predict search target drift. NERACOOS information will be integrated to the USCG SAROPS tool through the EDS.

### **INFORMATION REQUIREMENTS:**

**REAL-TIME AND HISTORICAL OBSERVATIONS:** Operational requirements from the USCG require coverage of 80% of the area for 80% of the time of surface currents from HFR. Offshore – 6 km resolution is required (~10 HFR sites in the Gulf of Maine). Near-shore and densely populated shallow areas (Massachusetts Bay and the Sounds of southern New England) – 2 km resolution to resolve more complex currents. Historical observations are required for developing statistical current models. In-situ subsurface measurements of currents (speed and direction), wind, wave, water and air temperatures are also necessary at sufficient spatial resolution to inform SAR as well as minimizing model uncertainty. Thirty to sixty minute temporal resolution is required.

**MODEL INFORMATION:** A statistically derived Short Term Prediction System (STPS) is required for 24 hour current forecasts from HF radar observations. Dynamical meteorological and ocean condition models such as the Northeast Coastal Ocean Forecast System also provide forecast information to the EDS for the following 2-3 days.

## Issue 1.3: Spill response

*Oil and other spills have the potential to cause wide spread ecological damage and broad economic impacts, and threaten human health. Spill response personnel and groups (including federal, state, and local efforts) require up-to-date and reliable information that will allow rapid response to minimize adverse impacts and to assist in monitoring spill impact. Archived information is important for damage assessment. Key regional partners include the Emergency Response Division (ERD) of NOAA's Office of Response and Restoration (OR&R), the US Coast Guard, the Environmental Protection Agency, State Environmental Protection agencies, and Canadian oil spill response agencies.*

### **1.3.1 PRODUCT AND SERVICES: Real-time observations and forecasts to track and predict spill trajectories and weathering, and for planning of response efforts**

Information provided by NERACOOS will be integrated into partners' tools and products, specifically those of NOAA's OR&R ERD such as General NOAA Operational Modeling Environment (GNOME) and Environmental Response Management Application (ERMA). Areas of risk include major ports, especially those that receive crude oil or its products (Portsmouth, NH; Portland and Searsport, ME; Providence, RI; and Saint John and Halifax, NS). Additionally, a database providing typical patterns of circulation within estuaries and bays would give responders a sense of normal conditions.

#### **INFORMATION REQUIREMENTS:**

**REAL-TIME AND HISTORICAL OBSERVATIONS:** Surface currents (30 minutes to hourly; HFR - region wide at 6 km resolution, higher resolution for areas of risk, buoys and drifters); Surface conditions including water temperature, salinity, wave height and direction, spilled agent or proxy if possible, meteorological conditions (30 minutes to hourly; region wide spatial distribution to minimize model uncertainties); Subsurface conditions including water temperature, salinity, currents, spilled agent or proxy if possible (30 minutes to hourly; region wide spatial distribution to minimize model uncertainties). Stream gauges for river discharge. Identification of the level of stratification (pycnocline).

**MODEL INFORMATION:** Surface currents (STPS for HFR). Regional scale coupled meteorological- hydrodynamic models for surface and subsurface properties for large scale distribution and boundary conditions (currents, water temperature, salinity, waves, water temperature, salinity, waves, meteorological etc.; 6 km spatial; hourly temporal; 2-3 day forecast window etc.); high resolution hydrodynamic models for areas of risk (currents, water temperature, salinity, waves, meteorological etc.; ~ 100m spatial; hourly temporal; 2-3 day forecast window). Nowcast allows for extrapolation of real-time observations to a broader geographic extent. Hydrological models for river discharge. All model products should come with measures of model confidence and uncertainties.

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## Issue 1.4: Offshore Energy

*The exploitation of tidal stream, wind, and wave ocean energy resources within the Northeast region is just getting underway. The potential is highest for offshore wind, lower for in stream tidal, and very limited for waves. In-stream tidal demonstration or initial stage energy generation projects are underway in the East River, NY; Muskeget Channel, MA; the entrance*

*to Great Bay, NH, Cobscook Bay, ME, Bay of Fundy, and in the Minas Passage of the upper Bay of Fundy. A wave energy demonstration site is in operation off the coast of New Hampshire and used to test prototype designs. Offshore wind energy development is the most active with state sites designed in Rhode Island (south of Block Island) and Maine (near Monhegan Island). Federal leasing is in process or completed for sites off the southern coast of RI (Area of Mutual Interest, AMI), south of Nantucket Sound, MA; and the center of Nantucket Sound, MA (permits issued Cape Wind, first in nation). The Department of Interior plans to designate specific development sites for floating offshore wind platforms in Maine waters by winter 2011-12. The Northeast region is expected to be one of the first in the nation with offshore wind energy farms and is one of the first with in stream tidal energy demonstrations. Several tidal in-stream energy turbines have been placed in the Minas Passage for testing, and commercial scale arrays are expected in 3-5 years. Key regional partners include energy developers, state coastal zone and environmental management managers, Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE), USCG, Army Corps of Engineers (ACOE), US Fish and Wildlife Service (FWS), the Nova Scotia and New Brunswick Departments of Environment, Canadian departments of Natural Resources (NRCan) and Fisheries & Oceans (DFO).*

**PRODUCT AND SERVICES: Information to facilitate siting and engineering, power production analysis, impact monitoring, and facility operation**

**INFORMATION REQUIREMENTS:**

**REAL-TIME AND HISTORICAL OBSERVATIONS:** To facilitate siting, power production analysis, impact monitoring and operation of demonstration or power production facilities, buoy based observation data on surface and subsurface currents, winds (speed and direction) at surface and up to hub height (approximately 70m), solar radiation, vertical salinity and temperature structure, wave height, period and direction, sea level, tides and depth resolved current speed and direction are required. One station should be located in the vicinity of each development, as noted above. Data should be provided at 15 minute intervals and accessible from the NERACOOS web site in real-time. Archived data should also be available to facilitate statistical estimates at the sites. Proposed buoy observations are meant to be sentinel stations and provide a long-term reference for time series analysis. Energy developers and regulators will require augmentation of this basic observation system to facilitate siting, operation, and monitoring of energy development projects. This enhancement of the observation program should be their responsibility. In some cases it will involve adding additional sensors to existing buoys (e.g., ultrasonic receivers to identify bats and understand how far offshore they migrate, acoustic receivers to track marine mammal movement). Offshore installations when established may also provide platforms for integration into the regional observing system.

**MODEL INFORMATION:** Validated hindcasts (20 years or longer is optimal, 3 years is the minimum) from circulation, meteorological, and wave models for currents, winds, sea level, and waves in the vicinity of the developments will provide data necessary to generate statistical analyses for the design of energy extraction devices and their foundations, for estimating power production potential, and for planning marine operations (construction and maintenance). This data should be web accessible.

Nowcasts and forecasts from the models noted above are required to assist in design, on-site assembly and operation of the energy-extraction devices. The information will be used to incorporate safety margins for survivability, plan on-site specific steps in construction, facilitate operation of extraction devices, estimate energy generation, and identify time periods when special precautions may need to be implemented. Forecasts should be 2 to 3 days in the future. Both hindcasts and forecasts need to be at spatial resolutions on the order of hundreds of meters in the vicinity of the developments and at time steps of 15 to 30 minutes. Model simulation results can be used by energy developers as input to higher resolution models of the specific energy project necessary for permitting, understanding device interactions and their influence on energy resources, and monitoring studies require by regulatory agencies.

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## **Issue 1.5: Aquaculture**

*Aquaculture, including shellfish and finfish farming, is an important industry in the Northeast region, most occurring within 3 miles of the coast. In the case of shellfish aquaculture, it occurs primarily in estuaries, rivers, and embayments. There is an experimental offshore aquaculture facility off the coast of New Hampshire and the potential for further development of offshore aquaculture for some finfish. Aquaculture siting requires accurate historical weather and ocean data. Aquaculture operations require accurate forecasts and real-time observations to improve cultivation practices, safety and efficiency. Management and regulatory agencies responsible for permitting and monitoring aquaculture operations require both historical ocean information and real-time observations to assess siting and assure operations meet regulatory guidelines. NERACOOS should develop and support products and services to deliver observations and forecasts to the operators of aquaculture facilities as well as the agencies that manage and regulate aquaculture activities to help support their decision making processes.*

### **1.5.1 PRODUCT AND SERVICES: Information for siting, monitoring, and operations of aquaculture facilities**

The development of offshore aquaculture will require accurate climatology data products that describe the probabilities of meteorological and oceanographic conditions.

Aquaculture operators, especially offshore, will require web and mobile products and services that provide easy access to real-time weather and ocean conditions and forecasts near their facilities. Products are needed that can allow threshold exceedance warnings for a parameter to be generated. Agencies responsible for siting and regulating aquaculture facilities require site specific historic and ongoing information on water circulation and water quality.

#### **INFORMATION REQUIREMENTS:**

**REAL-TIME AND HISTORICAL OBSERVATIONS:** Development and siting requires accurate and long-term meteorological and oceanographic observations including air temperature, wind speed and direction, wave direction, height and period, as well as depth resolved water temperature, salinity, and current speed and direction. This data is needed to produce climatologies of the range of conditions. Operations of facilities require realtime weather and ocean observations including wind speed and direction, air temperature, visibility,

water temperature (surface and bottom) salinity, current speed and direction. Water quality information (at multiple depths) is also important for aquaculture and includes pH, turbidity, dissolved oxygen, chlorophyll a, nutrients and presence and concentration of harmful algae and fecal coliforms. Also required is data about freshwater runoff and river discharge. Aquaculture operations require data close to their operation to support effective decision making.

**MODEL INFORMATION:** Hindcasts of weather and ocean conditions may be able to provide site-specific probabilities of meteorological and oceanographic conditions to facilitate siting. Now-casts and forecasts would be important for operational aspects. Water quality models are also important.

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## **Issue 1.6: Tourism**

*Coastal tourism is a significant economic driver in the region and includes activities such as beach visits, fishing, surfing, kayaking, sailing and power boating. Tourists need up-to-date information about the weather and ocean conditions to make decisions about their tourism activities. Coastal tourism operators including whale watch operators would also benefit from this information.*

### **1.6.1 PRODUCTS AND SERVICES: Real-time beach safety information including rip tides, waves and water quality**

Tourists would benefit from having web and mobile access to the latest beach conditions and warnings information.

#### **Information Requirements:**

**REAL-TIME AND HISTORICAL OBSERVATIONS:** Hourly observations of meteorological and surface ocean conditions including wind speed and direction, ultra violet radiation, air and water temperature, wave height, period and direction, current speed and direction as well as nuisance species (e.g., jellyfish). Water quality information specifically of beach closures is also important. Historical conditions provide information on probabilities of finding conditions. For example, the timing of the warmest waters for planning vacations.

**MODEL INFORMATION:** Forecasts, weather, and ocean conditions as listed above and of dangerous conditions including rip tides, dangerous waves, and poor water quality.

## 2. CLIMATE VARIABILITY AND CHANGE

### Issue 2.1: Changes in ocean conditions over time

*Climate variability and change affects a broad range of parameters, processes, and issues in the Northeast region including distribution, abundance, and productivity of species and habitats, sea level rise and coastal inundation, and acidification of ocean waters. To understand these changes and to develop and evaluate adaptation strategies, current climate conditions need to be put into a historical context and observations need to be incorporated into regional modeling efforts that produce hindcasts, nowcasts, and forecasts. It is necessary to make historical and current observations available in formats designed to serve an array of stakeholders including modelers, resource managers, weather forecasters, coastal managers and communities, and the public at large.*

*Climate effects in the region are caused by both large-scale forcing in the North Atlantic and local-scale forcing within the region. To track and forecast these effects, it is necessary to make observations on boundary forcing as well as key internal climate-system parameters. Sustained observations are necessary to provide the requisite time-series for climate scale analyses. External forcing includes freshwater input, atmospheric forcing, and advection across the northern, southern, and offshore boundaries. Key internal climate-system parameters include temperature, salinity, density, nutrients, currents, components of the carbonate chemistry system, and sea level (see section 4 for more on sea level).*

#### **2.1.1 PRODUCT AND SERVICES: Provide sustained key observations, hindcasts, nowcasts and forecasts on external forcing conditions and internal climate-system parameters**

##### **INFORMATION REQUIREMENTS:**

##### **REAL-TIME AND HISTORICAL OBSERVATIONS:**

**EXTERNAL FORCING OBSERVATIONS:** Advection across the boundaries of the region must be quantified. Twice monthly in-situ, observations of volume transport by autonomous mobile assets are required across the northern boundary (western Scotian Shelf & Northeast Channel), the Gulf of Maine Coastal Current (perpendicular to the coast of Maine), and the southern boundary (west of Nantucket Shoals) of the NERACOOS region. The southern boundary conditions should be monitored in collaboration with MARACOOS. Higher frequency sampling and mooring deployments should be embedded into the twice-monthly autonomous mobile sampling to understand the scales of variability in volume transport. In addition, satellite altimeter volume transport estimates need to be derived for the Northeast shelf/slope consistent with estimates made further to the north along Labrador, Newfoundland, and Nova Scotia. Finally, transports across the shelf/slope boundary must be quantified through collaboration and coordination with the NSF funded OOI-Pioneer Array, which is designed specifically to measure shelf/slope boundary fluxes.

Atmospheric forcing in the region must be observed and developed into products for use by NERACOOS partners. Daily measurements of atmospheric variables are required to support a high-resolution (~10 km) gridded reanalysis and nowcast analogous to the NCEP reanalysis and WRF model nowcast and forecasts. Measurements should be made from



NERACOOS assets in the region and assembled from other platforms (e.g. airports, ships, etc.). Measurements should include wind speed, wind direction, wave characteristics, air temperature, humidity and heat flux.

Daily, watershed-level estimates of freshwater input into coastal waters are required to quantify freshwater input into the coastal ocean. These observations will be based on the USGS stream flow measurements but combined to estimate total input by watershed. Historical and current estimates will be developed and distributed. Gradients in estuaries and the coastal ocean related to freshwater input must also be quantified and tracked.

*KEY INTERNAL CLIMATE-SYSTEM PARAMETERS:* Measurements of key internal climate-system parameters will be made from NERACOOS assets deployed in the region including fixed and mobile platforms. Again, sustained observations are necessary to provide the requisite time-series for climate scale analyses. Parameters include depth resolved temperature, salinity, density, and nutrients. Sea-level and carbonate chemistry are also key parameters but are dealt with separately in issue 2.2 and 2.3. Both coastal and offshore, as well as surface and sub-surface observations are needed. An emphasis on gradients is necessary and developing an understanding on how these gradients change is critical (e.g. salt wedge in an estuary, boundary between coastal and shelf waters). Measurement frequency will depend on platform and emphasis will be placed on high accuracy measurements. In addition, integration of data from other sampling programs (e.g., state, NOAA) and from other platforms (e.g., satellite, ships of opportunity) is critical to provide a comprehensive view of the past, current, and potential future states of key parameters in the Northeast region. To the extent possible, key climate parameters should be measured concurrently with data on species and habitats to ensure that climate effects on ecosystems can be observed and modeled (see Section 3). Satellite remote sensing provides the ability to achieve sustained synoptic observations of surface ocean conditions.

**MODEL INFORMATION:** Hindcasts of historical meteorological and oceanographic conditions from the 1970s to present will provide invaluable spatial and temporal information on changing conditions throughout the region. A high-resolution atmospheric forcing reanalysis product is needed for the same time frame. These needs are currently being met with the Northeast Coastal Ocean Forecast System (scheduled to be completed in 2012). This historical database as well as the ongoing forecasts and nowcasts provide the ability to simulate and visualize a range of scenarios, for example, the effects of extreme weather events with rising sea level. Climate forecasts of future conditions downscaled to a regionally relevant resolution may also be useful.

### **2.1.2 PRODUCT AND SERVICES: Climate observations distribution and products**

There is a need to distribute climate observations and model information in both near real-time and on a historical basis. Near real-time data will be used to support modeling and assessments of current state. Historical data will provide a statistical reference for current observations and support retrospective analyses. Forecast products will be developed in collaboration with global climate modeling centers (e.g., Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey). Five main products are required:

**2.1.2.1 Climate indicators** – A defined set of core climate indicators for the region is needed. These indicators must include both external forcing as well as key internal parameters. These indicators should also include large-scale climate indices used to

describe basin-scale processes that are known to affect the Northeast region (e.g., North Atlantic Oscillation, El Niño Southern Oscillation). These indicators must be produced annually and reported to the public<sup>1</sup>. The development, storage, access and presentation of these indicators would be facilitated by the tools described below. The indicators developed/used by NERACOOS would be coupled with the NOAA Climate Normals Program to the extent possible.

**2.1.2.2 Climate data catalog** – A catalog of all climate related information collected in the region is needed. Several catalogs and archives exist, but none are comprehensive. This catalog will represent an ever growing accumulation of references to datasets including a set standard of metadata. The catalog will include historical datasets as well as ongoing observational programs.

**2.1.2.3 Data discovery tool** – Based on the data catalog, users can identify the key climate information and boundary forcing data collected in a given region. Set regions will be defined (e.g., Long Island Sound, Cape Cod Bay) and users can define their own regions (lat/long rectangles and polygons). Users can also notify NERACOOS of data not included in the catalog. The discovery tool will return user selected elements of the data catalog metadata.

**2.1.2.4 Data warehouse tool** – Information included in the catalog will be consolidated in a data warehouse (to the extent possible). The purpose of the warehouse will be twofold: serve as a source of data for assimilation in regional modeling efforts (see Issue 3.1) and serve as a source for data climatologies (see below) and regional retrospective analyses. A wide variety of data products will be housed (e.g., site specific temperature records, CTD observations).

**2.1.2.5 Climatology and trend development tool** – Based on the data warehouse, users can identify a variable (e.g., water temperature, wave height, habitat distribution, species abundance), a region, and a time frame and the tool calculates a climatology (mean), anomalies to the climatology (deviations from the mean), and completes a trend analysis based on user defined time frames (annual, monthly, weekly, daily). Specific data requirements can be programmed and provided automatically to users for incorporation into other climate variability and change products developed by users to support their specific needs (for example, the State of Connecticut could display a NERACOOS temperature climatology and trend analysis for Long Island Sound).

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<sup>1</sup> see OZCOASTs for an example <http://www.ozcoasts.org.au/>

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## Issue 2.2: Ocean acidification

*Ocean acidification is becoming widely recognized as the “other” CO<sub>2</sub> problem, in that the secular increase in atmospheric CO<sub>2</sub> related to fossil fuel use, is equilibrating into the surface ocean, lowering its pH. In coastal regions, acidification can be greatly amplified by acidic freshwater inputs and eutrophication. Changes in CO<sub>2</sub> and pH can affect species growth, survival, and behavior. Many non-calcareous species are affected by acidification, but it is the calcifying organisms (e.g., corals, shellfish, and marine plankton) that are considered the most vulnerable. Shellfish harvesting and aquaculture are major industries throughout the Northeast. Recent research suggests that crustacean, fish and marine phototrophs may be at risk. It is vital for shellfish and finfish managers and growers to have timely knowledge about the state of ocean acidification and the impacts to living resources. It is the goal to provide information to these stakeholders but also to contribute to the NOAA Ocean and Great Lakes Acidification Research Plan. Key regional partners include NOAA (Pacific Marine Environmental Laboratory, PMEL, and Atlantic Oceanographic and Meteorological Laboratory, AOML, National Marine Fisheries Service, NMFS, and Stellwagen Bank Marine Sanctuary, SNMS).*

### **2.2.1 PRODUCT AND SERVICES: Information for researchers, including real-time status of pH, pCO<sub>2</sub> and calcite mineral saturation state, documentation of trends in acidity (over various timescales) and alerts for impending acidic conditions**

#### **INFORMATION REQUIREMENTS:**

**REAL-TIME AND HISTORICAL OBSERVATIONS:** Real-time data necessary to estimate carbonate parameters including pH, pCO<sub>2</sub>, temperature, and salinity are critical. Measurements of net community productivity are also important. These data should be at ~3 hour time resolution in order to resolve potentially important diurnal dynamics. Discharge data from USGS (or appropriate models) and depth resolved oxygen data are also necessary. Periodic in-situ sampling of carbonate parameters is important to assure accurate sensor readings. Deployment of assets should be optimized to account for critical shellfish habitat (pelagic and benthic), estuarine systems, pelagic coastal waters and fish and shellfish hatcheries. Each deployment site will likely have varying requirements.

**MODEL INFORMATION:** Alerts for impending acidic conditions need development but would be based on forecasts for river discharge and water conditions requiring meteorological, hydrological, hydrodynamical, and OA water quality models.

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## Issue 2.3: Sea Level and Lake Level Change<sup>2</sup>

*Vemeer and Rahmstorff* are projecting a sea level rise of 75-190 cm over the next 90 years. This rate will cause acceleration in the drowning of near coast lands, raise ground water table positions, cause salt water intrusion, and drowned kettleponds may become anoxic basins (Pettacumscutt River in RI and Frash Pond, in CT.). Secondary symptoms include increased flooding frequency from surge, accelerated shoreline retreat, and changes in the salt wedge position, which could impact industrial freshwater intake for cooling. Scientists and resource managers are anticipating that certain critical coastal habitats may drown such as tidal wetlands and coastal barrier beaches while increased light attenuation will cause the loss of submerged aquatic vegetation at deeper bed boundaries. Rising sea levels may alter the resonance of ocean tides (especially in locations like Bay of Fundy and Long Island Sound). Human response to flooding and erosion such as use of flood and erosion control structures have the potential to adversely impact ecosystem as in the case of “marsh squeeze”. Global phenomenon such as warming of the oceans and accelerating melting of terrestrial glaciers are complex. Accurate forecasts are required and need to be downscaled to be useful to managers. Potential impacts may be felt on coastal development, ports and harbors and even cities seemingly distant from the sea like Hartford. Key users include hazard and emergency managers, resource managers (coastal, wildlife and fisheries), insurance companies, scientists and engineers.

### **2.3.1 PRODUCT AND SERVICES: Improved forecasts for sea level rise and land subsidence**

**INFORMATION REQUIREMENTS:** Coastal and hazard managers need more precise predictions on sea level rise and for shorter time intervals (~20 year increments) and endeavor to achieve more consistency in numbers used by states. Wetland managers and researchers need sea level trends on intervals shorter than the metonic cycle since plans and animal responses to shorter term sea level trends. Tools are required that can translate a sea level rise forecast into an inundation simulation and visualization tool. Typically these are ‘flat-water’ projections but the ideal project would add modeled water levels.

**REAL-TIME AND HISTORICAL OBSERVATIONS:** Continued deployment of current tide gauges in the region including those deployed by NOAA CO-OPS. Additional real-time and secondary tide gauges are also needed in the region. Temporary gauge deployments are needed for calibration and validation of models forecasting inundation levels and to verify virtual tide gauge models. Streaming or providing links to real-time tide gauge data from USGS and the USACE are needed so users locate the information. NERACOOS should integrate all tide gauge data for the region and analyze, where appropriate, long-term tide gauge records that are not NOS assets (e.g., USGS and USACE).

**MODEL INFORMATION:** Forecast sea level for current conditions and future conditions. Inundation models and tide level models (virtual tide stations) are needed throughout the

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<sup>2</sup> The Coastal Hazards section will address issues, observations and products specific to hazards planning and resiliency.

region to address gaps. In many instances managers want information at the scale of individual bays, embayments and tidal rivers. Models are required to forecast the fate of coastal habitats (e.g., tidal wetlands and submerged aquatic vegetation) from sea level rise. These should incorporate varying sedimentation rates across the marsh surface and consider the effects of sea level rise cycles within the lunar nodal cycle. Managers want the most accurate sea level rise forecasts for shorter intervals such as ~20 years. The downscaling products would not be produced by NERACOOS, but the outputs could be integrated with the models above. The effect of sea level rise on the tidal range in basins such as the Bay of Fundy and Long Island Sound also needs to be forecast.

## 3. ECOSYSTEMS, FISHERIES AND WATER QUALITY

### **Issue 3.1 (merged with 3.2): Healthy ecosystems, productive habitats and sustainable fisheries**

*Information needs to support ecosystem-based approaches to management are beyond the capabilities of any one organization, yet such approaches are necessary to maintain the region's ecosystem services. The ecosystem approach requires coordination and cooperation among multiple regional institutions. An organized research-observing-modeling framework is necessary to assess and forecast the state of the ecosystem and its constituent habitats and living marine resources. NERACOOS is uniquely situated to serve a coordinating role and to fill observational and modeling gaps in the scientific support framework for the ecosystem-based approaches to management.*

#### **3.1.1 PRODUCT AND SERVICES: Support ecosystem approaches to management in the region through observing coordination and integration and provision of key observations and modeling**

##### **INFORMATION REQUIREMENTS:**

##### **REAL-TIME AND HISTORICAL OBSERVATIONS:**

*Sentinel, fixed-station sampling for water column and benthic properties*—Relatively high-frequency biological observations are required to complement ongoing observing of the region's ocean and climate conditions. These observations will help to document changes in biodiversity and phenology related to climate change and variability, and will be used in assessments of human activity efforts on the ecosystem. Fixed station, high frequency sampling complements the broader scale seasonal surveys conducted by state and federal agencies (e.g. state trawl surveys, NMFS Northeast Fisheries Science Center (NEFSC) ecosystem surveys). The Canadian Atlantic Zone Monitoring Program uses a twice-monthly, fixed station design in the Bay of Fundy and on the Scotian Shelf; extension of this design throughout the NERACOOS region would greatly contribute to observations supporting an ecosystem approach. NERACOOS will work closely with regional partners to choose sentinel sites that could be sampled over the long-term, including estuarine, nearshore, and shelf locations. A core set of observations are required (e.g., temperature, salinity, dissolved oxygen, plankton, benthos, nutrients) using traditional (e.g., CTD, nets) and new technologies (e.g., video, genetics). Additional observations can be made based on site-specific or partner-specific needs. Co-location with other NERACOOS or regional observing activities would provide added value.

*Fishers as Observers* – One limitation on ocean observing is access to the ocean. Traditional platforms are expensive (moorings, AUVs, ships, satellites). The use of commercial and recreational fishing vessels as observing platforms is cost-effective, involves fishers in the observing process, and allows increased dialogue between fishers and observing systems, which will improve the development of observing products designed to build sustainable fisheries. There have been several successful pilot programs in the Northeast region, including plankton monitoring, benthic video monitoring, and the deployment of temperature probes on lobster pots and fishing trawls. These pilots are limited, however, in

their engagement with fishers, in the quality of data collected, and in the time between data collection and availability. There is the regional need for involvement of fishers in ocean observing and the near real-time transfer of high quality data from fishing activities to a data warehouse. Once transferred to the data warehouse, the data would be available with other regional observations for access by a wide array of users and for assimilation into forecasts models. These models could then serve as the basis for developing products for fishers (e.g., wave forecasts, by-catch forecasts) as well as other regional stakeholders (e.g., Harmful Algal Bloom forecasts).

#### **MODEL INFORMATION:**

*Species and habitat forecast system* – Many activities in the marine environment require species distribution and abundance and habitat distribution and productivity information. Forecast needs include distribution of protected species for marine transportation, distribution of by-catch species for fishing operations, change in distribution of submerged aquatic vegetation for state managers, occurrences of Harmful Algal Blooms for coastal managers, and abundance and distribution of key lower trophic level species/functional groups for NOAA Integrated Ecosystem Assessments. Non-native species and vegetative habitat are also of interest. A comprehensive modeling and observation based system will be developed to provide forecasts for species of interest. These forecasts would be based on species habitat and physical-biological models that are developed based on long-term observations made in the region (and stored in the data warehouse). Data assimilative models would access the data warehouse to produce nowcasts and forecasts of oceanographic conditions. The forecasts will be short-term (1-5 days) or longer term depending on needs of specific stakeholders. This system would continually be improved through collaborator advancement in habitat modeling, data assimilation, and oceanographic modeling.

*Observing System Simulation Experiments (OSSE) test-bed* – OSSE's are a tool to help optimize the deployment of observing assets to address specific objectives. A model is used as truth and the sampling designs are optimized based on this truth. NERACOOS will support regional OSSE development and implementation to assist multiple stakeholders in deploying observing assets (e.g., offshore energy, government agencies) for an array of objectives (e.g., change in tidal wetland area, ground truthing satellite measures of chlorophyll).

#### **3.1.2 PRODUCT AND SERVICES: Climate Observations Distribution and Products**

*Data catalog* – A catalog of all ecosystem, habitat and fisheries related data collected in the Northeast region is needed. The catalog will include point, vector, and polygon data. This catalog will represent an ever growing accumulation of references to datasets including a set standard of metadata. The catalog will include historical datasets as well as ongoing observational programs.

*Data discovery tool* – Based on the data catalog, users can identify the key ecosystem, habitat and fisheries data collected in a given sub-region. Set sub-regions will be defined (e.g., Long Island Sound, Cape Cod Bay, western Gulf of Maine) and users can define their own regions (lat/long rectangles and polygons). This later functionally can be used to identify available data for specific Coastal Marine Spatial Planning units. Users can also notify NERACOOS of data not included in the catalog. The discovery tool will return user

selected elements of the data catalog metadata. A wide variety of data types will be included such as environmental, species-specific, habitat, bathymetry, etc.

*Data warehouse tool* – Data included in the catalog will be consolidated in a data warehouse, to the extent possible. The warehouse will serve data to a number of stakeholders including regional modeling groups, Coastal Marine Spatial Planning practitioners, coastal managers, federal and state agencies, and the general public.

### **3.1.3 PRODUCT AND SERVICES: Cumulative impacts of multiple stressors**

Coastal and marine ecosystems are impacted by multiple stressors including eutrophication, habitat loss, exploitation, invasive species, pollution, and pathogens. It would be extremely difficult to assess the cumulative impacts of multiple stressors, given the difficulty in assessing one stressor. There is a critical need to catalog multiple stressors and provide integrative tools for examining the spatial and temporal distribution of these stressors. Part of this need involves classifying an event in a data warehouse (e.g., report of brown tide in a particular time and place, a hypoxic event in a specific estuary). These reports can then be accumulated and tracked by stakeholders. Part of this need involves quantifying the potential cumulative stress on particular component of the ecosystem. To meet these needs NERACOOS must integrate observations made by other organizations and fill observational gaps. In addition, NERACOOS must provide tools for assessing the effect of individual stressors on specific habitats and species, and tools to evaluate the impact of multiple stressors on key ecosystem services and biological communities.

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## **Issue 3.3 Harmful algal blooms**

*The waters of the Northeast region are prone to “blooms” of specific types of microscopic algae that can produce potent neurotoxins. Filter-feeding shellfish can accumulate concentrations of these toxins such that the shellfish themselves become a public health threat to consumers. Monitoring of Harmful Algal Blooms (HABs) includes testing molluscan shellfish for toxicity, as well as monitoring offshore and near shore waters for the presence of the algal species. Although Paralytic Shellfish Poisoning (PSP; causative agent Alexandrium spp.) is perhaps the most prevalent “red tide” human poisoning syndrome in the Gulf of Maine and Long Island Sound, other syndromes can also occur in the waters of the North Atlantic, such as Amnesic Shellfish Poisoning (ASP; causative agent Pseudo-nitzschia spp) and Diarrhetic Shellfish Poisoning (DSP; causative agents Dinophysis spp. and Prorocentrum lima). Additionally, portions of Long Island experience brown tides, which turn the water deep brown, making it unappealing to swimmers and fishers alike. Although brown tides are not a public health concern for human consumption of shellfish, these algal blooms can have many adverse effects on estuarine species and ecological integrity.*

*HABs are economically detrimental to the region, causing undesirable water conditions and financial loss to the shellfishing and tourist industries. Approximately 3,000 harvesters and dealers in Maine depend directly upon access to healthy shellfish beds, and Maine’s Department of Marine Resources (DMR) estimates total annual economic value of this industry at over \$50 million, with the largest proportion of that value generated from May through August. Economic studies indicate that a one-week statewide closure of shellfish harvesting due to PSP (softshell clam, mahogany quahogs, and mussels) costs the state*



*approximately \$1.2 million in lost harvester sales, with a total economic loss of \$2.9 million. The typical duration of closures in Maine ranges from one to four months. The average annual value of economic activity generated by the Massachusetts shellfish industry is estimated to be between \$135 and \$180 million. Between 40% and 60% of the total revenue is generated May through September. The 2005 Alexandrium bloom was estimated to cost the Massachusetts shellfish industry \$50 million. Peconic Bay on Long Island supplied about 30% of the bay scallops to U.S. markets and was a 2 million dollar industry before the first brown tide event in 1985. Brown tide also results in eelgrass declines.*

### **3.3.1 PRODUCTS AND SERVICES: Early information to coastal managers for when conditions are conducive for HABs (includes alerts for shellfish harvesters, growers and others)**

Managers require real-time sea conditions and operational forecast systems for HAB species abundance and distribution. Near shore conditions are important. Secure communication between managers and researchers on conditions along the coasts are important due to connectivity of States and Federal waters and monitoring programs, and the sensitivity of the information. The information provided by the system is often used to inform individual State's tissue toxicity monitoring efforts as are results from neighboring State's monitoring. Efforts continue within the region to use ocean color satellite remote sensing to produce a synoptic HAB warning product.

#### **INFORMATION REQUIREMENTS:**

**REAL-TIME AND HISTORICAL OBSERVATIONS:** Surface currents (30 minutes to hourly; HFR region wide at 6 km resolution, higher resolution for areas of risk, buoys and drifters); Surface conditions including water temperature, salinity, wave height and direction, HAB species abundance and toxins, meteorological conditions, and nutrients (30 minutes to hourly; region wide spatial distribution to minimize model uncertainties); Subsurface conditions including water temperature, salinity, currents, nutrients, HAB species abundance (30 minutes to hourly to daily; region wide spatial distribution to minimize model uncertainties). Optical measurements may be useful for elucidating some harmful species (brown tides) in specific embayments. Ocean color remote sensing, especially hyperspectral sensors, may be useful for synoptic assessment of differing phytoplankton groups. Stream gauges for river discharge. Yearly cyst maps are important for *Alexandrium spp.* as at present they are used to initialize the forecast model.

**MODEL INFORMATION:** Surface currents. Regional scale coupled meteorological-hydrodynamic-ecosystem models for surface and subsurface properties that include HAB growth dynamics and toxicity for large scale distribution and boundary conditions (currents, water temperature, salinity, waves, water temperature, salinity, waves, meteorological etc.; 6 km spatial; hourly temporal; 3 day forecast window etc.; 6 km spatial; hourly temporal; 3-5 day forecast window); high resolution hydrodynamic models for areas of risk (currents, water temperature, salinity, waves, meteorological etc.; ~ 100m spatial; hourly temporal; 3-5 day forecast window). Hydrological models for river discharge and hydromet models for longer term forecast of weather patterns.

### **Issue 3.4 Hypoxia and Nutrient Enrichment**

*Nutrient enrichment and its response indicators of hypoxia, algal blooms, submerged aquatic vegetation (SAV) decline, marsh degradation and erosion, and shifts in trophic status are common features of Northeastern US estuarine and coastal waters, including many in the region. Measurements of physical, chemical and biological variables are necessary to describe effects and trends, including physical and chemical precursor conditions to algal blooms or hypoxic events. Temperature and salinity define stratification strength (a critical factor in deep water hypoxia development) and currents link nutrient sources to effects. Coastal and estuarine typology also influences system response to nutrients. Nutrient loads vary with weather and are biologically mediated on daily and seasonal scales and, under stratified conditions, can produce highly productive conditions in surface waters that feed respiration in bottom waters, creating bottom-water hypoxia and anoxia. Underlying climate trends may increase nutrient loads, alter system metabolism and strengthen stratification, thus exacerbating hypoxia and ecosystem change. Integrated monitoring in a regional or national network is necessary to provide sufficient information to quantify and predict estuarine and coastal effects of nutrient enrichment and provide guidance to managers.*

### **3.4.1 PRODUCTS AND SERVICES: Data and information that quantifies nutrient sources effects and improves early warning and long-term predictive capability for conditions conducive to hypoxia and other nutrient enrichment effects**

#### **INFORMATION REQUIREMENTS:**

##### **REAL-TIME AND HISTORICAL OBSERVATIONS:**

*Nutrient Sources and Delivery* – Understanding and predicting nutrient enrichment effects in estuaries and coastal waters rely on watershed assessments of nutrient sources and their processing. Mathematical watershed models provide a useful framework for relating sources to delivery and provide both quantity and quality data.

Monitoring to support models that have been applied to much of the Northeast region (e.g., Spatially Referenced Regressions On Watershed attributes, SPARROW, and Generalized Watershed Loading Function with an ArcView (AV) geographic information systems (GIS) interface, AV-GWLF) or to construct more sophisticated mechanistic models (e.g., Hydrological Simulation Program –Fortran, HSPF) is necessarily intensive for accurate calibration. Meteorological parameters, especially temperature, precipitation, wind, humidity, snow pack, cloud cover, solar radiation, dew point, and evaporation, must be continuously monitored and may be available in sufficient density from existing weather station networks (e.g., NWS, airports). Continuous wet and dry depositional monitoring of nutrients and acidifying compounds is recommended to supplement limited data provided by national efforts such as the National Atmospheric Deposition Program (NADP), the Atmospheric Integrated Research Monitoring Network (AirMon) and the Clean Air Status and Trends Network (CASTNet). Land cover (especially agriculture, developed lands, impervious cover, vegetation classes), soils, and hydrography (stream length, slope, elevation, catchment area) must be current, and land cover updated annually. Stream flow data should be continuous and ideally interpreted in a GIS database such as the USGS StreamStats system, which allows for interpolation and extrapolation to points throughout the watershed. Pollutant point sources (e.g., sewage, industry) should be monitored regularly, at least on a monthly basis for major sources. Stream water quality monitoring (See Table 1 for recommended parameters) should be paired with gauging locations at a

density sufficient to capture storm water and nonpoint contributions that reflect variations in land cover, as well as consolidate entire watershed loads (e.g., Connecticut Department of Energy and Environmental Protection (CT DEEP) and USGS ambient monitoring network). Monthly water quality sampling is the minimum frequency, and targeted monitoring of catchments to reflect a range of land covers and conditions at a higher frequency across the hydrograph is essential for accurate quantification. Because some pollutants, especially nitrogen and carbon, are not conservative in the aquatic environment, studies of attenuation throughout the annual cycle and across the range of runoff conditions are critical to ensure source loads are properly related to delivered loads and management efforts are thus effectively targeted. In some areas, groundwater nutrients are important contributors to local waters (e.g., Long Island Sound embayments, south coastal Rhode Island and Cape Cod) but may undergo lengthy response lag times as legacy nutrients are flushed from soils. To be accurately quantified in models, and to improve predictive capability for the benefits of management, groundwater nutrient concentrations must be measured, and groundwater transport modeled (e.g., Chesapeake Bay and Broad Brook, CT analyses).

*Response Indicators* – Primary response indicators include dissolved oxygen (DO); area, volume and duration of hypoxia; productivity and respiration; chlorophyll-a; phytoplankton including HABs; trophic shifts; SAV loss (distribution, area, density); and marsh degradation and erosion.

Many of the response indicators useful to nutrient enrichment assessments are covered under Issues 3.1 and 3.2 (Sentinel, fixed-station sampling for water column and benthic properties) and Issue 3.3 (Harmful Algal Blooms). The dissolved oxygen (hypoxia) indicator would benefit from high-frequency monitoring (on the order of hours) at multiple depths (with temperature and salinity) to ensure an adequate profile that captures the pycnocline depth and especially bottom water condition. Sampling for DO should vary in spatial and temporal density and be more intensive during periods of hypoxia susceptibility. Relevant sampling periods and locations are reported in NOAA's National Estuarine Eutrophication Assessment, which relies on input from local experts, and EPA's National Coastal Condition Report, which relies on probabilistic, but infrequent, sampling designs, for example. NERACOOS data can complement local hypoxia monitoring initiatives, such as the Connecticut Department of Energy and Environmental Protection's (CT DEEP) biweekly surveys of Long Island Sound supported by the EPA Long Island Sound Study (LISS), providing essential short-term variations caused by diel cycles and advective movement of water that are missed by grab sampling. Light and dark bottle or stable isotope monitoring of productivity should be added and conducted periodically to define nutrient use efficiency and impact of carbon on oxygen levels, which helps calibrate models and provides a relationship to hypoxia effects. Phytoplankton should be broadly characterized through remote sensing and High Pressure Liquid Chromatography (HPLC) photopigment techniques on at least a weekly basis, with increased frequency during peak bloom periods, perhaps conducted in response to hourly fluorescence measurements and complemented with periodic, quantitative counts. SAV distribution and health parameters should be measured and mapped as an indicator of nutrient enrichment effects, on an annual basis.

**MODEL INFORMATION:** Estuarine and coastal eutrophication models provide analytical and predictive ability that include management scenario testing that considers source loads and hydrodynamics that lead to hypoxia dimensions or biological indicator endpoints. An example is the System-wide Eutrophication Model (SWEM) that covers the Long Island Sound – New York/New Jersey Harbor – New York Bight complex.

In variable estuarine environments, calibration data requirements are intended to capture the range of physical and chemical conditions and their interactions that define a useful range of eutrophic conditions. Accurate model calibration and validations as well as predictions of hypoxia or algal blooms are complicated by the highly variable interactions of nutrient loadings with the physical and biological factors that drive the process. Combined with source loading and delivery (above) the physical conditions as well as the chemical conditions (see Table 1) of receiving waters must be intensively monitored over a range of conditions (e.g., wet to dry periods, hot to cool, etc.) to develop an accurate predictive and analytical tool. Physical oceanographic monitoring needs are similar to those defined for other issues and are supportive of eutrophication monitoring. While parametrically complete, continuous monitoring of physical factors is necessary for calibrating the hydrodynamics of a eutrophication model; spatial density should be reviewed and focused on domains with boundary conditions necessary to accurately model areas of impact. Complementary sediment models will generally be required. A calibrated and verified model is an essential tool not only for predicting (years scale) trends and management options, targets and outcomes, but for design of a monitoring program that might provide early warning (days to weeks scale) of a hypoxia event based on precursor physical, chemical and biological conditions. This will require monitoring at a spatial and temporal frequency that provides an accuracy and skill level defined by the model and specific to the local problem.

### **3.4.2 OTHER PRODUCT AND SERVICES FOR HYPOXIA and nutrient enrichment**

Other products and services that could be derived from NERACOOS and the National Water Quality Monitoring Network partner data, and the products defined in Section 3.4.1, would include model development (watershed and surface waters), trends analysis, and recommendations for management actions. Remote sensing information on land cover and change is essential to loading analysis and developing management priorities.

Meteorological data are a key to model development, especially watershed models, and are an essential consideration in predictive tools for early warning and landscape management benefits analysis. The close link between nutrient enrichment and HABs, covered elsewhere in this plan, could also lead to better warning of blooms that might lead to public safety closures of shellfish beds and bathing beaches. Climate effects, especially changes in temperature and precipitation (amounts, intensity and seasonal distribution), are important drivers of nutrient impacts and ecosystem change that may result in unanticipated effects as well as outcomes of management actions.

Table 1 - Required nutrient parameters for National Water Quality Monitoring Network

Component	Nutrient Analyses		Related analyses	
	Tier 1	Tier 2	Response Variables	Ancillary Analyses
Rivers, Great Lakes, Estuaries, Nearshore Coastal, Offshore Coastal	Total nitrogen* Dissolved ammonium Dissolved nitrate plus nitrite Total phosphorus* Dissolved ortho phosphate Dissolved silica	Total dissolved nitrogen Total dissolved phosphorus Particulate nitrogen Particulate phosphorus	Chlorophyll <i>a</i> Dissolved oxygen Conductivity/salinity	Dissolved organic carbon Dissolved inorganic carbon pH Total suspended sediments Photosynthetically active radiation Particulate carbon
Groundwater	Dissolved nitrate plus nitrite	Dissolved ammonium Dissolved ortho phosphate		Dissolved organic carbon
Atmospheric deposition	Dissolved nitrate plus nitrite Dissolved ammonium Dissolved ortho phosphate			Major ions pH
Wetlands (sediment only)	Particulate nitrogen Ammonium Dissolved ortho phosphate Particulate phosphorus		Chlorophyll <i>a</i>	Particulate carbon

\* May be determined by analysis of total dissolved nitrogen and particulate nitrogen (TN=TDN+PN)

\* May be determined by analysis of total dissolved phosphorus and particulate phosphorus (TP=TDP+PP)

n.b. Dissolved refers to samples that are filtered through GF/F (or equivalent) filters before analysis. Total nitrogen (or phosphorus) refers to unfiltered samples. Particulate nitrogen (or phosphorus or carbon) refers to samples collected on filters which are then analyzed.

Table 1 From: Caffrey, et al. 2007. Nutrient requirements for the National Water Quality Monitoring Network for U.S. coastal waters and their tributaries. November 13, 2007 Final.

### Issue 3.5 Minimizing the Impact from Polluted Waters

*Throughout the region, estuarine and coastal waters receive a wide range of contaminants from anthropogenic sources, notably 1) human pathogens, 2) toxic organic compounds such as hydrocarbons and pesticides, 3) inorganic chemicals such as elemental mercury (Hg), and 4) substances of emerging concern such as pharmaceuticals and personal care products (PCPP). Sources of these contaminants are diverse, but are primarily related to industrial and sewage discharges and stormwater and nonpoint source runoff. Human pathogens are associated with the fecal wastes of homeotherms (e.g. humans, livestock, birds, dogs, cats), and are primarily delivered as stormwater and nonpoint sources from coastal watersheds. Fecal borne human pathogens cause gastro-intestinal disease in swimmers at coastal beaches and consumers of contaminated shellfish. Toxic organic compounds are pervasive in the estuarine and marine environment. Petroleum hydrocarbons are leaked or spilled on the land, or transported via the atmosphere from combustion of fossil fuels (e.g., polynuclear aromatic hydrocarbons (PAH)), are broadcast across the land (e.g., pesticides), or are legacies of past discharge and disposal such as polychlorinated biphenyls (PCB), and find their way into runoff or are deposited directly onto estuarine and coastal waters. Many are associated with marine sediments that can be redistributed by resuspension during storms or by disposal of dredged materials. Inorganic chemicals, primarily heavy metals follow many of the same pathways as toxic organic compounds. Mercury is a widespread concern because is delivered via atmospheric deposition and from coastal watersheds, in addition to legacy point sources. When Hg is microbially transformed into its methylated form (MeHg) in estuarine and marine environments it bioaccumulates in marine food webs, leading to human health risks from fish consumption. Contaminants derived from PCPPs are primarily delivered via estuarine and ocean outfalls of wastewater treatment facility (WWTF) effluent, although groundwater from septic systems may be another important pathway in some areas. PPCPs are viewed as an*

*emerging rather than as an established issue, but merits exploratory monitoring to determine the level of risk to humans in addition to their documented systemic effects on wildlife from endocrine disruption. The biological activity of all of these pollutants is likely to be increased with climate-driven increases in temperature. Without adequate planning and management, their concentrations in estuarine and coastal waters will likely increase with human population densities in coastal watersheds.*

*These contaminants have negative economic impacts on both market and non-market uses of estuarine and coastal resources such as beach-going, swimming, boating, surfing, fishing, shellfishing, and seafood consumption. There are also costs associated with their acute and long-term effects on human health.*

*Key partners include the US EPA for contaminant issues, US FDA for pathogen contamination of molluscan shellfish, Gulf of Maine Council on the Marine Environment and NOAA for Hg monitoring through the Gulf Watch program, and state and local partners for issues such as beach and shellfish bed closures.*

### **3.5.1 PRODUCTS AND SERVICES: Early warnings for when pollution might be present (beach warnings, drinking water alerts, etc)**

**Pathogen Forecast Model:** Appropriate short term indicator test for pathogens (current method has 24 hour delay, so not ideal for forecast modeling). Adequate sampling of pathogen delivery through stormwater, combined sewer, and nonpoint source processes and relationships to storm events. Estuarine and coastal circulation models for each estuarine/beach system to be managed.

**Mercury Health Risk Model:** Adequate measures of MeHg concentrations in estuarine and coastal primary, secondary and tertiary consumers. Estimates of trophic transfer of MeHg for each estuarine/coastal system to be managed to identify primary source systems of MeHg in coastal food webs. Dynamic annual forecast model marine food web MeHg tissue concentrations.

**Pharmaceuticals and Personal Care Products Pilot Study:** Pilot sampling of selected WWTF effluent to quantify input concentrations of targeted compounds (e.g. benzodiazepine sedatives). Assessment of indicator species effects and food web bioaccumulation risk. Review of human health risks due to contact exposure and fish and shellfish consumption.

### **COMMON INFORMATION REQUIREMENTS:**

**REAL-TIME OBSERVATIONS:** Surface conditions including water temperature, salinity, wave height and direction, pollutant (e.g., pathogens and/or indicators, mercury, PCPP) levels, meteorological conditions, and nutrients (30 minutes to hourly; region wide spatial distribution to minimize model uncertainties); Subsurface conditions including water temperature, salinity, currents, nutrients, pollutant (e.g., pathogen and/or indicators, mercury, PCPP) levels (30 minutes to hourly to daily; region wide spatial distribution to minimize model uncertainties); Surface currents (30 minutes to hourly; HFR - region wide at 6 km resolution, higher resolution for areas of risk, buoys and drifters). Rainfall (including that from the Next Generation Radar, NEXRAD). Stream gauges for river discharge. Also fecal indicator bacteria counts (24 hour lag) useful for creating predictive model for forecasts.

**MODEL INFORMATION:** Regional scale coupled meteorological-hydrodynamic-ecosystem models for surface and subsurface properties that include HAB growth dynamics and toxicity for large scale distribution and boundary conditions (currents, water temperature, salinity, waves, water temperature, salinity, waves, meteorological etc.; 6 km spatial; hourly temporal; 3 day forecast window etc.; 6 km spatial; hourly temporal; 3-5 day forecast window); high resolution hydrodynamic models for areas of risk (currents, water temperature, salinity, waves, meteorological etc.; ~ 100m spatial; hourly temporal; 3-5 day forecast window); Surface currents . Hydrological models for river discharge and hydromet models for longer term forecast of weather patterns. Decision Support Models (e.g., multiple linear regression, Receiver Operating Curves, etc.) that need historic data to develop.

**3.5.2 OTHER PRODUCT AND SERVICES FOR POLLUTED WATER: Assessment of Hg methylation processes in restoring tidal wetlands for incorporation into food web model**

**INFORMATION REQUIREMENTS:** Contaminant source and sediment mapping (above)

**3.5.3 OTHER PRODUCTS AND SERVICES FOR POLLUTED WATER: Drinking water quality- information on salt water intrusion into drinking water wells association with storm surge and sea level rise.**

## 4. COASTAL HAZARDS

### Issue 4.1 Providing hazard and disaster information when and where it is needed

*In 2004 the US Commission on Ocean Policy has made it clear that “rising populations and poorly planned development in coastal areas are increasing the vulnerability of people and property to storms, hurricanes, flooding, shoreline erosion, tornadoes, tsunamis, and earthquakes. In addition, climate change may lead to more frequent storms and sea-level rise, both of which increase coastal susceptibility. Not only can natural hazards have devastating impacts on people and property, but they may also have deleterious effects on the environment, particularly sensitive habitats.” It is therefore critical to numerous groups (coastal residents, State, Federal and local emergency managers & planners, scientists, etc.,) in the region to be able to predict, understand, and manage/mitigate coastal hazards. A well-designed observing system should provide essential observations on environmental conditions for both systemic, long-term events (i.e., sea level rise) as well as episodic events (i.e., seasonal storm events, flooding, and coastal erosion) to support and leadership in this arena. In the Northeast region there is a specific need to provide data and tools to adaptively manage these issues as the population and development continues to expand within vulnerable coastal and river systems.*

#### 4.1.1 PRODUCTS AND SERVICES: Improved capacity for regional Storm Inundation forecasting and hindcasting efforts

NERACOOS currently supports the northeast coastal and ocean forecast system (NECOFS - an integrated high-resolution model system that is capable of hindcasts, nowcasts, and forecasts of circulation and key ecosystem processes in coastal oceans and estuaries.) NECOFS in part drives several operational site-specific sub-regional systems (Saco, ME, Scituate, MA, and an experimental Long Island Sound Surge model) geared towards providing local-scale flooding and erosion predictions and data. These range from simple, low-cost visualizations to more robust and complex models. As proven, useable commodities, an expansion of these tools to other key locations within the region is needed.

#### INFORMATION REQUIREMENTS:

- Surface currents (hourly; HFR region wide at 6 km resolution, higher resolution for targeted areas of risk, buoys and drifters);
- Surface conditions (hourly; ideally dispersed region wide to minimize model uncertainties - an example density would approximate 1 asset per 50 miles of coastline); including
  - water levels,
  - wave heights and directions as well as meteorological conditions up to 60 nautical miles (nm) offshore to support new high resolution (gridded) forecasts for the Coastal Waters
- Stream gauges for discharge in key major riverine systems.

#### 4.1.2 PRODUCTS AND SERVICES: Storm Conditions Database



NERACOOS observational data and model outputs would be compiled for representative historic storms; observational data would be supplied to partners (NOAA, NWS, ACOE, FEMA) for forecasting predictive storms; results would be stored and managed in a centralized database for use in regional and sub-regional model validations as well as water level return period analyses (5, 10, 50, 100 year storms, etc.) This effort is required to fill a gap of similar data that is currently available and in use for rest of US East & Gulf coasts.

#### **INFORMATION REQUIREMENTS:**

- Surface currents (hourly; HFR region wide at 6 km resolution, higher resolution for targeted areas of risk, buoys and drifters)
- Modeled water level, wave output;
- Surface conditions (hourly; ideally dispersed region wide to minimize model uncertainties - an example density would approximate 1 asset per 50 miles of coastline); including
  - water levels,
  - wave heights and directions as well as meteorological conditions up to 60 nm offshore to support new high resolution (gridded) forecasts for the Coastal Waters
- Stream gauges for discharge in key major riverine systems.
- Incorporate data from any past and future storm deployments of tide and wave gauges.

#### **4.1.3 PRODUCT AND SERVICES: Pre and post-storm conditions assessment and reporting; rapid pre-storm asset deployment**

The ability to collect pre and post storm surveys of damage and overwash/splashover (erosion) are critical to help refine and validate future model projections of storm damage in addition to building a time series of data for shoreline management and emergency planning needs. These will render the region ready to mobilize in the collection of critical post storm data.

#### **INFORMATION REQUIREMENTS:**

- water level observations (high water marks);
- beach elevation profiles (neighborhood level within scope of event impact; survey assessments spread throughout the region)

#### **4.1.4 PRODUCT AND SERVICES: Improving the Northeast Coastal Ocean Forecast System (NECOFS) for extra-tropical storm forecasting**

In its current configuration, the NECOFS lacks the ability to reliably handle extra-tropical storm events, requiring the manual effort of shifting between two forecasting systems. It is therefore required, both from an efficiency as well as a data integrity/product service standpoint, to build a seamless integration of NOAA National Hurricane Center (NHC) model data into the NECOFS to support timely and accurate regional forecasting during extra-tropical storm events for both the region as a whole and for the sub-regional models driven by NECOFS. Additionally, the ability to forecast areas of potential high-impact from extra-tropical storm events will help in appropriately deploying assets of opportunity (e.g., temporary rapid-deploy USGS/ACOE tide/water level gages, or existing NERACOOS assets).

#### **INFORMATION REQUIREMENTS:**

- NOAA NHC extra-tropical storm data;
- Surface currents (hourly; HFR – region wide at 6 km resolution, higher resolution for targeted areas of risk, buoys and drifters)
- Surface conditions (hourly; ideally dispersed region wide to minimize model uncertainties - an example density would approximate 1 asset per 50 miles of coastline); including
  - water levels,
  - wave heights and directions as well as meteorological conditions up to 60 nm offshore to support new high resolution (gridded) forecasts for the Coastal Waters
- Stream gauges for discharge in key major riverine systems.

#### **4.15 PRODUCT AND SERVICES: Regional Virtual Water Level Network**

Using the NECOFS model, create and calibrate virtual tide/water level observation points to record and present predicted and historic data. These virtual stations will serve to address regional gaps in coverage where adding additional sensors is impractical. Locations to be verified/corroborated by the deployment of short-term water level gauges in a manner designed to reduce overall variance in modeled output.

#### **INFORMATION REQUIREMENTS:**

- Surface currents (hourly; HFR - region wide at 6 km resolution, higher resolution for targeted areas of risk, buoys and drifters)
- Surface conditions (hourly; ideally dispersed region wide to minimize model uncertainties - an example density would approximate 1 asset per 50 miles of coastline); including
  - water levels,
  - wave heights and directions as well as meteorological conditions up to 60 nm offshore to support new high resolution (gridded) forecasts for the Coastal Waters
- Stream gauges for discharge in key major riverine systems.

#### **4.16 PRODUCT AND SERVICES: Regional Sea Level Rise Inundation Simulator and Viewer**

Develop, using currently available and soon-to-be-delivered high-resolution elevation/bathymetric data and regional water level data, a regional approach to present sea level rise simulations beyond basic “flat-water” or “bathtub” approaches. This will take into account off-shore/on-shore water sources (coastal and riverine hydrology/hydrography) and interactions with coastal features (hardened structures, barrier beaches, etc.) to provide a more accurate and functional representation of how changes in water levels will affect the coastal landscape of both the built and natural environments.

#### **INFORMATION REQUIREMENTS:**

- High resolution topographic elevation data;
- Bathymetric data;
- Regional oceanographic water level data (observational and modeled output)
- Stream gauges for discharge, water levels in key riverine systems.

## 5. INTEGRATED PRODUCTS

### **Issue 5.1: Northeast Ocean Data Portal to Support Coastal and Marine Spatial Planning**

*The 2010 U.S. National Ocean Policy calls for regional-scale coastal and marine spatial planning (CMSP) supported by a robust data management system containing coastal and marine scientific datasets and products. CMSP is a collaborative process dependent on access to a wide range of data on environmental, socioeconomic and regulatory parameters. However, many of these data have been inaccessible and scattered among different providers. In response, the Northeast Ocean Data Portal (Portal); a decision support and information system for managers, planners, scientists and industry; was developed to assist CMSP efforts for the northeast region from the Gulf of Maine to Long Island Sound. The Portal working group is endeavoring to enhance access to data, interactive maps, tools, and other information needed for decision making related to ecosystem-based management, offshore energy siting, commercial fishing, biological and habitat concerns, vessel traffic, avifauna, and ocean uses. The primary CMSP audience includes regional managers, ocean stakeholders and technical staff, although the information is useful in other ocean management and industry contexts.*

#### **5.1.1 PRODUCTS AND SERVICES: Support regional-scale CMSP through development of integrated data products**

##### **INFORMATION REQUIREMENTS:**

**Access-** Current, credible and comprehensive data are only useful if people have ready access. The process of CMSP requires efficient access to multiple, concurrent data streams and products from widely disparate sources. The Portal is being developed as an integrated data network aimed at making pertinent information accessible for all ocean stakeholders. There is a critical need to acquire, catalogue, analyze, and develop datasets that will inform decision making, support research, and provide necessary data for advanced models and tools that can be used in the planning process. The informational requirements for the Portal are divided into four dataset categories: Administrative and Regulatory Boundaries; Ocean Uses; Biological Resources; and Physical Oceanography. The conceptual approach to Portal development has been based on: 1) the identification and collection of priority datasets (as identified by regional managers); 2) the provision of raw data to potential consumers for analysis and product development; 3) the development of data products and tools specifically for CMSP; and 4) the continued maintenance of Portal datasets and products, while encouraging data providers to serve out and maintain their own dynamic products.

**Administrative and Regulatory Boundaries** – Administrative and regulatory boundaries comprise a significant component of the data layers associated with CMSP, as they serve as the primary boundaries for government activities and as guides for the regulation and development of coastal and ocean resources held in the public trust. The initial development of these policy layers focuses on understanding various levels of local, state and federal marine jurisdictions, the designation of coastal barrier resources systems and

an understanding of permitting areas like the outer continental lease blocks. Following the development of these initial administrative datasets, there is a need to maintain existing datasets, to identify and develop additional datasets (i.e. additional marine jurisdictions, and federal and state marine protected areas), and to continue to explore the various administrative and regulatory policies pertinent to spatial representation and CMSP.

**Ocean Uses** – Ocean uses refer to the management of traditional and emerging uses of ocean and coastal resources. Data layers under this category include, among others, existing or proposed utilities and infrastructure, industrial facilities, navigation and transportation corridors, recreational activities and commercial fishing. The presence of these datasets on the Portal is designed to aid in the characterization and management of human use within the northeast. Human use, socio-economics and indicators of preference for resource utilization represent a category of spatial datasets that have historically been under developed or non-existent. While significant datasets have been identified and developed to represent these uses, additional dataset development is essential to characterizing the utilization of and dependence on ocean resources and services. There is a further need to ensure the continued collection and serving of these datasets to assist with these characterizations. To date, the following datasets have been identified, are on the Portal and require continued maintenance:

- Utilities and Infrastructure: permitted Cape Wind area; LNG sites; and submarine cables
- Industrial: regulated facilities; and disposal sites
- Navigation and Transportation: wrecks and obstructions; aids to navigation; unexploded ordinance locations; unexploded ordinance areas; anchorage areas; shipping channels; and large vessel traffic from automated identification systems (AIS)
- Commercial Fishing: NMFS vessel trip report products; marine farms; and NMFS vessel monitoring system product

In addition to maintaining the datasets already on the Portal, there is a critical need to obtain and develop new datasets. Priority datasets identified by the Portal working group and regional managers include, but are not limited to: recreational boating and fishing; cultural and historic areas; demographics information; submarine cables and pipelines; energy facilities; military hazard and restricted areas; recommended shipping routes; port facilities; aquaculture sites; disposal sites; power transmission pathways; hunting areas; beach use and swimming designations; ecotourism and scenic value; aids to navigation; and anchorages.

**Biological Resources** – Biological resources provide an understanding of where various ocean and coastal habitats are located, and the location of these resources aids in the analysis of marine avian, mammal and fish species distributions, as well as species habitat needs and stresses. To this point, a number of these datasets have been developed and identified for the Portal, although these datasets are underrepresented and there is significant data collection needed to guide the development of new products and tools for biological resource analysis in a CMSP framework. Continued maintenance of existing datasets is also needed to accurately characterize species distributions, resilience and dependence on ocean and coastal habitats. Long-term planning involves the engagement of

agencies collecting these data and encouraging them to provide products for CMSP at various time scales. Currently there are significant gaps in habitat and species composition data that should be developed for CMSP applications in the northeast. The Portal working group has prioritized the development of the following datasets: Wetlands habitat classifications; Essential fish habitat designations; Shellfish habitat/beds; Updates for habitat areas for specific fish species including Atlantic Cod and Herring; Benthic habitat characterizations; Bird habitat and nesting sites; Cetacean critical habitat and sighting information; Submerged aquatic vegetation; Primary production areas; Parks, reserves and sanctuaries; Ecological function/service classifications; and NMFS habitat areas of particular concern.

**Physical Oceanography** – Oceanographic modeling can provide valuable information for decision makers, such as understanding local and regional currents that help dictate habitat type. The Portal currently contains access to oceanographic time series data provided by NERACOOS buoys and tide stations, as well as data products characterizing current velocity, bottom shear stress and wind speeds. Additionally, geologic and bathymetric datasets such as depth contour, shoreline position, sediment grain size, and seabed form are available. However, in many cases, more comprehensive, higher resolution, and broader geographic data products are required to support ocean management. The Portal is designed to continue data and tool development by leveraging existing oceanographic data collection efforts and modeling approaches to compile raw data and create new spatial products, such as the effort to develop hindcast data products from the NeCOFS model that provides forecasts for the region. The portal will continue to provide access to raw oceanographic and geologic data from NERACOOS and its partners and develop data products specifically for CMSP, but significant investments are needed to further develop the tools and analyses required to make these data available.

### **5.1.2 OTHER PRODUCT AND SERVICES: Functionality and decision support tools for CMSP**

#### **INFORMATION REQUIREMENTS:**

**Functions to support and enhance data accessibility** – A number of simple functionality enhancements are needed to assist with the demonstration, digestion and dissemination of the various datasets catalogued on the Portal. These enhancements will also further the development of additional data products and tools for ocean and coastal resource managers. The functionality enhancements identified as priorities by the Portal working group are:

- Enhanced data search capabilities
- Enhanced data extraction capabilities
- Web mapping service enhancements
- Enhanced geoprocessing for both data hosted by the portal working group and data served from outside sources
- Development of a media viewer to enhance access to scientific reports, underwater video, seafloor imagery, spreadsheets, and other non-traditional geospatial data
- Password protection for sensitive layers and for different levels of user access

**Advanced tools to support decision making** – Accommodating new ocean uses in a seascape that already includes multiple competing uses is of significant concern to practitioners of CMSP. The practical application of data sources to assist in the development of these new uses and their associated infrastructure requires: 1) efficient access to comprehensive data; and 2) tools to rationally weigh the social, biological and economic tradeoffs between competing interests.

Investment in these tools is critical to support stakeholders, managers and policy makers in identifying vulnerable habitats, gauging ocean use compatibilities and running multiple scenarios for potential siting choices to ultimately achieve the greatest overall social and economic benefit.

**Tools to extract time series from modeled data** – There are currently no publicly available mapping application tools that pull modeled time series data into an easily accessible viewer format. The potential benefit of these tools is the ability to generate high resolution data products for a user defined time period and geography. Recent technological and oceanographic modeling advancements have made the development and dissemination of these types of tools and databases possible. Modeled outputs are key foundational data for CMSP with numerous applications, including identifying and classifying oceanographic conditions, habitats and siting new ocean uses, such as renewable energy. The development of extraction tools for modeled time series data will have broad ranged applicability to all sectors of ocean resource management, as these data represents the conceptual foundation for developing ecological indicators. These indicators assist managers in understanding changes occurring throughout specific habitats or resource categories, and, over time, to adopt adaptive management strategies for dealing with resource resiliency, impacts and mitigation. High resolution time series data, such as for oceanographic parameters, will be broadly applicable, with potential implications towards alternative energy facility siting, marine mineral extraction, ecosystem function valuations, and habitat characterizations among others analyses.

**Site suitability assessment tools** – There are numerous use compatibility analyses available to inform CMSP but available assessments are typically for general demonstration purposes and therefore not specific to ocean uses and resources for a given area of interest. Assessing the potential compatibilities between uses, and among uses and resources, is an important step towards understanding and informing the tradeoff decisions that are inherent in CMSP. Initially, these assessments begin with technical and economic feasibility analyses aimed at narrowing potential siting areas, avoiding undesirable areas based on environmental variables, and minimizing costs associated with development. The development of first stage site suitability tools will allow decision makers to interactively screen locations most desirable for various activities based on their environmental and economic preferences. These potential siting areas can then be compared with existing uses and resource distributions to begin tradeoff discussions.

**Stakeholder collaboration and data acquisition tools** – The ability to synthesize data collection from practitioners in the field with management analysis and planning is essential to understanding the distribution and resource use of traditional ocean uses and industries. The functionality of these tools is often straight forward and provides stakeholders with the ability to inform the planning process by identifying specific areas on

a temporal and spatial scale that are essential to the economic sustainability of their trade. This temporal and spatial analysis takes the form of identifying areas that are not only historical or suitable for immediate/short-term use, but also areas that may meet the long-term spatial needs and resource demands of an expanding industry or practice. Existing uses can then be compared with emerging and potential future resource characterizations and requirements to demonstrate various management scenarios, and advance stakeholder collaboration towards the development of planning alternatives. Further development of these tools is necessary to characterize the human use of ocean resources, inform CMSP and provide individuals with business dependent on ocean resources an avenue for affecting plan development.

**Ecological valuation, vulnerability and cumulative impact tools** – Ocean ecosystems are available for multiple activities and, although no single use may be significant in and of itself, cumulative impacts can have substantial effects. To determine the value of specific habitats, the vulnerability of those habitats to specific uses and assess the effects of cumulative impacts, it is necessary to integrate ecosystem and habitat data with spatial and temporal human use data. Development of a standard, scalable and transferable methodology for understanding habitat location, the value of that habitat and/or its associated resources, and the vulnerability of each habitat type to impacts from current or emerging uses is an important component of CMSP. The results of these analyses can be viewed at different spatial and temporal scales, depending on the level of detail in the data. Impacts associated with human uses and vulnerability analysis provide a foundation for other decision support tools such as ecosystem service tradeoff analysis because they are based on an analysis of indicators of ecosystem health. A standardized classification of ecosystems/habitats is required to make meaningful comparisons of an ecosystems' vulnerability to various human uses.

**Scenario analysis and tradeoffs tool** – Marine ecosystems provide essential services that people value and benefit from, including: food, recreation, jobs, transportation, wildlife viewing and opportunities for rest and relaxation. When conflicts arise over which services are more important (e.g. when whale migration routes cross cost-effective shipping channels), how do managers make informed decisions? Because these are value-based decisions, visualizing and discussing potential tradeoffs is vital to effective ecosystem-based CMSP. Ecosystem service tradeoff models integrate biological, physical, social and economic information to enhance informed decision making, and are essential tools for integrated, ecosystem-based CMSP. Several tradeoffs models and tools are currently in various stages of development. The Portal should build off these models by integrating their outputs (data and visualizations) as well as by providing direct and dynamic access to select functionality. Further work is needed to determine the appropriate use of these tools in the Portal and to develop the data and analyses necessary to define the extent, and social and economic value of key ecosystem services. Current ecosystem and socio-economic data may initially limit tradeoff modeling, but development and use of these models in the planning process will inform the prioritization of data needs.