<u>Northeast Ecosystem Framework</u>

The Northwest Coastal Monitoring Workshop geographic region extends from Long Island Sound (LIS) northwards through the Georges Bank (GB)/Gulf of Maine (GOM) region, encompassing the coastal watersheds, estuaries and near coastal waters (within the 3-mile territorial sea boundary), the offshore Exclusive Economic Zone (3-200 mile offshore region), and far field oceanic forcing/migration of biota. The Ecosystem Framework for this extensive geographic region will focus upon the critical open water/benthic habitats for microbes, plants and animals; key environmental factors; and important anthropogenic impacts within this system. The Northwest Atlantic Coastal Monitoring Program to be identified at the workshop would combine existing local/state/federal monitoring programs with identified data gaps to measure the trends in the important biological, chemical, and physical variables that define the status of this ecosystem and converts this data into information useful to managers. Process oriented research is an essential supporting requirement to establish cause and effect relationships between the monitored state variables of the system. Various types of multivariate statistical analyses and mathematical modelling approaches can be used to establish relationships between trends in the monitoring data and to identify gaps in our understanding of the ecosystem processes. The legislative mandates of the different management agencies and their associated information needs for decision making also play a strong role in the data collection programs for existing monitoring programs. Even though these management information needs and the associated regulatory requirements will not be discussed in the Ecosystem Framework, it is important to realize that the biota migrate between jurisdictional boundaries and that human impacts on the biota and their habitats can be transboundary in extent as well.

For the offshore region the large scale hydrography is linked to the surface circulation patterns where the cold, relatively fresh seawater from the Gulf of St. Lawrence/Labrador Current area mixes with the warmer, more saline offshore slope water in the Northeast Channel of the Gulf of Maine (GOM), giving rise to a counter-clockwise coastal current in the GOM and seasonally stratified (three layer) water in the deep central basins of the GOM. A portion of the GOM gyre feeds into the clockwise circulation pattern around Georges Bank where the shallow water is mixed by tidal currents and supports the high primary and secondary productivity of this bank, making it a historically important fisheries region. Another portion of the Gulf of Maine Coastal Current sweeps around Cape Ann into Massachusetts Bay and exits around Cape Cod moving southward (along with water from GB) into the Southern New England (SNE)/Middle Atlantic Bight (MAB) regions. This southward flow can alter the shelf/slope water boundary within the MAB which has influences on the bottom water temperature and salinity patterns and can change the distribution of fish/mobile shellfish species either seasonally or interannually. Thus both the shelf and slope water masses exhibit a general north to south flow and the North Atlantic Oscillation (atmospheric pressure gradient between Iceland and the Azores) can influence volume of cold, relatively fresh seawater entering the GOM from the north.

The coastal river discharge can influence the temperature and salinity patterns in estuaries and near coastal waters. The loading of nitrogen (N) and/or labile organic carbon (OC) can lead to low dissolved oxygen (DO) levels, resulting in hypoxia/anoxia in these systems during summer stratification. Coastal eutrophication from excess nutrient enrichment can also lead to the loss of submerged aquatic vegetation (SAV) and create anoxic soft sediments which are important habitats for nekton and benthic infauna/epifauna. The coastal rivers entering the GOM also appear to play an important role in generating the harmful algal blooms which cause shellfish bed closures to the south as a result of the accumulation of the paralytic shellfish poison (PSP) toxin. For the GOM as a whole the major input of N comes through the Northeast Channel and not from the coastal rivers or ocean discharge pipes from sewage treatment plants (such as the Massachusetts Water Resources Authority's ocean outfall). Also the wide scale GOM circulation pattern can influence the DO levels in the bottom water even at the MWRA outfall discharge point, so that many of the river discharges in the GOM exert only local effects.

These localized water quality impacts can exert an important influence on the migration of anadromous/catadromous fish species between the ocean and coastal waterhsheds, as well as impacting biota and habitats within the estuaries themselves. The Southern New England (SNE) coastal waters lie near the biogeographic boundary at Cape Cod and thus has seasonally varying biota from the Virginian and Acadian Provinces, with fish/motile shellfish species exhibiting either north/south or inshore/offshore migration patterns in response to large seasonal changes in temperature. The Hudson River Estuary has a strong influence on the water quality, benthic habitat quality, and DO levels in the water column within western Long Island Sound (LIS). Further offshore in the MAB the slope/shelf water boundary and strength of seasonal stratification influences the bottom water temperature/salinity/DO concentrations and these are influenced by the regional hydrographic regime rather than the coastal rivers. Shifts in the MAB shelf/slope boundary influence the extent of the cold pool bottom water on the outer shelf.

Table 1. Phytoplankton Biomass and Primary Production on Northeast Continental Shelf (O'Reilly and Zetlin, 1998)

Shelf Region	Peak Biomass (ug/l Chlor. a)	Annual Production (gC/sq.m yr)
Mid-Atlantic Bight		
Coastal	4-16 (Jan-Feb)	505
Mid-Shelf	2-4 (March-April)	300
Outer Shelf	1-2 (March-April)	310
Georges Bank		
Well Mixed	8-16 (March-April)	455
Stratified	1-2 (April-May)	285
Gulf of Maine		
Nearshore	1-8 (April-May)	260
Deep Basins	1-4 (May-June)	270

Based on Marine Resources Monitoring, Assessment and Prediction Program (MARMAP Program, 1977-1988)

The phytoplankton biomass on the Northeast Continental Shelf follows seasonal temporal and spatial patterns that reflect stratification of the water column, increases in the light intensity, and the introduction of nitrogen into the surface waters from depth during the well mixed periods. The peak chlorophyll a biomass reflects the winter-spring bloom which proceeds in the Mid-Atlantic Bight (MAB) Region from the inshore in January/February to the shelf edge in April/May. In the Georges Bank (GB) Region the winter-spring bloom proceeds from the well mixed area in February/March to the offshore, stratified area in April/May. In the Gulf of Maine (GOM) the winter-spring bloom moves from the nearshore area in February/March to the deep basins in April/May. The fall bloom in September/October in the GOM is often more wide spread than the winter-spring blooms which are dominant in the MAB and GB regions. In the southern portions of the shelf the winter-spring bloom is dominated by diatoms and during the summer stratification period a deep chlorophyll maximum often develops above the pycnocline. As one moves northwards on the shelf there are often a diatom dominated portion of the winter-spring bloom followed by a dinoflagellate dominated portion. During the summer stratification period when recycled nitrogen fuels the primary production, phytoflagellates dominate the plankton. There also tends to be an inshore/offshore gradient in phytoplankton composition from diatoms to phytoflagellates. The MARMAP surveys shown in the Table 1 are based upon cruise transects, but the Coastal Zone Color Scanner (CZCS) and Sea-viewing Wide Field-of-View Sensor (SeaWiFS) satellites can be used to convert ocean color into estimates of the chlorophyll biomass in the upper layer of the water column.

Table 1 shows the spatial patterns in primary production with high values in the nearshore MAB and GB mixed region, with lower values in the GOM and at the shelf edge. The seasonal changes in the phytoplankton abundance/composition along with the levels of primary production in different regions are critical in determining the seasonal abundance/composition of the zooplankton community after a shore temporal lag and the benthic community abundance/secondary production following a longer lag period. The extend to which the biomass/production of pelagic, herbivorous fish and marine mammal species is controlled by these bottom-up zooplankton prey availability factors is not well known, since top-down selective predation by piscivores also plays a role in structuring the herbivore community. Certainly the mixed areas on Georges Bank with high primary production also have high secondary production for commercially harvested fish species.

Long Island Sound (LIS) is 145 km long and 17 km wide at its maximum extent with a mean depth of 20 m. It is open at the western end to the East River/Hudson-Raritan Estuary and at its eastern end to the ocean through the Race/Block Island Sound region. Since Long Island is a terminal morraine, the bottom of LIS has a number of sills and complex bathymetry which interacts with the tidal currents and freshwater input from the Connecticut coast (72% of the freshwater discharge emanates from the Connecticut River which is near the Race) to produce a complex hydrographic flow pattern with vertical salinity gradients and east/west jets along the northern and southern coasts. Given this complex hydrography, the residual currents (remove tidal and meteorological forcing focusing on net gravitational current) may provide the best estimate for the transport directions for the dissolved and suspended sediment-attached pollutants in the sound. The seasonal stratification of the water column in the summer has important implications for the development of hypoxia in the bottom waters in the Western and Central

Basins and plays a role in the annual cycle of phytoplankton/zooplankton. The influx of anthropogenically generated nutrients (from wastewater treatment plants in the western basin) generate surface phytoplankton blooms (and dissolved oxygen supersaturation). When coupled with the development of the pycnocline and respiration of particulate organic matter in the bottom waters, the dissolved concentrations are reduced below 3 mg/l which can have negative effects on the biota. In 1987 anoxia (0 mg/l DO) developed in the bottom waters. The other major anthropgenic problem in LIS is toxic contaminants with riverine loading and wastewater treatment plants being major sources. Most of the sediment toxicity and impacted benthic communities appear to occur in the estuaries and not in the sound itself.

Long term studies of satellite ocean color data suggests that there have been changes in the peak spring and fall phytoplankton blooms and changes in the timing of the fall bloom. Field studies have suggested that the Tidal Mixing Paradigm may be operative in which tidally induced turbulence and water depth combine to produce a mixed water column inshore, separated by a transition zone from a stratified water column further offshore. The primary production tends to be highest in the transition zone with peak biomass above the pycnocline in the stratified waters and distributed throughout the water column in the mixed layer. Diatoms tend to dominate the mixed region, while dinoflagellates/small flagellates are the major phytoplankton in the stratified region. For the zooplankton a boreal assemblage (Temora longicornis, Acartia hudsonica, Pseudocalanus) dominates at temperatures below 19N C, while a warm water assemblage (Acartia tonsa, Oithona similis, and Paracalanus crassirorostris) dominates from mid- summer into the early fall. There is also an inshore (Acartia, Centropages, Cladocera, and meroplankton) to offshore (Metridia and Calanus) gradient in the zooplankton composition. The relationship between phytoplankton composition/nutritional value and the resulting egg production, grazing, and growth of herbivorous zooplankton is not well understood, even though there is an obvious seasonal coupling within the planktonic community. It is thought that the diatom-copepod-fish larvae food chain is more effective in supporting fish populations than the flagellate-protozoan/micro-zooplankton-jellyfish food chain.

In the early 1980's there appeared to be a regime shift in the offshore fish community on GB from demersal species (cod, haddock, yellowtail flounder) to pelagic species (Atlantic herring and mackerel) which appears to be a consequence of commercial fisheries harvesting. Even though many of the pelagic fish species are planktivores, there does not appear to have been a decrease in the zooplankton abundance levels or changes in the species composition. Shifts in the pelagic planktivorous fish composition from sand eels to herring caused changes in the distribution patterns of fish-eating cetaceans and changes in the diets of piscivorous fish species. The abundance levels of Calanus finmarchicus appear to play a role in the breeding success of planktivorous cetaceans, such as the North Atlantic right whales. Changes in the abundance/ species composition of the zooplankton community has been related to the distribution patterns of baleen whales. There are suggestions that the NAO cycle pattern may influence the distribution patterns of cetaceans, even though the exact mechanisms are not well understood (may be mediated through the zooplankton). There are also suggestions that the NAO cycle can influence the distribution patterns/abundance of the omnivirous/carnivorous groundfish, even though the mechanisms are also poorly understood.

Due to shifts in the species targeted by the commercial fishing industry there has been a shift in the composition of the fish community over time from demersal species to elsamobranchs to pelagic species. This human activity has yielded much greater impacts than the more subtle impacts of climate change on bottom water temperature and its biological consequences. The overharvesting of Apex predators and piscivorous fish species has changed the fish species composition and changed the predator/prey interactions within the system which has implications on the biodiversity within the ecosystem.

The benthic infauna and epifauna are influenced by sediment type (mud/silts, sand, boulder/cobble, etc.); depth; three dimensional biological/geological structure on the bottom; temperature/salinity/DO concentrations; levels of bottom trawling fishing activity; etc. The influence of the decline in the demersal fish species abundance on the predator/prey interactions with the benthic fauna is not well known, but in areas closed to commercial fishing the scallop populations have increased in abundance and size. The three dimensional structure of the epifauna on the bottom has also recovered in the areas closed to commercial fishing, especially on hard bottoms. There are been few long-term monitoring programs on the composition/abundance of benthic infauna/epifauna and even less is known about the meiofauna/microfauna. Since most of the benthic biodiversity lies within these smaller size classes and a significant fraction of the secondary production occurs within these size classes as well, our views on the benthic ecosystem and its coupling to the overlying pelagic ecosystem are likely distorted. Studies in the water column on the microbial loop community suggest that it may form a parallel food web to the grazing food chain from diatoms to zooplankton to zooplanktivorous fish/cetaceans to piscivorous fish and cetaceans. The same situation may apply to the macrobenthic infauna/epifauna in relationship to the meiofauna/microfauna. Thus we lack a basic understanding of the habitat requirements and trophic importance of these small sized organisms, both in the benthos and in the water column.

Table 2. Benthic Macrofauna on the Northwest Atlantic Shelf and Slope (Sherman et al., 1988)				
Biotic Component	*Gulf of Maine*	*Georges Bank*	*Southern New England*	
			Shelf	*Slope*
Annelida	292;35	546;28	531;22	149;53
	16;12	**8;3**	**30;11**	**4;22**
Mollusca	306;37	47;2	244;10	58;20
	32;25	**80;34**	**171;64**	**1;6**
Arthropoda	150;18	1052;54	1386;58	22;8
	2;2	**10;4**	**17;6**	**0.1;0.6**
Echinodermata	43;5	121;6	123;5	19;7
	56;44	**102;51**	**36;14**	**10;52**
Key: Density: no/m^2 ; % composition **Biomass: wet-weight biomass g/m^2; % total**				

If one examines the broad scale distribution of benthic macrofauna on the Northwest Atlantic shelf and slope (Table 2), certain patterns emerge in regards to the mean density (numbers/square meter) and mean biomass (mean wet-weight in grams/square meter) within the different sub-regions (Gulf of Maine or GOM, Georges Bank or GB, and Southern New England or SNE Shelf and Slope). The mean density is higher on GB and in SNE than in the GOM, and in SNE the shelf abundance exceeds that on the slope. Annelids and arthropods dominate the GB and SNE Shelf abundance, while molluscs are relatively more numerous in the GOM. The biomass pattern exhibits a dominance of molluscs and echinoderms on the shelf in all three regions, while annelids and echinoderms dominate the slope mean biomass. The biomass density and mean biomass of the benthic macrofauna generally follows the primary productivity in the overlying waters.

Table 3. Benthic Macrofauna Composition and Sediment Type in the New England Region (Sherman et al., 1998)				
Biotic Component	***Gravel***	***Sand***	***Sand-Silt***	***Silt-Clay***
Annelida	505;33	558;25	310;30	232;32
	16;9	**15;7**	**26;15**	**16;19**
Mollusca	84;6	99;5	276;27	354;49
	94;52	**121;49**	**74;43**	**18;21**
Arthropoda	712;47	1336;61	276;27	34;5
	20;11	**12;5**	**7;4**	**0.6;07**
Echinodermata	23;2	95;4	104;10	65;9
	6;3	**88;36**	**37;22**	**43;50**
Key: Density: no/m^2; % composition **Biomass: wet-weight biomass g/m^2;% total**				

Table 3 shows the distribution of benthic macrofauna in the New England region in relationship to sediment type. The gravel and sand bottom abundance is dominated by annelids and arthropods, while molluscs become more dominant in the softer (sand-silt and silt clay) bottoms. If one examines the mean biomass distribution, molluscs and echinoderms are dominant in sand and sand-silt habitats, while the dominants in gravel are molluscs and in silt-clays one finds more echinoderms. Annelids represent a greater portion of the biomass in sand-silt and silt clay habitats. This shows that the bottom habitat type and primary productivity in the overlying water are key factors influencing the biomass and abundance of the benthic macrofauna. There has not been a region-wide survey of the benthic macrofauna distribution for over twenty years, so that this is an existing data gap.

To illustrate the influence of depth, organic carbon loading, and sediment type on the macrobenthic invertebrates, the benthic assemblages in the Gulf of Maine (GOM) are discussed. The nearshore shallow, assemblage (0-50 m) exhibits the greatest abundance of individuals and has over 500 species (high biodiversity) due to a variety of sediment types and high organic loading from coastal rivers/estuaries, relatively high phytoplankton production, and input of detritus from coastal macrophytes. Further offshore under the Maine Intermediate Water mass is the boreal mud community which has fine sediments which contain a greater percentage of deposit feeders, with the infauna abundance being 25% lower than that inshore due to the reduced organic carbon loading. Species diversity is still high in this assemblage. Characteristic megafauna species include the sea pen, Pennatula aculeata, and the cerianthid anemone, Cerianthus borealis. On Fippenies and Jeffrey's Ledges one finds sand and gravel habitat (due to current winnowing of the sediments) underlying the Maine Intermediate Water and this community is dominated by filter feeders such as sea scallops (Placopecten magellanicus), a variety of sponges, and the polychaete, Myxicola infundibulum. On Georges Bank juvenile Atlantic cod are often found in these gravel areas because their coloration mimics that of the surrounding habitat, thus protecting them from predation. Also found under the Maine Intermediate Water is the rock ledge community which is dominated by large colonial filter feeders (blue mussels, barnacles, ascidians, sponges, bryozoans, etc.) and other species (crabs, sea urchins, starfish, etc.) characteristic of hard bottoms. Much of the biodiversity in this system comes from the small epibionts attached to the large colonial filter feeders. Depending upon the available organic carbon loading these communities may or may not be limited by the space available. In portions of the Wilkinson and Jordan Basins one finds the boreal-slope transition community in muddy substrates or with a muddy veneer overlying sand and gravel. In this area the Maine Bottom Water mixes with the Maine Intermediate Water and the depositional nature of these deeper basins gives rise to the mud and clay sediment type. Characteristic fauna in this assemblage include the brittle star, Ophiura sarsi, and the tube-dwelling amphipod, Erichthonus sp. The deepest parts of these basins are characterized by the upper slope assemblage and the sediment type is sand mixed with fine particles and gravel. Characteristic members of this assemblage include the large, foraminiferan, Bathysiphon, and several deepwater isopods. This assemblage is found more commonly outside of the GOM on the upper slope and has low organic carbon loading levels/reduced abundance values for the macrobenthic invertebrates present.

In regards to human impacts on the offshore ecosystem (EEZ) it appears that commercial fisheries harvesting is the major anthropogenic stressor. For whales ship strikes and interactions with fixed fishing gear are important human stressors, while food availability is an important source of natural variation. Sea turtles, bottlenose dolphins, and harbor porpoises are also impacted negatively by fixed fishing gear (gill nets, long lines, lobster pots, etc.). Loss of sea turtle breeding beaches outside of the Northwest Atlantic and mortality during harbor dredging operations outside the region are also important sources of human-induced mortality. Since many cetaceans and sea turtles migrate into our region from elsewhere, habitat degradation/loss, commercial fishing interactions, ship strikes, targeted direct harvest, etc, can lead to anthropogenic-induced mortality. Migratory fish species, such as summer and winter flounder, striped bass, bluefish, etc, are also influenced by habitat degradation/loss and commercial/ recreational harvesting outside of our region, but the relative importance of these human sources of mortality are only understood in a qualitative sense. The same can be said for the influence of changes in offshore Essential Fish Habitat (EFH) on the productivity of fish species. Thus even though there is a well understood relationship between nitrogen enrichment and loss of eelgrass beds and bay scallops within estuaries, the same can't be said for the relationship between bottom trawling and loss of benthic three-dimensional structure and cod/haddock breeding success. Thus the focus of offshore fisheries management is on direct harvesting of the targeted species and the bycatch of nontarget species in order to derive target fishing mortality rates and maximum sustainable biomass of adults. The indirect effects of fisheries harvesting on the biodiversity of the offshore ecosystem and on EFH on the bottom are only understood qualitatively.

Table 4. Level of Knowledge Matrix For the Gulf of Maine				
Region/Category	**High**	**Moderate**	**Poor**	**None**
<u>Watersheds</u>:				
Biotic Species		X		
Water Transport			X	
Water Quality		X		
Habitat Quality		X	?	
Offshore Linkages			X	
Onshore Linkages			X	
<u>Estuaries</u>:				
Biotic Species		X		
Water Transport			X	
Water Quality		X		
Habitat Quality		X	?	
Offshore Linkages			X	
Onshore Linkages			X	
<u>Coastal Ocean</u>:				
Biotic Species		X		
Water Transport			X	
Water Quality		X		
Habitat Quality			X	
Offshore Linkages		X		
Onshore Linkages			X	
<u>Offshore Ocean</u>:				
Biotic Species		X		
Water Transport		X		
Water Quality		X		
Habitat Quality			X	
Offshore Transport			X	
Onshore Transport			X	
<u>Far Field Ocean</u>:				
Biotic Species			X	
Water Transport			X	
Water Quality			X	
Habitat Quality				X
Onshore Linkages			X	

For the Gulf of Maine (GOM) Table 4 qualitatively evaluates the level of knowledge available from existing monitoring program and modelling/process-oriented research projects for 5 system components:

- Biotic Species: composition/relative abundance
- Water Transport: volume or flux
- Water Quality: biological and chemical
- Habitat Quality: association between biota and habitat types
- Offshore Linkages: biotic and abiotic
- Onshore Linkages: biotic and abiotic

As one moves from coastal watersheds to the offshore ocean, the available information on biotic species, water quality and habitat quality diminishes. The level of information on water quality appears to be better than that on water transport and habitat quality. Information on the functional value of habitat (Level 3 and 4 for NMFS Essential Fish Habitat delineation) is missing and habitat quality is defined on the basis of association with particular biota or qualitative changes in the abundance/distribution of biota following habitat loss/degradation (Level 1 and 2 for NMFS EFH). The linkages between different regions in the onshore/offshore spatial gradient is poorly understood and needs process-oriented research and modelling to elucidate the net biotic/abiotic fluxes of energy and materials. There are numerous biological and chemical measurements used to operationally define water quality, but the relationship of these parameters to biological integrity is only understood qualitatively. Most of the water quality focus has been on nutrients, toxic chemical contaminants, and microbial pollutants (bacteria, viruses, and harmful algal blooms). In the future ocean observing systems and satellite information may fill some of the data gaps that exist from the present shipboard monitoring programs, even though the latter will be needed to provide sea truth data.

We lack the pre-requisite understanding of the physical/biological/chemical interactions within the offshore ecosystem and the coupling between the far field ocean forcing/migration and inshore coastal watersheds/estuaries with the EEZ. This has prevented scientists from developing predictive models of the offshore ecosystem and we employ models that are limited in spatial/temporal extent to support management. For example, fishery stock assessment models focus on the fishing mortality from direct harvesting and lump all other sources of mortality under natural mortality. Even though there is a lot of scientific discussion on using an ecosystem approach to manage fisheries, there is no operational understanding of what this means on the ground. Even conventional fisheries management approaches suffer from the data rich, but information poor syndrome and there are significant time lags between gathering the data and converting it into information that can be used in the management process. This situation is probably not unique to fisheries management. Thus management information needs drive the monitoring programs, rather than a basic understanding of the critical couplings within the ecosystem and how these are likely to be impacted by a plethora of potential anthropogenic stressors that will accompany increased developmental activities within the EEZ (wind farms, aquaculture, mineral extraction, etc.). A regional monitoring program will need to address these emerging issues and not just those like commercial fishing which are our current focus.

Selected Background Reading:

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