The Health of the Gulf of Maine Ecosystem: Cumulative Impacts of Multiple Stressors

Workshop Report

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Gulf of Maine Circulation Modeling: Workshop Proceedings, RARGOM Report 94-1, Braasch, E. editor

Gulf of Maine Habitat: Workshop Proceedings, RARGOM Report 94-2, Stevenson, D. and Braasch, E. editors

Table of Contents

Foreword

The Gulf of Maine is an internationally important economic region. Bordering the United States and Canada, the region is a resource of inestimable value: it supports commercially important species of fish and shellfish, aquaculture, tourism, and recreation. Its coastal areas provide for residences and economies serving 3.6 million persons. Located between 41 and 46 degrees N latitude, and 71 and 65 degrees E longitude, the Gulf of Maine and its contained physical system, consists of watersheds, estuaries, and embayments, coastal waters and predictable hydrographic features, as well as the water columns and basins of the central Gulf of Maine. Generally, large areas of the Gulf remain relatively pristine and healthy. *Available data indicate, however, that the Gulf of Maine is increasingly being affected by anthropogenic stressors which have potentially synergistic and cumulative effects, as well as individual effects, not only in watersheds and estuaries, but in central areas of the Gulf.*

One hundred fifty years ago, the region was characterized by robust fisheries, developing economies and regionally uncontaminated habitats. Currently, important segments of the populations face an economic crisis linked to the exploitation of available resources and local habitat degradation. *Fisheries, introduction of contaminants of environmental concern from point and non-point sources, and habitat degradation and loss in the inshore, and fisheries and habitat degradation in the offshore regions, are the dominant stressors of the Gulf of Maine.* The inshore region is also subject to natural stressors, as well, that may exacerbate the effect of anthropogenic stressors.

Continued population growth and associated urbanization and industrialization in the watersheds leading to estuaries, embayments, and coastal waters, will be the principal factors determining the well-being of these waters in the future. Recovery of degraded waters and rebuilding of fisheries, marine mammal populations, other protected species, and their food webs, will depend greatly on an increased knowledge of linkages which exist between the various aquatic systems such as exist in the watershed, estuaries and embayments, coastal waters, and the central portion of the Gulf of Maine. Likewise, the numerous linkages that exist between the habitats (and degree of impact on habitats), food chains, fish stocks, and marine mammals must be better understood than is the case today.

Because components of the Gulf of Maine ecosystem are poorly known or not understood sufficiently, a conservative or precautionary management approach must be followed, so that managers can avoid the risk of making decisions with harmful, and potentially irreversible impacts on the ecosystem. As we enter the next century, there is increasing need for effective stewardship of resources while further knowledge of the region is acquired. Future generations should inherit a region where the resources have been conserved and are available through sustainable productivity. The individual concerns and interests of various elements of society must not be the sole principal determining factors, but must become a part of regional planning for the resources.

The Gulf of Maine must be understood and managed as a total and not as a series of separate entities bordered or divided by arbitrary geopolitical boundaries, if it is to be ensured of a sustainable productivity. To have effective management of the aforementioned resources will require that there be "fused geopolitical management" of these various components of the Gulf of Maine ecosystem. Just as anthropogenic activities, and certain environmental changes result in "fractured linkages" between various components of the ecosystem, the present situation--diffuse research and management attempts resulting from the legitimate concern of numerous government and non-government organizations--prevents effective scientific management of the Gulf of Maine.

In the near future, existing organizational resources must be used in a cooperative, coordinated scheme to carry out needed research and management. Entities presently exist in the

Gulf of Maine to conduct research, establish priorities for research and management, and conduct the necessary theoretical, field, and laboratory studies; these groups, given the resources, can provide the data and information essential to management.

The Gulf of Maine, its habitats and resources, and the various options for management and future legislation and regulation, must be described and promoted in educational institutions, and the media, so that the citizenry is fully informed and educated as to present and future conditions, especially in regard to the steps that must be taken to manage the overall system on an integrated geopolitical basis.

A scientific workshop was held from 18-20 September 1995 to assess the human-caused factors affecting the health and stability of the Gulf of Maine marine ecosystem and to identify research and management options to restore and/or maintain the environmental quality of the ecosystem. This report summarizes the working group deliberations on three topics: anthropogenic stressors, fisheries, and marine mammals/protected species. Full working group reports and plenary papers will be presented in the workshop proceedings, RARGOM Report 96-1 (scheduled for publication in spring 1996).

Executive Summary

by
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Major Factors Affecting the Overall Health of the Gulf of Maine Ecosystem

Below are the human-caused factors affecting the health and stability of the Gulf of Maine ecosystem and its constituent parts. Not surprisingly, results from the three workshop working groups (anthropogenic impacts, fisheries, and protected species/ marine mammals) were strongly correlated with the outcomes of plenary discussions. With the exception of migratory species, the major perturbations are internal, rather than external to the system, and can be grouped in the following categories:

- **Over fishing** and related impacts,
- **Contaminant introduction**, primarily in the near shore coastal zone (toxins, nutrients, and pathogens), but via atmospheric input as well,
- **Physical alteration and loss of critical habitat** especially for sensitive or key species (in riparian, coastal and offshore regions),
- **The effects of human activities on endangered or threatened species** such as right whales; (although these effects on endangered or threatened species may be of relatively minor significance to overall ecosystem dynamics, the effects on these populations are very important);
- **Factors external to the Gulf of Maine** which affect seasonally resident and resident populations (including atmospheric deposition, global warming, effects on migratory populations in other ecosystems or regions), and
- **Decision-making practices** which can best be characterized as based on local, site specific, short-term, crisis-oriented decision-making, need to be replaced by regional, long-term, information and risk based management.

Options

Based on the aforementioned understandings that were developed during the workshop, the following were deemed to be overarching issues and needs relating to future research, management, and educational activity in the Gulf of Maine:

Research

- Identify critical linkages between ecosystem components and subsystems and their sensitivity to cumulative and individual stressors. Significant advances have been made in understanding subsystems, but the ecosystem dynamics of the Gulf of Maine as a whole are poorly understood. A combination of field and modeling studies must be conducted at logistically feasible and manageable levels of effort.
- Use interdisciplinary research approaches, working to link cumulative and individual stressors of the system to their effects, (reflecting the strong gradient of anthropogenic stressors in the Gulf of Maine).
- Evaluate resilience (recovery from disturbance) of ecosystems and ecosystem components known to be affected by natural and anthropogenic stressors (response to multiple stressors) and establish predictable recovery(ies).

- Develop criteria to assess sensitivity of coastal embayments and estuaries from an interdisciplinary perspective of habitat change, contaminant introduction, fisheries harvesting, and physical and biological processes. Because embayments and estuaries are both directly or indirectly affected by anthropogenic activities in adjacent watersheds, linkages between any two such systems also need to be established.

Management

- Seek cost-effective solutions through increased integration of rigorous scientific assessment of the problems and potential solutions. There are numerous examples (case studies, for instance ocean disposal and its cessation in the New York Bight apex), where management decisions have resulted in measurable improvement in environmental quality.

- Develop and implement integrated management strategies encompassing the key or sensitive components of both the Gulf of Maine *per se* and its watersheds, to avoid loss or degradation of key components, disruptions of linkages, and collapsed ecosystems, and avoid the need for costly remedial actions in the future.

- Strengthen existing (1) water quality criteria (and create sediment criteria for significant toxins), and (2) enforcement activities to protect marine habitats and resources in the Gulf of Maine.

- Use scientifically sound, cost-effective actions to restore and protect environmental quality. Given existing knowledge regarding physical, biological and chemical processes in the Gulf of Maine this will require a comprehensive regional approach for success, which is based on interagency, inter institutional, and international shared efforts and accountability.

- Adopt a precautionary approach in the face of uncertainty or insufficient information.

Education and Information Sharing

- Increase public educational efforts, recognizing that communication between all users of the Gulf of Maine region's resources is crucial to the establishment and operation of effective conservation and management measures.

- A Gulf-wide data and information directory is needed, and it must be nurtured, supported, and used on an international, interagency basis. Types of information important to informal decision-making need to be accessible for general use, and include: research activities being conducted, data being compiled and archived by different organizations, and how those datasets can be accessed and used.

Discussion of the Major Factors

The following section provides a brief analysis of the major factors affecting the overall health of the Gulf of Maine ecosystem and its key components and *summarizes key ideas presented at the workshop for future activity* in these areas. These thoughts emerged from the three working groups gathered at the workshop (Anthropogenic Stressors, Fisheries Harvesting, and Marine Mammals/Protected Species) and subsequent discussions held by the workshop organizers and reviewers.

Fisheries Harvesting: Overfishing and related impacts

Fisheries harvesting is the dominant stressor of exploited resources in the offshore region of the Gulf of Maine, resulting in changes in abundance and species composition of both targeted and non-targeted species.

Nature of the Problem:

Many of the fishery resources that support ocean fisheries in the Gulf of Maine region are at or near record low stock sizes and landings. A number of bottom-dwelling groundfish stocks (cod, haddock and yellowtail flounder) have been severely depleted due to years of overfishing under a variety of fishery management regimes. The reduced yields from the depleted stocks are causing serious economic and social repercussions in the Gulf of Maine/Georges Bank region. This situation has lead to gear conflicts between otter trawl and gill net fisheries; resource allocation controversies between inshore and offshore fishers and between the recreational and commercial users; and political jurisdictional issues between the state and federal governments in the United States and for transboundary stocks between the United States and Canada (especially in relation to the Hague Line on Georges Bank).

Status of Knowledge:

New England fish resources have supported important fisheries for well over 400 years. During this period, there have been technological revolutions in how fish are caught, handled, processed, distributed and sold. The arrival of vast fleets of factory-based trawlers, primarily from eastern Europe and Asia, beginning in the early 1960s, brought about tremendous competition between domestic and distant-water fleets, and ecosystem-scale overfishing of virtually all components of the offshore fishery resource of the Northeast United States.

With the extension of United States jurisdiction to 200 nautical miles (Exclusive Economic Zone), over-exploited resources began to recover, and domestic fishing effort increased. Restrictive management programs, in place since the waning days of foreign fishing, were abandoned in the early 1980s. The New England Fishery Management Council initially retained the quota-based fishery management system it inherited from the earlier management schemes adopted by international convention, but eventually abandoned direct controls on fishing mortality in 1982. Since 1982, fishing mortality rates on groundfish resources have steadily increased, whereas harvest rates on principal pelagics (Atlantic mackerel and ocean herring) have continued to decline. Evidence from stock and recruitment data indicates that current harvest rates on most groundfish species are higher than those that would allow for replacement for the stock (recruitment overfishing--see further explanation below). Declines in spawning stocks and recruitment to the groundfish stocks in many cases are more severe than what occurred under distant-water fleet effort 20-30 years ago.

The term "overfishing" is used to describe conditions that result in sub optimal use of fishery resources, based on both biological and economic criteria. Recruitment overfishing results when the number of fish that are spawning diminishes to the extent that reproduction is inhibited in the population, resulting in an overall decline in the number of fish available for harvesting. Growth overfishing is based upon economic criteria, in which lower than maximum yields are obtained for a given number of participants in that component of the fishing industry. Many of the New England groundfish stocks are considered to exhibit recruitment overfishing. The rebuilding of the many of the groundfish populations will require a significant period of time with low fishing mortality rates, with some stocks rebounding relatively quickly (5 years) whereas others may take a decade or more. Monitoring the recovery will require continued reliance on research vessel surveys (fishery-independent stocks assessments) and "sentinel" fisheries in which commercial vessels target specific stocks at a low harvesting level in order to supplement the research survey information. Rebuilding these depleted stocks will also require a shift in the management approach with an emphasis on protecting the resource, rather than the process being driven by short-term economic and sociological concerns.

In addition to the direct effects of over harvesting, there are many indirect effects of fish harvesting, such as bycatch of non-target species, impacts of trawling on the soft bottom benthic prey of groundfish, and increase in other fish species, which has altered the ecosystem on which the commercial groundfish depend. The increased abundance of pelagic predators and elasmobranch predators as a consequence of fisheries harvesting of the targeted groundfish species will complicate the recovery of species in the New England multispecies groundfish plan, even if fishing mortality is reduced. The groundfish also compete with marine mammals and seabirds for prey species, so there will be conflicts in the use of prey species at the base of the food web.

Indirect ecosystem effects, as well as direct effects of fishing activities on target and non-target resources, must be considered in the plans to rebuild the depleted groundfish populations. An ecosystem-based management approach must be adopted to optimize ecosystem yield, rather than economic yield, with the fishery resource yield to humans based on an understanding of the limits of ecosystem productivity and recognition of the non-consumptive as well as consumptive values of key ecosystem components.

Overfishing was judged as the major anthropogenic stressor in the offshore waters of the Gulf of Maine. It should be recognized, however, that for species which use coastal waters/estuaries for either spawning or nursery areas, contaminants and habitat degradation will influence the success in rebuilding the fish species used by man. Such species would include winter flounder, striped bass, river and blueback herring, lobsters, bay scallops, soft shell clams, hard shell clams and urchins. Impacts of overfishing are also seen in marine mammals, seabirds and turtles and other forms no longer subject to direct harvesting. Even though the emphasis in this report concerns the biological condition of the stocks, the overfishing issue has components that include the behavior of fishers in a declining socioeconomic scenario; the number, size and composition of fishing fleets; the lack of selectivity of otter trawls, and the market demand for under-utilized species.

Research options:

- Determine the food chain interactions between abundant and depleted species in order to develop appropriate recovery plans for groundfish,
- Continue and expand sea sampling programs on fishing boats at sea to estimate bycatch mortality of nontarget species and harvest rates for targeted species. This activity should be augmented with a feedback mechanism so that fishers can modify their fishing methods and, in addition, this information should be made more readily available to researchers and concerned Non-governmental Organization constituents (except for proprietary information),
- Determine/quantify the relationship between gear type and fishing capacity/power,
- Improve selectivity (and reduce bycatch) of mobile fishing gears,
- Determine the impacts of mobile fishing gear on the soft bottom benthic organisms that are prey for ground fish, and
- Establish the socioeconomic factors affecting excess fishing capacity.

Management options:

- Develop and implement strategies to reduce the excess fishing capacity within the region,
- Establish and employ a regional planning approach to deal with transboundary political jurisdictional problems in managing fisheries (state/federal governments and U.S./Canada),
- Implement an adaptive management plan, with a risk adverse approach (to account for uncertainty or insufficient knowledge) to rebuild the multispecies groundfish complex within the Gulf of Maine/Georges Bank ecosystem,
- Enhance communication between scientists, managers, and the fishing industry (commercial and recreational) on the need to rebuild stocks and the measures required to achieve this goal,
- Educate fishers and the public about long-term benefits associated with rebuilding ground fish stocks,
- Develop markets for highly abundant species (mackerel and herring) and elasmobranch predators (skates and dogfish) to provide alternatives harvesting opportunities for fishers.

Anthropogenic Impacts: Contaminant Introduction

There are gradients of contaminants of environmental concern in the water column and sediments of the Gulf of Maine nearshore zone reflecting known sources (related to human population density) and physical circulation (transport) patterns. However, the linkages between the cumulative stressors of anthropogenic and natural processes on ecosystem functioning are poorly understood in the Gulf of Maine, and other comparable water bodies.

Nature of the Problem:
Anthropogenic effects on key species and sensitive components of the ecosystem were considered within the context of several subsystems of the Gulf of Maine system because these subsystems reflect distinct differences in the magnitude and type of anthropogenic stresses exerted in each area. The subsystems identified were watersheds and their associated estuaries, the nearshore coastal zone, and the open Gulf. Each of these receive contaminants, are impacted by physical alteration and loss of habitat, and the degradation of resources. Major stressors to the Gulf of Maine ecosystem are nutrient over-enrichment (eutrophication), the introduction of contaminants of environmental concern, and toxic algal blooms.

Status of Knowledge:
Natural inputs of nutrients to the Gulf as a whole are dominated by ocean inputs through the Northeast Channel. Nutrient problems are most likely to exist in the estuaries and coastal embayments bordering the Gulf of Maine. The geographical distribution of anthropogenic nutrient inputs to the nearshore ocean is generally related to population centers and are expected to increase. Approximately half of the nutrient loadings are from sewage treatment plants that discharge into the tidal waters. There are no documented eutrophication problems in the open waters of the Gulf of Maine. Data are available to quantify the nutrient and organic carbon loadings from the watersheds in the Gulf of Maine. Preliminary interpretation of these data suggest that current nutrient loadings decrease in a gradient away from the metropolitan Boston area. Anthropogenic nutrient inputs to a number of Gulf of Maine estuaries are relatively low compared to that in many other East Coast systems.

Contaminants of environmental concern, generally organic and inorganic compounds either produced or mobilized by mankind, have been inadvertently or intentionally released to the marine environment where they can, if exceeding threshold concentrations, have deleterious effects on the viability of component species of ecosystem. At present, most threshold concentrations are not well documented. The release of such contaminants in the Gulf of Maine have resulted in readily observable ecosystem level effects, usually in the vicinity of the major urban areas along the coastline. They include observations of highly contaminated sediments with respect to both metals and organic toxic compounds, high incidence of neoplasia in winter flounder and severe degradation of benthic habitat. *Most of the impacts can be related to the discharge of sewage effluent and contaminated runoff from urban areas,* usually in nearshore coastal embayments with restricted circulation.

Watersheds draining into the Gulf of Maine that are densely populated and/or heavily industrialized are also degraded with respect to both water and sediment quality. Discharges of rivers draining such areas are significant sources of contaminants to the Gulf of Maine and, as development proceeds into the 21st Century, are expected to become an even more important source of a variety of stressors, primarily in the near-shore zone, unless properly controlled. A considerable wealth of knowledge has been acquired on acute toxic effects as well as environmental levels present in mobile and sentinel species, or species representatives of several trophic levels, for certain groups of contaminants of environmental concern. These include metals (mercury, lead, and cadmium), organometals (methyl mercury and the butyltins), organochlorines (polychlorinated biphenyls (PCBs), chlorinated hydrocarbons and pesticides), and polyaromatic hydrocarbons (PAHs), which have been monitored in the sediment, mussels, fish (livers), marine mammals (blubber), and birds (eggs) from the Gulf of Maine. For example, metal concentrations in mussels and lobsters from the more polluted waters near Boston have been observed to approach levels considered to be unfit for human consumption. These levels, however, generally are not held to be necessarily deleterious to the health of the organisms themselves.

Organochlorines are known to bioaccumulate in the marine food web such that whales are reported to contain concentrations 100 times found in fish, whereas fish in turn contain concentrations 1,000 times those in plankton, and plankton contain concentrations 1,000 times that in seawater. The problem of organochlorine contamination is judged a global problem, resulting from atmospheric transport and deposition to the surfaces of lakes, coastal and ocean waters, as well as locally where much higher concentrations have been identified in sediments, mussels, and other organisms in waters neighboring human population centers. Both global and local sources of organochlorines have resulted in the accumulation of these compounds in the food chain. A similar set of observations have been made for mercury and lead as well. Regulations restricting organochlorine use were instituted in the late 1960s (e.g.

DDT) and 1970s (PCBs) and have, for example, resulted in marked reductions in recently measured concentrations of these compounds in the harbor porpoise. The scientific community is continually identifying new contaminants of concern, for example, in the last decade, the presence of highly toxic dioxin in pulp mill effluents. However, the presence of these compounds in a recent survey of the mussel population near the mouth of the St. John River was not detected by the Gulfwatch (a Gulf of Maine Council monitoring program). The most urgent need of the global scientific community is to understand the long-term orchronic effects of each category of contaminant on both mobile and sentinel species. This knowledge must be expanded to include the cumulative effects of multiple contaminants on key species. Finally, an active vigil is required to identify, evaluate and quantify newly developed toxic compounds.

High densities (blooms) of certain phytoplankton species commonly occur in the marine environment. Some bloom species produce toxins, for example, saxitoxin causing paralytic shellfish poisoning (PSP) and domoic acid causing amnesic shellfish poisoning (ASP), that can be accumulated in higher trophic level species, particularly the shellfish, thus creating a potential danger to humans and marine mammals that may ingest them. To avoid human health problems, shellfish beds are often closed, resulting in the loss of harvestable resources. The planktonic species responsible for toxic and nuisance blooms are known. Blooms of these species occur primarily in the coastal waters throughout the Gulf of Maine, but have influenced offshore areas, including Georges Bank. The conditions or causes that trigger bloom events are not well understood, although anthropogenic introduction of contaminants of environmental concern such as nutrients and/or metals such as copper, iron, and lead is believed to be a possible contributing factor. While toxic events are known to have occurred throughout recorded history, their frequency has increased markedly in recent decades. There is evidence that the occurrence of red tide blooms in the western Gulf of Maine are influenced by "seed populations" formed in the vicinity of Penobscot Bay and transported to the southwest along the coast by coastal currents.

Research options:

- Identify and quantify the major sources of contaminants of environmental concern to the Gulf of Maine and its key biota, its estuaries and watersheds, and the relationship between land-use patterns and source strength of these contaminants.
- Identify those embayments and estuaries and biota that are most sensitive to the introduction of contaminants by considering their physical circulation patterns and contemporary and projected source loadings.
- Determine patterns of transport of contaminants on a region-wide basis to avoid unexpected and deleterious accumulation and bioaccumulation of contaminants in sensitive regions and species of the Gulf of Maine.
- Develop methods to assess better the individual and cumulative effects of multiple stressors (physical, chemical and biological; both anthropogenic and natural) on the key ecosystem components and the ecosystem dynamics in the Gulf of Maine.
- Establish the factors that trigger nuisance algae bloom events, particularly the extent to which nutrient and other contaminant loading in coastal waters contributes to the occurrence of such events.

Management options:

- Synthesize available data and, if necessary, document the current state of eutrophication and contamination of Gulf of Maine nearshore waters and sediments caused by both point and non-point sources.
- Establish or improve on present data base management systems for syntheses and integration of data and information for making decisions about management strategies and regulations to control the introduction of contaminants of environmental concern (nutrients, metals, organics and pathogens).
- Design, develop and implement appropriate regional as well as local cost-effective management and control strategies and regulations, with emphasis on source reduction and/or pretreatment as well as appropriate land-use planning to contain the introduction of contaminants of environmental concern and insure the cumulative effect of contaminant fluxes do not exceed levels at which the individual component of the ecosystem and human health effects are observed.
- Design and implement a comprehensive monitoring program of estuarine and nearshore coastal waters and representative biota, to identify and track the magnitude and location of eutrophication as well as the accumulation of contaminants of environmental concern.
- Continue dockside monitoring of shellfish for contaminants to protect human health and insure product safety. Other management recommendations will rely on increased understanding of the cause of bloom events.

Anthropogenic Impacts: Physical Alteration and Loss of Critical Habitat

A large percentage of the human population in Maine, New Hampshire, and Massachusetts as well as the Canadian Maritimes is located within the watersheds of the Gulf of Maine estuaries. Human activities have influenced estuarine ecology through changes in hydrology and physical habitat alteration.

Nature of the Problem:

Hydrologic changes in watersheds and estuaries include: diversion of freshwater for municipal and agricultural purposes; damming of freshwater flow for energy and flood control; restriction of tidal flows via roads, causeways and fill; and changes in quantity and quality of surface water runoff from shoreline development. Physical alteration of habitats is primarily related to dredging and filling activities and erosion of sand barriers resulting from hard stabilization (e.g., seawalls and jetties).

Hydrologic modifications have led to loss of estuarine habitat because of changes in discharge, salinity regimes and sediment transport. For example, wading bird feeding habitat in the Bay of Fundy was greatly reduced over a century ago through freshwater diversion and other of man's activities. The delivery of freshwater, sediments, and contaminants has been increased by shoreline development. Eelgrass habitats become more susceptible to wasting disease with reduced freshwater inputs. Salt marshes degrade and subside due to partial or total restriction of tidal flow. Invasive plants out-compete natural marsh vegetation. Structures that modify hydrology also impede fish passage and have led to a near demise of anadromous fish populations. Also, dredging and hard stabilization alters flow patterns and sediment distribution and transport, directly affecting soft sediment habitats and contributing to erosion of barrier beaches and salt marshes.

Status of Knowledge:

Habitat refers to the biological, chemical, and physical/geological characteristics required by a species to survive and thrive in the aquatic environment. In nearshore wetland, subtidal seagrass, beaches, mudflat, hard substrate intertidal/subtidal regions, and soft sediment subtidal systems, the physical/geological nature of the environment plays a crucial role in determining habitat features. In open water column environments the chemical characteristics and physical water mass movements determine the temporally varying nature of the habitat features. Superimposed upon these habitat features are biological interactions, such as competition and predation, that help determine the success of a species in time and space. Habitat alteration can be due either to habitat loss (quantitative) or habitat degradation (qualitative). For many species in the Gulf of Maine, critical life history requirements are poorly known, so that we cannot specify what their essential habitat requirements might be. We do know that habitat changes in other coastal wetland regions, such as the Chesapeake Bay, have led to dramatic declines in many species that support important fisheries.

In many instances, the seasonal distribution of a species is used to infer its habitat characteristics. This approach ignores the fact that for many intertidal organisms physical factors define the upper limits of an organisms distribution, while biological factors often limit the lower limits of distribution. Biological competition and physical stress from desiccation/salinity/temperature can interact, forcing an organism to occupy a distribution that is non-optimum for that species. Even though the emphasis in this discussion will be on the forcing functions of hydrologic alteration, habitat loss/change, and habitat degradation, it should be borne in mind that there is a biological component to these interactions that may be critical. The critical qualitative characteristics that cause an organism to choose and occupy a given habitat are poorly understood and require sufficient knowledge of the species' natural history characteristics.

Hydrological alterations can include the impacts of potential sea level rise; changes in flow patterns due to channelization, construction of seawalls and jetties, or dredging activities; altered drainage patterns in coastal wetlands; or secondary impacts resulting from sediment erosion/deposition. The altered hydrology not only causes a direct physical impact, but it can change the transport of pelagic larvae of marine species and alter sediments that support wetland plant species. For example, inundation of wetland areas can cause water logging in the soils and the buildup of hydrogen sulfide, toxic to many plants. Loss of barrier beaches can result in erosion of the soil that supports many wetland plants. As sea level has risen many barrier beach/wetland complexes are already retreating landward, where they encounter the fixed barrier of human development which restricts their migration, while at the same time removing the buffers that protected the human habitations from flooding and storm events. Human build-out in coastal areas has also provided impetus for the construction of seawalls, jetties, rip/rap construction on coastal dunes, and other physical structures. Those structures have altered the flow of water with its accompanying effects on sediment erosion/deposition critical to maintaining coastal habitats in the face of sea level rise.

Human construction activities have greatly changed the pattern of sediment input to the marine environment with its accompanying load of non-point contaminants (especially nutrients). Many benthic animal populations are restricted to given types of sediments and increased sediment input can change the essential habitat features for these species. For example, juvenile lobsters occupy burrows under rock and rubble regions at the subtidal/ intertidal interface, with these habitats being lost if excessive sedimentation occurs. Many benthic species are also important elements in the diets of finfish species. Sediment input reduces the oxygen available in the water column that is used by animals to ventilate and respire. The sediment input also can result in nutrient enrichment which stimulates algal blooms in the water column or macroalgal growth in benthic environments. Dying algal blooms may use up residual oxygen in the water column resulting in fish kills. Proliferation of macroalgae can displace eelgrass beds which are important habitats for bay scallops and juvenile winter flounder and tautog.

Alteration of benthic habitats by mobile fishing gear is the primary stressor affecting offshore regions of the Gulf of Maine. The effect of repeated disturbance on the production and diversity of benthic ecosystems is poorly understood. Anthropogenic activities in the nearshore coastal waters and estuaries are the major stressors, and include: urbanization, aquaculture operations, impacts on the benthos from mobile fishing gear, drainage of wetlands, armoring of the coast to protect human habitation, construction of dams in coastal rivers, and gravel mining/oil and gas development. Because many Gulf of Maine fish species depend on estuarine habitats during some portion of their life cycle, these activities have a considerable potential to influence coastal fisheries. The lack of data, as well as the lack of access to existing data via an easily accessible, user friendly database associated with a geographic information system (GIS) for the Gulf of Maine region inhibits attempts to adequately characterize the anthropogenic stressors in space and time, and to delineate their individual and cumulative contributions to habitat alteration.

Research options:

- Conduct a Gulf-wide assessment of sensitive species and key habitat loss and degradation due to hydrologic alteration, which would support improved management of coastal habitats. Such an assessment should include:
  - development of criteria to select sites for habitat restoration through hydrologic restoration, and
  - design and location of shoreline buffer zones to reduce the quantity of and improve the quality of surface water runoff.
- Assess and document the extent and impact of ever increasing urbanization and resulting land use change on adjacent living marine and other aquatic resources.
- Assess the multiple impacts of the growing aquaculture industry and determine if aquaculture operations are having a significant negative impact on the biota and stocks of fish and wildlife using nearshore habitats.
- Integrate knowledge of physical habitat alteration, contaminant sources and other stresses in order to understand better the relative susceptibility of various estuaries and embayments to multiple anthropogenic impacts.
- Determine the impacts of inshore habitat loss and alteration on inshore, nearshore, and offshore living marine resources.
- Ascertain the impacts of mobile fishing gear on offshore benthic ecosystems and the capacity of those ecosystems for recovery after repeated disturbance.

Management options:

- Manage more carefully the amount and timing of freshwater diversion, control of tide gates, design of culverts and causeways (or replacement by bridges), dredging and filling, and aggregate mining to maintain or restore ecosystem function to estuaries,
- Establish shoreline buffer zones and schemes to reduce delivery of sediments, runoff, and contaminants from non-point sources,
- Establish strict controls on coastal aquaculture to avoid contamination of seafloors and the surrounding water columns, and
- Establish stronger regulations to protect bird roosting, feeding, and nesting habitats.
- Articulate management goals, so that scientists can define the critical system parameters to be monitored in order to establish habitat alteration is being improved as a result of management actions.
- Interact more effectively with the public to relate management goals to public concerns, plus explain the benefits to be accrued from management action, revealing the full costs to be borne by private citizen groups.

Protected Species: Impacts to Marine Mammals and other Protected Species

Most populations of marine mammals in the Gulf of Maine have been severely reduced by human activities. For example, most of the large baleen whales were over harvested in previous centuries and continue to be affected by human activities today. In general, our knowledge of the natural history and habitat requirements of the protected species is not fully sufficient to assess all the effects of individual and cumulative stressors on these ecosystem components in the Gulf of Maine.

Nature of the Problem:

Although marine mammals, sea turtles, and birds are no longer hunted for commercial purposes, human-caused mortality and injury continue to pose serious threats to such species and populations. Many species of birds, as well as marine mammals and turtles, are caught and killed in both actions and in lost and discarded fishing gear. Such incidental mortality, combined with mortality from ship strikes, may be preventing or impairing recovery of endangered right and humpback whales. Incidental take in fisheries, particularly gillnet fisheries, may be threatening the continued existence of the harbor porpoise population in the Gulf and adjacent areas. Anthropogenic contaminants, toxins from algal blooms, and repeated disturbance by bird and whale watchers, recreational hikers and boaters, etc. may also be affecting some species adversely.

Status of Knowledge:

Little is known about the food and other habitat requirements, habitat-use patterns or essential habitats of marine mammals, seabirds, and sea turtles that inhabit the Gulf of Maine seasonally or throughout the year. Therefore, while it is reasonable to assume that some critical habitats and habitat components are being affected adversely by anthropogenic contaminants and some land-use fishing practices, available information is insufficient to judge the significance of the threats or how best to avoid or mitigate them.

Information on the population status and trends data is relatively good for some protected marine mammal species (northern right whales and humpback whales) and shore birds (piping plovers and least terns), but is fragmentary for many species of sea turtles, sea birds, and other ceteceans that occur in the Gulf of Maine. We do have reliable population and trend data on at least two species of baleen whales; the humpback whale is believed to be making a recovery, but the northern right whale population remains one of the most endangered species, with only 300 or so animals remaining in the Northwest Atlantic. Harvesting of this population has been prohibited since the 1930s, yet the population has grown little, if at all, since then. The cause(s) of lack of population growth in right whales are not fully understood, but ship strikes within and outside the Gulf of Maine Ecosystem are believed to have an important effect on their distribution and abundance.

As is the case with many protected species, small cetaceans are vulnerable to several human-caused stressors, the most important being incidental mortality in commercial fisheries. Large numbers of harbor porpoises are killed in gillnet fisheries in both United States and Canadian waters, with recent deaths averaging over 1,850 per year. The National Marine Fisheries Service, in its 1993 Proposed Rule (58 FR 3108), reported that this level of incidental take is unsustainable.

Two pinniped species, the harbor and grey seals, are of concern because they are increasing in abundance and range, and face increasing potential conflict with mariculture and commercial fishing endeavors.

There are four categories of bird species that have protected status in the Gulf of Maine: colonial breeding birds, raptors, shorebirds, and non-breeding pelagic birds. Human activities such as coastal development, habitat degradation and destruction, disturbance, and the generation of organochlorine contaminants threaten these populations. Human-created waste habitats (dumps) have also spurred explosive population growth of gulls, which then displace and prey on other seabirds.

The leatherback sea turtle, a summer visitor to the Gulf of Maine, is the only threatened marine reptilian species found in this region. The primary known threats to this species in the Gulf of Maine are entanglement in commercial fishing gear, ship strikes, and ingestion of marine debris. Other human activities, primarily outside the region, pose more critical threats to these animals, and include: direct exploitation, harvesting of eggs, and nesting disturbance.

Two threatened fish species, the Atlantic salmon and the shortnose sturgeon, have been afforded protection under the Endangered Species Act because of past over-exploitation, degradation of estuarine habitats and loss of spawning habitat.

Our current knowledge is not adequate to describe the full range of effects of individual human activities, or the cumulative impact of these activities, on protected populations. We have outlined several categories of threats in this report: direct mortality, commercial harvesting of prey species, habitat loss and degradation, and environmental contaminants. While the impacts of these stressors on protected populations are of critical concern from the standpoint of maintenance of biodiversity and the conservation of endangered species, the extent to which the status of these populations pose an overall threat to ecosystem dynamics of the Gulf of Maine as a whole is probably quite low. However, the demise of endangered species populations would clearly represent a compromise to overall ecosystem health. To conserve effectively these species and their ecosystem, managers and researchers, and those who derive their income from the region's resources, need to integrate more fully their daily responsibilities and work toward a shared stewardship goal, thus reflecting the interrelated nature of the Gulf of Maine system of which we are members.

Research options:

- Obtain better information on the natural history and demography of marine mammals and their ecological relationships with other components of the Gulf of Maine ecosystem.
- Determine when and where right and humpback whales are vulnerable to ship strikes and entanglement in fishing gear so that better preventative measures and management protocols can be formulated and implemented.
- Determine (1) the size, productivity, and discreteness of harbor porpoises and other population(s) affected by incidental mortality in commercial fisheries, and (2) the level, age, sex composition, and temporal and spatial distribution of incidental mortality of the affected population(s).
- Determine effective means for reducing the incidental mortality of harbor porpoises in gillnets by examining (1) whether time/area closures will ensure that the level of incidental take does not reduce the population or maintain it below its maximum net productivity level and (2) whether acoustic devices attached to nets could reduce incidental mortality while having no impact or other species.
- Determine the feeding patterns, food preferences, and principal feeding areas of harbor seals and gray seals to judge how, and to what extent, growing populations of these pinniped species may affect commercially important fish stocks.
- Determine the effects of noise pollution from vessel traffic and other sources on marine mammals and other protected species.
- Determine what, how, and at what levels anthropogenic contaminants may affect the survival and productivity of birds, particularly those that feed in estuarine and nearshore areas.
- Obtain accurate estimates of the species and numbers of birds being killed or injured incidental to commercial fisheries, and by entanglement in and ingestion of marine debris in the Gulf of Maine;
- Determine the feeding habits, dietary requirements, principal prey species, and principal feeding area of the various bird species that are part of the Gulf of Maine ecosystem. Fisheries managers should take into account the food requirements and feeding ranges (locations) of seabirds when developing fishery management plans for important seabird prey species.
- Detect and determine the likely cause(s) of future bird population changes and trends.
- Determine the movement patterns, feeding habits and food requirements of the leatherback turtle to understand whether any part of the Gulf of Maine is critical to the survival and recovery of the species.

Management options:

- Develop and implement a "Take-Reduction Plan" for harbor porpoises as soon as possible.
- Expand efforts to locate and free right whales from entanglement in fish gear and reduce ship strikes.
- Conserve and protect important on-land nesting sties, roosting sites, and adjacent buffer areas.
- Increase public awareness of the causes and possible consequences of disturbance of birds in nesting, roosting, and feeding areas.
- Eliminate garbage dumps and other artificial sources of food responsible for the increases in gull populations in areas where gulls are displacing or otherwise impacting on other bird populations.
- Continue and expand seabird restoration programs (for species such as roseate terns, Atlantic puffins, and garnets), to increase their distribution to historic levels and decrease their vulnerability.

Congressional Mandate

This workshop was mandated by Sec. 20, "Marine Ecosystem Protection", of the Marine Mammals Protection Act Amendments of 1994. The relevant portions are reproduced below:

"No later than one year after the date of enactment of the Marine Mammal Protection Act Amendments of 1994, the Secretary of Commerce shall convene a regional workshop for the Gulf of Maine to assess human-caused factors affecting the health and stability of that marine ecosystem, of which marine mammals are a part. The workshop shall be conducted in consultation with the Marine Mammal Commission, the adjacent coastal States, individuals with expertise in marine mammal biology and ecology, representatives from environmental organizations, the fishing industry, and other appropriate persons. The goal of the workshop shall be to identify such factors, and to recommend a program of research and management to restore or maintain that marine ecosystem and its key components that:

(A) protects and encourages marine mammals to develop to the greatest extent feasible commensurate with sound policies of resource management;

(B) has as the primary management objective the maintenance of the health and stability of the marine ecosystems;

(C) ensures the fullest possible range of management options for future generations; and

(D) permits non wasteful, environmentally sound development of renewable and nonrenewable resources.

"On or before December 31, 1995, the Secretary of Commerce shall submit to the Committee on Merchant Marine Fisheries of the House of Representatives and the Committee on Commerce, Science and Transportation of the Senate a report containing the results of the workshop under this subsection, proposed regulatory or research actions, and recommended legislative action."

The Workshop

A scientific workshop was convened by the Regional Association for Research on the Gulf of Maine (RARGOM) at its headquarters at Dartmouth College from 18-20 September, 1995. The goals of this regional workshop were:

a) to assess human-caused factors affecting the health and stability of the Gulf of Maine marine ecosystem; and
b) to identify research & management options to restore and/or maintain the environmental quality of the ecosystem.

Workshop participants discussed the status of key ecosystem components that characterize the Gulf of Maine, from three perspectives: Anthropogenic Impacts/Natural Environment, Fisheries Harvesting, and Marine Mammal/Protected Species. In each category, the state of knowledge was surveyed; individual stressors (direct and indirect) were identified, and their cumulative impacts described. The themes of habitat, biodiversity, and ecosystem function were emphasized throughout. The workshop focused on problem identification and on the pros and cons of possible alternative research and management strategies.

Invited participants were selected from the research community, resource users, and state/federal managers with expertise in the fields of marine biology, ecology, and the various branches of oceanography. Participation by the broader public was encouraged through initial plenary presentations.

Day 1 was devoted to the plenary session conducted by scientific experts from within and beyond the Gulf of Maine region. Topics that addressed facets of the three workshop themes were used to structure these plenaries. This session was open to a wide audience and provided time for public participation through discussion following the individual speakers and also during a public input session during the afternoon. Total attendance was 63 people.

Day 2 was devoted to in-depth review and analysis of historical and contemporary data and information by pre-assigned working groups in the three categories. The objective of the second day was to produce detailed outlined working documents which were used to draft the workshop proceedings. Each working group was asked to consider three primary questions as they related to its topic: (1) What is the nature of the problem? (2) What is the status of knowledge? and (3) What are the options for future research and management activity? Each group was also charged with prioritizing research needs by their degree of urgency and availability of relevant information.

Day 3 was spent distilling the working group discussions, developing broad report outlines, and synthesizing ideas forthcoming from Days 1 and 2.

This report is a summary of the major conclusions and research and management options from each working group, in response to each of these questions. The reader is referred to the three working group reports in the workshop proceedings (RARGOM Report 96-1, in preparation) for more detailed summaries of their deliberations.

Plenary Papers

Gulf of Maine Circulation

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Introduction

The Gulf of Maine is a semi-enclosed coastal sea on the eastern North American shelf, stretching from the Cape Cod Islands eastward to the Bay of Fundy and the Nova Scotian shelf, and from the coast of Maine/New Brunswick seaward to the shelf break on the southern edge of Georges Bank (Figure 1). The Gulf represents a major international resource, with heightened interest in recent decades in tidal power, oil and gas, and fisheries.

In this overview I am charged with providing a summary of physical perspectives on the Gulf Ecosystem -- specifically, the hydrodynamic circulation patterns which are likely to be important in understanding the system. The essential questions of interest are the standard physical ones:

- where does the water come from?
- what causes its motion?
- what are the residence times in various locations?
- what are the exchanges and transit times among locations?

Answers to these form a baseline for more complex investigations of the ecosystem function.

In the limited space here I will try to present conventional opinion, accompanied by a collection of useful illustrations from standard sources. Rather than reinterpret or re-argue each of these opinions, I will let the pictures and the references to the original work suffice, in the hope that the reader will pursue those and seek new ecological interpretations, synergies, or contradictions. In addition I append a sampling of recent simulation results which constitute a new vehicle for exploring "how the Gulf works" and are generally compatible with conventional views.

The discussion will generally proceed from large to small scales of motion, starting with the Northwest Atlantic system adjacent to the Gulf and proceeding to the Bounding Banks (Georges Bank, Browns Bank, Nantucket Shoals), the Gulf of Maine proper, and the Maine Coastal Current. We divide the latter two at roughly the 100m isobath. Estuarine circulations (20 m and shallower) will not be addressed. For a related summary from an observational perspective, see Pettigrew (1994).

The Gulf circulation is heavily constrained by the topography. However, it is important to avoid the trap of "Location-Based Thinking" about Gulf ecosystem function. Essentially, the Gulf and its sub-structures are an open system at time scales of ecological importance, and the complexity of the 3-D circulation patterns and their seasonal modulation provides numerous opportunities for long-distance exchange by specific combinations of simple behaviour with place and time of spawning, migration, or aggregation.

The Northwest Atlantic Shelf/Slope System

The Gulf of Maine is situated adjacent to the southern reach of the Labrador current system, as illustrated in Figure 2 (Chapman and Beardsley, 1989). This system provides the general southwestward transport tendency shown. The Gulf of Maine circulation is a side excursion in this system, with 2 distinctive branches "upstream" of the Gulf. The inshore branch is heavily

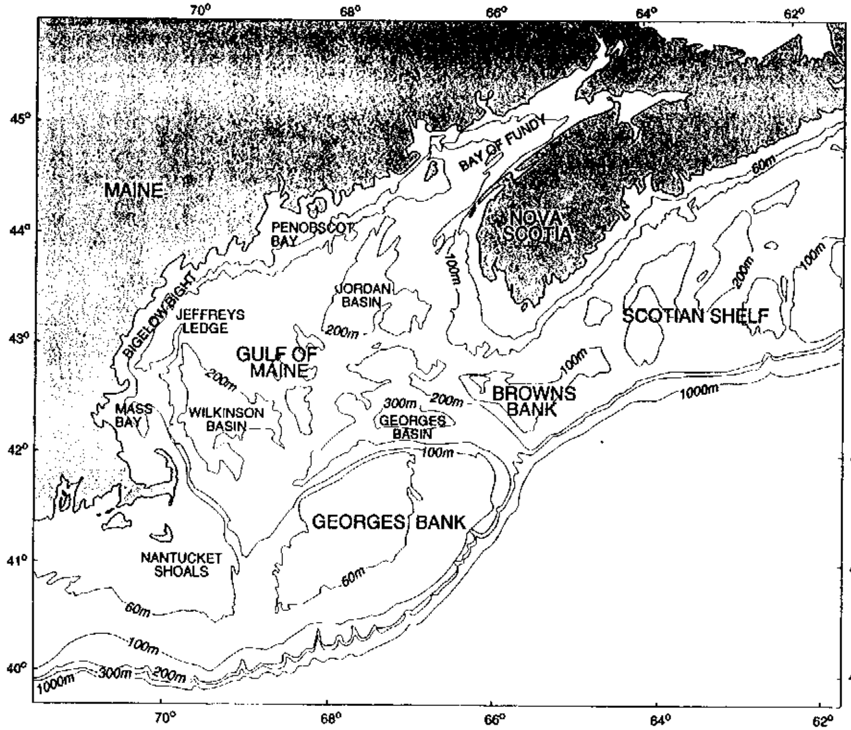

Figure 1: The Gulf of Maine

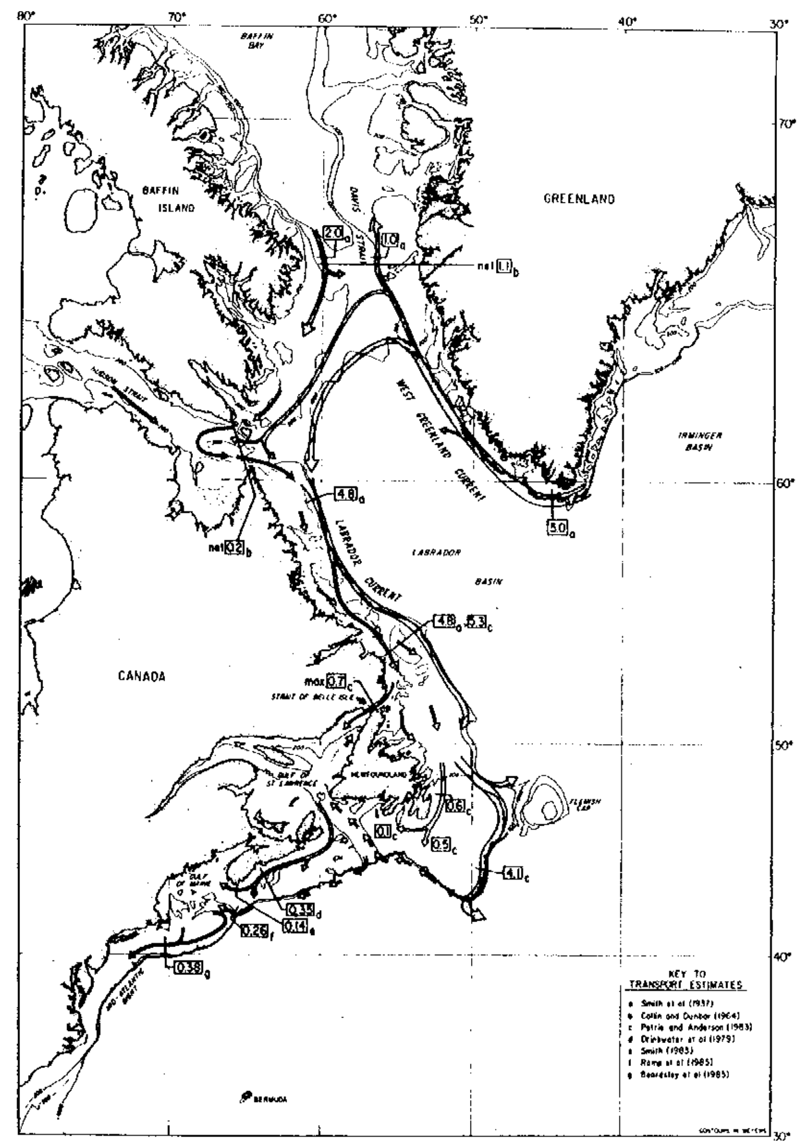

Figure 2: Northwest Atlantic Circulation
(from Chapman and Beardsley, 1989).

influenced by the Gulf of St. Lawrence, and provides a basic input of cold, fresh water to the Gulf, North of Browns Bank. At the shelfbreak, a second source of deeper, slope water enters the Gulf at Northeast Channel. As a point of reference, the unit of transport -- 1 Sverdrup = 10^6 m^3/s -- is comparable to roughly one Gulf of Maine volume per year. So, we are dealing at this scale with renewal rates of order one year, on average, for the Gulf. There are of course slower and faster pathways through it.

Figure 3 is an attempt to quantify the transports between the Gulf and the shelf (Butman and Beardsley 1987). As suggested in this illustration, the general circulation within the Gulf is counterclockwise (see discussion of the Interior Gulf, below), and the detailed estimates of the various transports accompanying the picture are as follows:

Transport	Mean(Sv)	Range (+/-)	
T_{CS}	.141	.082	(Cape Sable Inflow)
T_{SL}	.262	.059	(Slope Water Inflow)
T_{P-E}	.001		(Net Precipitation)
T_R	.003		(GoM Watershed Runoff)
T_N	.384	.69	(Nantucket Shoals Outflow)
T_{OS}	.023	.122	(Off-Shelf Loss)

The along-shelf flows into the Gulf are greater than the insitu water inputs (i.e. local runoff plus direct net precipitation) by about a factor of 100. This is the sense in which the Gulf is an open hydrodynamic system.

The Bounding Banks

The Gulf is a deep (300 m) shelf sea bounded at its seaward extent by four prominent bank structures: the nearshore area off Cape Sable; Brown's Bank; Georges Bank; and Nantucket Shoals (Figure 1). Each of these structures presents topography less than 60 m deep, effectively isolating the deep Gulf waters from the slope waters. Three primary channels intersect these shallow structures and connect the Gulf with the prevailing southwestward shelf/slope current system described above. The deep Northeast Channel is the principal hydrodynamic connection with slope water and a major inlet to the Gulf; the channel north of Brown's Bank is the principal inlet for Scotian Shelf water; and the shallower Great South Channel provides both exchange with the New England shelf to the West and a recirculation pathway for clockwise flow around Georges Bank. A comprehensive review of Georges Bank is available (Backus and Bourne, 1987), covering the scientific and resource management issues in an historical perspective. Georges is our primary focus here.

A special feature of the Gulf is its strong barotropic resonance at semi-diurnal frequencies. The dominant M2 tide, present seaward of Georges Bank at roughly 0.5 m amplitude, grows monotonously to 4 m in the Bay of Fundy and exceeds 6 m in its furthest extremity, the Minas Basin. This resonance results in strong gradients in elevation amplitude (0.5 m) and phase (90^o) over the banks; these elevation gradients are further enhanced in the velocity response by the shallow bank topography -- tidal currents reach 100 cm/sec atop Georges. Five common tidal constituents account for 80% of the total current variability observed in the Georges Bank area. (Brown and Moody, 1987).

At seasonal timescales, observations from moored and drifting instruments indicate a general clockwise circulation around the major topographic features, with current speeds as high as 30 - 50 cm/sec (Butman and Beardsley 1987). These motions are of enormous ecological

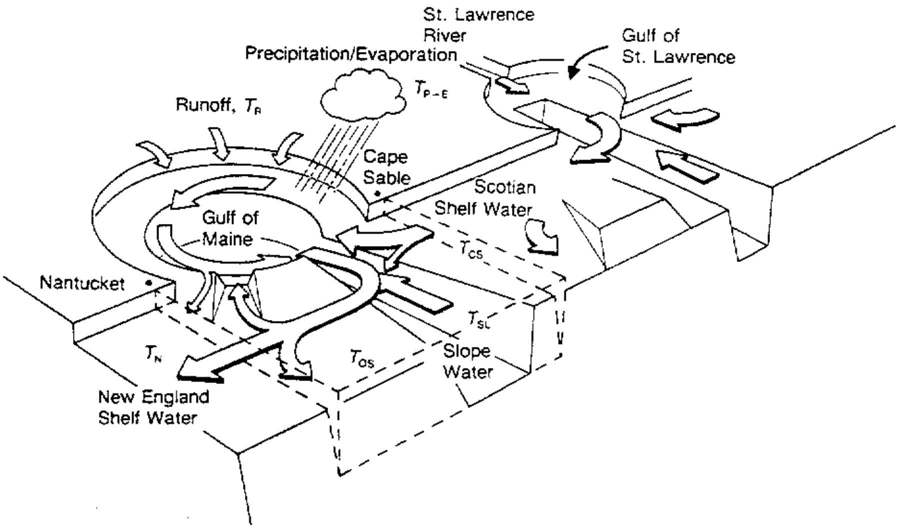

Figure 3: Schematic of Gulf transports (from Butman and Beardsley, 1987).

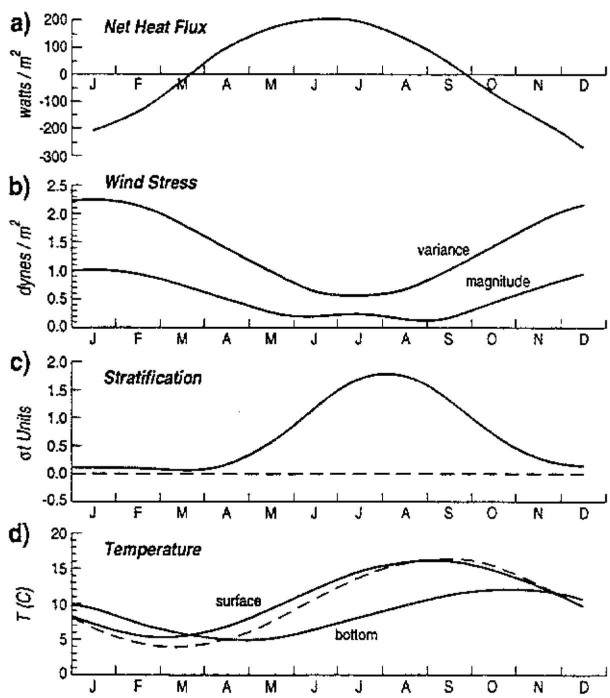

Figure 4: Seasonal conditions on Georges Bank (from USGLOBEC NW Atlantic Implementation Plan, 1992)

importance, and result from the juxtaposition of several dynamical influences:

- the general Gulf-wide circulation, an excursion of the mean southwestward shelf current system around and through the banks as described above;
- tidal rectification, estimated to produce partly closed, clockwise circulations of order 10-20 cm/sec (Lynch and Naimie, 1993);
- frontal processes, notably the presence of strong tidal mixing fronts on the banks which create clockwise currents estimated at 10-30 cm/sec on Georges Bank during the stratified portions of the year (Naimie et al, 1994).

The seasonal progression of the latter effect is illustrated in Figure 4. Summer conditions of weakening wind and net heating support stratified conditions near the Bank, except in the shallow areas where tidal mixing is sufficient to overturn the water column. Shoalward of this mixing front (crudely the 60 m isobath) we find well-mixed conditions year-round, and a strong frontal circulation associated with the contrast. Figure 5 illustrates the frontal structure on Georges Bank during summer. The related intensification of the around-bank circulation is shown in Figures 6 and 7, based on model calculations (Naimie 1996).

These are mean seasonal tendencies. The actual circulation in a given period can be strongly influenced by episodic winds and Gulf Stream rings. These sources of variability can be critical in some ecological contexts. Also critical is the strong depth-dependence of the Bank circulation. During winter and early spring, the surface waters of the Bank are very lossy due to the influence of the strong northwest winds (Figure 4). Studies by Werner et al (1993) have highlighted the importance of this phenomena by dividing the Bank into a lossy surface layer and a retentive lower layer (Figure 8). This conceptualization is quite useful in understanding the retention of larvae in the Bank system.

The Interior Gulf

The classic Gulf of Maine Circulation pattern was published by Bigelow in 1927 and is reproduced in Figure 9. This represents inference of the mean near-surface, summer circulation. It is generally compatible with contemporary views. The surface inflows and outflows at Cape Sable and Nantucket Shoals are depicted more or less as discussed above, as is the partly-closed gyre at Georges Bank. For present purposes, the most significant feature in this picture is the counter-clockwise gyre in the interior Gulf, centered over Jordan and Georges Basins. Recent studies generally confirm and refine this feature, as illustrated in Figure 10 (Brooks 1985). This Figure presents additional structure in terms of a) separate gyres over the three deep basins (Georges, Jordan and Wilkinson) and b) the addition of distinctly different flow patterns at depth. The latter are thought to represent the seasonal inflow of denst slope water through Northeast Channel, and its subsequent spreading among the deep basins. The distribution of this dense water then accounts for the separate gyres present near the surface, where corresponding low pressure would be expected to occur over the dense water pools. The formation and evolution of distinctive water masses in the Gulf as a result of inflow, mixing, and heat transfer is illustrated in Figure 11 (Brown and Irish, 1992, 1993) in terms of a box model highlighting vertical structure and exchange. These processes occur on seasonal or inter-annual time scales, and significant attention has been directed to their quantification.

The Maine Coastal Current

It is widely accepted that there occurs an easterly current along the northern margin of the Gulf (Bigelow, 1927; Bumpus and Lauzier 1965; Pettigrew 1994). Such an occurrence is qualitatively consistent with buoyancy inputs from freshwater runoff at the coast and the attendant along-coast frontal structure. It is also qualitatively consistent with the general counter-clockwise circulation in the interior Gulf, discussed above. The transport pathways within such a coastal

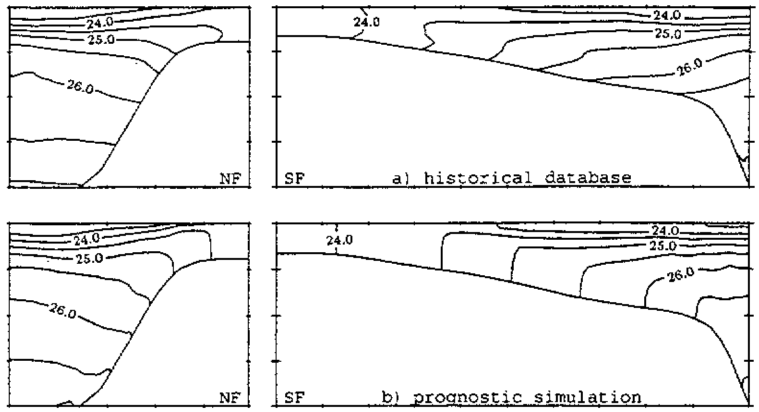

Figure 5: Georges Bank stratification, July-August. (from Naimie, 1996).

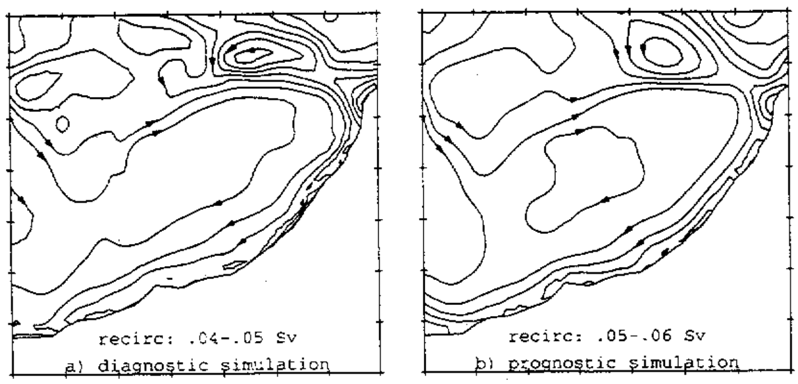

Figure 6: Computed Georges Bank streamfunction during March-April (from Naimie, 1996). The contour interval is 0.1 Sv.

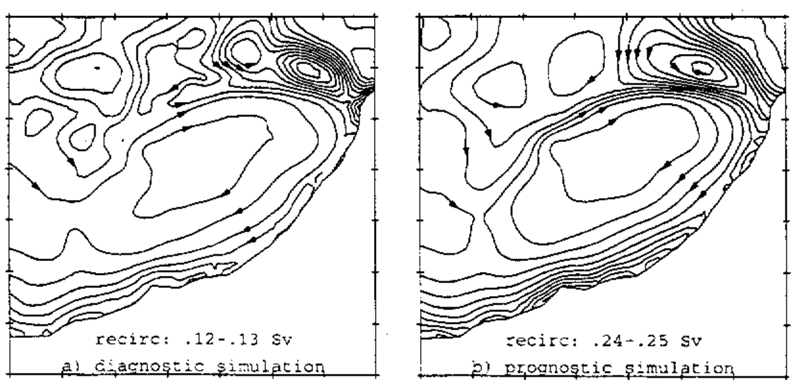

Figure 7: Computed Georges Bank streamfunction during July-August (from Naimie, 1996). The contour interval is 0.1 Sv.

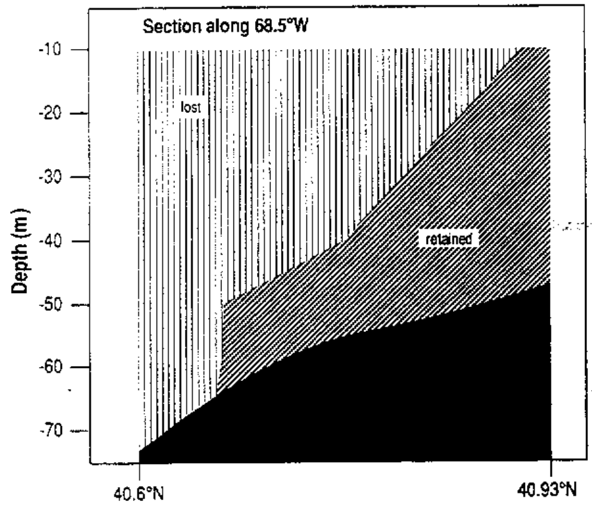

Figure 8: Cross-section on southern flank of Georges Bank indicating retentive and lossy areas of the bank for larval cod (from Werner et al, 1993).

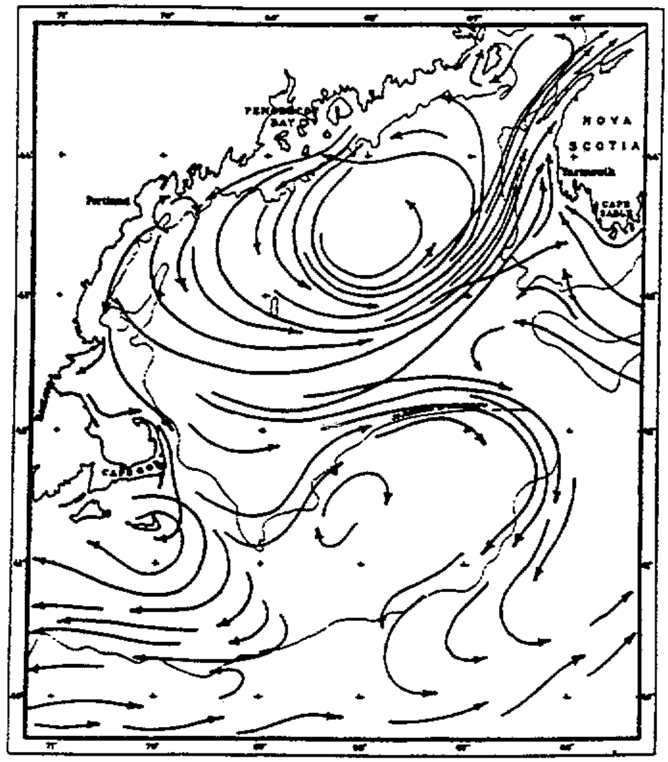

Figure 9: The classic Bigelow (1927) circulation.

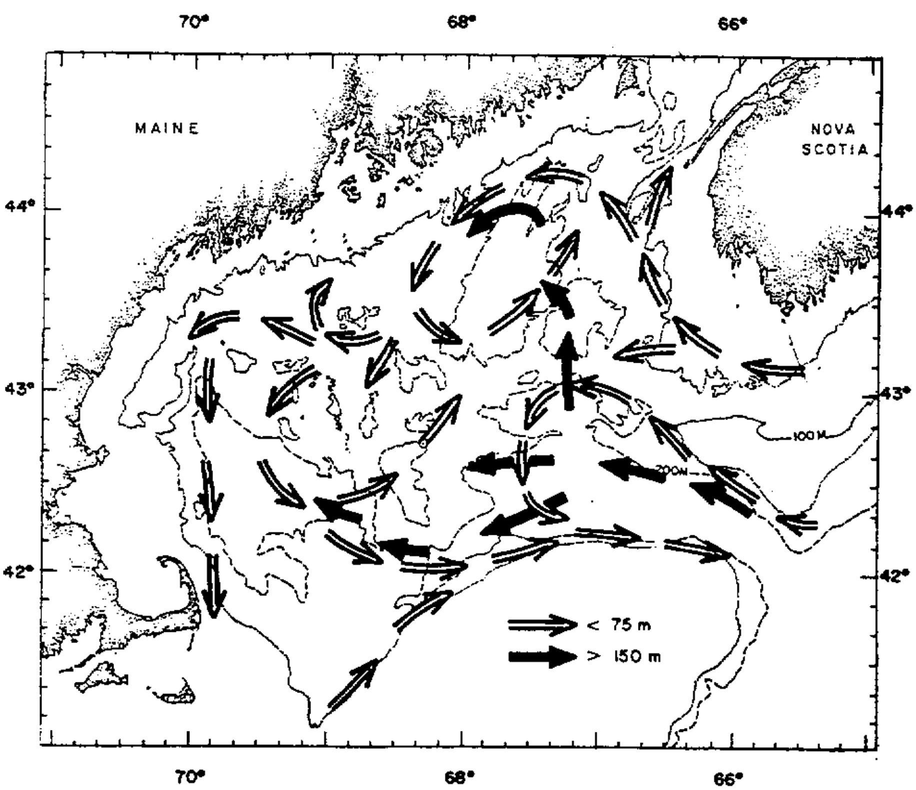

Figure 10: Spring circulation (from Brooks, 1985) illustrating both near-surface and deep flows.

current system are of intrinsic interest from several points of view (Townsend et al, 1987; Townsend, 1991; Franks and Anderson, 1992a,b.)

Lynch et al (1995) conceptualize the MCC as a composite of seven legs or segments and three branch points (Figure 12). The upstream, Eastern segment extends from Grand Manan basin to Penobscot Bay. Bisagni et al (1994) discuss a formational hypothesis for this branch, involving freshwater inflow from the Scotian Shelf and the Saint John River, with strong local tidal mixing in the Grand Manan area, which is consistent with observed sea surface temperature patterns and several previous studies.

South of Penobscot Bay a widely-reported offshore meander occurs (e.g. Brooks 1985). We identify this as the first of the three branch points, separating Eastern and Western segments of the MCC and originating the southward Jordan segment. This branching structure is consistent with the topography here, where the deep relief of Jordan and Wilkinson Basins is interrupted by a broad shoal. Other offshore steering mechanisms potentially operative here include geostrophic steering by the buoyant Penobscot outflow, and by the cyclonic circulation over Jordan Basin associated with slopewater intrusion. These effects respectively push and pull the Jordan segment offshore. Brooks and Townsend (1989) advanced the hypothesis that this branch point is controlled by the latter -- the "slopewater steering" mechanism. Sea surface temperature analysis by Bisagni et al supports this hypothesis. More recently, Brooks (1994) suggests offshore steering by the Penobscot plume.

The Western segment of the MCC presumably originates as that portion of the Eastern segment which returns shoreward, plus a portion of the Penobscot River outflow. Following the Western segment, we encounter local contributions from the Kennebec, Androscoggin, Saco, and Merrimack Rivers, and arrive at the second branch point offshore of Cape Ann. At this point, the MCC is divided between an inshore, "Massachusetts" branch and an offshore, "Stellwagen" branch. This branch point was studied in detail as part of a comprehensive modeling investigation of Massachusetts and Cape Cod Bays. Blumberg et al (1993) studied the sensitivity of the Bays' circulation to local (using the present terminology) influences on modeled circulation patterns. One conclusion of that study was the importance of the offshore boundary conditions which in the present terminology are synonymous with both upstream inflow and the Gulf-wide circulation. Signell et al (1994) report similar conclusions based on hindcasting experiments with the same model -- basically, model skill deteriorated in regions where local influences were not dominant. Drifters released in the Bays (Geyer et al, 1992) demonstrate complex local behaviour with residence times of order 10 to 20 days in the Massachusetts segment of the MCC, with an extreme of 50 days. This segment rejoins the Stellwagen segment at its exit from Cape Cod Bay at Race Point.

Downstream, the Stellwagen segment undergoes another bifurcation into a "Nantucket" segment exiting the Gulf at Great South Channel, and a "Georges Bank" segment which either recirculates in the topographic cul-de-sac north of the Channel (herein the "SCOPEX" gyre) or finds its way to the northern flank of Georges Bank. Drifter studies and related observations (Chen, 1992; Beardsley et al, 1993; Geyer et al, 1992; Chen et al. 1995) clearly illustrate this branch point and the two implied exit segments of the MCC. Brooks (1985) suggests that the Georges Bank segment itself bifurcates with one segment returning to Jordan Basin and the other transiting the northern flank of the Bank.

This classification of the circulation into segments and branch points is offered as a conceptual framework. During a given period of analysis, the MCC and all its complexities may be characterized by

- the existence, location, and relative strength of the branch points;
- the along-shelf transports, speeds, and Lagrangian transit times in the segments; and
- the attendant 3-D cross-shelf exchanges along the various segments.

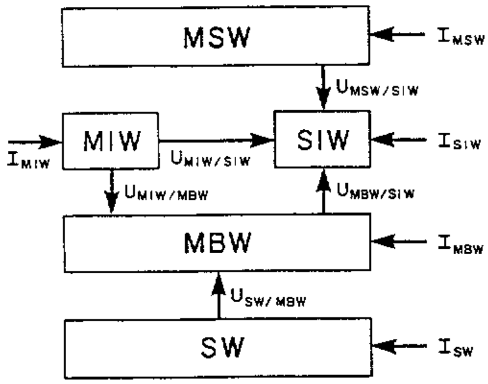

Figure 11: Box-model schematization of water mass formation and exchange (from Brown and Irish, 1993).

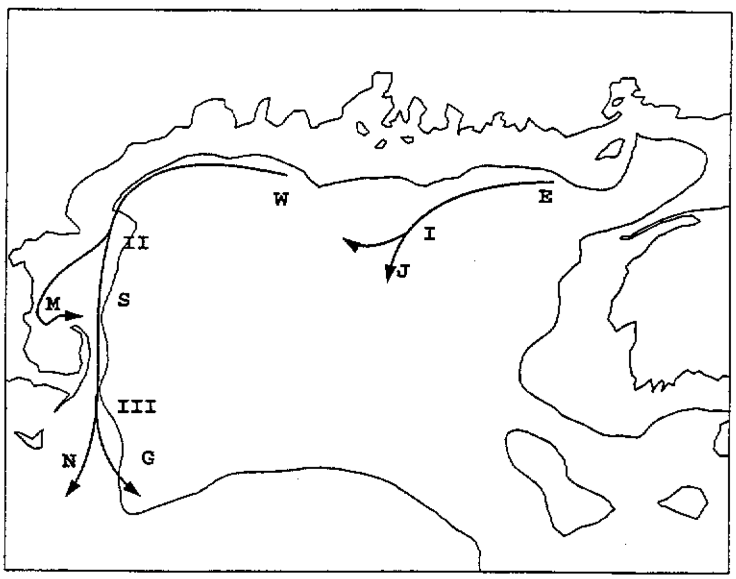

Figure 12: Suggested segmentation of the Maine Coastal Current (from Lynch et al, 1995).

Understanding the controls on these features -- both in terms of mean and variability -- is a central challenge, as is relating them to the transport and fate of nutrients, pollutants, and planktonic species.

Comprehensive Circulation Model

The availability of a valid, comprehensive circulation model for the Gulf is prerequisite to understanding and managing the Gulf ecosystem. The need for such a model has been articulated in several recent forums. Above we have sketched in qualitative terms the general features of the circulation. What is needed from computational models today is a quantitative, three-dimensional description of the transport, transit times, and branch points described; their variability at decadal, seasonal, and shorter time scales; and a clearer picture of the controlling physical processes. Such a comprehensive model is now becoming available through the sponsorship of NSF, the RMRP, SeaGrant, and GLOBEC programs (Lynch et al 1995, 1996). The results of this modeling effort for Georges Bank are depicted above (Figures 5-7) and have been subjected to considerable srutiny for their realism. Below we sample some of the recent results of this model in the central Gulf and Coastal Current regimes; these results are qualititively consistent with the general ciriculation patterns depicted above; quantitative comparisons are still ongoing. All calculations attempt to approximate climatological mean conditions.

The March-April and May-June gulf-wide circulation fields are displayed in Figures 4-6 and Figure 7, respectively. The expected cyclonic circulation in the Gulf of Maine is apparent in both seasons. Each of the three deep basins exhibits separate but interlinked cyclonic tendencies. The seasonal variations in horizontal and vertical detail are substantial.

In March-April the streamfunction (Figure 13) reveals a combined recirculation of .125 Sv over Jordan and Georges Basin. Nested inside this is an inner gyre comprising an additional .125 Sv over Georges Basin. A separate .075 Sv cyclonic gyre exists over Wilkinson Basin. These structures persist at depth and reflect the impact of slope water accumulated in the deep basins. Encompassing these circulation features is a Gulf-wide cyclonic gyre which results largely from the .300 Sv of inflow from the Scotian Shelf entering the Gulf of Maine from the Northeast. The coastal current division into eastern and western segments is evident, with a prominent offshore meander at the Penobscot branch point. There is also a branch point at Cape Ann, with significant transport into Massachusetts Bay. Downstream at the SCOPEX branch point, .150 Sv departs the coast toward Georges Bank and .100 Sv continues along the coast toward Nantucket Shoals.

Lagrangian trajectories of passive particles "drogued" at a depth of 60 m (Figure 14) generally confirm the circulation pattern in Figure 13 and add information regarding the time-scales related to the various circulation features. For example, particles retained in the Bigelow gyre over Jordan and Georges Basins complete approximately half of the circuit around this feature in 60 days. Of particular interest in the context of the MCC are the particles which depart the coast via the Jordan Segment of the MCC, cross Wilkinson Basin, and are subsequently advected towards the exit segments of the MCC.

In May-June, the cyclonic Georges Basin gyre is stronger and more localized (Figure 15). The Jordan Basin gyre is significantly weaker and the Wilkinson Basin gyre has moved south toward the SCOPEX region. Like March-April, there is a large gulf-scale cyclonic circulation which is supplied by upstream conditions on the Scotian Shelf. However, the details of this circulation are different, with the May-June solution having significantly greater transport near the beginning of the Eastern Segment of the MCC. The MCC generally follows the coast past the Penobscot branch point . The coastal current largely bypasses Massachusetts Bay after proceeding past Cape Ann. As in March-April, there is a bifurcation in the SCOPEX region, with similar transports toward Georges Bank and Nantucket Shoals.

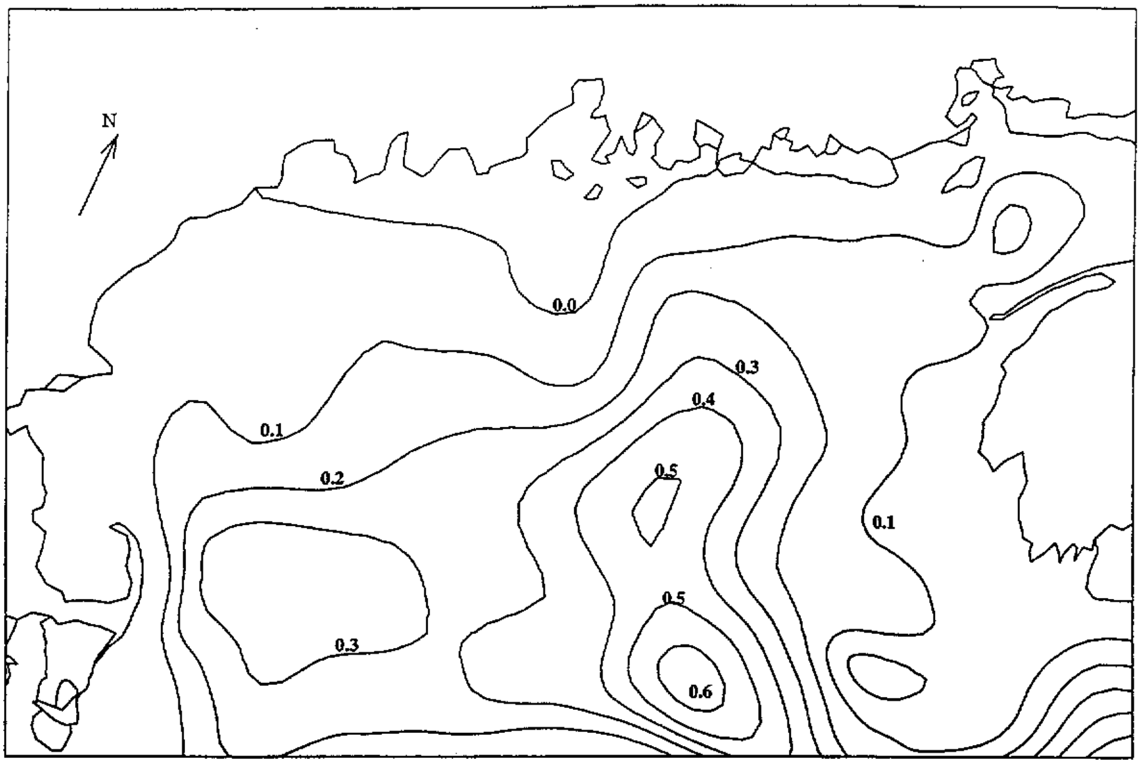

Figure 13: March-April streamfunction; contour interval is 0.1 Sv (from Lynch et al, 1995).

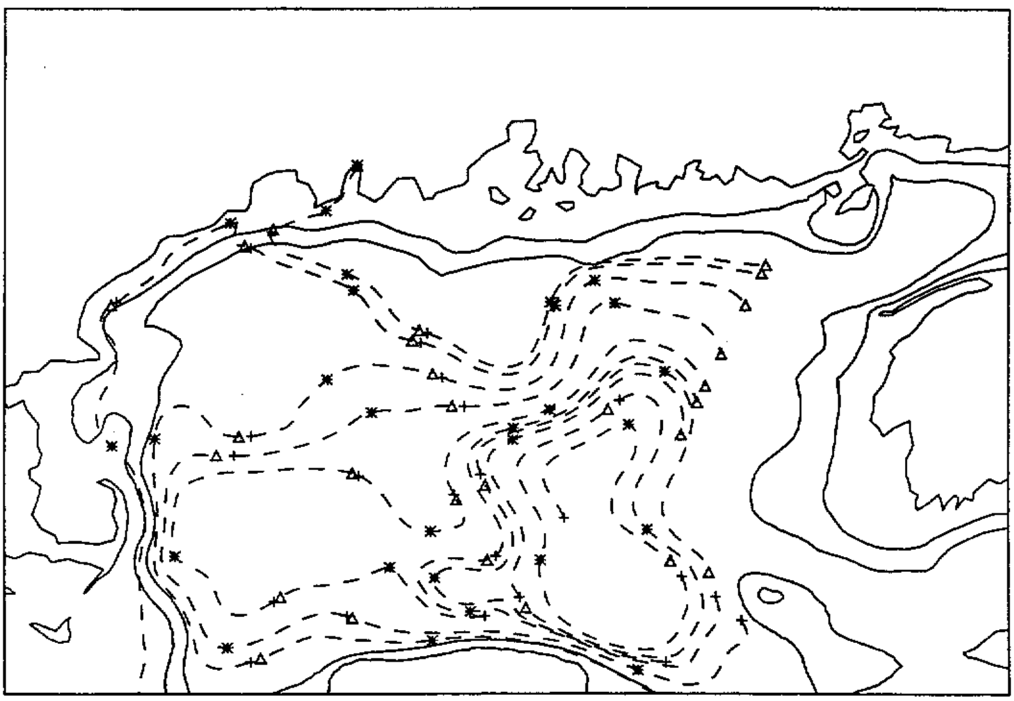

Figure 14: March-April drifter paths, fixed at 60m below surface (from Lynch et al, 1995).

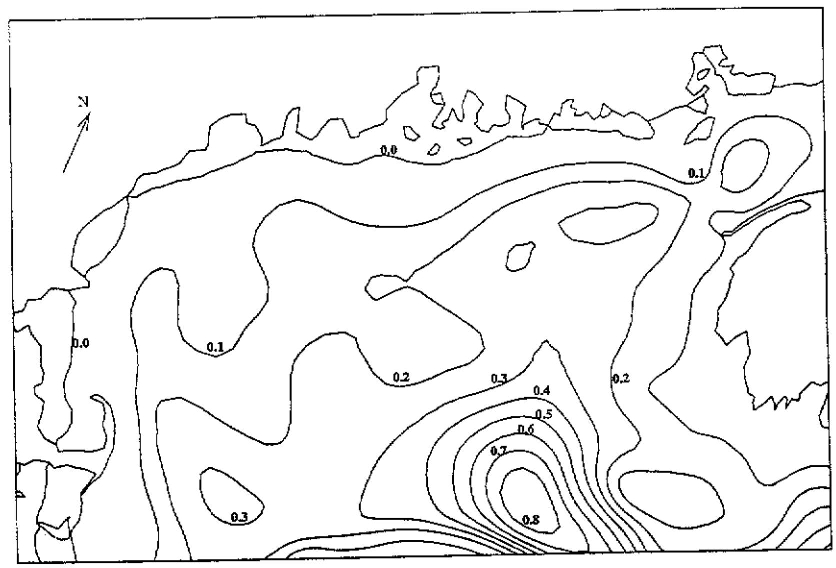

Figure 15: May-June streamfunction; contour interval is 0.1 Sv (from Lynch et al, 1995).

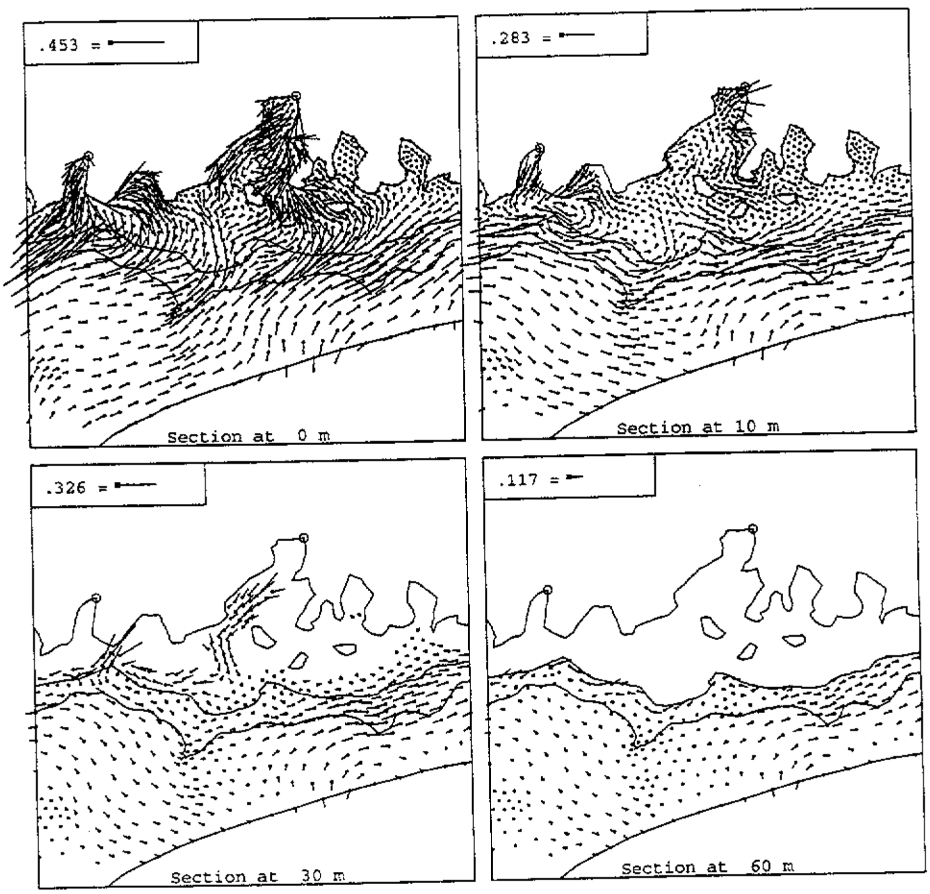

Figure 16: March-April circulation at the Penobscot branch point (from Lynch et al, 1995).

A more highly-resolved set of calculations is available for the Coastal Current area. Boundary conditions for these are taken from the larger-scale calculations above. Figures 16 through 18 approximate March-April conditions.

The Penobscot branch point is illustrated in detail in Figure 16. The surface flow is influenced by both the northwesterly wind and the freshwater inputs, while at greater depth a nearshore return flow is evident. Return flow is especially strong near the two river sources. When this type of structure is vertically averaged, anti-cyclonic cells appear as shown in the bays and estuaries in Figure 9b. In Penobscot Bay, the near-surface flow favors the eastern shore, also seen in Brooks 1994. The outflow continues out among the islands and connects to the MCC, with a portion joining the Jordan segment and exiting the model to the south, and a portion generating additional westward flow closer to shore. The Kennebec and Androscoggin river outflow enters the Gulf through a narrow bay which is dominated by the source flow. The river outflow bulges out, extending in both directions along the coast with most of the fluid turning right and adding to the coastal current. Seaward of the 60m contour, the meander at the Penobscot branch point dominates the entire water column.

At the Cape Ann branch point, there is a significant turning of the MCC into Massachusetts Bay, as shown in Blumberg et al (1993). In Figure 17, the Eulerian velocities at depth reveal that this effect prevails throughout the water column. The Merrimack river outflow shows little tendency to spread upstream, being immediately swept into the ambient coastal current and increasing its speed. The Bay circulation is generally cyclonic, with a high-speed exit around the tip of Cape Cod.

In Figure 18 we illustrate Lagrangian drifter trajectories computed in the MCC. These generally confirm the Eulerian circulation patterns displayed at the 10m section in the previous Figures, including the entry and exit points associated with the meander at the Penobscot branch point.

Figures 19, 20 are representative of May-June conditions. The differences noted above between the two "seasons" are preserved in greater detail here. The meander at the Penobscot branch point is reduced in this season with most of the flow continuing along the coast and only a small amount farther offshore diverting into the Gulf (Figure 19). The surface velocities show the effect of the southwesterly wind in the bays without rivers, while the estuaries are still influenced by the smaller freshwater sources. The Kennebec and Androscoggin outflow bulges out in both directions, as in MA. Seaward of the 60 m isobath, the MCC largely follows the along-coast topography throughout the water column.

In Massachusetts Bay (Figure 20), the surface water along the coast is pushed in an eastward direction by the wind. However, further away from the coast the flow is dominated by the MCC and the Merrimack river. As in MA, the MCC branches into the Bay at Cape Ann, but remains somewhat offshore and its penetration of the southern portion of the Bay is significantly reduced.

Overall, these features are qualitatively realistic by comparison with consensus opinion reported above and with contemporary moored and drifting measurements of the circulation. Quantitative comparisons are ongoing and we invite further scrutiny of these computed results as a catalyst for thinking in detail about the Gulf ecosystem.

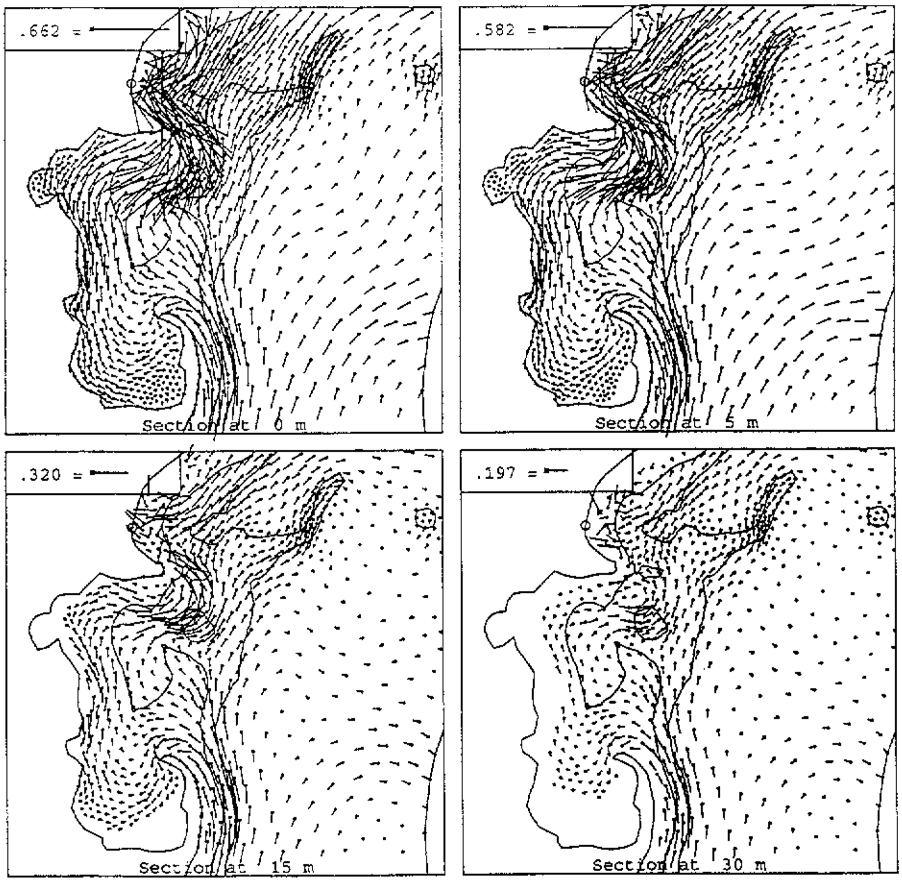

Figure 17: March-April circulation at the Cape Ann branch point (from Lynch et al, 1995).

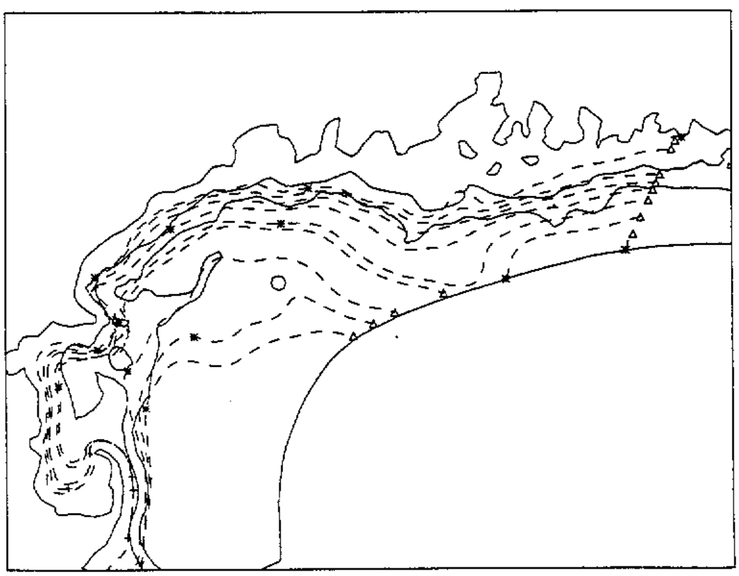

Figure 18: March-April drifter paths, fixed at 10m below surface (from Lynch et al, 1995).

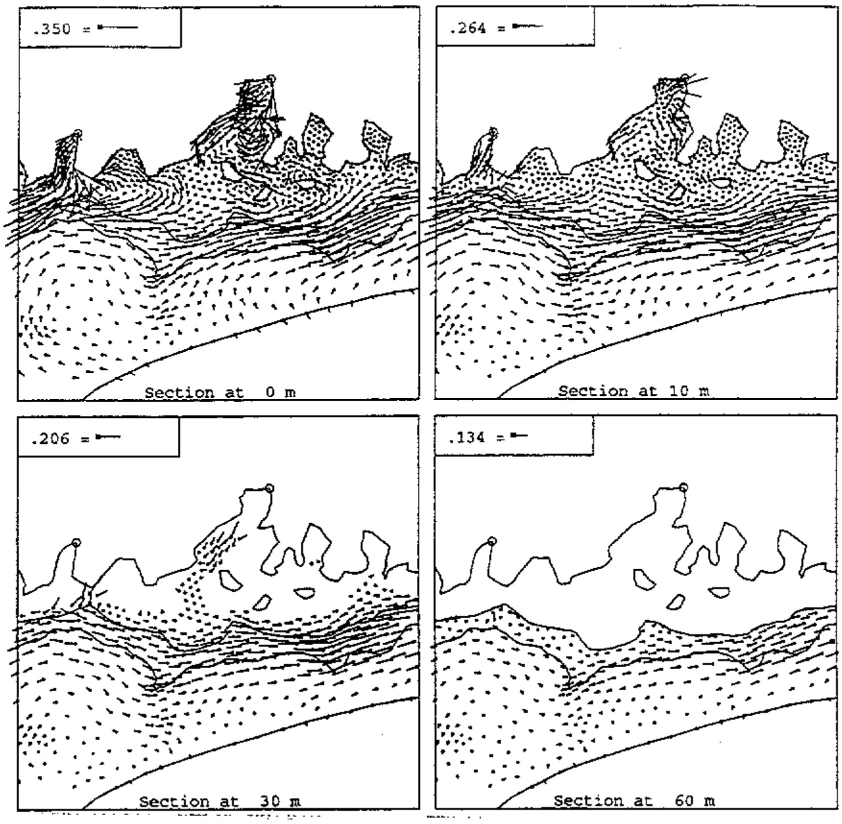

Figure 19: May-June circulation at the Penobscot branch point (from Lynch et al, 1995).

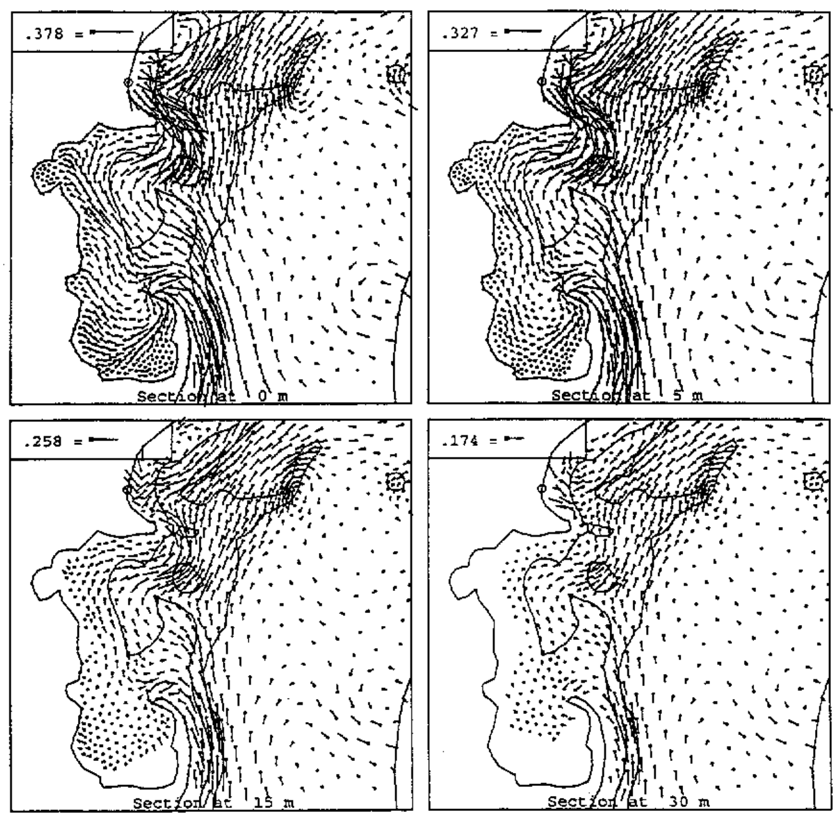

Figure 20: May-June circulation at the Cape Ann branch point (from Lynch et al, 1995).

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Influences of Oceanographic Processes on the Biological Productivity of the Gulf of Maine

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KEY WORDS: Gulf of Maine, physical oceanography, nutrient budget, primary production.

I. INTRODUCTION

The Gulf of Maine is a continental shelf sea on the east coast of North America, situated between Cape Cod, MA and Nova Scotia, Canada (Figure 1). Its rich biological productivity, resulting from a suite of complex oceanographic processes, has for centuries supported a bountiful fishery. The Gulf's unusual morphometry, with deep basins and limited access to the open Atlantic Ocean, the strong tidal mixing of its shallower waters, and the seasonal cycle of intense winter cooling, springtime freshwater runoff, and summer warming, act individually and collectively to affect the physical, chemical, and biological oceanography of the Gulf, and in many ways clearly set it apart from the nation's other continental shelf ecosystems.

The purpose of this article is to review selected aspects of the oceanography of the Gulf of Maine important to biological productivity, highlighting in the process a few of the more important research questions facing scientists and environmental managers, and thus suggesting new avenues of research.

II. DOMINANT PHYSICAL PROCESSES IN THE GULF OF MAINE

A. The Influence of Slope Water

The Gulf of Maine is more of an enclosed body of water than the expose gulf its coastline implies (Figure 1). Its interior waters are to a large degree isolated from the open Atlantic Ocean to the south by Nantucket Shoals, Georges Bank, and Browns Bank, which greatly restrict flows into and out of the Gulf. The Northeast Channel, between Brown's Bank and Georges Bank, allows limited exchanges of deep waters between the Gulf and the continental slope. Influxes along the bottom of relatively warm, salty, and dense slope water replace outgoing surface and intermediate waters and spill into the three major basins inside the Gulf: Georges, Jordan, and Wilkinson. Each basin exceeds 250 m depth, but all are isolated from one another below 200 m. It is the Gulf's shape, with a deep channel and central basins, coupled with variations in pressure gradients inside and outside the Gulf, that produces this general, estuarine-like circulation patterns.[1-6] It is this influx of deep water into the basins of the Gulf of Maine that, for the most part, may represent the single most important physical process affecting the internal circulation and biological production of the entire region.[7]

As slope water flows into the Gulf of Maine through the Northeast Channel, it spills first into Georges and then the Jordan and Wilkinson Basins. The spreading of the warm, salty water responds to the Coriolis effect, as it hugs the Scotian Shelf, replacing more of the bottom water in Jordan Basin than in Wilkinson Basin in the western Gulf. Vertical profiles of temperature and salinity in these two basins show significantly more slope water in Jordan Basin as defined by the depth of the 34 ppt isohaline (Figure 2). The large-scale circulation in the Gulf of Maine is generally cyclonic, or counterclockwise, and is

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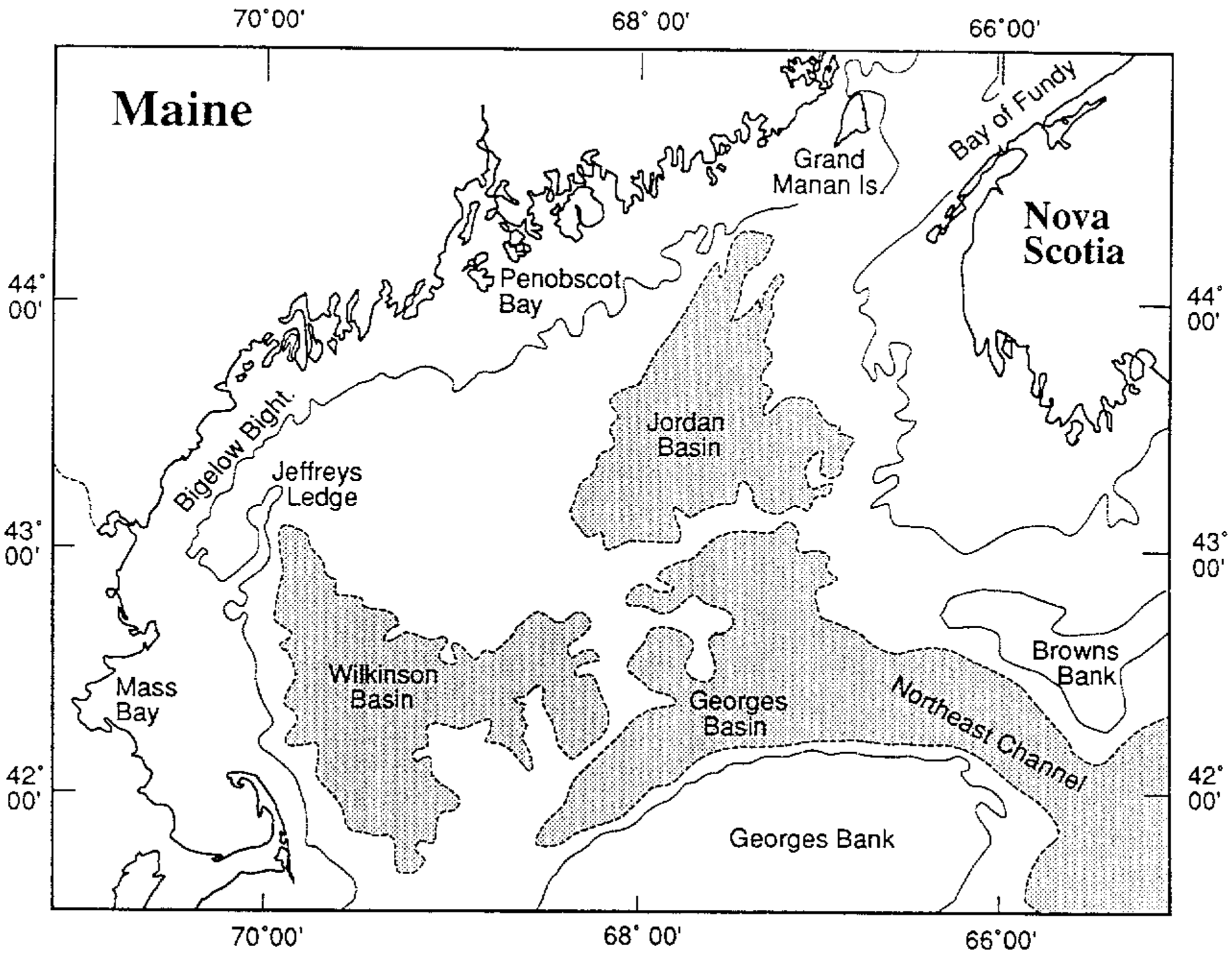

FIGURE 1. Map of Gulf of Maine showing the major features referred to in the text.

strongly baroclinic, reflecting the contrast between the dense slope water residing in the offshore basins and the fresher, tidally mixed coastal waters.[1,4] The contrast is reflected in the density field of the inner Gulf in Figure 3A where contours of dynamic topography suggest a general counterclockwise circulation pattern around the topographic lows with some evidence of separate gyres over the two northern basins, Wilkinson and Jordan. The intensity of the circulation around these lows reflects the relative volumes of slope water residing in each basin; the circulation over Jordan Basin is thus more energetic than in Wilkinson Basin. The density-driven residual circulation pattern for the region is shown in Figure 3B, as interpreted by Brooks.[4]

Although the importance of slope water to the mass balance and baroclinic circulation of the Gulf of Maine has been recognized for a long time,[1] we are gaining a greater appreciation of its variability and the resulting effects,[4] in particular the variable effects on the coastal circulation in the northeastern Gulf of Maine.[8,9] The eastern Maine coastal current represents the northern limb of the Jordan Basin gyre and transports the cooler, tidally mixed waters in the Grand Manan area down the Maine coast. A fraction of that current turns offshore as a plume of cold water in the vicinity of Penobscot Bay and enters a clockwise eddy over Jeffreys Bank (Figure 3), about halfway down the Maine coast; the remainder recirculates over Jordan Basin. This can be seen in the pattern of surface temperatures shown in Figure 4; during the warmer months,

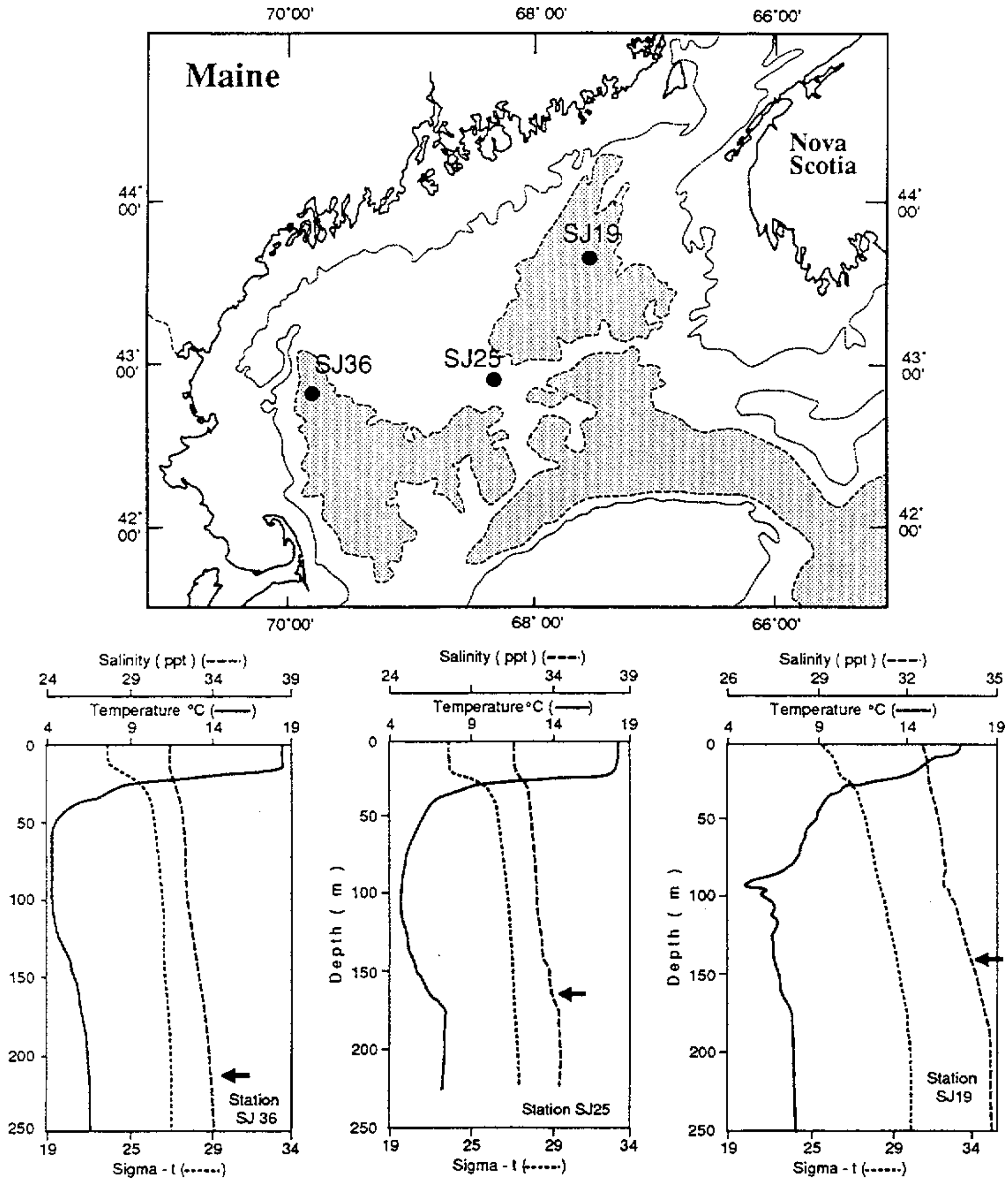

FIGURE 2. West to east differences in hydrographic structure of the offshore Gulf of Maine during summer as illustrated by vertical profiles of temperature, salinity, and density (σ_t) for three stations in the Gulf of Maine during August 1987 (data from *R/V Seward Johnson* cruise; Townsend, unpublished). The depth of the 34 ppt isohaline, which defines slope water, is indicated by an arrow; this water layer occurs closest to the surface in the eastern Gulf.

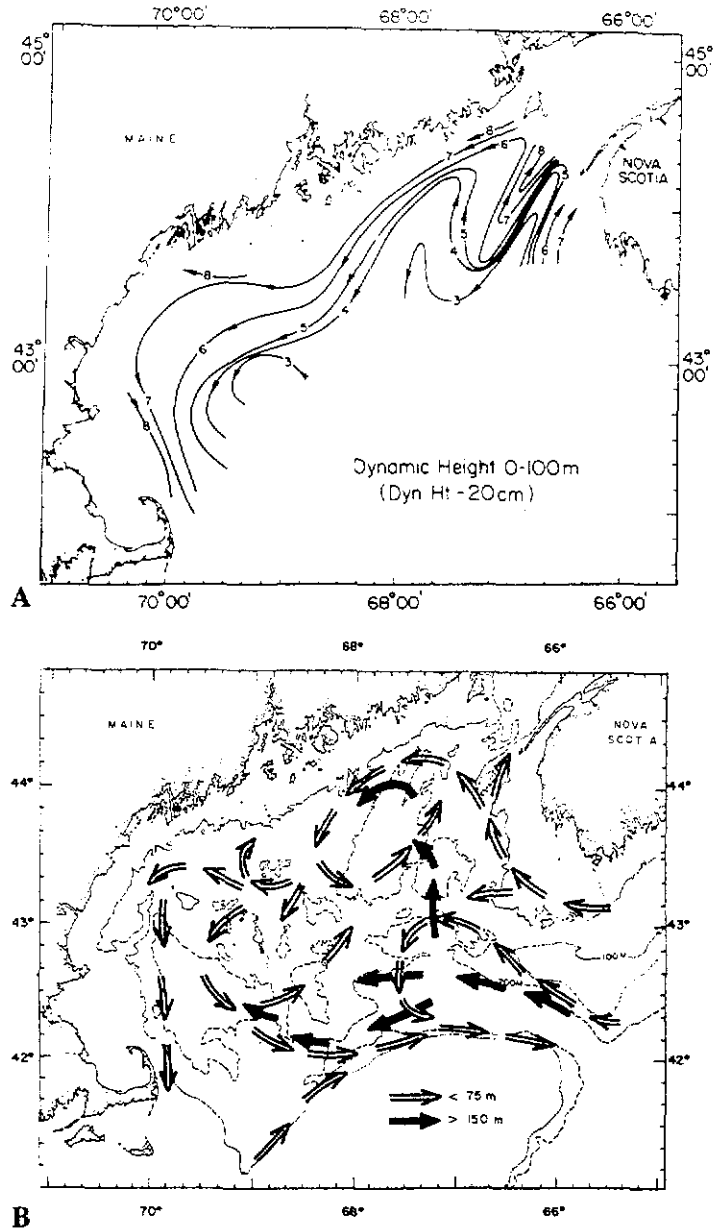

FIGURE 3. (A) Contours of dynamic height (calculated relative to a reference depth of 100 m) for the Gulf of Maine in July 1985 (from Townsend et al.[8]) and (b) the inferred residual circulation during the spring-summer period at the surface and at depth (from Brooks[4]).

this cool-water feature is clearly seen in satellite infrared images of sea surface temperature (Figure 5).

The influx of slope water through the Northeast Channel between 75 m and the bottom occurs in pulse-like events that may be correlated with the winter winds, but when time averaged, the transport appears to be seasonal, from a late-winter low to a maximum in early summer.[5] Reports of these inflow events have been few and anecdotal. Townsend and Spinrad[10] observed what appeared to be an anomalously greater volume

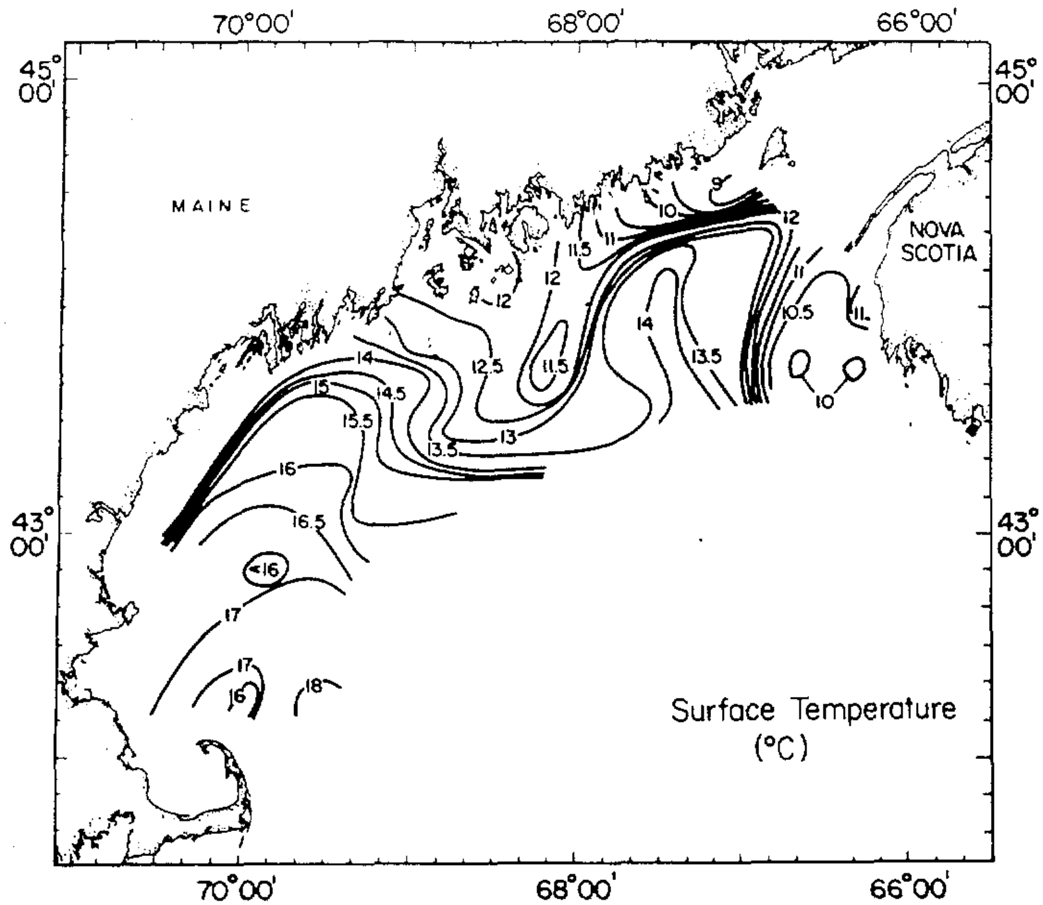

FIGURE 4. Cruise results from July 1985. (A) Contours of surface temperatures showing the advection of cooler, tidally mixed waters from the Grand Manan area down the Maine coast as part of the eastern Maine coastal current. The cooler water can be seen to turn offshore as a plume-like feature off Penobscot Bay. (B) Surface nitrate concentrations. (C) Nitrate concentrations per square meter integrated to 35 m. (From Townsend et al.[8])

of slope water in Jordan Basin in late March-early April 1984. The 34 ppt isohaline domed to within 116 m of the surface and produced a pycnocline between 90 and 100 m, which was shallower than the critical depth, and thus triggered an early spring phytoplankton bloom there. Citing a similar observation of enhanced doming of slope water in Jordan Basin by Cain,[11] and the concurrent observation by Fitzgerald and Chamberlain[12] of a large warm-core Gulf Stream ring just off the Northeast Channel, Townsend and Spinrad[10] suggested that Gulf Stream rings may be important in the episodic pumping of slope water into the Gulf. Brooks[13] provided the first account of the mechanism of Gulf Stream-slope water interactions by documenting a major inflow event apparently triggered when a ring streamer brushed against the mouth of the channel, forcing streamer-modified slope water to enter the Northeast Channel.

Brooks and Townsend[9] presented further evidence of the importance of episodic slope water intrusions in controlling the circulation in Jordan Basin and the coastal waters of the northern Gulf of Maine when they witnessed a redirecting of the eastern Maine coastal current, steered by the increase in baroclinicity caused by a greater influx of slope water into Jordan Basin. The influx of slope water and the resultant increased doming in the basin displaced the offshore departure point of the coastal current toward the east by about 100 km; the coastal current returned to its "nor-

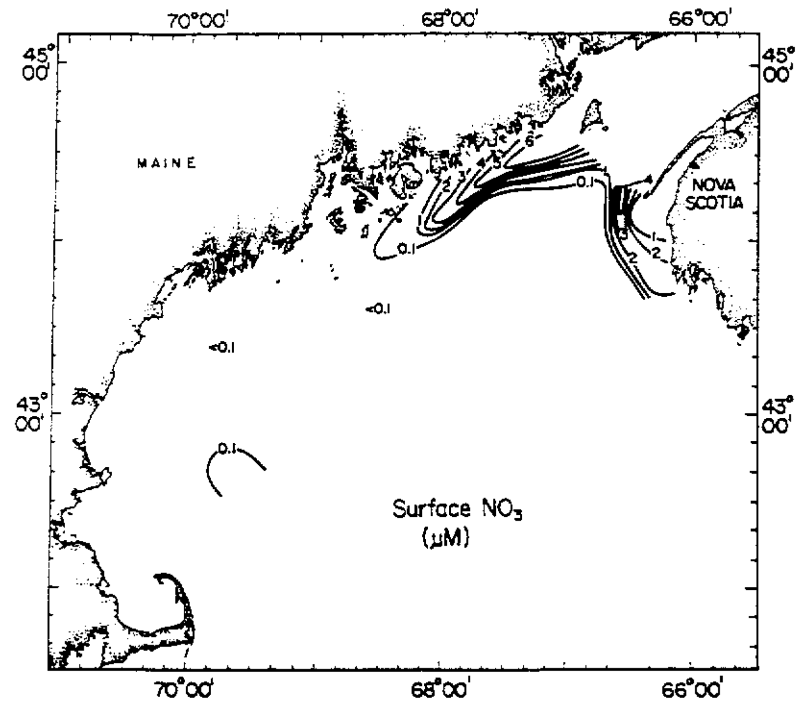

FIGURE 4B

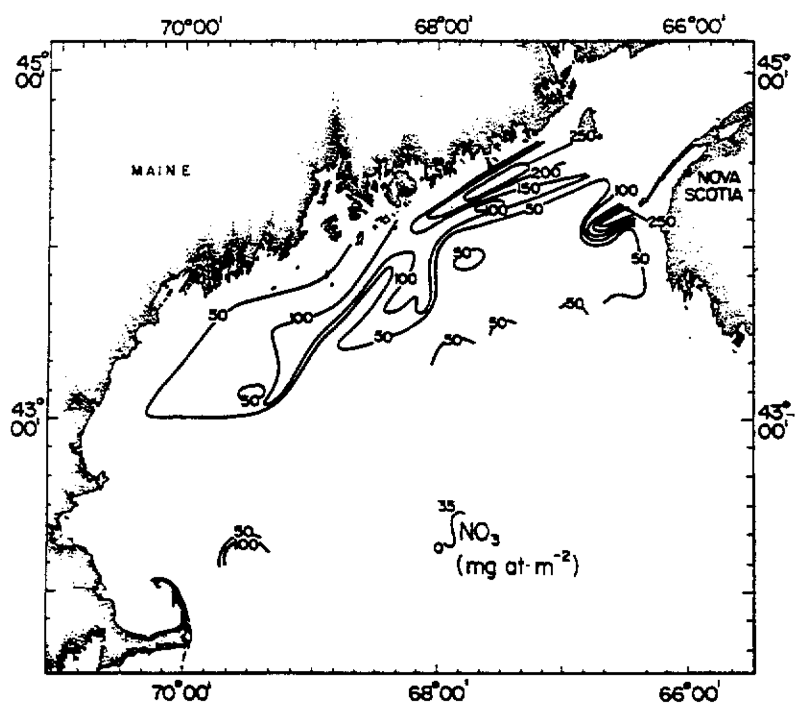

FIGURE 4C

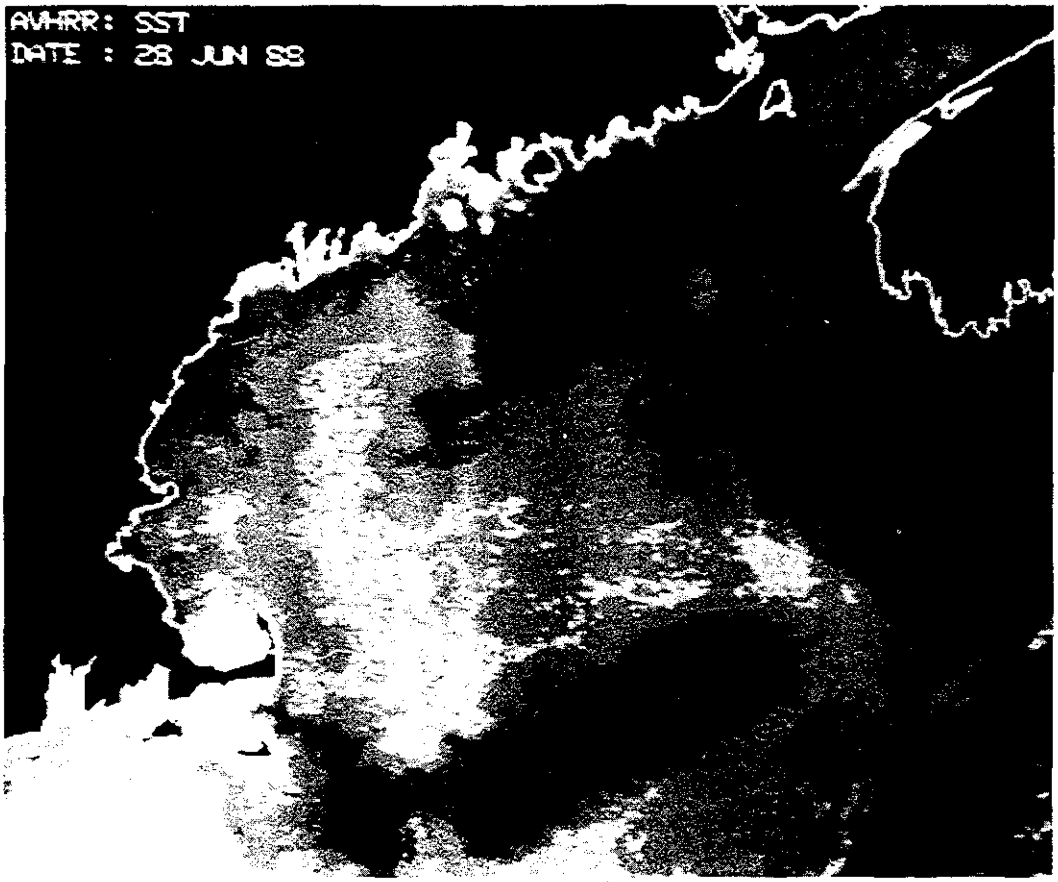

FIGURE 5. AVHRR thermal satellite image of sea surface temperature in the Gulf of Maine on June 28, 1988. The darker shades correspond to cooler surface water temperatures. The tidally well-mixed areas with cooler surface water temperatures include the Maine coast and the eastern Maine coastal current/plume system, the Bay of Fundy and southwest Nova Scotian shelf, Browns Bank, Georges Bank, and Nantucket Shoals.

mal" position as the slope water spread to the west over the following 3-week period. A secondary, divergent upwelling of nutrient-rich waters resulted when the coastal current was "steered" offshore further east than normal.

Slope water represents the major source of inorganic nutrients to the Gulf of Maine[1] and has nitrate concentrations as high as 20 μM,[14] which underscores the biological significance of slope water dynamics, in addition to its importance in driving the residual circulation. It is clear that a proper understanding of the biological and chemical oceanography of the Gulf of Maine depends in turn on a more complete understanding of those processes that affect slope water entry and spreading throughout the Gulf. Most of the slope water-derived nutrients occur in the eastern Gulf, reflecting the proximity to the Northeast Channel source (Figure 6). Vigorous tidal mixing along the southwest Nova Scotian shelf and along the eastern Maine coast[15,16] is responsible for lifting some of this nutrient-rich water into the surface layers where it becomes part of the coastal surface circulation. This was demonstrated by Townsend *et al.*[8] for the eastern Maine coastal current and its ensuing offshore-directed plume (Figure 4). They calculated that about 44% of the nitrate entering with slope water through the Northeast Channel (based on concentrations reported by Schlitz and Cohen[17]) makes its way into the tidally mixed surface waters of Grand Manan area of the eastern Gulf, and thus is made

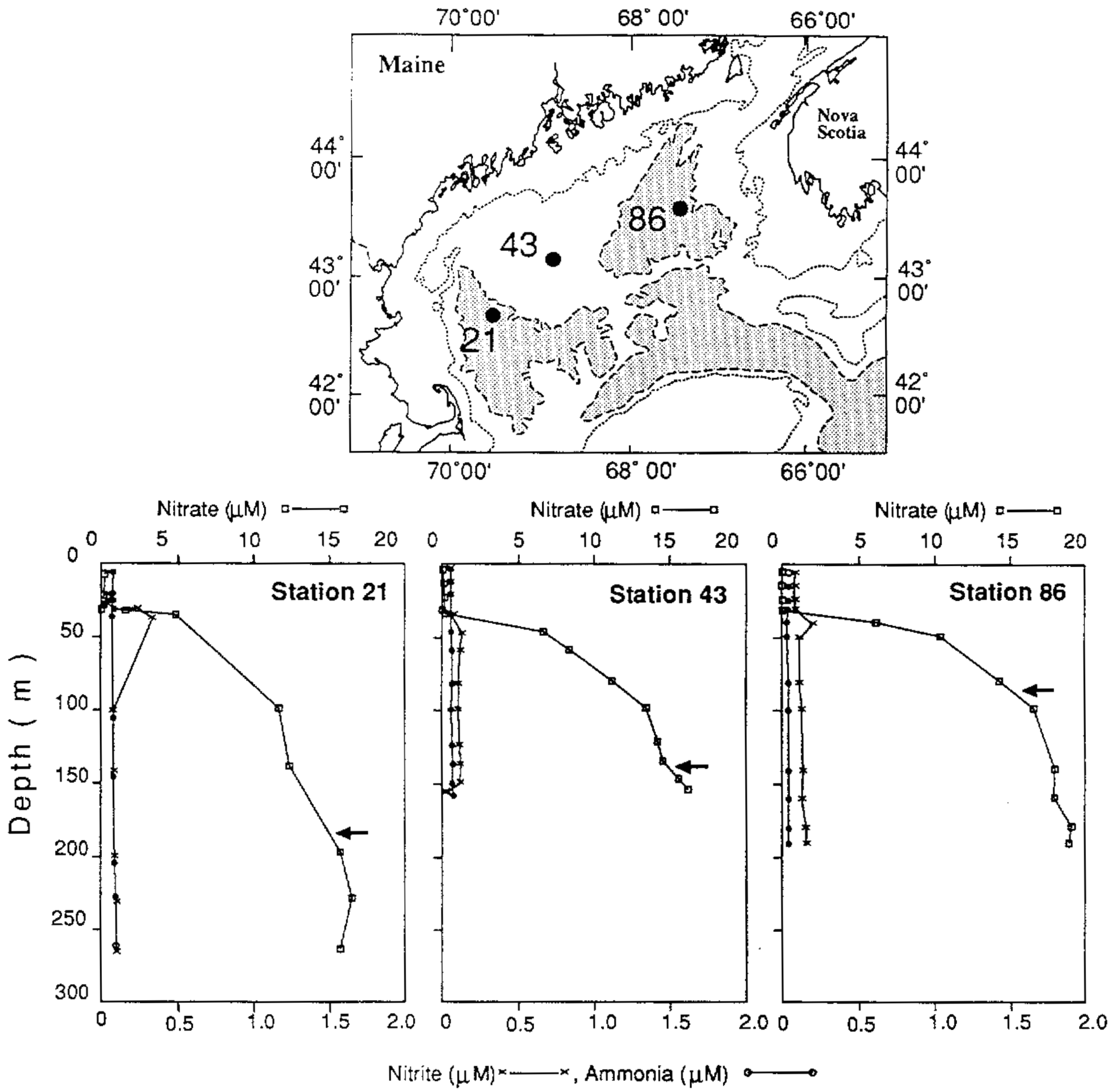

FIGURE 6. Vertical distributions of nitrate, nitrite, and ammonia from west to east in the offshore Gulf of Maine for three stations during July 1985 (data from Townsend and Christensen[14]). Notice the subsurface maximum in nitrite concentrations in the west, indicating nitrification in the intermediate water layer, and that the concentration of nitrate is greatest in the eastern Gulf, reflecting the proximity to the Northeast Channel, which is the slope water source for the Gulf. The arrows mark the depths of the 15 μM nitrate for each station.

available for biological uptake via the eastern Maine coastal current/plume. They demonstrated that the nutrients become depleted by phytoplankton uptake as the waters become increasingly stratified some distance downstream within the coastal current/plume system and that zooplankton then propagate in response to that bloom. The result is a chain of events transporting first dissolved, then particulate, nitrogen to the central and western Gulf of Maine, depending on the variable steering of those plume waters as affected by slope waters in Jordan Basin. Furthermore, Cammen[57] has documented the correspondence between the locations of these planktonic events in the coastal plume to the presence of phytoplankton-derived organic matter in the bottom sediments, which argues for a close coupling of benthic-pelagic processes associated with the coastal current/plume system.

B. Tidal Mixing

Because of the Gulf of Maine's morphometry it is in near resonance with the M2 tide and exhibits semidiurnal tides that range from about 2 to 3 m in Massachusetts, 5 m in eastern Maine, and >15 m in the upper reaches of the Bay of Fundy. These tides give rise to swift tidal currents that can, depending on the depth and bottom roughness, effectively mix the water column and prevent thermal stratification in the warmer months. The result is the maintenance of cool, tidally mixed areas throughout the shallower parts of the Gulf that are set apart by sharp thermal fronts from the warmer surface waters over the deeper, vertically stratified regions.[15,16,18,21] The tidally mixed regions of the Gulf of Maine include the southwest Nova Scotia shelf, Georges Bank, the eastern Maine coastal waters, and a narrower coastal band that surrounds the remainder of the Gulf;[16] these features are clearly visible in satellite imagery of sea surface temperature (Figure 5).

Tidal mixing in the Gulf of Maine[19] and the superposition of advective processes on tidally mixed waters[4,8,9,22] affect the overall distribution of less vertically stable waters and their high concentrations of inorganic nutrients. These patterns in turn dictate the spatial distribution of biological production in the Gulf,[1] particularly along the coast where the effects of tidal mixing are most important. The degree of vertical mixing and destratification of the water column can have important effects on phytoplankton production since mixing greatly influences the levels of the two main factors controlling photosynthesis: light and dissolved nutrients. A well-mixed, deep water column often restricts primary production because of light limitation. Nutrients, on the other hand, are usually in plentiful supply in mixed regions, being constantly renewed by a combination of upwelling and benthic regeneration. Yentsch and Garfield[21] suggested that the shallower mixed areas accounted for the majority of primary production in the Gulf of Maine. Stratified waters represent just the opposite situation from mixed waters, and cells tend to be retained in the upper mixed layer above the thermocline/pycnocline and hence are not light-limited. However, surface-water nutrients become rapidly depleted during the spring phytoplankton bloom, a brief period of intense production that begins with the onset of vertical stratification, which isolates phytoplankton cells in a surface layer of relatively high light and nutrient concentrations. After the bloom exhausts the available nutrients in the surface waters, the thermocline acts as an effective barrier to nutrient renewal from below during the remainder of the stratified season and phytoplankton standing stocks remain low throughout the summer. A compromise between the tidally mixed and stratified regions exists in the vicinity of the thermal fronts, where primary production may be enhanced due to the delivery of nutrient-rich deeper waters to an area of shallow stratification existing within the front itself. [8,23-25]

Production in stratified waters during the warmer months proceeds at a much reduced level, apparently confined to a subsurface phytoplankton chlorophyll maximum layer (SCM)[26,27] that derives its nutrients via diffusion through the seasonal pycnocline. Surface production levels are thus set by this diffusion rate and the level of nutrient recycling by the heterotrophs. Conversely, depending on depth and hence light limitation, the spring bloom in tidally mixed regions of the Gulf may exhibit only a muted increase in production, or one confined to only the shallower waters, but production in these shallow areas, as well as in the front, may persist throughout the warmer months.[8,21,25]

Thus, the Gulf of Maine may be characterized not only by regions that stratify or remain mixed by tides or advection of mixed waters, but also by regions that experience a spring bloom or maintain some persistent production level.[28] Considering only the Maine coast out to the 100 m isobath, the dividing line between these two extremes, as discussed above, falls roughly in the vicinity of Matinicus Island to the south of Penobscot Bay (Figure 1). To the east, the waters are more vertically isothermal and show little seasonal stratification, as opposed to the waters to the west that typically become stratified. Depending on the rate, duration, and a real extent of primary production in each region (i.e., comparing the relative importance of a spring bloom in waters that thermally stratify to more steady production in tidally mixed waters and frontal regions), one region may have a greater annual production than the other. Apart from the absolute level of production in each region, the temporal progression of production would also differ between them. It follows that the ensuring trophodynamics that transfer this carbon and energy up the food chain would differ as well, especially as these processes relate to pelagic-benthic coupling.

C. Water Mass Formations

One of the more important features produced in response to the Gulf's pattern of seasonal warming and cooling is the formation of distinct water mass layers. Each winter the Gulf undergoes intense cooling and buoyance extraction that leads to convective sinking of near-surface waters and overturn across the shallow seasonal pycnocline.[29] This vertical homogenization of the upper water column produces a uniformly cool and relatively freshwater mass that extends from the surface to the top of the dense bottom water layer, at about 150 m.[1,30] Such vertical mixing of the upper water column results in an upward delivery of deep nutrients, producing relatively high concentrations that often, in the early stages, initiates a fall phytoplankton bloom. The resulting nutrient concentrations in the upper water column in winter reach about 8 μM nitrate throughout the Gulf, with somewhat greater concentration in the bottom waters.[8,31]

Vertical stratification of the water column in spring and summer isolates a remnant of the previous winter's upper water mass to form a cold and somewhat fresh intermediate water layer sandwiched between a warmer, fresher surface layer and a relatively warm but salty bottom water layer of slope water origin.[30] The intermediate water layer is too deep to be warmed from the surface by solar insulation over the relatively short summer period and is sufficiently removed from the bottom to be tidally mixed.[30] This intermediate layer is colder and denser that the warm surface waters, but lighter than the warm, but salty bottom waters that enter from outside the Gulf (Figure 2 shows the intermediate water layer as a temperature minimum in the western Gulf). The intermediate waters serve as a trap for sinking carbon and nitrogen that has been biologically fixed at the surface, as reflected in the distributions of particulate maximum layers[32,33] and nitrite and ammonium maxima[26] (Figure 6), and is very likely important to the nutrient dynamics in the Gulf. The importance of this intermediate layer in nutrient cycling and to the ratio of new to recycled primary production remains unknown.

The greater volume of slope water in the eastern Gulf of Maine, as well as the greater tidal mixing, results in a more efficient erosion of the intermediate water layer in the eastern Gulf. Hopkins and Garfield[30] showed that the intermediate water layer is thickest and disappears latest from Wilkinson Basin and the western Gulf. This may become a clue to understanding the relative nature of nutrient dynamics in the eastern and western Gulf, as discussed later.

The three-layered system in the Gulf of Maine[30] further complicates the role of water mass exchanges between the Gulf and the open Atlantic in the Gulf-wide nutrient budget. The intermediate water layer is a site of significant nitrification (note the nitrite maximum in Figure 6) as organic matter from above is decomposed in transit to the bottom.[26] Much of the waters that exit the Gulf through the Northeast Channel are from the intermediate water layer, and thus while slope water intrusions provide the bulk of new nitrate entering the Gulf, some internally recycled nitrate, as well as particulate and dissolved organic carbon, may be exposed to the slope.

D. Freshwater Runoff

Numerous rivers of various sizes enter along the northern coastline of the Gulf, resulting in a significant spring freshet each year. This freshwater runoff is important to setting up the coastal circulation in spring[1,4] and in imparting stratification to nearshore waters which may be important for the initiation of inshore phytoplankton blooms.[10] Most of the freshwaters emptying from the rivers hug the coast in response to the Coriolis effect and flow into the western Gulf. The surface waters of the western Gulf typically are fresher and, in summer, significantly warmer than the eastern Gulf. In addition, a significant source of freshwater enters the Gulf around southwest Nova Scotia as relatively cold Scotian Shelf water,[34] which also contributes to horizontal property gradients and can affect the circulation in the eastern Gulf of Maine by providing a sharp contrast with the more dense waters residing offshore in Jordan Basin.

III. NUTRIENT SOURCES AND BIOLOGICAL PRODUCTION

There are only a few published accounts of the rates of primary production in the Gulf of Maine. The most complete set of measurements is provided by O'Reilly and Busch,[35] who reported an average annual rate of primary production of 290 g C m^{-2}. This compares to their estimates of 300 to 470 g C m^{-2} for Georges Bank. It is interesting to note that estimates of zooplankton production are greater for the Gulf of Maine than on Georges Bank, despite lower levels of primary production.[36]

By building upon the above discussion of the physical workings of the Gulf of Maine, we can perhaps add some insight into the rates of primary production as they might vary seasonally and spatially in response to the nutrient dynamics. Such exercises can be instructive since a more complete understanding of the spatial/temporal nature of nutrient fluxes might, in turn, help to explain the apparently significant difference in the nature of plankton trophodynamics that led to the observed differences in zooplankton production between the Gulf and Georges Bank, and add to our understanding of processes affecting fisheries production.

A. Nutrient Fluxes

The data available to undertake an evaluation of nutrient fluxes in the Gulf of Maine are by no means complete, but are certainly adequate for this overview. Much of the information stems from a review by Schlitz and Cohen,[17] who presented a useful compilation of data and calculations to produce an annual nutrient budget for the Gulf. Taken further, we can see that the timing and locations of these nutrient fluxes may hold important implications for the ensuing trophic dynamics.

Fluxes of nutrients into the euphotic zone of the Gulf of Maine can be placed into a number of categories: winter convective overturn, vertical eddy diffusion through the seasonal pycnocline, coastal upwelling, the eastern Maine coastal current/plume system (also the result of upwelling), and recycled production. The relative contributions of each of these to the total annual primary production estimate of O'Reilly and Busch[35] are discussed briefly in the sections that follow.

1. Winter Convective Overturn

The level of nutrients available for the spring phytoplankton bloom are the result of vertical overturn the previous winter; this homogenizes the water column from the surface down to about 150 m, or to the top of the slope water layer offshore. This produces a nutrient (nitrate) field in winter on the order of 8 mg-at NO_3-N m^{-3} (or 8 μM) over the upper water column.[37] Assuming that the spring bloom develops when thermal stratification caps off the top 35 m, and that the area of the Gulf of Maine, excluding Georges Bank, is approximately 1.03×10^{11} m^2, this then provides 2.8×10^{10} g-at NO_3-N, or 3.9×10^{11} g N available for primary production. Applying the Redfield ratio of 6.625 for C:N gives an estimate of new primary production in the spring bloom of 26 g C m^{-2}. This assumes that the phytoplankton bloom exhausts the nutrients in the mixed layer above the thermocline and that there is no renewal during the bloom period.

2. The Eastern Maine Coastal Current/Plume System

Townsend *et al.*[8] have estimated the flux of nitrate into the surface waters of the inner Gulf via this system by taking an average nitrate concentration at the origin of the coastal current/plume in the east (approximately 5 mg–at

NO_3-N m^3) multiplied by the volume transport of plume waters to arrive at a flux of 1.51×10^{11} mg-at NO_3-N d^{-1}. Assuming that this process is important to primary production over 9 months of the year, when light is not limiting, gives a flux of 5.7×10^{11} g NO_3-N. Dividing this value by the approximate area of the inner Gulf of Maine (inside a line from Cape Cod to Nova Scotia; 57,500 km^2) and again applying the Redfield ratio gives a level of new primary production of 56 g C m^{-2} 270 d^{-1} for the inner Gulf, or 36.6 g C m^{-2}, averaged over the entire Gulf of Maine.

3. Vertical Eddy Diffusion

The upward flux of nutrients across the pycnocline fuels the surface chlorophyll maximum (SCM), which is a pervasive feature throughout the stratified regions of the Gulf during the warmer months of the year. Though extremely difficult to measure, the upward diffusion of nutrients to the SCM can be estimated based on the one-dimensional Fickian diffusion equation,[38–42]

$$F = K_z \, dNO_3/dz$$

where F is the nitrate flux, K_z is the vertical eddy diffusivity, and dNO_3/dz is the nitrate concentration gradient with depth, z. This estimate is highly sensitive to the choice of the vertical eddy diffusivitiy, K_z, which can be approximated using the empirical relation of King and Devol,[40]

$$K_z = 643 \, (10^6 \, E)^{-1.61}$$

where $E = d(\sigma_t)/dz \times 10^{-3}$. This equation gives a typical value for K_z in the offshore waters of the Gulf, using data in Townsend and Christensen[14] for the summer months, of approximately 0.3 $cm^2 \, s^{-1}$, or $0.3 \times 10^{-4} \, m^2 \, s^{-1}$; a typical value for dNO_3/dz = approximately 0.5 mg-at NO_3-N $m^{-3} \, m^{-1}$. This gives a nitrate flux (F) of 1.5×10^5 mg-at NO_3-N $m^{-2} \, s^{-1}$, or 1.29 mg-at N $m^{-2} \, d^{-1}$. Multiplying by the area of the Gulf and applying the Redfield ratio gives a potential new primary production of 0.12 g C $m^{-2} \, d^{-1}$, or 32 g C m^{-2} $year^{-1}$ (270 d).

Again, this estimate is extremely sensitive to the selected value of K_z. It could be argued that the eddy diffusion coefficient should be compartmentalized with regard to both season and area, since the estimate of $K_z = 0.3 \times 10^{-4}$ is calculated for stratified stations during summer. The values of K_z and dNO_3/dz will, in fact, be quite different around the Gulf depending on season and location. For instance, values of K_z during summer range from 5.1×10^{-4} in the eastern Gulf near the plume, to 0.3×10^{-4} in the basins, to 0.1×10^{-4} nearshore in the west, and 0.7×10^{-4} off Penobscot Bay and over Jeffreys Bank, etc. Previous workers have used values $\geq 1 \times 10^{-4}$. Garside[42] used $K_z = 4 \times 10^{-4} \, m^2 \, s^{-1}$ for open ocean flux calculations based on information in Denman and Garrett.[41] Loder and Platt[43] used 1×10^{-4} for the North Sea, basing their number on results from Pingree and Pennycuick[44] for the English Channel. The point here is that each of the latter estimates gives greater rates of vertical flux than one based on $K_z = 0.3 \times 10^{-4}$. If we use a value of $K_z = 1 \times 10^{-4}$, we arrive at an estimate of new primary production in the SCM in the Gulf of Maine of 108 g C m^{-2}.

Although primary production in the SCM layer is limited by both lower subsurface light levels and by nutrients, which must diffuse upward, it is possible, as the previous estimate suggests, that the SCM is much more productive than generally thought and that it is not the static, elevated-biomass feature sitting atop the pycnocline as it first appears. When associated with frontal regions where the pycnocline is sloped, there can be a shallow baroclinic current along the frontal boundary as well as strong current shears on either side of the front and between the surface and deeper water layers.[9] This is particularly true for tidal fronts, where there is evidence of upwelling between the vertically well-mixed region and the stratified region, causing the sea surface slope to be depressed along the front, and producing a current shear along the front on either side. The result is that the increased phytoplankton standing stocks we see in the SCM in these regions occur despite being constantly eroded and carried away from the point of production by these shallow currents. This then suggests that the SCM is quite dynamic and productive, and could be critical to explaining the differences in style of secondary production between the seasonally stratified Gulf of Maine and the tidally well-mixed Georges Bank.

4. Coastal Upwelling

Graham[45] has argued that coastal upwelling is the most important physical process operating in Maine coastal waters. Quantifying it is difficult, but we can arrive at its relative magnitude by first considering estuarine upwelling and then boldly assuming that Eckmann upwelling is of the same order. Upwelling at the mouths of Maine's estuaries can be based on an average annual freshwater discharge into the Gulf of 95 km^3 $year^{-1}$ [46] and a crude salt balance argument whereby the seaward extension of the estuaries has a salinity of roughly 1.5 to 4 ppt less than the source salinity of about 33 ppt. Therefore, from 8 to 22 times as much Gulf of Maine source water as freshwater mixes at the mouths of the estuaries (Dyer,[47] for instance, uses an average dilution factor of 19). If the source waters are from 20 to 30 m depth, as is the case in the Shepscot River estuary,[48] and the source nitrate concentrations are those of Maine Intermediate Water (5 to 8 mg-at NO_3-N m^{-3}), then we can estimate the new primary production to be 8.3×10^{11} g C $year^{-1}$; averaged over the entire area of the Gulf, this converts to about 8 g C m^{-2} $year^{-1}$, which is very little. However, if viewed as local primary production restricted to the very small areas of the estuaries and waters immediately offshore, this level of production appears very important.

It is interesting to speculate here. Most of the freshwater runoff in Maine occurs in April, which is after the early spring phytoplankton bloom triggered simply by increasing daylength and controlled by bathymetry.[10] This could mean that an early bloom can continue longer in some cases when runoff occurs earlier than normal, thus providing a secondary source of nutrients, or it can cause a second bloom that spring, which is what appears to happen.[49,50]

On a Gulf-wide scale, the estuaries appear to be unimportant to the total fisheries production in the Gulf of Maine, but if we apply their local production to serve the needs of only a select group of consumers, perhaps a particular life his-

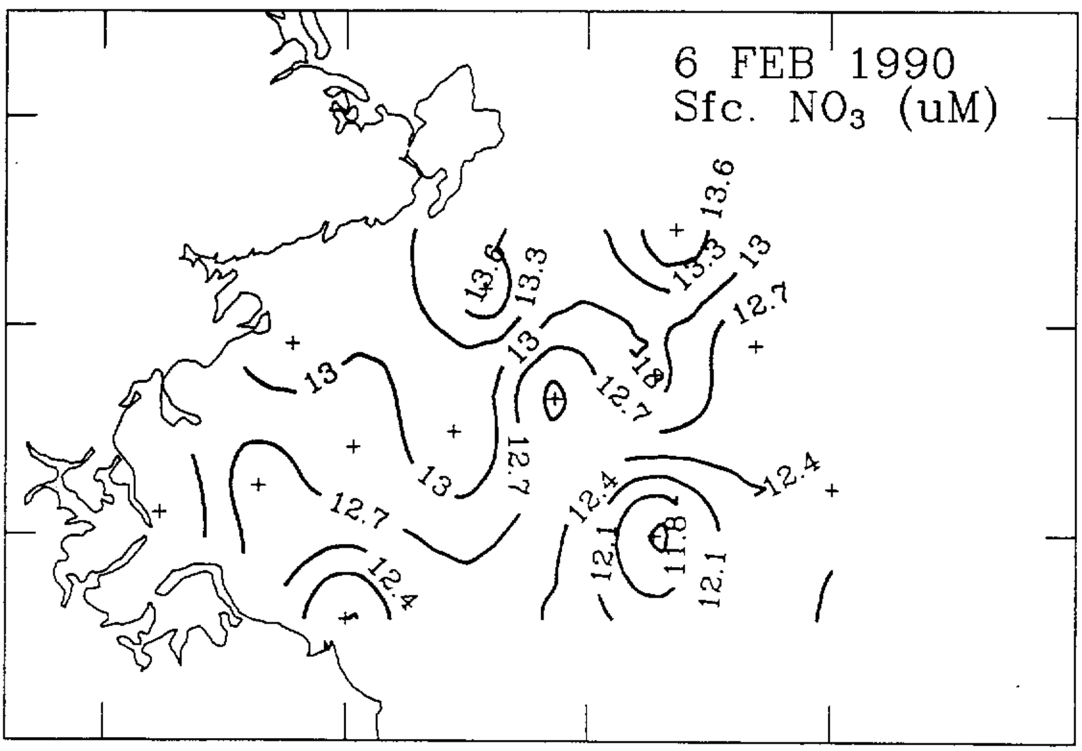

FIGURE 7. Contours of surface nitrate concentrations in northern Massachusetts Bay on February 6, 1990 (from Townsend et al.[56]). Concentrations were nearly uniform with depth throughout the well-mixed water column. Note the highest concentrations at the northeasternmost stations.

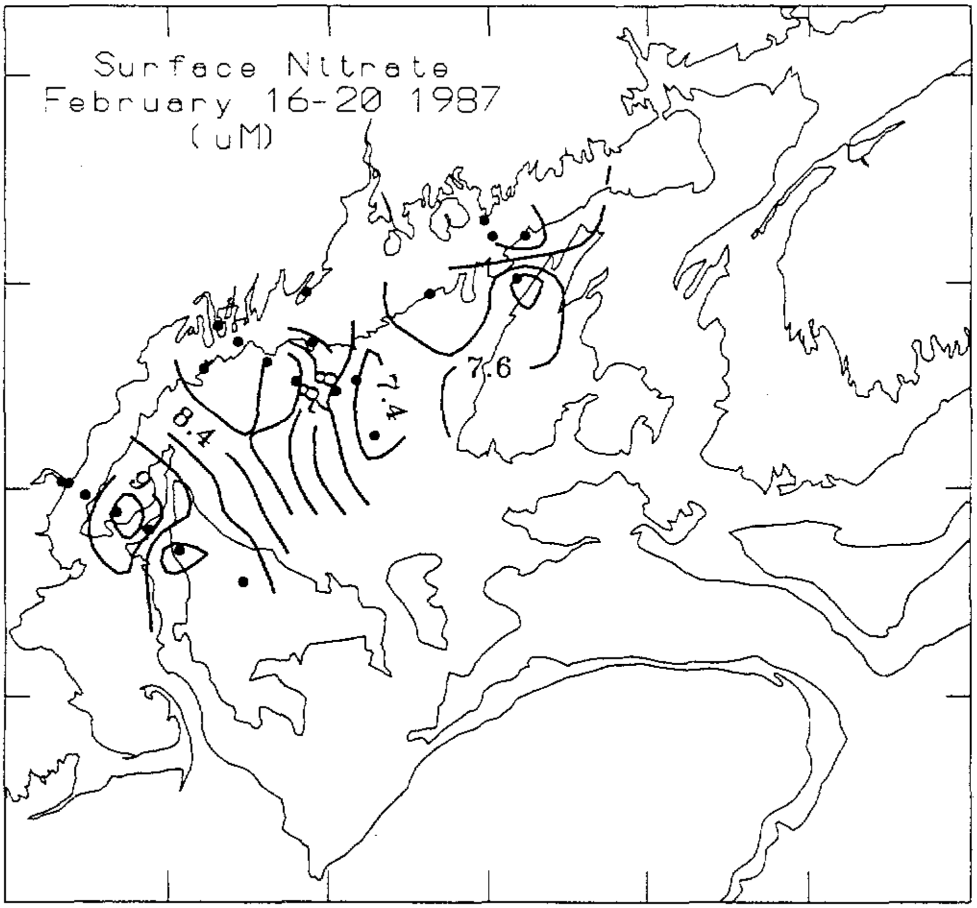

FIGURE 8. Contours of surface nitrate concentrations in the Gulf of Maine during February 16 to 20 1987 (from Townsend et al.[37]). Concentrations were nearly uniform with depth throughout the well-mixed water column. Note the highest nitrate concentrations in the western Gulf over Bigelow Bight and Jeffreys Basin. The 100 and 200 m bottom contours are given.

tory stage such as the juveniles of certain commercial species, then one could make a strong argument for the importance of the intense production at the mouths of the estuaries in supporting nursery areas, even though they represent only a very small fraction of the total Gulf of Maine production.

In addition to Graham's[45] study of upwelling on the Maine coast, Denman and Herman[51] and Garrett and Loucks[52] have demonstrated significant upwelling on the southwestern Nova Scotian shelf. Lauzier[53] showed that the bottom currents were about 2 cm^{-1} shoreward there. It appears, as summarized by Denman and Herman,[51] that "the supply of nutrient-rich slope water onto the continental shelf in the eastern Gulf of Maine and the subsequent phytoplankton production are most likely controlled by a combination of centrifugal upwelling, wind events and tidal mixing." It is difficult to assign a value to the upwelling of nitrate here, but as a first guess we can assume it is of the same order as that upwelling in the Grand Manan area, i.e., 57 g N $year^{-1}$, giving rise to a new primary production of 36.6 g C m^{-2} $year^{-1}$ (if averaged over the entire Gulf).

5. Recycled Production

King et al.[54] used an enzyme method to estimate recycling of nitrogen by a number of size

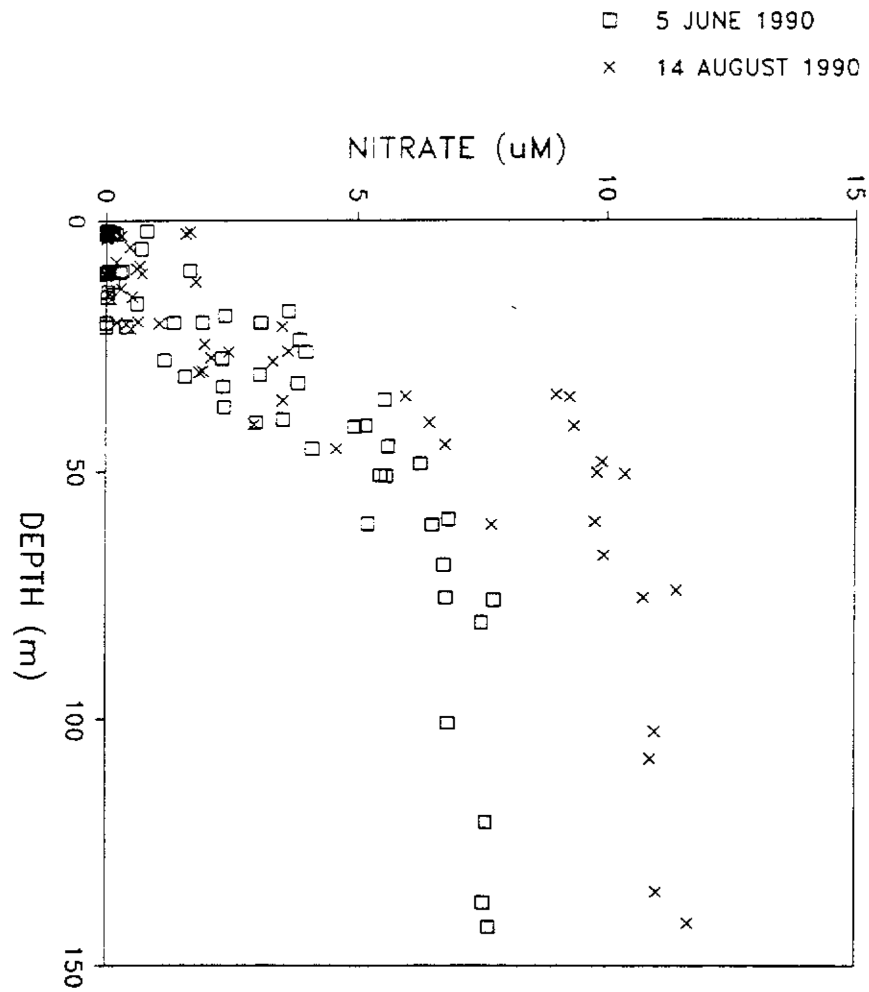

FIGURE 9. Nitrate concentrations as a function of depth for the Massachusetts Bay area shown in Figure 7, in June and August 1990 (from Townsend et al.[56]). Note the higher nitrate concentrations at depth in August. Those higher concentrations were from the northeasternmost stations, suggesting an influx of higher nutrient waters from the north.

fractions of zooplankton at a few summertime stations in the Gulf of Maine. They calculated an average recycling rate of 0.622 mg-at N m^{-2} d^{-1} for the inner Gulf stations, which converts to a primary production level of about 16 g C m^{-2} $year^{-1}$. Schlitz and Cohen[17] have also presented estimates of recycled production levels in the Gulf of Maine, but using relations in Vidal and Whitledge[55] in which between 0.42 and 0.71 μg-at N/mg dry weight of zooplankton per day is regenerated. A mean zooplankton biomass of approximately 7.85 g dry weight m^{-2} for the Gulf of Maine[17] gives about 1.18 g-at N m^{-2} 270 d^{-1}, or a corresponding primary production of about 110 g C m^{-2} $year^{-1}$, which is quite a bit greater than King et al.[54] measured using an enzyme assay. King et al.[54] did not effectively sample the larger copepods in their study, such as *Calanus finmarchicus,* however, which would mean that recycled production was underestimated. It is possible that the true value lies closer to that predicted by Schlitz and Cohen.[17]

6. *A Nutrient Trap in the Western Gulf*

There are limited data showing that winter nutrient levels are sometimes highest in the Bi-

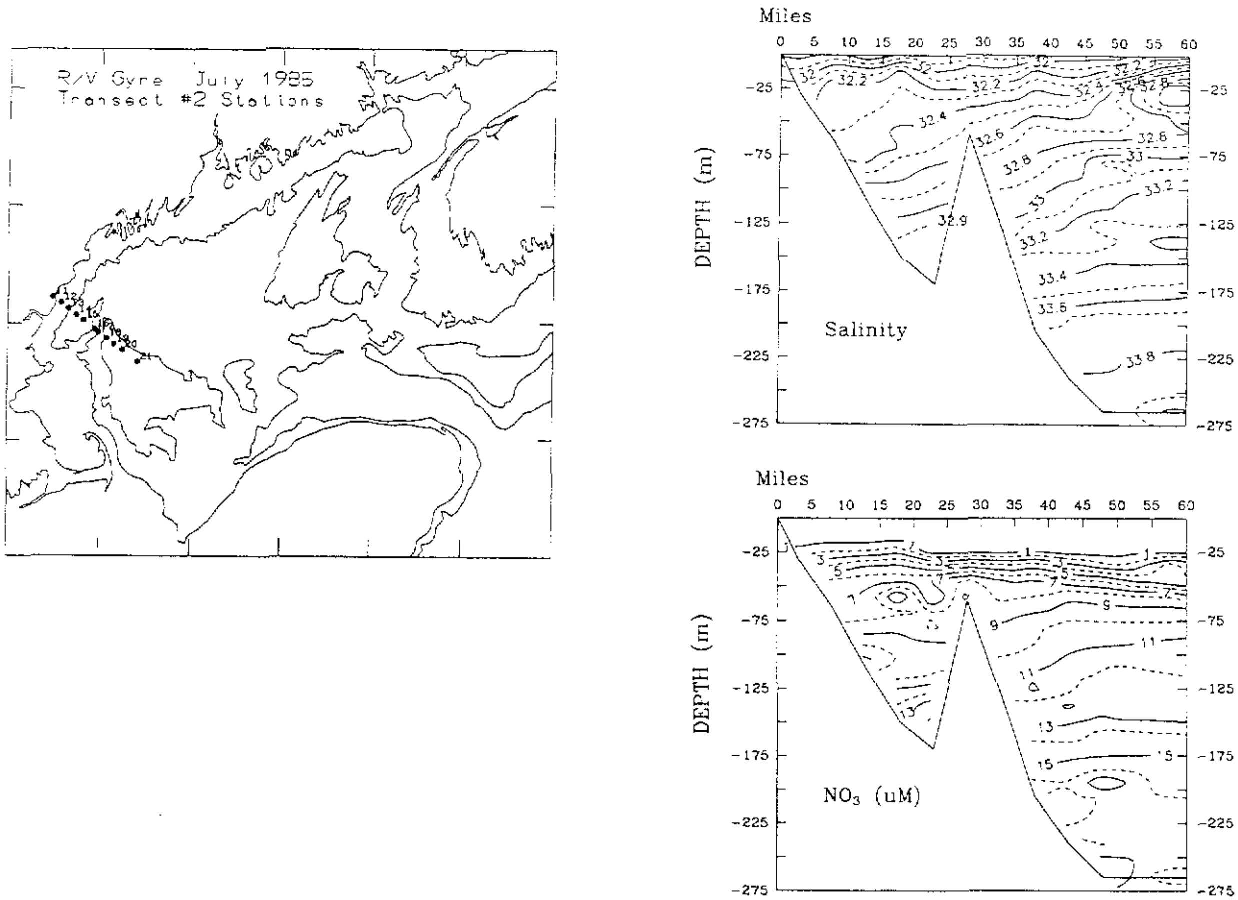

FIGURE 10. Vertical sections of salinity and nitrate for a transect from the coast across Bigelow Bight, Jeffreys Basin, Jeffreys Bank, and the offshore Gulf of Maine (from Townsend and Christensen[14]). Note the elevated nitrate concentrations at depth in Jeffreys Basin, which do not correspond with the nitrate concentrations at similar salinities offshore.

gelow Bight portion of the western Gulf (Figure 1) — far removed from the suspected slope water source in the eastern Gulf [37,56] (Figures 7 and 8). These high nutrient concentrations could result from a nutrient trap that may be operating in the western Gulf of Maine, particularly the Bigelow Blight-Jeffreys Basin area, whereby nutrient recycling at depth acts in concert with the overlying surface flow of productive waters. The evidence comes from Townsend et al.,[56] who have shown that relatively high-nutrient waters appear to enter Massachusetts Bay from the north both in winter (Figure 7) and in summer (Figure 9), but those high-nutrient waters did not reflect an influx into Massachusetts Bay of bottom water of immediate slope water origin.[56] In addition, earlier survey work in this area[14] has shown that the higher nutrient concentrations in the deeper waters of Bigelow Bight in summer (Figure 10) were not associated with higher salinity waters, again suggesting that slope waters are not the direct source. The nutrient trap that may account for these elevated nutrient concentrations operates as carbon and nitrogen are biologically fixed in the surface waters over the western Gulf and, in particular, Bigelow Bight. As these waters flow in a general southwest direction along the coast, the biogenic particles sink to the more sluggish waters beneath where the nitrogen is regenerated, thereby enriching the deep waters over time. Surface nutrient concentrations in the Gulf during winter are thus often greatest here as a result of vertical convective mixing with the deeper, nitrogen-enriched waters in Bigelow

TABLE 1
Summary of Nitrogen Sources and Resulting Rates of Primary Production in the Gulf of Maine

Nitrogen source	Resulting primary production (g C m^{-2} $year^{-1}$)
New nitrogen	
Winter convective overturn	25.2
Eastern Gulf plume	36.6
Vertical eddy diffusion	32.3—108
Upwelling	
Coastal Maine	
Estuarine	8.0
Eckmann	8.0
Southwest Nova Scotia	36.6
Recycled nitrogen	16—110
Total primary production	162—364

Bight. These waters appear to escape the area throughout the year and flow to the south, thus affecting the nutrient budget of Massachusetts Bay. Furthermore, depending on the nature of the coastal currents, as discussed above, as well as interannual variability in freshwater runoff, there may be significant interannual variability in the level of nutrients accumulating at depth. Because of the present uncertainties in the exact nature and variability of this nutrient trap in recycled primary production in the Gulf of Maine, it is not included in the the production estimates reported here.

B. Estimated Primary Production

The above-estimated primary production rates based on nutrient fluxes in the Gulf of Maine are summarized in Table 1. These estimates of primary production give a wide bracket to the measurements of O'Reilly and Busch[35] of 290 g C m^{-2} $year^{-1}$, which does not help to redefine the Gulf's overall biological productivity; however, this exercise is valuable in that it points to the times and places where primary production is important and it helps to illuminate those aspects of the biological oceanography where we lack information. Two areas most in need of further research as revealed here relate to the level of primary production resulting from vertical diffusion and that resulting from recycling, each of which can have important ramifications for the nature of the ensuing trophodynamics.

IV. CONCLUSIONS

The oceanography of the Gulf of Maine is made up of a complex assortment of physical processes that drive water mass exchanges with the open Atlantic, and drive the vertical mixing and residual circulation inside the Gulf. Superimposed on these is the seasonal warming and cooling of the upper water column. All of these processes act to control primary production in subtle but very important ways, many of which we know very little about. The relative proportions of primary production consumed by secondary producers in the water column vs. the benthos, for example, will depend on where and when there is significant primary production.

Our examination of production during the summer stratified season strongly suggests that it is higher than we might have at first assumed, due to what may be a high rate of production within the SCM, as a result of increased vertical diffusion of nutrients, especially in frontal regions where current shears are important. In some ways, this might have been expected since there is evidence of higher zooplankton aggregations and presumably increased grazing in these layers. It is also likely that the source of nutrients that diffuse upward throughout much of the western Gulf, at least, derive from nitrification in the intermediate water layer, where a subsurface nitrite maximum is commonly observed. Further support of the idea of significant nitrification and the importance of nutrient recycling in the Gulf of Maine is revealed in the unbalance between the nitrogen supplied through the Northeast Channel and both the estimated and measured rates of primary production reported here. The nitrogen flux through the Northeast Channel can account for only about 85 g C m^{-2} $year^{-1}$, [8,17] leaving the remainder to be driven by recycled nutrients. Moreover, we can speculate that nitrification and nutrient recycling are more important in the western Gulf of Maine which typically exhibits greater standing stocks of zooplankton.[8]

The message here is that an increased understanding of the biological oceanography of the Gulf of Maine and the variability in its commercial fisheries, for example, will depend on future research efforts that take an interdisciplinary approach to the problems touched upon here.

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Dynamics of Gulf of Maine Benthic Communities

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Introduction

Benthic organisms are an integral component of the Gulf of Maine (GOM) ecosystem because they support food webs involving pelagic species, they are a source of commercially important stocks, and because they comprise a large fraction of marine biodiversity of the Gulf region. In addition, several benthic species play key ecological roles influencing many taxa beyond the local community. While there is an increasing amount of information on patterns of distribution and abundance of macrofauna at the scale of local sites, there is little quantitative information on distribution of the benthos on larger GOM - wide spatial scales. Our understanding of the nature and causes of change in communities of bottom dwelling species is limited, yet this dynamical insight is needed to develop an effective ecosystem -based management plan for marine resources of the GOM (e.g. Langton and Haedrich 1995). The goals of this overview are to provide an outline of the state of our understanding of the dynamics of populations and communities living primarily in hard, but also soft substrate habitats of the Gulf of Maine. The importance of benthic habitats to the Gulf of Maine ecosystem and approaches to habitat management were the subject of a recent Workshop on Gulf of Maine Habitat (reviewed in Stevenson and Braasch 1994), therefore habitat - related issues will not be reiterated here. A recent review of environmental quality in GOM benthic habitats was provided by Larsen (1989).

My review is organized into three sections. The first addresses the question: What are the major processes driving the dynamics of benthic populations and communities ? The second considers aspects of stability, namely, How persistent are benthic populations and communities in the GOM? How resilient are they to natural and anthropogenic disturbances and invasion by introduced species ? The last section summarizes what is known about regional biodiversity patterns. Since there isn't space for an exhaustive review of all processes potentially causing changes in the GOM benthos, I will restrict my attention to several abiotic, or physical forcing phenomena as important causes of natural variability in the benthos and to trophic interactions as a principal suite of biotic phenomena shaping populations and communities.

Processes Driving Benthic Dynamics

Physical Forcing

Subtidal benthic environments of the GOM are characterized by swift currents, an annual temperature range of up to 20 ° C, intensive tidal mixing and frequent storms. They are among the most physically - stressed ecosystems in temperate regions. Despite this rigorous environmental setting, there is little appreciation for the role of physical factors in regulating population sizes of GOM benthos by causing stress -related mortality, by dictating the dispersal and subsequent settlement of benthic larvae, and by creating spatial and temporal variability in food supply and ultimately secondary production.

Within the background of large anti-clockwise circulation in the GOM (Brooks 1985, Pettigrew 1993) some currents that have the potential to act as boundaries to the dispersal of passive larvae, possibly causing differences in the recruitment of benthic invertebrates on large spatial scales (e.g. eastern vs. western Gulf). For example, the eastern Maine coastal current typically separates from the central GOM coast to turn offshore east of Penobscot Bay (Brooks and Townsend 1989). Many benthic invertebrates in the GOM such as mussels, clams scallops, barnacles, crabs, lobsters, brittle stars, sea cucumbers and sea urchins, are passively dispersed by currents for several weeks at some stage of their larval life. By transporting larvae offshore from the Penobscot region and by restricting dispersal farther downstream, this offshore spin-off of the coastal current could isolate invertebrate populations in the eastern from the western Gulf. The eastern Maine coastal current is likely to have other effects on the benthos beyond larval dispersal, because it is nutrient rich plume (Townsend et al. 1987). Preliminary data on patterns of infaunal invertebrate density in soft bottom habitats indicate that abundances are elevated in the path of the coastal current (L.Watling, personal communication), suggesting that it may stimulate secondary production in the benthos.

On smaller spatial domains of the mesoscale, differences in wind driven circulation around islands and variable near -bottom flow regimes can cause pronounced differences in larval recruitment. For example Wahle and Incze (in prep.) have attributed predictable differences in benthic recuitment of the American lobster, *Homarus americanus* , to differences in wind -driven larval transport between the eastern and western sides of Damariscove Island. The western side of the island has some of the highest levels of lobster recruitment in New England (Wahle and Incze in prep). They show that this results from the greater supply of neustonic postlarvae due to higher wind driven surface drift. In shallow rocky subtidal communities off Nahant, MA Sebens and Graham (in press) established a positive correlation between dispersal distance and flow speed for invertebrate larvae. The general implication of both of these studies is that changes in benthic populations can result from spatial and temporal variation in the current regime.

Tidal mixing causes nutrient exchange between the water column and the benthos (Townsend 1992). In the Fundy region, tidally driven nutrient fluxes enhances the secondary production of suspension feeding bivalves (horse mussels, *Modiolus modiolus* (Wildish and Kristmanson 1984). Lesser et al. (1994) found that the growth rates of an active suspension feeder (sea anemone, *Metridium senile*) were greater in high flow environments on Cashes Ledge than in lower flow regimes at the same depth off Monhegan Island. The opposite result was obtained for horse mussels. Horizontal fluxes of particulate food utilized by benthic suspension feeders are often higher in rocky subtidal habitats offshore on Cashes Ledge than in the coastal zone (Genovese and Witman 1993), which is counter to the oligotrophic characterization of surface productivity the central Gulf (Yentsch and Garfield 1981).

Non- linear internal waves (solitons) are oceanographic processes capable of horizontal and vertical transport (Shanks 1985, Pineda 1991) and thus hold great potential for understanding variability in food and larval supply to benthic habitats in the Gulf of Maine. Semi-diurnal internal waves were initially described in the Gulf of Maine by Haury et al. (1979), but their potential importance to the benthos wasn't recognized until recently (Witman et al. 1993, Patterson and Witman, in prep). In the central GOM, solitons passing over the peak of <u>A</u>mmen <u>R</u>ock <u>P</u>innacle (ARP, 28 m depth) on Cashes Ledge are characterized by maximum amplitudes of 27 m and an average period of 10.6 minutes (Witman et al. 1993). They cause rapid increases in bottom temperatures up to 9°C in 10 min., and two to three -fold increases in chlorophyll <u>a</u> concentrations (Fig. 1). Recent water sampling with remote plankton pumps that are triggered by the contact of internal waves with the bottom indicated a 3.9 fold increase in average chlorophyll <u>a</u> (acetone extracted) in wave vs. non-wave events in July 1994 (Witman and Patterson, unpublished). Given their potential as a mechanism to transfer plankton and nutrients from the water column to the benthos, logical questions are: 1) do they enhance benthic production ? 2) how deep do they penetrate along the flanks of offshore ledges? Since they are such large features involving periodic fluctuations of temperature, current velocity and chlorophyll <u>a</u> across a nearly 30 m span of water column , it possible that internal waves may influence the feeding behavior of fish and cetaceans by aggregating phytoplankton and zooplankton.

The depression of the thermocline and Subsurface Chlorophyll Maximum (SCM) by internal waves at Ammen Rock Pinnacle, causes a large and predictable pulse of warm phytoplankton - rich water to the bottom. Recent data from thermistor strings sampling down to the deep slopes of ARP shows that the large temperature spikes signaling internal wave events often penetrate down to 35 m (Fig. 1), but that the amplitude of elevated temperature diminishes with depth roughly between 27 - 37 m (Fig.1). The temperature signal of the downwelled wave is gone by 47 m (Fig. 1). These data strongly suggest that the influence of internal waves on the benthos decreases with depth between 27 and and 37 m. Using empirical data on phytoplankton and zooplankton distribution during and after internal waves, information on the frequency and duration of the waves at ARP, and estimated metabolic costs associated with higher temperatures during the waves, Patterson and Witman (in prep) have estimated the contribution of internal waves to the secondary production of suspension feeding benthos at ARP. The simulation indicates that the scope for growth of sea anemone *Metridium senile* populations at 30 m depth is strongly modulated by solitions with 8 solitons per day required to maintain a positive scope for growth during the stratified season (May - October; . Patterson and Witman in prep). The scope for growth of the active suspension feeding mussel *Modiolus* is also enhanced by the pulsed food supply regime of internal waves, but to a lesser extent than the sea anemone. These results indicate the potential for enhancement of benthic production by internal waves, underscoring their importance as an ecosystem - level process that should be considered in management models of GOM populations.

Storms cause chronic natural disturbances to wave exposed intertidal and shallow subtidal populations and are thus an important natural process shaping the dynamics of Gulf of Maine benthic communities. At sites in southern Maine and New Hampshire, storm dislodgment of horse mussels that become overgrown by kelp regulates the depth zonation of the mussel population (Witman 1987). Horse mussels were excluded from shallow depths (< 9 m) at wave exposed sites unless the mussel beds contain mutualistic sea urchins which graze the kelp off mussels to eliminate dislodgment mortality. Dislodgment during storms represents the most significant source of mortality for adult horse mussels, with up to 35,000 mussels killed at Sea Point Beach during a single northeaster in October 1982 (Witman, 1987). Storms play a major role in regulating the population sizes of blue mussels *Mytilus edulis* (J. Witman observations at Nahant, MA), two species of sea stars (*Asterias vulgaris* and *Asterias forbesii*, Menge 1979), sea urchins (J.Witman unpublished data from Kittery Point, K. Sebens, unpublished data from Nahant MA). Storm dislodgment may also limit the shallow distribution of the stalked ascidian, *Boltenia ovifera* (J.Witman and S.Zamjoiski unpublished data). In addition, hundreds of juvenile lobsters are cast ashore and killed during severe northeasters at Nahant, MA and Sea Point Beach, ME. Although most storm related mortality occurs from November to March when northeasters are most common (US Weather Service, Portland, ME), significant storms can occur any time of the year. In addition to causing large mortalities of individuals, storms can cause a localized depletion of predators (i.e. sea stars), which can have important implications for sessile prey species like mussels if they are not dislodged as well. Storms also affect ecological succession by opening up bare space for colonization in storm generated patches (Witman 1987). In shallow soft bottom benthic habitats, storm generated waves cause sediment re-suspension (Bothner et al. 1994) which is likely to re-distribute pollutants as well as organisms. There is considerable spatial heterogeneity in storm effects in the rocky subtidal zone as shallow epifaunal communities on vertical walls off northern Massachusetts are not regulated by storm disturbance (Sebens 1986) unlike communities on horizontal - sloping oriented surfaces at the same depth.

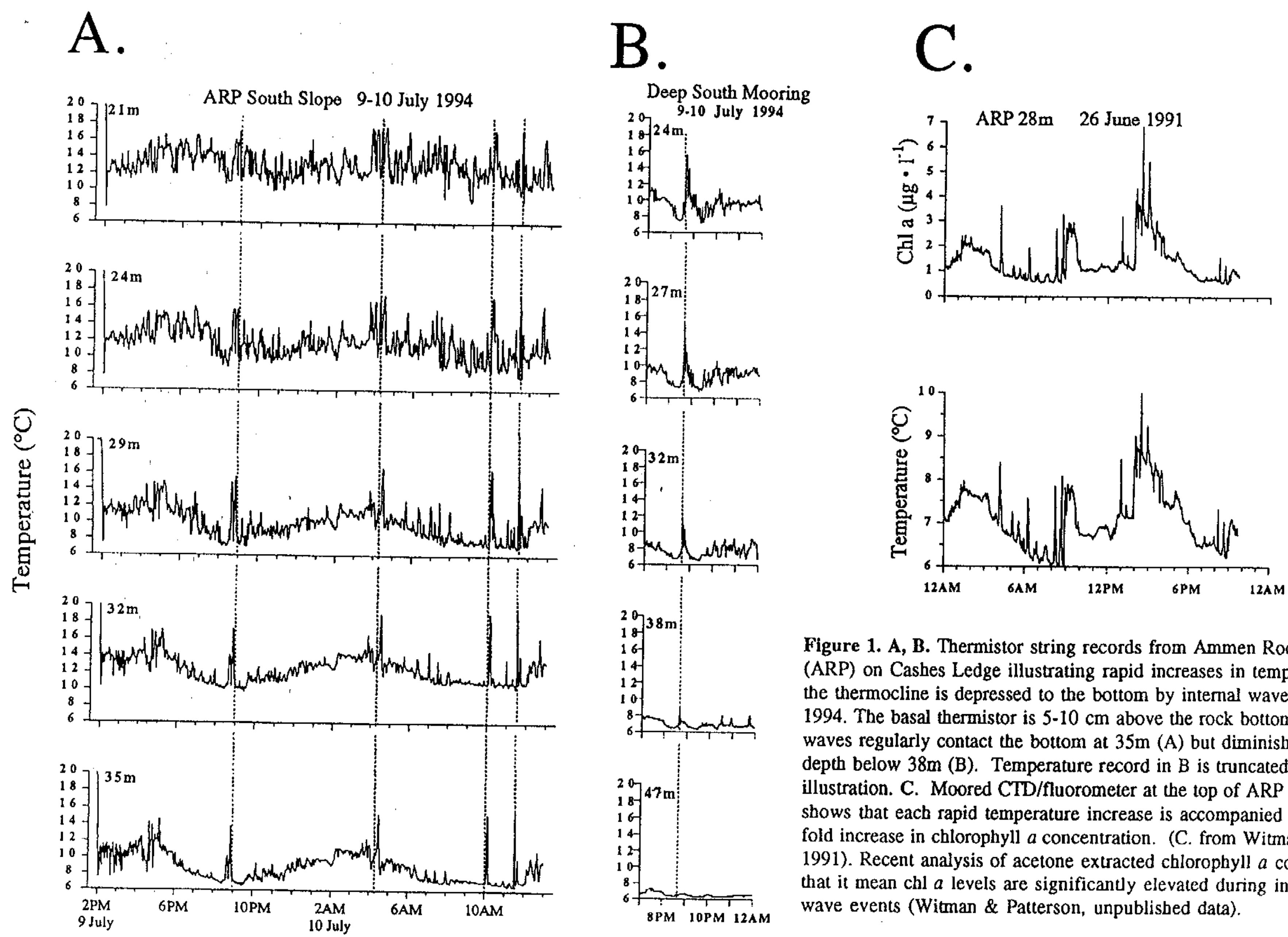

Figure 1. A, B. Thermistor string records from Ammen Rock Pinnacle (ARP) on Cashes Ledge illustrating rapid increases in temperature as the thermocline is depressed to the bottom by internal waves in July 1994. The basal thermistor is 5-10 cm above the rock bottom. Internal waves regularly contact the bottom at 35m (A) but diminish with depth below 38m (B). Temperature record in B is truncated for illustration. **C.** Moored CTD/fluorometer at the top of ARP (28m) shows that each rapid temperature increase is accompanied by a 2-3 fold increase in chlorophyll *a* concentration. (C. from Witman *et al.* 1991). Recent analysis of acetone extracted chlorophyll *a* confirms that it mean chl *a* levels are significantly elevated during internal wave events (Witman & Patterson, unpublished data).

Summary of Storm Effects on Gulf of Maine Benthos

- Reduces population sizes and changes species distributions:
  species: *Homarus, Haliclona, Suberites, Laminaria, Strongylocentrotus, Boltenia ovifera, Mytilus, Asterias, Mytilus, Modiolus*
- Changes ecological succession:
  habitats: subtidal and intertidal kelp and mussel beds, intertidal barnacle zone
- Indirect effects on herbivore populations: colonization of storm generated patches by *Ulva* in the rocky intertidal following the Halloween northeaster (1991) leading to increased food supply of herbivorous gastropods at Nahant, MA

Trophic Interactions

Biotic processes such as competition, predation, recruitment, mutualism and biological disturbance have large influences on benthic populations and communities in the Gulf of Maine. This review focuses on trophic interactions as a class of biotic interactions that are obviously central to the goal of constructing an ecosystem based management model for GOM species. The potential roles of ecologically important keystone species will also be discussed.

Figure 2 shows food webs from offshore and coastal benthic communities in hard substrate habitats constructed from the literature and from unpublished diet information. The offshore web is representative of communities at 30 m depth habitats on Cashes and Jeffrey's Ledge, while the coastal web is representative of communities in the 10 - 30 m depth range at the Isles of Shoals, Monhegan Island, Pemaquid Point and Nahant. Both webs are simplified from complex 'connectedness' webs (sensu Paine 1980) containing over 63 links between functional groups of species. They have been simplified to illustrate some of the strong trophic interactions and to highlight potential differences in the trophic structure of coastal and offshore benthic ecosystems resulting from overfishing. Large demersal fish such as cod and wolfish and pelagic species (pollock) are more abundant on offshore than on coastal rocky ledges at the same depth (Witman and Sebens 1992, unpublished video data on pollock), so cod and wolffish exert a comparatively greater influence on the structure of offshore benthic communities. Cod stomach content data indicate that they prey heavily on brittle stars (*Ophiopholis aculeata*) and tubicolous polychaetes (Witman and Cooper 1983, Witman and Sebens 1992). The stomachs of both cod and wolffish contain rock crabs (*Cancer* spp.) and small sea urchins on Jeffrey's Ledge (Witman and Sebens 1992). Wolffish were the major predator of tethered *Cancer* crabs in predation intensity experiments on Cashes Ledge and they also consumed lobsters and large urchins in other tethering experiments performed at the same sites (R. Steneck and R. Wahle, unpublished data). Taken together, these data suggest that crab populations offshore are regulated by predation from cod and wolffish, and that any "trophic cascades" (Carpenter and Kitchell 1987) will occur through these links, possibly resulting in a release of predation on polychaetes, mussels and ophiuroids due to reduced abundances of their predators offshore. The occurrence strong trophic cascades in the Gulf of Maine is complicated by the fact that other predators are present in the offshore communities to prey on the polychaetes, mussels and ophiuroids potentially released from crab predation. The best examples of trophic cascades occur in low diversity communities (Strong 1992). The diversity of generalist predators in these food webs may reduce the probability of strong trophic cascades in the GOM system.

Sea urchins are nearly absent on offshore on Cashes Ledge (J. Witman, unpublished data) and their populations are restricted to small body sizes on Jeffrey's Ledge (Hulbert et al. 1983).

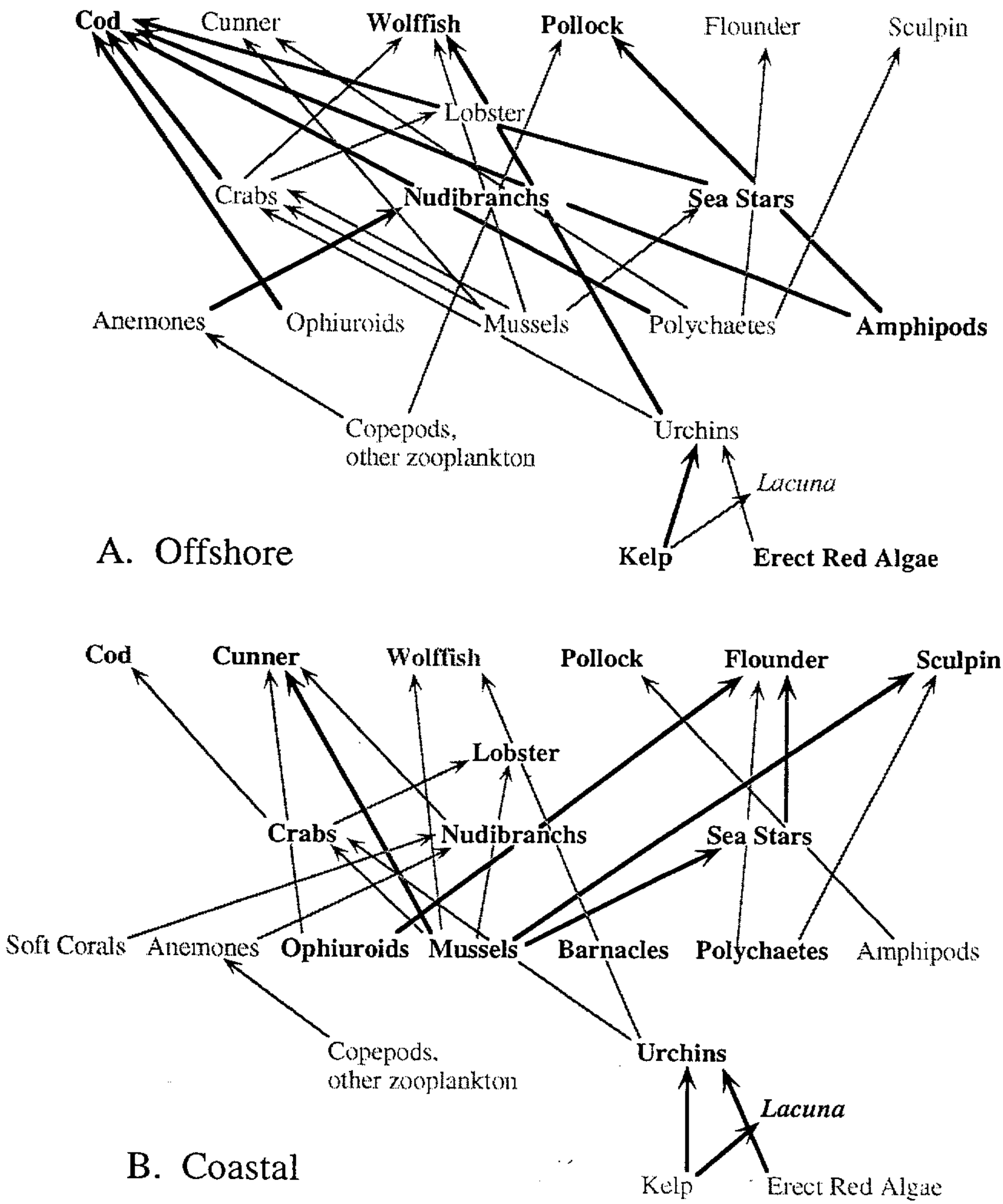

Figure 2. Generalized food webs for offshore (**A**) and (**B**) coastal rocky subtidal communities in the Gulf of Maine. Strong trophic interactions and abundant species are indicated in bold, weak interactions and species occuring in low abundances are indicated in grey. Note that many strong interactions are linked to cod offshore (**A**), but not in the coastal zone (**B**) where the abundance of large predatory fish such as cod has been reduced by overfishing. Small mouthed fish are important consumers in the coastal food web. The coastal food web is also charcterized by abundant sea urchins and populations of a snail *Lacuna vincta*. Both of these grazers that regulate kelp populations in coastal zone. The greater densities of crabs in the coastal webs may result from decreased predation from large fish.

Although other factors such as restricted larval recruitment and limited nutritional value of red algal food resources on Jeffrey's Ledge undoubtedly contribute to these patterns, fish predation pressure on urchins is certainly high enough to exclude them from sites on Cashes Ledge, and to crop their size structure on Jeffrey's Ledge. A potential consequence of herbivore control by large fish offshore is that laminarian kelp are much more abundant at on Cashes Ledge at the same depth (30 m) in the coastal zone Vadas and Steneck 1989 Witman and Sebens 1988). Another strong trophic interaction offshore is that episodic predation from nudibranchs (*Aeolidia papillosa*) regulates the abundance and distribution of *Metridium senile* over large expanses of rocky habitat (tens of m^{-2} area; Fig 3). *Metridium* is zooplanktivorous, consuming copepods as well as invertebrate larvae (Sebens and Koehl 1984). There may be decreased predation on near bottom zooplankton as a result of large scale predatory regulation of anemone populations, but this is speculative.

To better understand the effect of large fish on offshore hard bottom benthic communities, we conducted a six week fish exclusion experiment at 33m depth at Ammen Rock Pinnacle in summer 1989 (Witman and Sebens, in preparation). All large fish were excluded from 0.75 m^2 areas of the benthic community by attaching plastic mesh cages to the substratum (n = 4). The experimental design included sideless cages, fences, and open plots of substrate which served as cage controls. Our results indicated that:

Summary of Fish Exclusion Experiment on Cashes Ledge

- tube dwelling polychaetes and amphipods were significantly reduced in fish access treatment and controls (6 species total)
- there was no effect of fish exclusion on mobile species of polychaetes and amphipods (4 species total)
- ophiuroid densities in fish access treatment and controls were reduced (but not significant)
- one gastropod species ,*Colus pygmaeus* , was significantly reduced in fish access treatment and controls
- no effect of fish exclusion on caprellid amphipods and small sea stars

Coastal food webs are typified by greater consumer pressure from small- mouthed fishes such as cunner, sculpin, flounder and juvenile pollock at higher trophic levels (Witman 1985, Witman and Sebens 1992, Langton and Watling 1990, Ojeda and Dearborn 1991, Langton et al. 1994), from decapods at intermediate trophic levels, and from urchins and the herbivorous gastropod *Lacuna vincta* at lower trophic levels (Fig 2, Fralick et al. 1974). We hypothesized that the removal of historically large cod populations by overfishing the coastal GOM region, resulted in a release of predation pressure on crab populations (Witman and Sebens 1992). Crabs (*Cancer irroratus, C. borealis*) are significantly more abundant in coastal habitats at 30 m than at the same depth offshore. Because of the greater importance of relatively small mouthed fishes inshore, much of their influence on prey communities is restricted to size -specific effects. For example, cunner preyed heavily on juvenile mussels *Mytilus edulis* and sea urchins off Pemaquid point in Maine (Ojeda and Dearborn 1991) and on juvenile mussels off Nahant (Loher 1992). Nudibranchs (*Aeolidia papillosa*) have been suggested to regulate *Metridium* populations in coastal habitats (Sebens 1986) and depleted soft coral populations were observed simultaneous with increasing populations of the predatory nudibranch *Tritonia plebia* (Allmon and Sebens 1988). Mussels are consumed by a diverse group of predators inshore. At some shallow sites (off Nahant MA, Isles of Shoals) predation by *Asterias vulgaris* and *A. forbesii* may be extensive enough to limit the penetration of the *Mytilus edulis* mussel zone into the subtidal (J. Witman, unpublished data). Sea urchins act as omnivores, consuming small *M. edulis* at shallow coastal sites (Briscoe and Sebens 1988). Green sea urchins are also well known for their ability to regulate the depth distribution of kelp (*Laminaria saccharina, L.digitata*) at subtidal sites in the Gulf of Maine (Witman 1985, 1987) and southern Nova Scotia (Johnson and Mann 1988).

Because of the ability to convert kelp forests to the alternate states of coralline algal flats , affecting the abundance and diversity of a large number of species associated with kelp beds (Witman 1985), the green sea urchin *Strongylocentrotus droebachiensis* clearly functions as a keystone consumer in hard bottom benthic communities. The role that sea urchins play as keystone species includes:

Summary of Sea Urchin Effects as Keystone Species

- transformation of kelp and other upright algal assemblages into coralline algal flats
- reduction of macroalgal productivity and ultimate loss of kelp generated particulate detritus
- loss of a spatially complex habitat (kelp bed)
- and a reduction of invertebrate and algal species richness (with the exception of horse mussel beds for invertebrate richness)

Green sea urchins now represent the second largest invertebrate fishery in the Gulf of Maine (R. Langton, personal communication). The large scale removal of sea urchins from shallow coastal habitats is undoubtedly already converting many benthic ecosystems from coralline algal flats to kelp beds, with many unstudied direct and indirect effects on coastal ecosystems.

Fish are likely to play important roles in the organization of soft bottom community structure (Langton and Watling 1990). The large ophiuoid *Ophiura sarsi* comprised the main dietary component of American plaice at 148-156 m depth 22 km off Portland (Packer et al. 1994). Langton and Watling (1990) suggested that offshore soft bottom habitats support a greater diversity of prey functional groups, but that the biomass of fish prey is an order of magnitude greater in the coastal soft bottom habitats.

Stability

The extent to which natural communities are stable and predictable remains a central question of ecology (May 1973, Pimm 1991). Following Connell and Sousa's (1983) terminology, a system is deemed stable if there are one or more equilibrium points (e.g. population density) at which the system remains when faced with a disturbing force, or to which it returns when perturbed. The practical significance of investigating the stability of benthic communities is that the insights gained about responses to natural perturbations can be used to predict the trajectory of the population or community to some anthropogenic disturbances. The spatial dominant of Gulf of Maine kelp beds, *Laminaria saccharina* displays resilience stability in response to storm disturbance (Witman 1987). Indeed, its ability to recover quickly from disturbance is an important component of its competitive dominance over other macroalgal species (Johnson and Mann 1988). In contrast, the horse mussel, *Modiolus modiolus*, has low resilience, but high resistance stability from sea urchin grazing, consequently it dominates horizontal to sloping rock surfaces below the shallow zone (> 10 m) where physical disturbance is paramount. *Modiolus* populations at intermediate depths (12-18 m) display the highest persistence of any subtidal invertebrate species in the Gulf of Maine. For example, *Modiolus* beds have persisted for the past 16 years (Fig. 3) in subtidal communities at the Isles of Shoals (18 m depth). The beds showed a 5 - 38% increase in the number mussels forming the bed over the past 16 yrs. Given their remarkable persistence and life span of 50 - 60 years, horse mussel beds probably retain their structural integrity for well over a hundred years.

Summary of Ecological Importance of the Horse Mussel, *Modiolus modiolus*

- *Modiolus* beds represent the most persistent biogenic habitat in the GOM subtidal zone

- The mussel beds are a spatially complex habitat where over 23 species of macro-invertebrates attain high densities

- The horse mussel beds increase species diversity (e.g. species richness) by providing a refuge from severe urchin grazing.

It is clear that there would be large ecological effects including a loss of biodiversity if horse mussel beds were harvested.

The soft corals *Alcyonium siderium* and *Gersemia rubiformis* are often the most conspicuous invertebrates on vertical rock walls in the coastal GOM (Sebens 1986, Witman and Sebens 1988). Monitored *Alyconium* populations at Halfway Rock in Massachusetts Bay (7 m depth) showed high persistence from 1980 - 1984 until their populations crashed under combined predation from sea urchins and the nudibranch *Tritonia plebia* (Allmon and Sebens 1988). *Alyconium* populations at Gull Rock (off Monhegan) are characterized by similar persistence, and remain unaffected by nudibranch predation (Fig. 3, J. Witman, unpublished). Population densities of *Gersemia rubiformis* (20 m depth Gull Rock) have not changed over the past 5 yrs (Fig. 3). Due to restricted larval dispersal (Sebens 1983), populations of these soft coral species will be slow to recover from disturbances that clear large areas of substrate. Populations of another cnidarian, the anemone, *Metridium senile*, at Ammen Rock Pinnacle are characterized by low resilience stability because the populations have failed to recover 5 years after a second episode of predation by the nudibranch *Aeolidia papillosa*. (Fig. 3, J. Witman unpublished data). In addition to affecting anemone populations, nudibranch predation on anemones is important for opening up large areas of free space for primary succession in these space limited epifaunal invertebrate communities.

Comparatively little is known about the stability of invertebrate communities in soft bottom habitats because there is no long term monitoring of soft bottom benthos in subtidal habitats of the GOM (L. Watling, personal communication). Repeated surveying of sea pen (*Pennatula*) and sabellid polychaete (*Myxicola infundibulum*) populations over a two year period suggests that disturbance from fishing gear changes their spatial structure from aggregated to random distributions (Langton et al. 1990). An important ongoing study of trawling disturbance on the benthos of Jeffreys Ledge is being conducted by P. Auster, L. Watling and R. Langton. Auster et al. (1995) have recently estimated that the entire seabed of the Gulf of Maine is subjected to some form of fishing gear disturbance each year. While this may be a slight overestimate since the rough bottom topography of bedrock ledges such as Cashes Ledge, Pigeon Hill on Jeffrey's Ledge and many sloping ledges and rock walls of coastal islands hinders trawling, disruption of benthic organisms from fishing gear is clearly the most significant disturbance to the benthos of the Gulf of Maine. The ability of the benthic populations to recover from fishing gear disturbance will depend on the frequency and magnitude of the disturbance and life history of each species affected.

Species introduced into a new biogeographic region by human activities , or species that have invaded by natural dispersal can have large effects on native communities (Lodge 1993). A relatively small number of species have invaded GOM benthic communities within the last decade (Berman et al. 1992). Their effects are largely unknown. The table below summarizes our knowledge of the influence of recent (last 10 yrs) invading species.

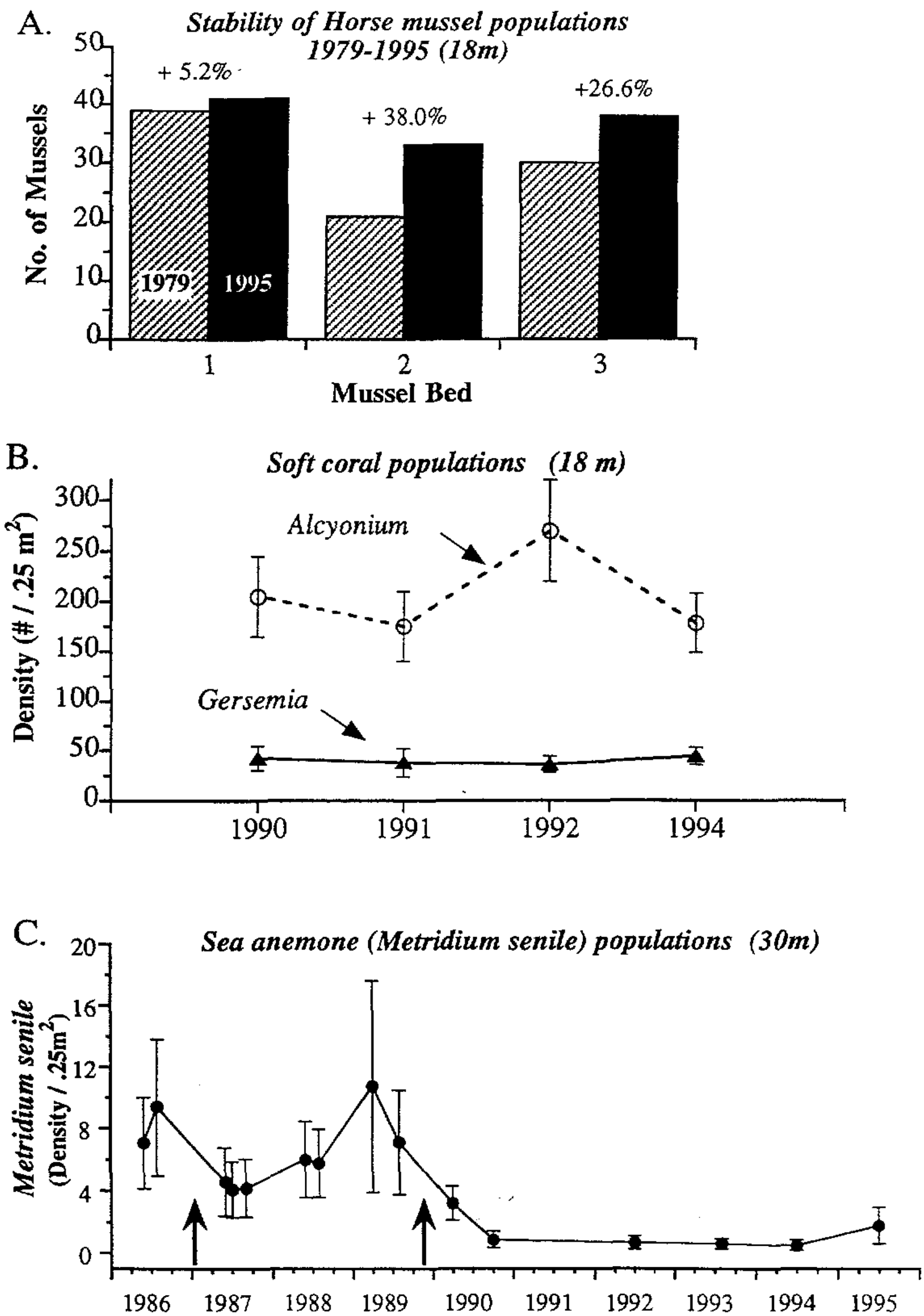

Figure 3. Stability of representative benthic invertebrate populations in rocky subtidal habitats of the GOM. (**A**) shows the remarkable persistence of three horse mussel (*Modiolus modiolus*) beds off the Isles of Shoals, NH. Percent increase in numbers of mussels is shown above the bars.(**B**) Mean densities of soft corals in monitored rock wall habitats at Gull Rock off Monhegan Island. Error bars represent 1 std. error. (**C**). Fluctuations in mean densities of sea anemones over a 10 yr period at 30 m depth at Ammen Rock Pinnacle. Arrows indicate nudibranch predation events. Note that the predation caused a local population collapse.

Effects of Some Introduced Species in GOM Subtidal Communities

Taxon	Effect
• Bryozoan: *Membranipora membranacea*	- reduction of kelp populations by encrusting blades (coastal sites: Lambert et al. 1992, also on Cashes Ledge. J. Witman unpublished)
• Ascidians: *Botrylloides diegensis*	competitive displacement of a hydroid (Lambert 1985)
Botrylloides sp.	unknown - invaded monitored soft coral populations at Gull Rock 1992 (J. Witman data)
Styela clava	unknown (Berman et al. 1992)
• Nudibranch: *Tritonia plebia*	reduction of prey populations (*Alcyonium siderium* in Massachusetts Bay (Allmon and Sebens 1988).
• Macroalgae: *Codium fragile*	colonized coralline algal flats at Isles of Shoals increasing the spatial heterogeneity of the benthos *C.fragile* is persistent due to low preference by urchins (J. Coyer, personal communication)

Biodiversity

There is little quantitative information about spatio-temporal patterns of species diversity in subtidal habitats of the Gulf of Maine. Our knowledge of the biogeography of the Gulf of Maine (GOM) is based largely on investigations of intertidal invertebrates by E.L. Bousfield and his co- workers (Bousfield and Laubitz 1972, Bousfield and Thomas 1975). The Gulf region represents a transitional area between Virginian and Boreal species provinces, with a decreasing proportion of Virginian species and an increasing proportion of boreal species north of Cape Cod (Bousfield and Thomas 1975). Species with centers of distribution in sub-arctic and cold- temperate regions also occur in the GOM (ibid. 1975). A total of 225 invertebrate species were recorded from 8 - 30 m depth at the Isles of Shoals by destructive sampling with an airlift (Witman 1984). There was a significant increase in the mean species richness of the mussel bed community with depth from 8 to 30 m on a sloping granite shelf off the Isles of Shoals. For example, mean richness increased from 64.8 + 10.06 SD at 8 m depth to 89.0 + 5.56 SD at 30 m depth, largely due to the higher richness of the 30 m amphipod community (Witman 1984). Sebens (1986) hypothesized that the diversity of epifaunal species on subtidal rock walls was maximal at intermediate levels of biological disturbance from sea urchins. A total of 149 species of epifauna and infauna were recorded from 30 - 42 m depth at rocky pinnacle on Jeffrey's Ledge (Witman et al. 1980, Hulbert et al. 1981) by sampling with identical methods as at the Isles of Shoals. A preliminary analysis of the composition and species richness of soft substratum communities in the deep basins of the GOM revealed 125 invertebrate species (Watling et al. 1985). Because it is so undersampled, it is certain that the species richness of invertebrates in subtidal habitats of the Gulf of Maine is higher than previously thought. For instance, a quantitative investigation of deep (> 30 m) rocky subtidal communities revealed four undescribed species of poescilosclerid sponges at Cashes Ledge (Witman and Sebens 1990).

A preliminary analysis of regional patterns of species richness (S) at 30 - 33 m depth in the GOM has been conducted from quantitative quadrat photography of epifaunal invertebrate communities on rock walls (J. Witman, in prep). Vertical rock walls were chosen as a target habitat for this assessment of regional variation in species richness because they are simple, nearly two dimensional habitats that are extremely similar from place to place, enabling comparisons between sites without the confounding influence of habitat heterogeneity, a factor known to affect diversity (Pianka 1966, Ricklefs 1979) . The main question addressed by the study was, is there significant spatial variation in the mean species richness of sessile invertebrates among rocky subtidal sites in the GOM region ? If so, are there any differences between the coastal and offshore region? Following Tilman's (1982) and Abramsky and Rosensweig's (1984) correlation between species diversity and productivity, we hypothesized that the higher productivity of the coastal zone (Yentsch and Garfield 1981), might support a higher species richness of suspension feeding invertebrates than the supposedly more oligotrophic offshore waters of the central Gulf. Onshore - offshore comparisons of species richness were possible because four of study sites were located in the coastal zone and three were located in the offshore region of the GOM, defined as shoreward of the 100 m isobath (Witman and Sebens 1992).

Figure 4 shows that the mean species richness of sessile invertebrates at 30 - 33 m depth ranged from 9.15 species per 0.25 m^2 at Columbia Ledge to a maximum of 14.6 species per 0.25 m^2 at North Ammen Rock Pinnacle. A Kruskal Wallis test rejected the null hypothesis of no difference in mean S among sites (Table 1). Thus, there is highly significant spatial variation in the average number of sessile invertebrate species in rock wall communities throughout the Gulf of Maine. A Tukey multiple comparisons test identified which sites differed in mean S (Table 1). The coastal productivity hypothesis would be supported if the mean S of the coastal sites (Star Island, Halfway Rock, Gull Rock, Monhegan Island) was higher than that of the central GOM sites (ARP and NARP). There was no evidence to support the productivity hypothesis, as there was no significant pattern of onshore - offshore differences in mean species richness (Table 1). Rather, mean S was significantly lower at Columbia Ledge in the eastern coastal Gulf than at the other six sites. In addition, mean species richness was significantly higher at North Ammen Rock Pinnacle (NARP) on Cashes Ledge than at Pigeon Hill, located on the inner edge of the offshore region. There is a more even representation of the 11 major invertebrate taxa at one of the coastal sites (Halfway Rock) than offshore at Ammen Rock Pinnacle where the species richness is largely a function of the number of species in just three taxa; the sponges, bryozoans and ascidians Bryozoan and ascidian taxa comprise most of the community at Columbia Ledge, the site with the lowest S, and the species richness of sponges is reduced there relative to the other sites.

The possibility of identifying an explicit regional (spatial) pattern of species richness was compromised in this analysis by the inclusion of temporal variation, since photographic sampling was conducted over a ten year period (1981 - 1991). Consequently, epifaunal invertebrate communities at 30 m depth were re- sampled photographically and destructively using an airlift for invertebrate species richness at 8 sites from the eastern to the western Gulf of Maine during one cruise in August 1994 to eliminate temporal variation. This new data base will be analyzed for regional variation sometime in 1996.

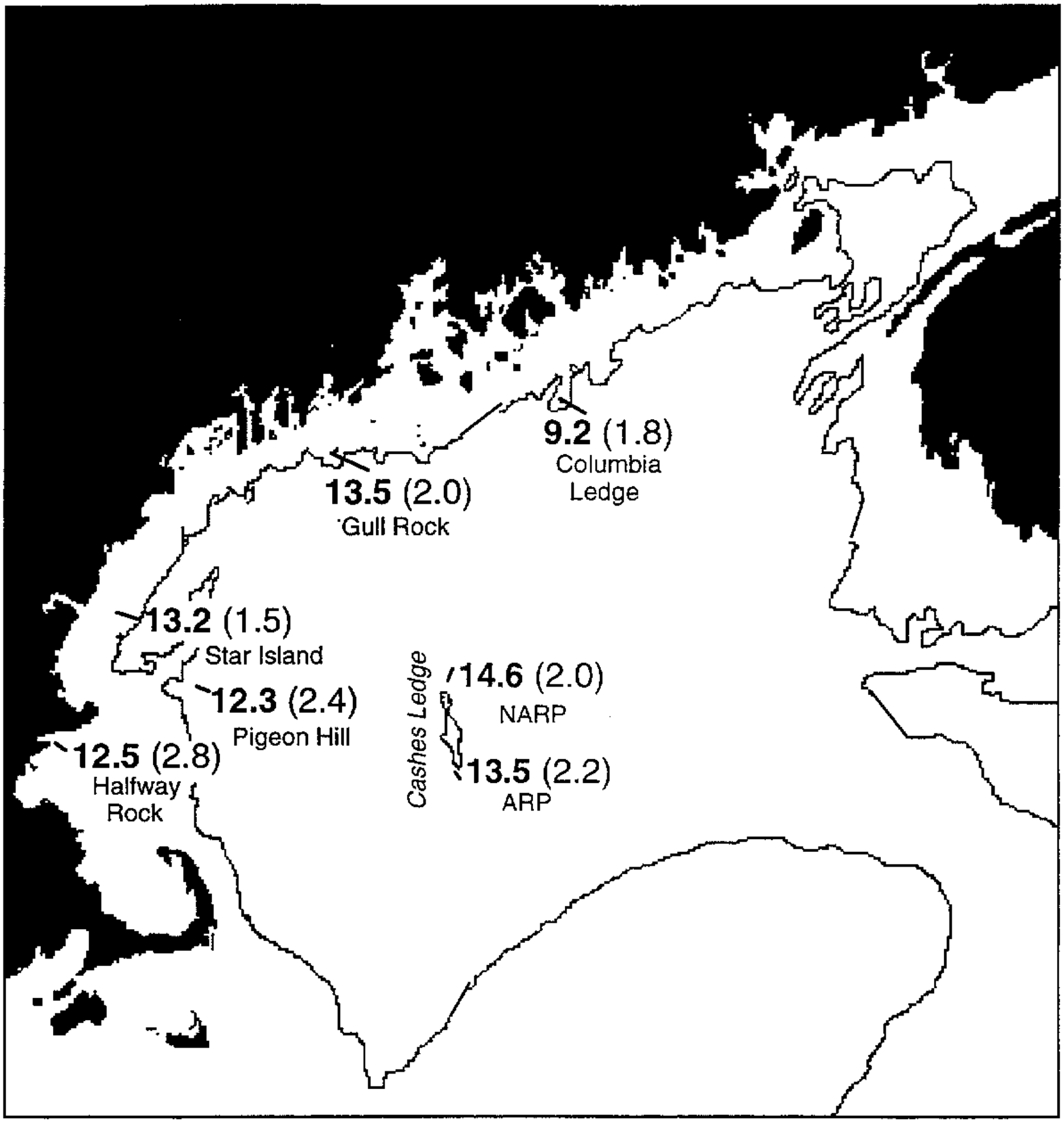

Figure 4. Species richness of sessile epifaunal invertebrates in rock wall habitats at 30 -33 m depth. Data represent mean values (+/- one standard deviation) of richness per 0.25 m^2 photo quadrat. Sample sizes are 32 0.25 m^2 quadrats per site representing 8.0 m^2 of habitat per site with n = 224 quadrats total.

Table 1. Results of a Kruskal Wallis and Tukey multiple comparisons tests of spatial variation in mean species richness of sessile invertebrates among the 7 sites shown in Fig. 4. The K-W statistic , H = 70.68 is significant at p < .0001, rejecting the null hypothesis of no difference among sites (n = 224 cases {photo quadrats} with 7 groups) . For the Tukey's test, the direction of the inequality sign shows which sites differed in mean species richness. Significance alpha level is p < .05.

Site Ranking	Tukey statistic (q)	p <
NARP > Pigeon Hill	5.18	.025
NARP > Columbia Ledge	10.1	.001
ARP > Columbia Ledge	8.61	.001
Star Island > Columbia Ledge	8.06	.001
Gull Rock > Columbia Ledge	7.99	.001
Halfway Rock > Columbia Ledge	6.78	.001
Pigeon Hill > Columbia Ledge	5.55	.010

Summary

The most conspicuous changes in the benthos of the Gulf of Maine are brought about by storms, predation, recruitment variability, the harvesting of ecologically important species (e.g. cod and sea urchins) and by disturbance from mobile fishing gear. There little known about spatial and temporal heterogeneity in the distribution and diversity of benthic invertebrates across the entire GOM region. There is a similar lack of information about broad scale variability in larval recruitment and in the factors influencing secondary production. Because of the absence of long term monitoring in soft bottom habitats, almost nothing is known about the dynamics of subtidal soft bottom communities. Monitoring of hard bottom habitats has revealed that horse mussel beds form unusually persistent biogenic habitats that are ecologically significant for increasing diversity, and has revealed the importance of episodic predation events. At least five species have invaded GOM benthic communities with potential effects varying from the depletion of localized populations to an increase in habitat spatial heterogeneity. Internal waves are important physical forcing phenomena that should be considered in ecosystem based management models because they are ecosystem -level events capable of enhancing the growth of benthic suspension feeders and potentially aggregating plankton consumed by pelagic species. As a likely consequence of the removal of large demersal fish (e.g. cod) by overfishing the coastal zone, coastal and offshore food webs are considerably different. Several strong trophic interactions have been identified, yet trophic cascades in Gulf of Maine benthic ecosytems may be diffused by the occurrence of many generalist predators in the food webs.

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Ecosystem-Based Management of Northwest Atlantic Groundfish

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Abstract

Ecosystem-based management attempts to balance biological and environmental interactions with human social and economic values to attain a sustainable maximum ecosystem yield. The concept has been applied to freshwater and terrestrial systems, but marine fisheries management, with its focus on single species, has been driven more by economic and narrow biological considerations than by broad ecological principles. The collapse of USA and Canadian groundfish stocks in the northwest Atlantic under traditional management programs suggests a need to shift towards an ecosystem-based management approach for the region. Implementation of this approach for marine fisheries requires the incorporation of clearly articulated human values into policy development for the governance of human behavior that recognizes the biological limits to fish production.

Introduction

Understanding the relationship between fisheries and the marine ecosystems within which they exist is fundamental to the goal of sustainable fishery management. Until the development of quantitative methods for describing populations in the late 19th and 20th century (1) much of the knowledge compiled on northwest Atlantic fisheries was anecdotal. The fisheries of prior centuries were variable but profitable for extended periods of time over the technological range of resource exploitation (2). During the 20th century, with the development of the otter trawl and a shift from sail to diesel powered vessels, technology enabled fishermen to harvest the resources over larger areas of the oceans. In recent decades technology has not only allowed for an extended geographic range of exploitation but also a finer scale of exploitation through the electronic location of aggregations of fish. Some of these fished populations have been reduced to levels exceeding their ability to replicate themselves (3). The collapse of important northwest Atlantic groundfish stocks in both the United States and Canada has stimulated much discussion about alternatives to traditional fisheries management in the region (4). One of those alternatives is ecosystem-based management.

The basic tool of management for North American fisheries scientists has been population dynamics models. These, whether concerned with single or, more recently, multi-species, are expressions of population growth under equilibrium conditions. The unit of analysis is the regional population, or stock of fish, and the models provide quantitative estimates of the numbers of fish of a given age in that stock. This level of explanation appeals to management because it allows an apparently rational output for setting catch quotas and assessing their consequences. Unfortunately, population dynamics models treat the observed fluctuations in fish stocks with little consideration of the confounding ecological and environmental factors that interact with the population itself. Just as one example, fishing mortality is made explicit in these models while all the other causes of mortality for the fish stock are lumped together in one black box.

Although ecosystem-based management cannot yet match the seductive quantitative qualities of a population dynamics approach, it does offer a more realistic alternative that attempts to address and explain the many interactions and multiple scales that operate throughout a fisheries ecosystem. The purpose of this paper is to examine briefly the history of ecosystem-based management, argue the case for its institution, present some examples whereby failure to recognize ecosystem principles has lead to serious problems, and offer some sense of what will be needed for a conversion to this approach, including especially the necessity to carry out analyses on a number of ecosystem scales.

Defining Ecosystem-Based Management

Ecosystems are defined in terms of communities of plants and animals and the physical environment they live in. They are usually geographically defined as discrete units, varying in size from small areas where groups of species occur together on scales of 100s to 1000s of square kilometers to watersheds (5), to a large linked systems like the Great Lakes (6), to distinctive marine areas of 200,000 km^2 or more (7). Humans are often thought of as operating outside these systems, but they must be considered an integral part of them. The concept of an ecosystem embodies the idea that interactions are much stronger within the system and between its component parts than they are outside or across the system's boundaries; that is the system is largely self sufficient in converting the energy it receives to nutrients and other food resources it uses. The traditional view is that humans extract material from the ecosystem according to socio-economic rules, a view reflected in fisheries in the concept of a maximum sustainable yield (8) Ecosystem-based management, with humans defined within the system, takes a perspective that the over-riding rules for the governance of human behavior are ecological ones. Humans can share in the resources of the system, but the magnitude of that share must not upset the balance required to keep the system's cycles running and sustainable.

The share that goes to humans, that is some ecologically acceptable level of harvest, might best be identified as the "Maximum EcoSystem Yield" or MESY (Figure 1). This share would be based on an appreciation of multispecies relationships as opposed to the single species focus inherent in the outdated notion of "optimal yield" (9). It is the ecological underpinnings of a fishery, not economic measures, that ultimately determine sustainability, and basic to that sustainability is a preservation of the natural capital in the ecosystem (10). An approach based on MESY would take into consideration not just the requirements of the target species but would consider the give and take required for ecosystem maintenance of all the species in the system. It would guarantee that the natural cycles in the food webs, cycles that have co-evolved in the system over millennia, would continue, and would resist any implication that there is an optimum which is ecosystem independent.

The first stage of ecosystem-based management is the coupling of ecosystem science with the formulation of management objectives and development of policy to achieve these objectives (11). A clear understanding of human social and economic values needs to be developed concurrently with the integration of ecosystem studies in a region. The human values must be quite specific so that fishery managers can accommodate them when decisions are made. A reduction of fishing effort has value as an ecological objective, for example, since the biological consequences are reasonably obvious, but the social and economic controls for overfishing have to be succinctly stated in terms of fleet composition and gear type if they are to be incorporated into a region's management policy.

The Genesis Of Ecosystem-Based Management In Aquatic Systems

Fisheries management in the northwest Atlantic and elsewhere (12) remains focused on the biology of individual species, however ecosystem-based management is beginning to be applied to freshwater and terrestrial systems (13). The need for an ecosystem approach in aquatic systems was first proposed for the Great Lakes in 1978 (14), and ecosystem-based management decisions have followed (15). More recently, the U.S. Environmental Protection Agency adopted a watershed approach to ecosystem management (16) that should bring together stakeholders in freshwater and estuarine areas to develop strategies for ameliorating water pollution. The U.S. Forest Service is also embracing ecosystem management, although without necessarily engendering the support from fishery stakeholders (17).

In Canada as well, ecosystem-based management has found more rapid acceptance in terrestrial and freshwater situations than in the marine environment. The national parks already provide protected areas for entire identified ecosystems. Provincial reserves protect areas of particular ecological importance, such as old growth forests inhabited by the endangered pine marten and rare stands of red pine in Newfoundland. Acting under the pressures resulting from the collapse of the marine fishery, Newfoundland's Economic Recovery Commission suggested that certain resources might be better managed for ecotourism at the local level. This quickly became translated into so-called watershed management, and in early 1995, the Province designated two freshwater areas where recreational trout fisheries will be managed experimentally by local authorities instead of, as in the past, by the federal government. In British Columbia local citizens have also very recently formed the West Coast Sustainability Association to promote ecosystem-based management of the fisheries resources as the key to survival of their coastal communities.

The official government language in Canada has supported an ecosystem-based approach to marine systems for some time, but fishery managers have tended to emphasize setting catch quotas for target species although this is rapidly changing (18). As the fishery crisis in the northwest Atlantic approached during the late 1980s, certain fishermen's organizations, backed by editorial comments in newspapers, called on the federal government to truly adopt an ecosystem perspective. In 1986, the Newfoundland Inshore Fishermen's Association tried to address the problem in the courts, essentially by demanding that an environmental impact assessment of the fishery be conducted. This effort was unsuccessful but it focused people's attention on an ecosystem-based approach to fishery management. In the USA attempts at molding the relationship between science and policy has been the focus of a symposium series sponsored by the Ocean Studies Board of the National Research Council, with the Gulf of Maine having been addressed in 1994 (19). Such meetings should help assuage stakeholder concerns and promote the concept of ecosystem-based management in the marine environment.

National Comparisons

In 1976 both Canada and the U.S. extended their national jurisdiction to 320 km (200 miles). This action was taken as large, foreign, distant water fleets were overfishing offshore stocks on Georges Bank and completing their decimation of the Atlantic cod stock off

Newfoundland. At the time, there was relatively little Canadian or U.S. participation in the offshore fishery. Most effort was being concentrated inshore, particularly in the community-based fisheries that had existed for hundreds of years around the coast. Jurisdictional extensions, and the elimination of foreign fishing they implied, were seen as important sustainable economic opportunities on both sides of the border. In Canada, the time of massive expansion of the fishery eventually resulted in, through government intervention, the amalgamation of a number of smaller fishing companies into two very large corporations at the same time that a severe economic downturn occurred. These corporations focused primarily on the fish resources of the continental shelf. In the U.S. the fishing fleet also grew, with the assistance of government tax breaks as investment tax credits, but without the creation of large conglomerate fishing fleets.

One of the major distinctions between the philosophies towards fishery management in the USA and Canada is access to the fishery. The Canadians have restricted access through licenses that bestow property rights whereas the USA has maintained open-access fisheries. Although both nations license their fishermen, use of a license in the USA to control access is only now becoming important. Amendment 5 to the Multispecies Groundfish Management Plan has established a moratorium on new entrants to the fishery and therefore placed a value on a documented history of fishing. This is perhaps the first official recognition in the USA that an open-access ethic does not result in a sustainable fishery (20). It is readily apparent, however, that even the more stringently controlled fishery in Canada has not been sustainable. Indeed, the parallel overcapitalization of the fishing fleet in both the USA and Canada after extended jurisdiction is striking and emphasizes the lack of importance placed on the biological constraints on fishery production under both management regimes. Government policy has generally encouraged the development of the fleets without developing a vision of what the fishery should look like relative to the ecosystem's potential for expanded fishing effort.

The advent of large-scale modern domestic fishing fleets changed work ethics in both countries, but particularly in Canada. The major capitalization in vessels resulted in a steady supply of fish which also caused processing plants to expand. The industrial fishery brought with it a social safety net in Canada but not the USA. In Canada, where owners of processing plants came to own the fishing vessels as well, fishers were now employees, and entitled to the same type of unemployment insurance system that applied in other Canadian industries. As the fishery collapsed in recent years the social system supported fishers. Their need to move, shift to harvesting other resources, or reduce their consumption was no longer there. Ten weeks of work in the fishery became all that was required to qualify for unemployment insurance support throughout most of the rest of the year.

Government policy has also encouraged exploitation of so-called alternative species when target species became rare. In Canada the government controls this through the issuing of different licenses. The result has been a "fishing down the food chain" whereby once an important target species becomes diminished (eg. Atlantic cod), that species' prey (capelin in this case) became the next target for the industrial fishery. Depending on the level of exploitation, this potentially breaks the rules of ecosystem-based management, and even in economic terms it does not necessarily make sense. The prey species usually has a lower economic value than the original predator species had. Nonetheless, it can be viewed as a means of providing employment during an interim period while the original important species would recover (21). The question of what and particularly how much those recovering predatory species would eat is not often seriously considered. In the USA there has been no large-scale government attempt to redirect fishing effort to species lower on the food chain. There has, however, been a coordinated effort to exploit pelagic species through issuance of Internal Waters Processing Permits. This program empowers the states to allow foreign factory ships to buy and process Atlantic herring and mackerel directly from the local fishing fleet. The level of harvest has, however, been conservative relative to the estimated total biomass of these species. Although Atlantic herring is traditionally a major prey item for Atlantic cod (22) it would appear that there is little threat of suppressing a recovery of Atlantic cod at the current levels of fishing.

In contrast to Canada, the species composition on the US fishing grounds has changed. Currently dogfish and skate dominate on Georges Bank and there is an abundance of pelagic species such as mackerel and Atlantic herring (23). These species substitutions have helped stabilize the aggregate biomass of fish on Georges Bank and consequently has afforded some alternative fishing opportunities on pelagic fish, as described above. The federal government has also attempted to redirect exploitation towards dogfish and skates, as well as previously unexploited deep-water fish, through the Fishing Industry Grants program, but this is currently at an experimental scale. The focus of this effort is to encourage industry to develop markets and fisheries for these species and it has yet to be determined if these markets will develop to a scale where they would compromise an ecosystem-based management approach. Farther north in Newfoundland, however, the aggregate biomass has declined without compensation by non-targeted species and there has not yet been a recovery of targeted species (24).

The Challenge of Implementation

Development of ecosystem-based management for the marine environment may require several levels of administration. There has been much discussion of local versus centralized control of fisheries (25), but cumulative effects of harvesting must be monitored across local, state or provincial, and federal lines of authority for fish stocks that range widely. It is also of paramount importance to understand the behavioral relationships that exist between fishers, the fish that they catch, and the prey of the harvested species. Fishers, based on economic need, hunt for aggregations of fish, whether fish aggregate for feeding, breeding or to exploit limited habitat. Commercial landings data documents the location of the catch, within a defined statistical area, but does not incorporate fisher's knowledge of the fish. Such knowledge is required to manage fish stocks as they move through different jurisdictions and come under different administrative control.

A scientific program of research is also required that recognizes the multiple scales on which fish and fishers interact (26). It must integrate this multiscale understanding so that management can work within the biological constraints of an ecosystem. The basis for such a program exists in the extensive monitoring programs conducted by the federal governments in the USA and Canada, but analysis of the data has to extend beyond recognizing patterns in the distribution and abundance of fish to include an understanding how those patterns were established and are maintained over time. This type of analysis can be daunting but there are some ecosystem properties that simplify the process (27). Predator-prey relationships, for example, can be described in terms of the actual species of prey eaten or may be grouped by predator size or aggregated by common function or life history traits (28). Such aggregations reduce the complexity of the system, making management options more tractable, but require an understanding of the natural history of both predators and prey, especially under changing conditions. Atlantic cod, pollock and white hake, for example, continued to be major fish predators despite a dramatic decline in their favored prey, Atlantic herring, during the 1970s.

Habitat can also be considered in functional terms. It is possible to identify habitat types that are essential for the survival of different life stages of commercially important species.(29). The gravel pavement on the northern edge of Georges Bank, for example, has been shown to be essential for the survival of juvenile cod (30) and protection of such areas should have a positive impact on the productivity of this species. Gravel is an equally important habitat type for juvenile lobsters (31) and the extent of such habitat types relative to a species geographic range can be used to simplify ecosystem management decisions. Although these examples for both predator-prey relationships and habitat types do not exhaust common ecosystem properties they serve as examples of the shift in thinking required from the current single species, and even multispecies, perspective of fisheries.

In order to even discuss such interesting matters as ecosystem properties, however, the problem of actually defining ecosystems in the real world must be addressed. One way to do this is by applying the analytical techniques traditionally used by biogeographers, which includes the mathematical identification and mapping of recurrent groups of species, or species assemblages. Groundfish survey data, which covers large areas and includes information on all species caught, are used for this analysis. The important criteria for recognition of an assemblage are the stability and persistence of the relative abundance of the different species (32). The area consistently occupied by an assemblages can be considered an ecosystem. These are regions within which ecosystem properties, such as predator-prey relationships (33), or changes resulting from general system perturbations (34), can be studied. Within the framework of such regions, management options such as protected areas (35), seasonal closures (36), and MESY make sense.

Implementation of ecosystem-based management is not difficult in concept but has been elusive in practice. Optimum yield as a strategy defined in the U.S. Fishery Conservation and Management Act of 1976 was never supposed to result in the collapse of fisheries. It was supposed to give managers a mechanism to temporarily allow for more aggressive harvesting to adjust for economic or social issues, knowing full well that there was a biological price to pay. In practice short term economic and social "imperatives" have dominated and the biological price has been catastrophic. The same is true in Canada, over optimistic projections of fishery production (37), and the formal establishment of a highly technological fishing industry, outstripped the ability of the stocks to reproduce themselves. Managers must realize that over optimistic harvesting allocations have major biological effects. Short-term loans may be "ecologically acceptable" but we have currently pushed the ecosystem to an alternate state, and perhaps even to a new equilibrium, particularly on Georges Bank where dogfish and skates have replaced the more marketable species (38). It is legitimate to ask if Atlantic cod, haddock and yellowtail flounder can re-establish dominance, and if so, how fast? If not what are the ecological factors controlling their recovery? Would a program of subsidized fishing, resulting in the removal of these lower value demersal species, hasten the recovery of the ecosystem to its former equilibrium by reducing predators or competitors? Would it be feasible, and would it speed recovery, to enhance wild stocks through the introduction of cultured fish of the appropriate size directly in essential habitats? Would a system of no-take reserves enhance fish production and fishery yield by protecting specific habitats? If we assume that the ecosystem will recover (39), what level of fishing effort will be allowable for sustainable fisheries in the future? Answering such questions and incorporating human values into the framework of biological limits is the true challenge for ecosystem-based management of marine systems.

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Notes

(1) See Ricker (1975) and Smith (1988).
(2) See Collins and Rathbun (1887) and Pierce (1989)
(3) See Ludwig et al. (1993), O'Neill (1993), Rosenberg et al. (1993), Sissenwine and Rosenberg (1993), Hutchings and Myers (1994), but also see Myers et al (1995).
(4) For example, Clay (1993), Hurley and Gray (1994), and Wilson et al. (1994).
(5) Perciasepe (1994).

(6) National Research Council of the United States and the Royal Society of Canada (1985).
(7) For example, large marine ecosystems as defined by Sherman (1994).
(8) But see Larkin (1977).
(9) See the U.S. Fishery Conservation and Management Act of *1976* for the formal definition of optimum yield.
(10) Ludwig et al. (1993) and Rosenberg et al. (1993).
(11) There is an increasing literature in the conservation biology arena that discusses the concept of ecosystem-based management. Most of these papers refer to terrestrial systems but the principals they espouse are equally applicable to the marine environment. A selection of these papers include: Harris et al. (1987), Slocombe (1993), Grumbine (1994), Alpert (1995) and Lackey (1995).
(12) Daan et al. (1990), NMFS (National Marine Fisheries Service) (1995) and Shelton and Morgan (1994).
(13) See Grumbine (1994), in particular, for a review paper but also see the volume edited by Woodley , Kay and Francis (1993).
(14) International Joint Commission (1978).
(15) National Research Council of the U.S. and Royal Society of Canada (1985); see also Great Lakes Fishery Commission Special Publication Series, eg. Eshenroder et al. (1991).
(16) Perciasepe (1994).
(17) American Sportfishing Association (1994).
(18) Brian Tobin, Minister of Fisheries for Canada, recently expressed the idea of "speaking for the fish" as the best way to sustain a fishery in a essay on fishery management, see Toban (1995).
(19) National Research Council (1995).
(20) See Edwards and Murawski (1993), for an economic view on open-access fisheries.
(21) Myers et al. 1995.
(22) Langton and Bowman (1980) and Bowman and Michaels (1984) document the stomach contents of Atlantic cod in the northwest Atlantic for the years 1969 through 1976.
(23) NMFS (National Marine Fisheries Service)(1995).
(24) Atkinson (1993).
(25) See Wilson and Dickie, this volume; Townsend, this volume.
(26) Langton et al. (1995).
(27) See Wilson and Dickie, this volume; Kerr, this volume.
(28) Tyler (1972), Langton (1982) and Langton and Watling (1990).
(29) Langton et al. (In Press).
(30) Lough et al. (1989) and Gotceitas and Brown (1993).
(31) Wahle and Steneck (1991, 1992).
(32) Gomes et al. (1992) and Haedrich and Fischer (1995).
(33) Gomes and Haedrich (1992).
(34) Gomes et al. (1995).
(35) Haedrich et al. (1995).
(36) Hutchings (1995).
(37) Ommer (1995).
(38) NMFS (National Marine Fisheries Service) (1995) and Sherman (1992).

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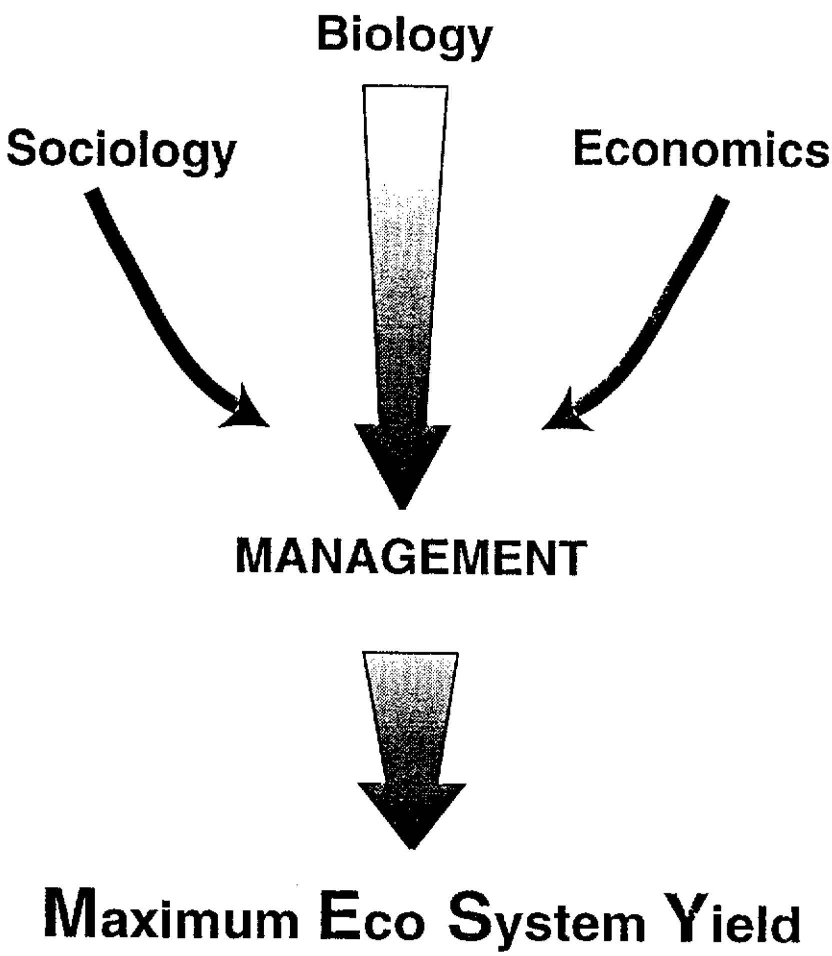

Figure 1. Fishery management is the result of a balance between the biological limits in an ecosystem and the human economic and social demands placed on the system. Successful management, resulting in a biologically sustainable yield, can be described as the maximum ecosystem yield or MESY.

The Health of the Gulf of Maine Ecosystem: Anthropogenic Effects on Protected Species

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The Gulf of Maine Ecosystem Workshop had its genesis in the Marine Mammal Protection Act Amendments of 1994, so it is appropriate that we consider some of the anthropogenic factors that influence the population dynamics of marine mammals and other protected vertebrate species. To many citizens, these species possess special qualities that warrant their protected status. These animals also have intrinsic importance, however, in addition to their societal value. For example, as apex predators, marine mammals are indicators of the general health of their environment; changes in their populations associated with environmental contamination or habitat deterioration warn us that our actions are affecting the health and stability of the entire ecosystem. In addition, these animals may play important roles in ecosystem dynamics; drastic changes in their status may have unexpected or undesirable effects on other populations.

In this paper, I will synthesize existing knowledge to provide a picture of what we do and do not know about the effects of anthropogenic factors on the protected species of the Gulf of Maine and, where possible, draw attention to particular management and conservation problems faced by these populations. I have limited my review to vertebrate species protected under legislation in the US or Canada.

Legislation Protecting Vertebrate Resources of the Gulf of Maine

In the Gulf of Maine, legislative and regulatory protection is afforded marine vertebrates at the international, national, and state or provincial levels. The following is only a partial list of this legislation. In the US, marine mammals are protected from harassment, capture and harvest by the Marine Mammal Protection Act of 1972. Canadian law pertaining to the conservation and harvest of marine mammals is contained in the Marine Mammal Regulations of 1993, a section of the Fisheries Act. In general, Canadian regulatory attitudes towards marine mammals reflect a utilitarian philosophy, while US regulations are more protective. This difference reflects the recent history of harvesting marine mammals in Canada and has important implications for the management of these animals in the Gulf of Maine, as discussed below.

In US waters of the Gulf of Maine, marine mammals are managed by the National Marine Fisheries Service (NMFS). NMFS has an active research program investigating the status and dynamics of these animals, including regular stock assessments for all species (Blaylock et al. 1995). These assessments include a determination of whether anthropogenic removals are likely to exceed the population's capability to sustain them (Barlow et al. 1995). In such cases, marine mammal stocks are designated as *strategic* and warrant special attention. Strategic stocks are assessed annually and Take Reduction Teams are formulated for each of these populations to find ways of reducing levels of anthropogenic mortality. In Canada, the Department of Fisheries and Oceans (DFO) manages marine mammal populations. Research by DFO scientists in the Gulf of Maine has focused on the dynamics of pinniped populations and their interactions with commercial fisheries (e.g. Bowen 1990).

The US Endangered Species Act of 1973 provides special protection to threatened and endangered species and their habitats; additional measures are available under state legislation in Massachusetts, New Hampshire and Maine. Several avian species, such as the osprey *Pandion haliaetus*, are protected under state endangered species legislation, but not under the federal statute. Canada does not have comparable endangered species legislation, but the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) reviews and publishes status reports on threatened and endangered species. Trade in many of these species is regulated under the Convention on International Trade in Endangered Species of 1973.

Non-game migratory birds are protected under the Migratory Bird Treaty Act of 1918, which provides the US Department of Interior authority to issue regulations and enforce the provisions of the Act. In Canada, non-game birds are managed by the Canadian Wildlife Service. One fish species, the Atlantic salmon *Salmo salar* is managed internationally under the North Atlantic Salmon Conservation Organization (NASCO), formed in 1982. Canada and the US also manage Atlantic salmon resources under domestic fisheries legislation.

Many of the issues affecting protected species in the Gulf of Maine involve interactions with commercial fisheries, either directly by entanglement in gear or indirectly through ecological interactions. In the US, federal fisheries management is proscribed by the Magnusen Fisheries and Conservation Act of 1976, and is administered by the New England Fishery Management Council. In Canada, federal fisheries are managed under the Fisheries Act, which provides the Minister of Fisheries and Oceans considerable latitude in formulating regulations and harvesting plans. The US approach is inclusive, involving the direct participation of fishers and their representatives. The Canadian approach is more centralized, although recent changes have brought about greater involvement of industry representatives in the decision making process. Neither approach has been particularly effective in developing and maintaining sustainable fisheries.

Finally, the habitat of these protected species is protected in US waters by the National Environmental Policy Act (NEPA) of 1969. One important aspect of NEPA is the requirement that Environmental Impact Statements be formulated before government agencies take actions that may significantly affect the quality of the environment.

Protected Vertebrate Species of the Gulf of Maine

The protected vertebrate species of the Gulf of Maine include: marine mammals, birds, sea turtles, and fish. Almost 20 species of marine mammals are common residents, seasonal residents, or visitors to the Gulf of Maine. Two species of baleen whale are of special concern: the northern right whale *Eubalaena glacialis* and humpback whale *Megaptera novaeangliae*. Populations of both species were greatly reduced by whaling in the 18th and 19th centuries. Under protection from commercial exploitation, the humpback population is believed to be recovering, but right whales are not. The most recent estimate of humpback abundance is approximately 5500 individuals (NMFS 1991a). The northern right whale population is one of the most endangered species of large cetacean in the world, with an estimated abundance of approximately 300 individuals (NMFS 1991b). Two other baleen whales, the fin whale *Balaenoptera physalus*, and sei whale *Balaenoptera borealis*, are listed under the US Endangered Species Act, but do not face significant threats from human activities in this region. All of these baleen whales are seasonal visitors to the Gulf of Maine; right whales and humpback whales make long-distance migrations to calving areas in more southern latitudes.

Of the eight species of small cetaceans or toothed whales in the Gulf of Maine, the harbour porpoise *Phocoena phocoena* warrants particular attention, because of the large numbers killed in gill net fisheries in both Canadian and US. waters. This mortality averaged over 1850 porpoises annually between 1989-1993 in US waters of the Gulf of Maine. Additional but unquantified by-catches occur in the Bay of Fundy and in the waters south of Cape Cod (Read et al. 1993). These incidental catches come from a population estimated at approximately 47,000 individuals (Blaylock et al. 1995). Current evidence indicates that this incidental mortality is not sustainable. Two other odontocete species, the white-sided dolphin *Lagenorhynchus acutus* and long-finned pilot whale *Globicephala melas*, are designated strategic stocks in the US because of incidental catches in commercial fisheries. These catches are a cause for concern, but are not believed to threaten the existence of either population.

Two pinniped species, the harbour seal *Phoca vitulina* and gray seal *Halichoerus grypus*, are also of concern, not because they are endangered, but because they are expanding in both abundance and range and facing increasing conflict with mariculture and commercial fishing operations. The grey seal population on Sable Island, for example, has been increasing annually at a rate of 12.6% since the early 1960s (Zwanenburg and Bowen 1990). Two other pinniped species, harp *Phoca groenlandica* and hooded *Cystophora cristata* seals are common winter visitors to the Gulf of Maine.

Many species of birds are provided protected status in the Gulf of Maine. These protected species may be classified into four categories: colonial breeding seabirds, raptors, shorebirds, and non-breeding pelagic seabirds. Colonies of breeding seabirds have been greatly reduced in extent and number by coastal development and disturbance, and also by the explosive population growth of gulls (*Larus* spp.), which displace nests and prey on the chicks of these seabirds. Raptor populations have been depleted by habitat loss and reproductive disruption caused by organochlorine contaminants. Nesting shorebirds, such as the piping plover *Charadrius melodus*, are threatened by human disturbance on beaches; other shorebirds face the loss or degradation of feeding habitat. One species of pelagic shorebird, the northern phalarope *Lobipes lobatus*, has virtually disappeared from the northern Gulf of Maine during the last decade for reasons that are still unclear. Little is known of the status of pelagic seabirds in the Gulf of Maine, although some are known to experience mortality in commercial fisheries. Many of these highly migratory pelagic birds breed or winter in remote areas of the Southern Ocean.

Only one species of marine reptile, the leatherback *Dermochelys coriacea*, is a common summer visitor to the Gulf of Maine. This species, the world's largest sea turtle, is endangered primarily by factors operating outside this region, including: direct exploitation, harvest of eggs, and the loss of nesting sites and nest disturbance (NMFS & USFWS 1992). Both in the Gulf of Maine and elsewhere, leatherbacks become entangled and die in commercial fishing gear and ingest marine debris. Two other turtles, loggerheads *Caretta caretta* and Kemp's ridleys *Lepidochelys kempii*, stray as far north as Cape Cod Bay during summer months (Lazell 1980).

Two fish species, the Atlantic salmon and the shortnose sturgeon *Acipenser brevirostrum* are afforded special protection because of their status. Most salmon runs in the Gulf of Maine have been extirpated or decimated by the loss of spawning habitat and past over-exploitation in commercial and recreational fisheries. The remaining salmon populations are threatened by the admixture of escaped domesticated fish from mariculture operations and a variety of other factors. Atlantic salmon may soon be listed as threatened under the ESA because of these threats (USFWFS & NMFS 1995). Shortnose sturgeon are primarily an estuarine species, but some individuals do venture into coastal waters. Populations of this species have been reduced by the loss and degradation of estuarine habitats and past over-exploitation (Dadswell et al. 1984). Finally, Atlantic sturgeon *Acipenser oxyrhynchus* are a candidate species for listing under the ESA. These fish often inhabit the same rivers as shortnose sturgeon, but adults tend to spend a greater period of their lives in salt water.

Current Threats to Protected Species of the Gulf of Maine

For few, if any, of these protected species is our knowledge adequate to fully understand the effects of human activities on their populations. Current monitoring programs enable us to assess the nature of the most significant threats to some (Atlantic salmon, right whales, harbour porpoises), but not other (pelagic seabirds) populations. There are several broad categories of threats to these protected species:

- direct mortality, including entanglement and vessel collisions
- commercial harvests of prey species
- habitat loss and degradation
- environmental contaminants

Direct mortality is the most obvious and, in some ways, the simplest problem to mitigate. Mortality from ship collisions, for example, is the most critical threat to northern right whales (Kraus 1990). Recent actions taken to solve this problem include the designation of right whale conservation zones on nautical charts of the Bay of Fundy and Browns Bank, similar designation of critical habitat in the US and real-time notification of large vessel operators of the presence of right whales (Kraus and Brown 1992). In other cases, the solution to such direct mortality may be clear but difficult to achieve. The by-catch of harbour porpoises in sink gill nets is an example of such a situation. Both Canadian and US management agencies have been reluctant to protect harbour porpoise populations by restricting gill net fishing effort in areas where the risk of entanglement is high, because of the adverse effect that such restrictions might have on fishers.

Conflicting management objectives in such situations must be resolved before effective conservation action can be taken.

The effects of commercial harvests of prey species on populations of protected resources are poorly understood. Many marine mammals and seabirds in the Gulf of Maine feed on forage species such as herring *Clupea harengus* and mackerel *Scomber scombrus*. These fish stocks are currently robust because fishing pressure on them is light. If market forces change and fishing pressure on these stocks increase, real or perceived competition may arise between commercial fisheries and seabirds or marine mammals. At the present time, the requirements of protected species are not considered when fishery harvesting plans are formulated.

The effects of habitat loss and degradation have been dramatic for populations of colonial nesting birds and in the loss of spawning areas for anadromous fish. The development of coastal islands and disturbance caused by visitors to nesting colonies has had a profound and direct effect on many avian populations. For some species, such as Atlantic puffins *Fratercula arctica*, nesting colonies have been maintained only by intensive management of local gull populations and strict regulations on human visitation. For other protected species, particularly cetaceans, we do not yet understand what constitutes required habitat, so it is impossible to assess the effects of habitat loss. Here the effects of chronic, sub-lethal human influences, such as underwater sound, may play an important role.

Environmental contaminants are known to have had deleterious effects on the reproductive success of raptors such as ospreys and bald eagles *Haliaeetus leucocephalus*. These contaminants may also cause less acute effects in other apex predators, which carry high burdens of organochlorine contaminants in their systems. Much current research, for example, is directed towards understanding the impact of these environmental chemicals on the development and function of the immune system in marine mammals (Swart et al. 1994; Lahvis et al. 1995). Once again, we do not yet understand the full impact of this class of anthropogenic threats on the demography of protected species in the Gulf of Maine.

Our lack of knowledge regarding the effects of individual factors makes it impossible to understand the cumulative impacts of human activities on these populations. For example, northern right whales are currently protected from direct harvesting, but are subject to mortality from ship collisions and entanglement in static fishing gear. It is possible to assess the impacts of such direct mortality by performing demographic analyses of the effects of these removals. But how do we assess the effects of other, less overt threats? Coastal development and disturbance from commercial vessel traffic, whale watching, and perhaps even research activities, may effect patterns of habitat use by right whales. The effects of underwater noise are unknown, as are potential changes in prey populations caused by the diversion of human wastes. In short, it is a simple task to compile a list of potential threats to these species, but difficult or impossible to assess the actual risk posed by all of these threats. Given this uncertainty, we cannot yet assess the cumulative impacts of multiple stressors on any of these protected species.

Protected Species in the Gulf of Maine: Looking Toward the Future

Several general shortcomings of the current regulatory environment emerge from this brief review. First, management programs need to recognize that the Gulf of Maine ecosystem spans the waters of two countries; the effective conservation of protected species requires a system of co-management in which regulations apply to ecological rather than political boundaries. This is a particular problem with marine mammals, due to profound differences in management philosophy in the US and Canada. For example, management actions taken in Canada to slow or stop the growth of expanding grey seal populations may be in direct conflict with US actions designed to protect new breeding rookeries of this species in the southern Gulf of Maine.

Second, agreement must be reached among user groups, government, and other interested parties on the goals we want to achieve in managing these resources. Current conflicts over coastal development, resource use and the conservation of protected species reflect the wide diversity of values held by users of the Gulf of Maine. This is perhaps the greatest challenge to protecting the Gulf of Maine ecosystem and the protected species that inhabit it. For example, one current management goal is to promote the recovery of the northern right whale population from its endangered status. What costs are we willing to bear in order to protect these animals? How should these costs be allocated among user groups and other members of society? At the present time these questions are addressed only when conflicts arise. We need a much broader discussion of what we want the Gulf of Maine ecosystem to look like 10, 25, or 50 years from now. These difficult questions must be addressed if we are to agree on common goals and programs to protect this system.

Third, current management, research, and monitoring activities need to be integrated across sectoral and taxonomic lines. For example, managers should consider the requirements of seabird and marine mammal populations when making decisions regarding allocation of fisheries resources. This will require biologists and managers working on different ecosystem components to interact on a functional basis. At the present time, such cross-disciplinary interaction is rare or non-existent.

These three management shortcomings point to a new approach to managing the protected species of the Gulf of Maine. Currently we treat these resources singly, on a species by species, or population by population, basis. Perhaps it would be more appropriate to treat each of these populations as components and use the ecosystem as the management unit. The concept of ecosystem management recognizes many of these tenets as central to the long-term sustainability of biological systems, as outlined in this definition (Grumbine 1994):

> Ecosystem management integrates scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of *protecting native ecosystem integrity over the long term.*

Surely this is what we are striving towards with our patchwork quilt of protective legislation in the Gulf of Maine. It seems unlikely that we can achieve many management goals with the current approach. Although it is not yet clear how to manage the Gulf of Maine on an ecosystem basis, I believe that it is time we start to take steps towards such a system. As noted above, a constructive first step would be public discussion about the eventual goals of such management.

Compared to many other coastal areas, the Gulf of Maine is relatively intact ecosystem. So far, only a few populations have been extirpated: several salmon runs, the great auk, the Atlantic walrus, and the Atlantic gray whale. We have experienced some success in stabilizing or restoring a few critically endangered populations of raptors and alcids. We still lack a basic understanding of the dynamics of many populations, however, and of the impacts of human activities on them. In the face of such uncertainty, we would do well to tread lightly and apply precautionary principles in management. It is also time to look at these resources with a new perspective, not as populations of fish, whales, porpoises or turtles, but as interrelated components of a system in which we are also a part.

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Contaminants in the Gulf of Maine:
What's here and should we worry?

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Abstract

The Gulf of Maine is a dynamic environment that has highly variable bottom type and localized depositional and transport processes. It is used and impacted by the people around it who hope to use the marine system for many purposes such as fishing, recreation, housing, sewage and dumped disposal, shipping, recreation, and preservation. In order to identify "pollution", which is defined as detrimental effects in the ecosystem that are attributable to human activity, the spatial and temporal distribution of contaminants in Gulf of Maine sediments are established using data that have been compiled into a Contaminated-Sediment Database for the Gulf of Maine. The potential for high contaminant levels in the sediments to induce toxic effects in the Gulf ecosystem is then assessed. In the Gulf of Maine, we have large urban centers that adversely affect the marine ecosystem well offshore through a variety of human activities. We are also in the fortunate position of still having many relatively pristine marine areas. It is unlikely that we will reach an endpoint of "zero toxic effects" in the ecosystem; however, much of the information needed to move closer to the shared goal of managing a sustainable ecosystem in the Gulf of Maine is currently available. Future success will rely on continued efforts to 1) identify rate-limiting physical and biological processes, 2) provide appropriate data synthesis and 3) involve the public.

Introduction

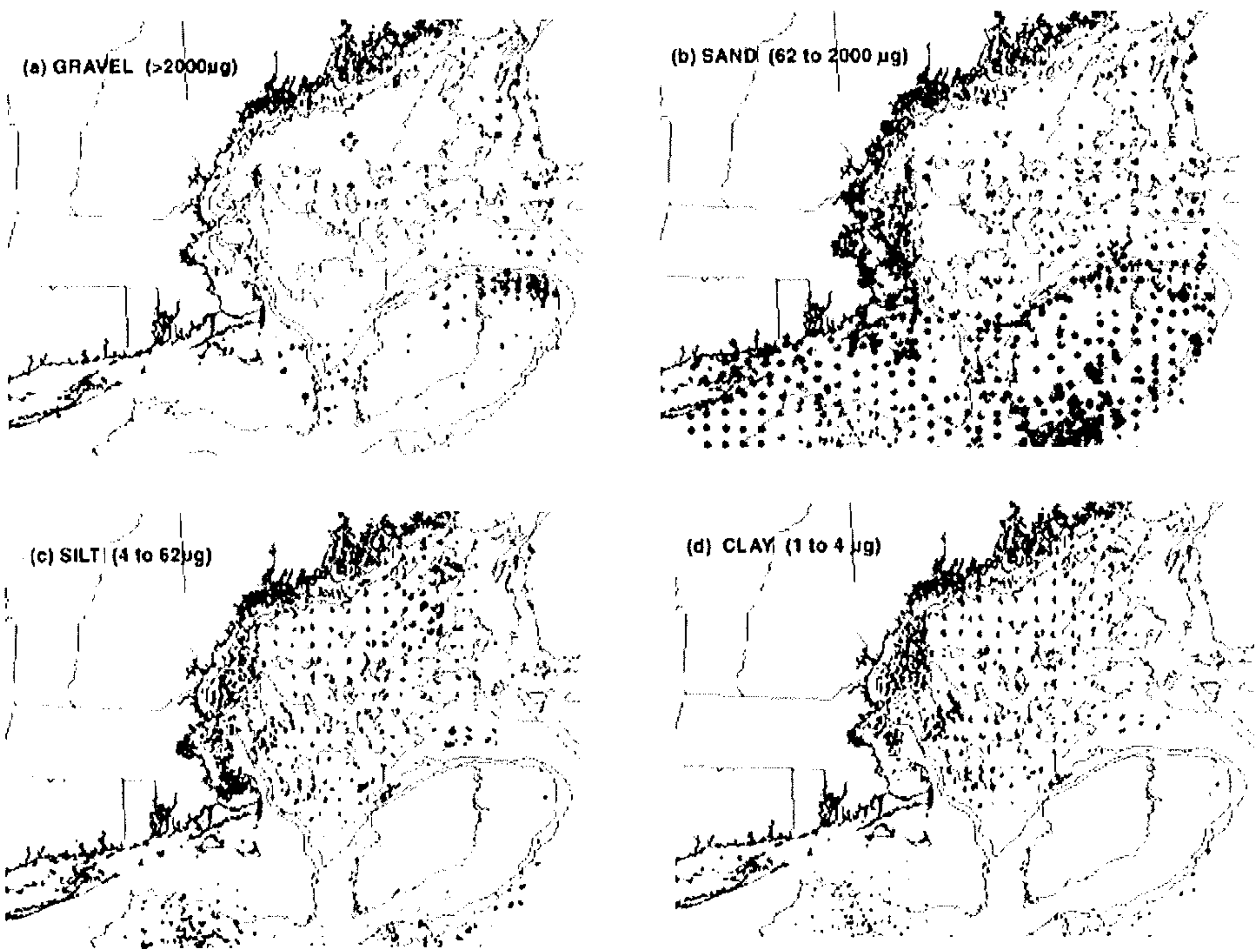
Should we worry about the level of sediment contaminants in the Gulf of Maine? This paper will present an overview of sediment contaminants in the Gulf of Maine, and discuss the information needed to manage or restore those systems that are degraded. It will focus on human activities, contaminant types and contaminant distribution. It will then touch on effects of pollution on the ecosystem health in the Gulf of Maine, more of which is being covered by the other papers from this conference. Finally, some thoughts on research and policy priorities will be presented.

The Gulf has population densities ranging from 0.1 to 10,000 people per square kilometer within 50 miles of its coast (Census Bureau, 1996). The Gulf of Maine has a glacial terrain with a great deal of bathymetric relief (NOAA-NOS, 1992) and a variety of sediment types (Fig. 1). These physical and geological regimes produce a variety of habitats and local ecosystems which support diverse marine populations. The area experiences large temporal variations in physical and geological processes; the shallow regions in particular undergo large fluctuation because of the storm driven transport and large tidal ranges in the region (Brooks, 1992; Hertzman, 1992). Figure 2 illustrates the coupling between atmospheric storm conditions and resuspension of the sediment surface. The dynamic marine environment is also affected by the people around it who hope to use the marine system for many purposes such as fishing, recreation, housing, sewage and dumped disposal, shipping, recreation, and preservation.

Information needs

This workshop strives to increase the effectiveness of environmental managers and scientists in reaching the shared goal of managing a sustainable ecosystem in the Gulf of Maine. Last year, the working group on sediment and water quality (HWG) in the Gulf of Maine at the "Habitat Workshop" (Buchholtz ten Brink & others, 1994) summarized management and scientific

GULF OF MAINE SEDIMENT TEXTURE



1. Sediment texture (% sand, silt and clay in surface sediments) of the Gulf of Maine. Data from the Atlantic Margin Sediment Database, USGS.(Hathaway, 1996).

goals (Table 1) associated with the impact of contaminants on marine habitats in the Gulf. The information that is needed to meet these goals can be presented as a matrix of information categories (Table 2), where interactions between the factors and categories are the processes that create ecosystem functioning.

Table 1. Summary of management and scientific goals
(from Buchholtz ten Brink & others, 1994)

What are managers trying to accomplish?
- Protection of human health: disease, reproduction
- Quality of (human) life: aesthetics, perception of risk
- Multiple use: recreation, commerce, waste disposal, resource utilization
- Protect living resources: recreation, diversity, health, commerce, sustainable fisheries
- Optimize ecosystem health for its own sake: habitat losses, restoration, biodiversity

What do scientists hope to accomplish?
- Advise managers and the public about which questions they need to ask
- Provide guidance on how to reach the desired endpoints
- Provide information on the implications of various practices

Table 2. Information categories.

[Human Activity] x [Contaminant] x [Habitat] x [Location] x [Resource or Activity] x [Toxic Effect]

There are many types of contaminants that affect sediment or water quality in the Gulf of Maine Ecosystems (Table 3). These categories have been evaluated by the HWG to identify the relative priority of needs for research or additional information. The criteria used for setting priorities included the degree of understanding about the occurrence, fate, and effects for the various contaminant types, and the relative value of the information. Toxic organic compounds, metals, and fertilizers were identified as contaminant categories which most needed additional information about their distribution and behavior in the marine environment.

Table 3. List of contaminants that affect sediment or water quality in Gulf of Maine ecosystems.
(from Buchholtz ten Brink & others, 1994).

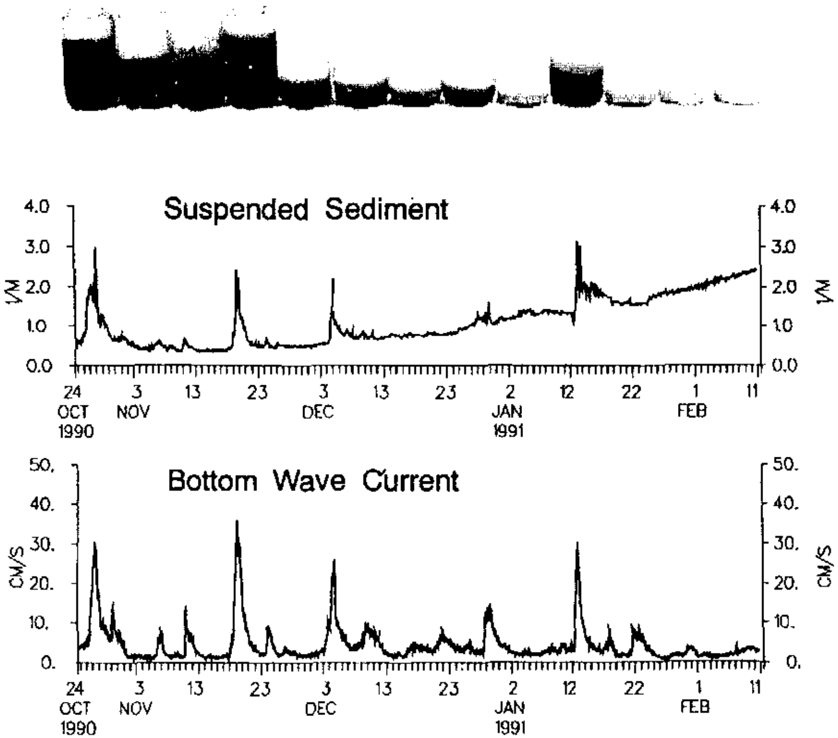
Contaminants in the Gulf of Maine

Metals
*metals exceeding regulatory disposal or health limits, e.g. Cd, Hg, Pb
*metals suspected of causing detrimental effects on organisms
others

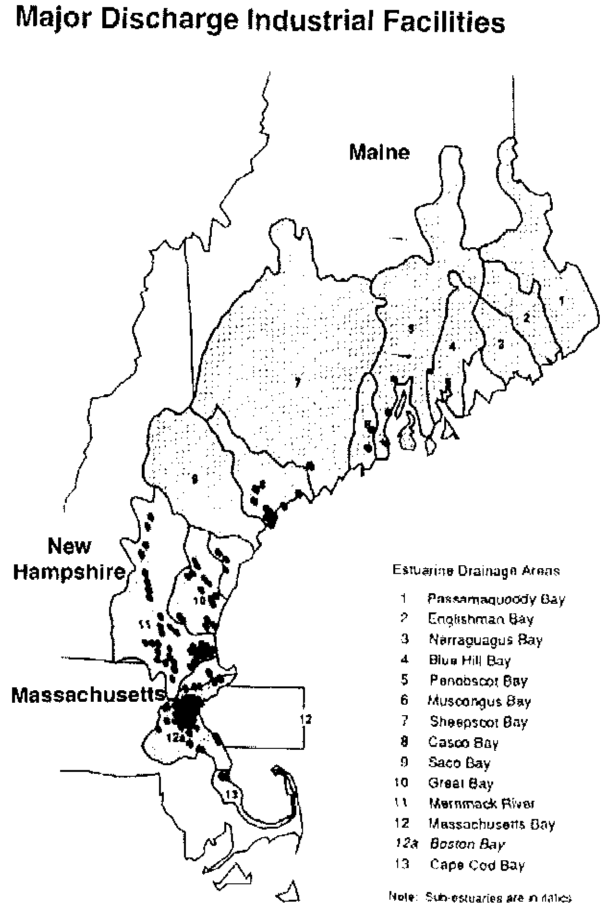
Fertilizers	**Pathogens**	**Environmentals**
*excess organic carbon	bacteria	temperature
*nutrients	viruses	salinity
	antibiotics	
Toxic organics	- **Radionuclides**	**Physical structure**
*Chlorinated hydrocarbons		turbidity
*PAHs		siltation
*Pesticides & herbicides		sediment structure
other hydrocarbons		

** asterisk indicates priority needs for research/ and information   - dash indicates low priority*

One can look at a list such as this and ask, what is the source of these contaminants in the Gulf of Maine? What are the human activities that generate them (Table 4) and which activities have the greatest impact? For which activities can adverse impacts be remedied quickly or easily? Some of these activities generate focused impacts on the ecosystem or environments while others provide a diffuse impact. What is the relative impact on the ecosystem of diffuse vs. focused activities and pollutant sources? How can cumulative effects be assessed? Research studies have been done to address some of these questions for some of the activities; other questions need more study.



2. (Top) Sample bottles from a time-series sediment trap located 4 meters above the bottom in Massachusetts Bay. Each bottle represents accumulations during a 9-day interval between October 1990 and February 1991. (Middle) Suspended sediment concentration based on light transmitted shows peaks in turbidity that correlate well with sample bottles. (The upward trend beginning in December was caused by algae fouling the lens of the tubidity sensor.) (Bottom) There is a clear correlation between the four most intense periods of wave activity and the peaks in suspended sediment shown by the upper graph and the bottles. This correlation indicates that waves are the major cause of resuspension. The samples in bottles are also used to measure suspended sediment attributes (such as texture and contaminant concentrations) during stormy and calm periods (from Bothner et al., 1994).



3. Location of approximately 200 facilities that are major effluent dischargers into Gulf of Maine watersheds (modified from EPA, 1995b).

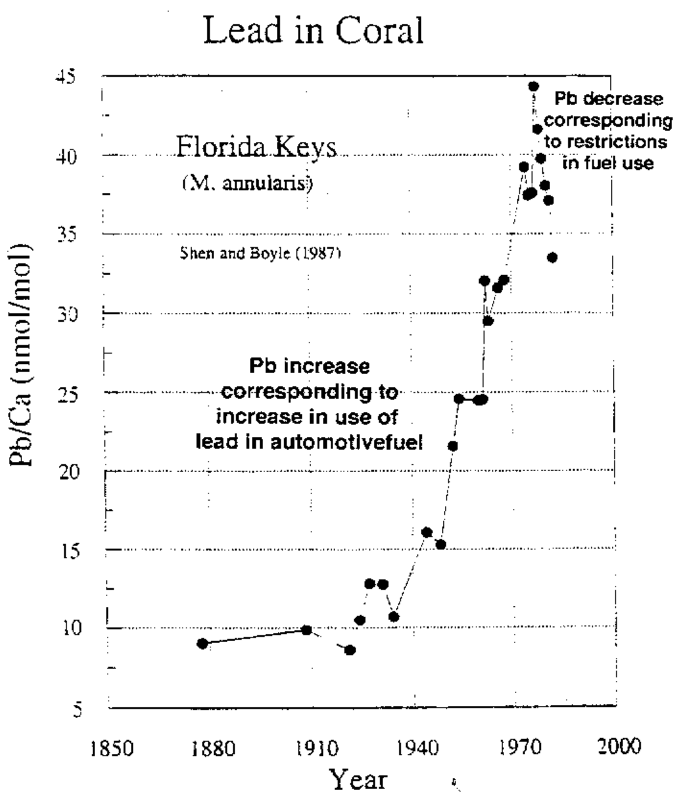
Table 4. List of human activities that have significant detrimental effects on the marine ecosystem (from Buchholtz ten Brink & others, 1994).

Human Activity		
Land use in the watershed residential industrial agricultural recreational commercial	**Non-point sources** aqueous atmospheric	**Marine recreation** debris sewage paint fuel turbulence
Marine industry shipping fisheries (processing, harvesting) aquaculture	**Marine construction** dredging damming and undamming draining and filling	**Waste disposal** dumping sewage

Each activity provides a source of contaminants to the ecosystem. EPA has recently completed a national inventory of contaminants in sediments and their sources (EPA, 1995b). The data for direct wastewater sources of contaminants to the Gulf and its watersheds is relatively robust because it is primarily gathered in the permitting process for waste dischargers, which are probably the greatest single type of contaminant source in the Gulf of Maine. There are approximately 200 (Fig. 3) industrial facilities whose effluent drains into the Gulf of Maine and are considered (EPA, 1995b) to be major dischargers. These facilities are concentrated around the greater Boston area and the industrialized rivers of New Hampshire. The EPA inventory of contaminant measurements in sediments is less robust, primarily because it was compiled from existing electronic databases under budgetary and time constraints.

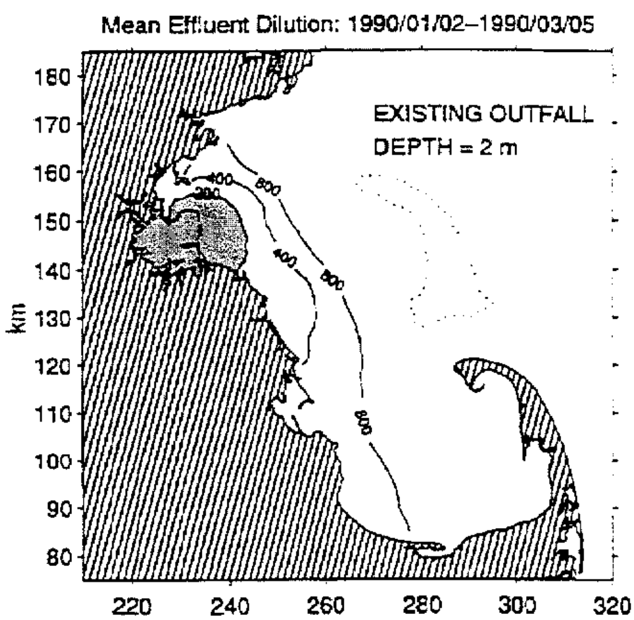
Atmospheric sources provide long-term input of both organic and inorganic contaminants. This source is one which has responded to regulatory action with decreases in the concentrations of pollution observed in the environment, but measurements providing information about concentrations and locations for atmospheric input of contaminants to the Gulf waters are sparse (Hanson and Norton, 1985; Menzie-Cura and Associates, 1991). The Gulf area lies under the path of aerosol fallout from midwestern industrial centers, as evidenced by the history of acidified lakes in New England, and also has its own industrial base. There is no systematic historical analysis of most metal or organic contaminants in the air available for the Gulf of Maine (T. Church, pers. com). Nor is there a historical record in the Gulf of Maine marine environment, as is available for Pb (primarily atmospheric input) in the Florida Keys for coral records (Fig. 4). Consequently, the historical and present atmospheric contribution for many contaminants must be estimated from data available in other geographic regions.

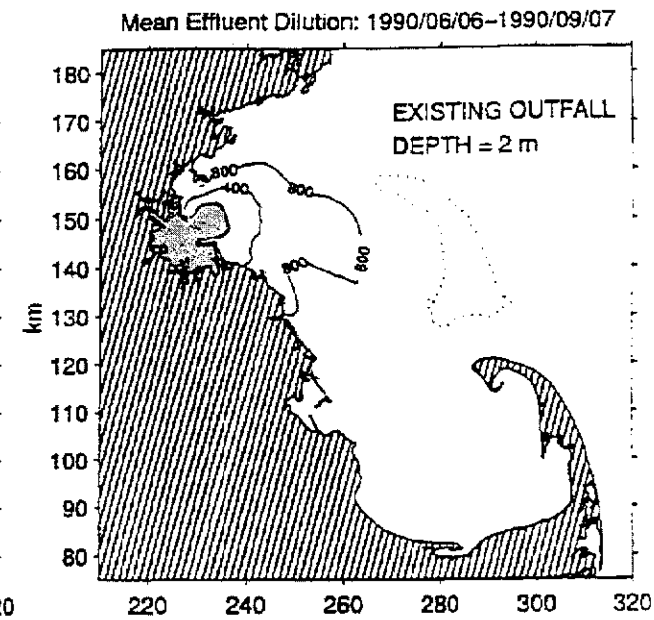
Dumping of dredged materials, often having high concentrations of contaminants, has occurred historically in Gulf waters. Now only clean dredged material is approved for ocean dumping. Sidescan sonar and bottom video (Bothner, et al., 1992); Schwab,et al., 1996) allow definition of both natural sediment character and evidence of anthopogenic disturbance, like dumping of mud or boulders on sand bottoms In addition, mapping of the easily identified dump deposits has shown that dumped material disturbs and alters the benthic habitat. In some cases, such as Stellwagon Basin (Valentine, et al., 1996), material dumped in the past was scattered far from the intended target areas. Sidescan and video also record disturbance and resuspension from bottom fishing and slow recovery of the seafloor ecosystem (Valentine & Lough, 1991). Discharge of sewage effluent into the ocean has a direct impact on the water column, acting as a source of carbon and nitrogen, i.e., a fertilizer . The temporal and spatial distribution of the input strongly influences the impact. For example, the dispersion of nutrients in the Massachusetts Bays ecosystem and the response of biota are sensitive to the time, place, and manner of input (Fig. 5). Septic system runoff provides a diffuse source, while urban treatment plant outfalls provide a point source. Input into a relatively closed embayment or of large volumes can create nutrient loading that leads to eutrophication, or blooms of noxious or toxic phytoplankton. Industrial sources for many contaminants, which may change over time, have been sharply reduced since the 1970's, and in Boston, more so since 1985. This has been achieved through improvements in technology, environment awareness, plant closures, and regulatory practice (Alber & Chan, 1994). These source reductions are reflected in improvements in water quality for <u>some</u> urban estuaries in the last



4. Lead concentrations in Florida corals reflect the correlation in magnitude and temporal variation between water concentrations (recorded in the coral) and lead use in automotive and industrial sources (modified from Shen and Boyle, 1987; Nriagu, 1989).

5. Model-generated contours for 1990 oceanographic conditions show the probable distribution of (pre-outfall pipe) sewage effluent in winter (left) and summer (right) for Boston Harbor and Massachusetts Bay. Effluent (200 times dilution shown in gray) reaches a larger area in winter than in summer (from Signell, et al., 1996).





decade and are now discernible in the sediment quality. The magnitude of impact caused by most of the other human activities listed is poorly known, at best.

Contaminant distribution

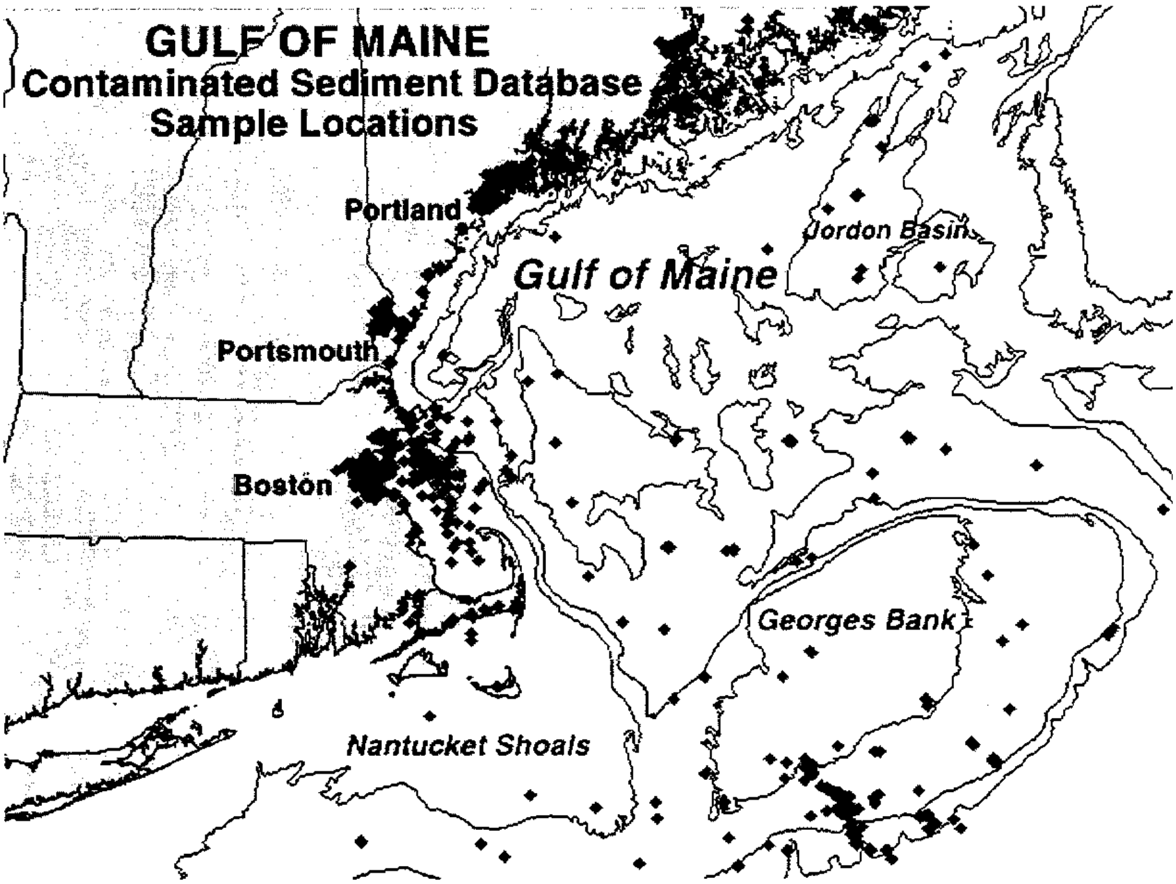
Knowledge of the spatial distribution of contaminants defines "hot spots", suggests an explanation of transport processes, and identifies needs for future studies. Elevated levels of metals (such as silver, copper, and lead), pesticides and herbicides, and certain hydrocarbon compounds result from past and ongoing anthropogenic input into the marine system and can be detected in the waters, sediments, and biota of the Gulf.

Construction of the Gulf of Maine Contaminated Sediment Database is a project currently underway (funded by the RMRP, (RMRP, 1995)) to gather all available existing data, published and unpublished, about contaminant concentrations in sediments of the Gulf of Maine into a single database (Buchholtz ten Brink et al., in prep.) . This database will provide a research and management tool for use in and around the Gulf of Maine. The sample density (Figure 6) available for contaminant data in Gulf sediments is not uniform in time or space. Coverage is good for Boston Harbor, Portsmouth Harbor, and Casco Bay, primarily because these have been the location of recent targeted water and sediment quality studies. Great Bay, N.H. samples are primarily from the 1970's and early 1980s. Massachusetts Bay, Cape Cod Bay, Georges Bank, Penobscott Bay, the Bay of Fundy, and the three deep basins (Wilkenson, Jordon, and Georges Basins) all have widely spaced samples available, while there are essentially no samples analyzed for contaminants in sediments for the remainder of the deep waters of the Gulf of Maine (Larsen, 1992). The coastal region has a set of samples from the US Army Corps of Engineers permitting and navigation project dredging programs (e.g., Normandeau Associates, 1994), which provide data in harbors; however, there is a wide range in the quantity and quality of data reported. Merging of the data from these multiple sources into a single document is expected to be completed in early 1996, with the edited database available later in the year.

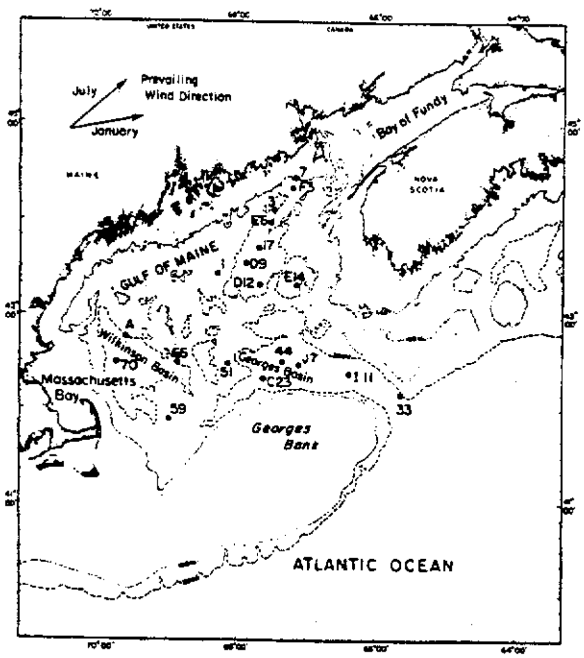
Maps of the distribution of specific contaminants in portions of the Gulf of Maine can be constructed from the Contaminated-Sediment Database and its data sources. The data can be presented from a single study, or from a collation of studies, to indicate spatial patterns, temporal trends, and statistical analysis. For example, a 1985 study of PCBs in the deep basins of the Gulf of Maine (Fig. 7 ; Larsen, et al., 1985) found PCBs present at every station. In Boston Harbor surface sediments, the mercury concentrations (Fig. 8) range from 0.01 to greater than 10 µg/g and are 100 times greater than background values throughout most of the Harbor. Many other contaminants have the same pattern (e.g., lead, Fig 9) of very high values in the inner harbor, decreasing values towards the outer harbor and Massachusetts Bay, with a lot of spatial heterogeneity in all regions. On a regional scale, metal contaminants are above natural levels throughout most of Mass Bay and Cape Cod Bay (Fig. 10-11) and the urban area is a source of contaminants to a large marine region via water, sediment, and atmospheric transport. A similar trend of high concentrations of lead near the land-based source, with values above background for a considerable distance offshore, is found in smaller urban estuaries, such as Portsmouth Harbor (Fig. 12). Lead contamination in coastal sediments comes from multiple sources: the atmosphere, sewers, and indirect runoff. Many other contaminants also have multiple sources; however, sewage is believed to be the primary source for silver contamination. Silver concentrations in surface sediments of Massachusetts and Cape Cod Bays (Fig. 13a; Bothner, et al., 1993) are highest near Boston Harbor and decrease offshore. They continue to decrease to the southeast and then become higher in Cape Cod Bay. Normalization to a naturally-occurring sediment component, e.g., the "mud", iron or aluminum fraction, sometimes helps correct for differences in sediment composition and dilution of contaminant-rich fine-grained material by sands.

The same type of dispersal pattern is seen for other contaminants that trace sewage, such as *Clostridium perfringens* spores and Ozmium isotope ratios. The concentration and inventory of contaminant deposited in a sediment at a given location (Fig. 13b) is a function both of the proximity to the source and of the current and transport processes for water and sediment, which result in focused deposition of the contaminant.

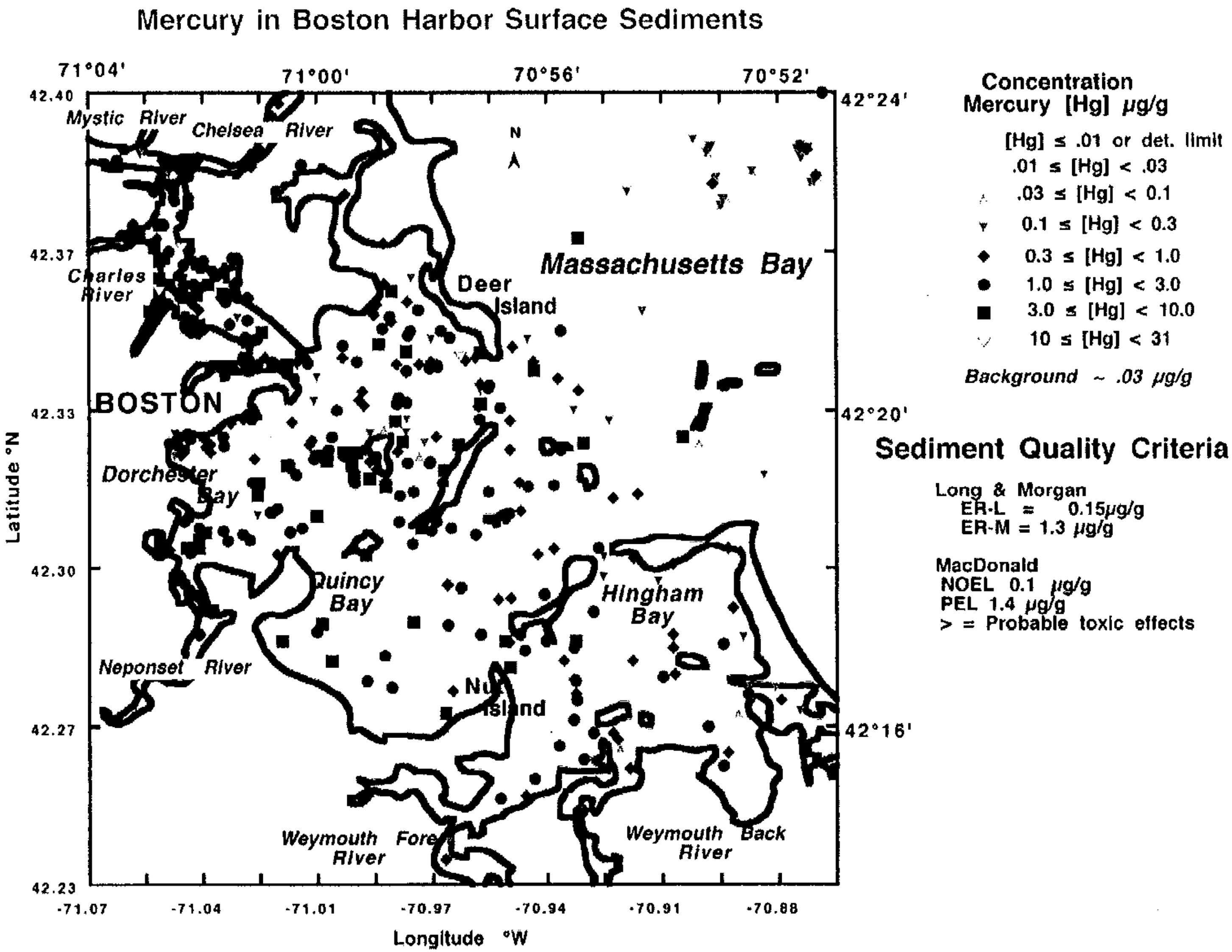
Distributions of contaminants in "surface" sediments indicate present conditions or those



6. Locations of approximately 5000 sediment samples having data for contaminants in the Gulf of Maine (Buchholtz ten Brink et al., in prep.).

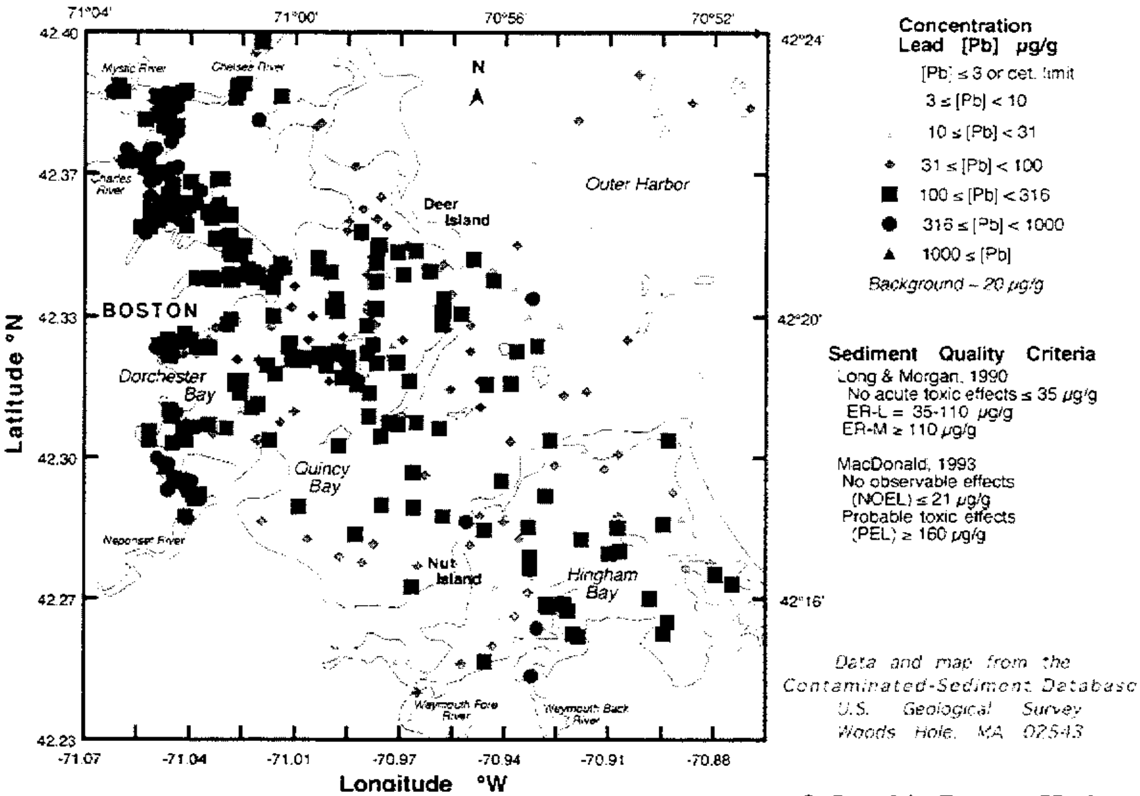


7. PCB sampling sites occupied in the Gulf of Maine, 1993. PCB concentrations ranging from trace amounts to 0.13 ppm (dry weight) were encountered at every station. (from Larsen et al., 1985).

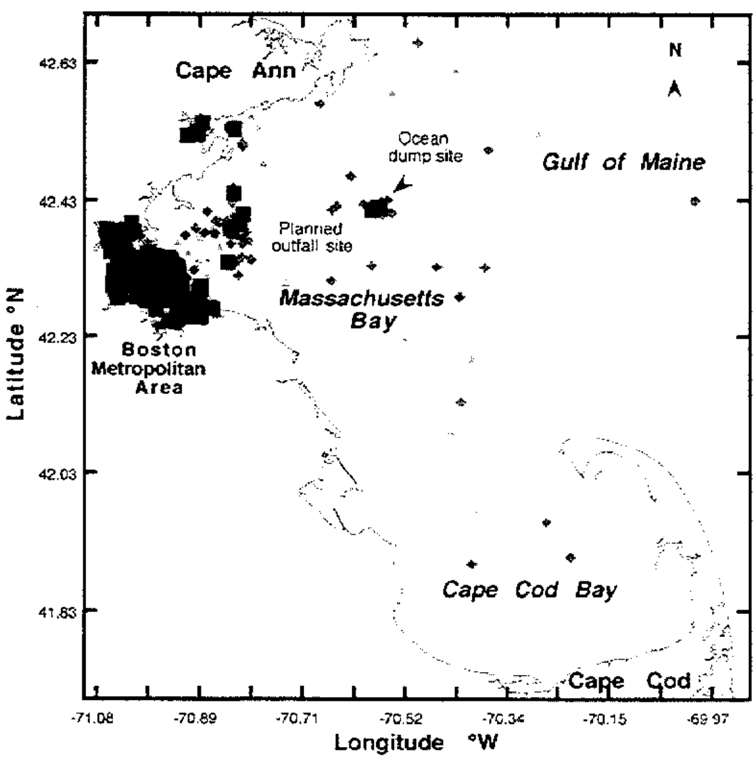


8. Mercury concentrations in Boston Harbor Surface Sediments (0-6 cm). Values (1970-1993 samples) range from background levels of 0.03 μg/g to 30 μg/g and are spatially heterogeneous (from Manheim, et al., in prep). Sediments having concentrations greater than 1.4 μg/g will probably induce toxic effects in biota (MacDonald, 1993).

Lead in Boston Harbor Surface Sediments

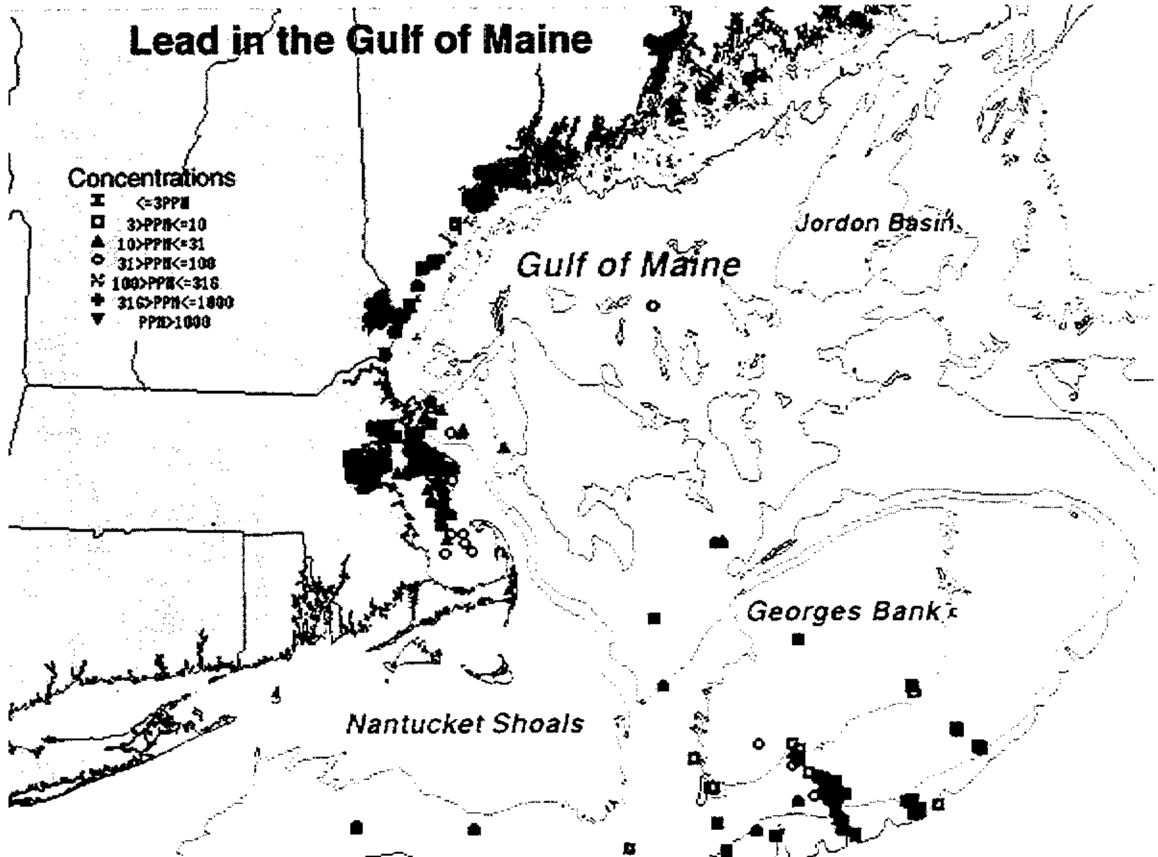


Lead in Massachusetts Bays Surface Sediments

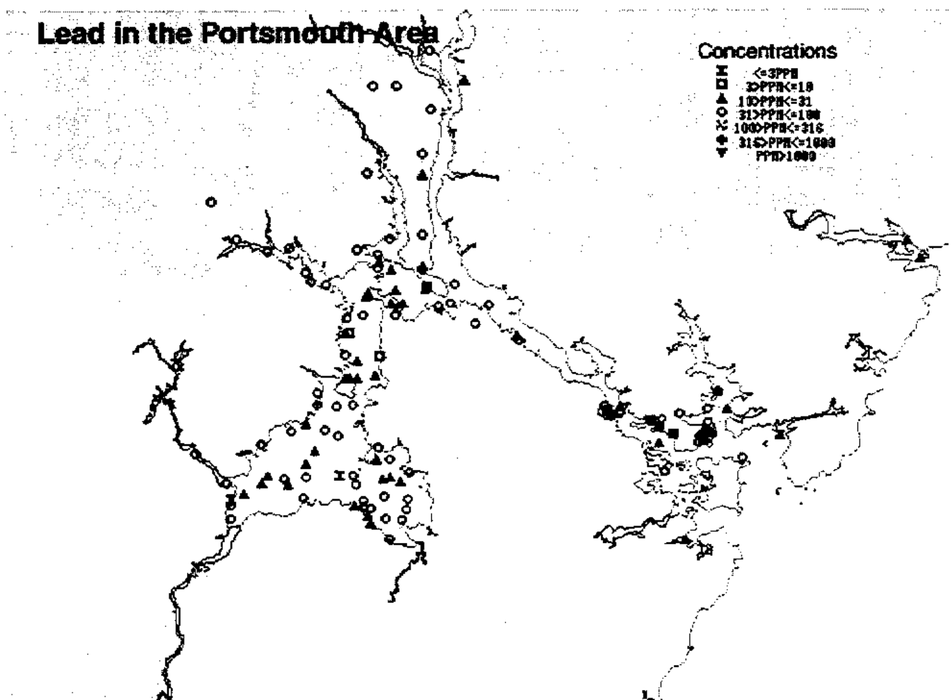


9. Lead in Boston Harbor surface sediments (from Buchholtz ten Brink et al., 1994; Manheim et. al., in prep). Many other contaminants have the same general pattern of heterogenerity in sample density and sample concentrations, with high values nearer the inner harbor and decreasing seaward.

10. Lead in Massachusetts Bays surface sediments (from Buchholtz ten Brink et al., 1994). Concentration values for lead (and Hg, Cu and many other contaminants) are above natural levels throughout most of Massachusetts and Cape Cod Bay. The urban area (greater Boston) is a source of contaminantsto a large marine region through transport of water, sediment, and aerosols bearing contaminants.



11. Lead in Gulf of Maine surface sediments (from Buchholtz ten Brink et al., in prep.). Concentrations range from background values (approximately 20 µg/g) to values as high as 1000 µg/g Pb. Sample density varies greatly in the Gulf; however, high values tend to be located near urban center.



12. Lead in Portsmouth area surface sediments (from Buchholtz ten Brink et al., in prep.); Navy, 1994))

of the recent past. In order to consider the historical record, one must look deeper in the sediments (cores) to identify the total mass of contaminants that have accumulated (the net inventory) or at surface samples that have been collected over a long period of time. A synthesis (Vallette-Silver, 1992) of sediment contamination profiles for urban areas around the world (Fig. 14) illustrates the increase in heavy metals and organic pollutants that has occurred in sediments since the onset of the industrial age in the mid-1880s. Boston has been the primary port and urban center in the Gulf of Maine during this time. Cores from Boston Harbor (Fig. 15; Bothner, et al., in prep.) have contaminant profiles similar to the world composite profiles. All of the metal contaminants have an upper layer of high concentration that is more than 10 times the background level, regardless of the sediment type. This highly contaminated layer is up to 1.5 m thick in depositional areas, but its thickness, and the core contaminant inventories, varies with the rate of sediment accumulation at any particular location. In areas that are non-depositional or erosional (Knebel & Circe, 1995), modern contaminants may not be present in the sediments at all. An estimated 7-11 x 10^7 m^3 of sediment that has metal concentrations which are more than 10 times natural background is present in Boston Harbor. The concentrations in surface sediments and the core inventories for metal contaminants are less outside the harbor than inside Boston Harbor (Buchholtz ten Brink, et al., 1994; MacDonald, 1991), but sediments at all locations may remain a source of contaminants well into the future if they are resuspended and remobilized rather than buried by cleaner sediments. Significant amounts of remobilization may be caused by biological mixing, chemical transformations, resuspension by storm waves, turbulence from deep-draft ships, or other natural and human activities (Santschi, et al., 1990 and references therein).

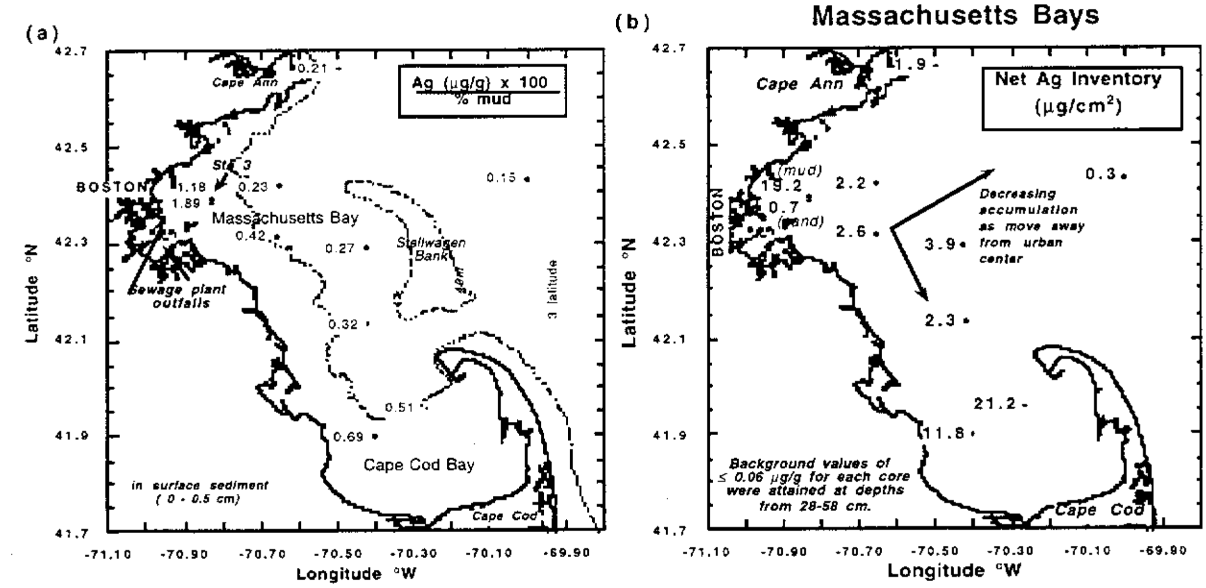
These maps and profiles of characteristic contaminants have established that there are many potentially harmful pollutants in sediments of the Gulf. A current question is whether efforts to reduce pollution in the last decade have been effective in reducing the contaminant levels in sediments. In Boston Harbor, sediment cores collected at a single location over a 16 year period (Bothner et al., in prep.) clearly show that surface sediment concentrations of Pb (and Cu, Zn, Hg and other metals) have decreased by approximately half since 1977. The inventories in the sediments, however, remain large and contaminants are still available for remobilization until they are buried, degraded, or confined to inert forms. Clean-up efforts, may, in fact, alter the ecosystem or sedimentary environment in manners that increase accessibility. For example, reductions in carbon loading can result in better oxygenation of bottom waters and a healthier benthic community that mixes a deeper layer of sediments, more significantly, removal of bottom or buried sediments that have high contaminant concentrations, could potentially resuspend large quantities of sediment and increase the bioavailability of the contaminants

Should we worry?

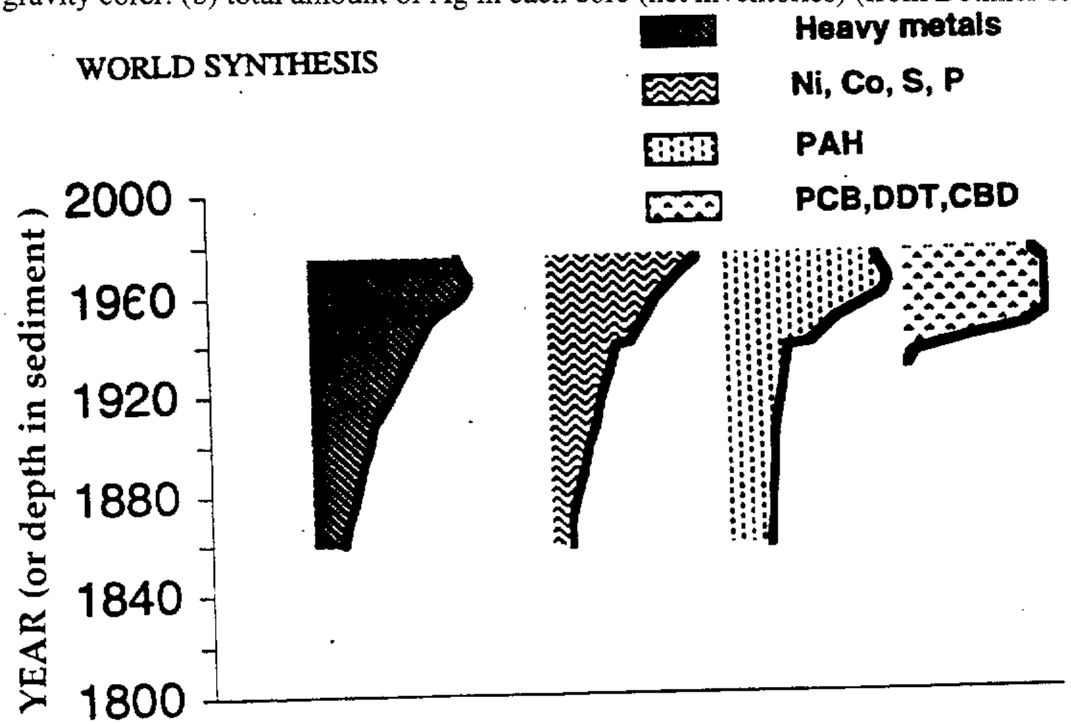
A *contaminant* is a substance introduced or a condition created by human activity that results in conditions that are significantly at variance with natural background conditions. *Pollution* occurs when conditions have been altered to such an extent that significant damage to resources or human health has been demonstrated. Although the term *pollution* has a negative connotation, society may, for various reasons, decide that certain levels of pollution must be accepted, or may have benefits that offset bad effects. These evaluations rest on the relative valuation (Table 2) of human activities and resource use (Table 5) and the negative effects attributable to the pollution. Questions that must be addressed (Buchholtz ten Brink & others, 1994) in making these decisions are: Which living resources or populations are affected or at risk? Are those at risk the same ones as those for which we have a good knowledge base? Are they the ones with the greatest perceived threat? What characterizes a deleterious effect for which management decisions should be made? What research is needed to decide?

The patterns of elevated contaminants in sediments and toxic biological effects occurring in association with population centers occur repeatedly in the Gulf of Maine. There are a number of cases in the Gulf of Maine that do justify concern.

Issues of population, community structure, and biodiversity have been addressed by other papers in this volume in the context of ecosystem health. Clear indicators of toxicity or diminished health (Table 6) in organisms and populations are needed in order to assess the effect of stressors,

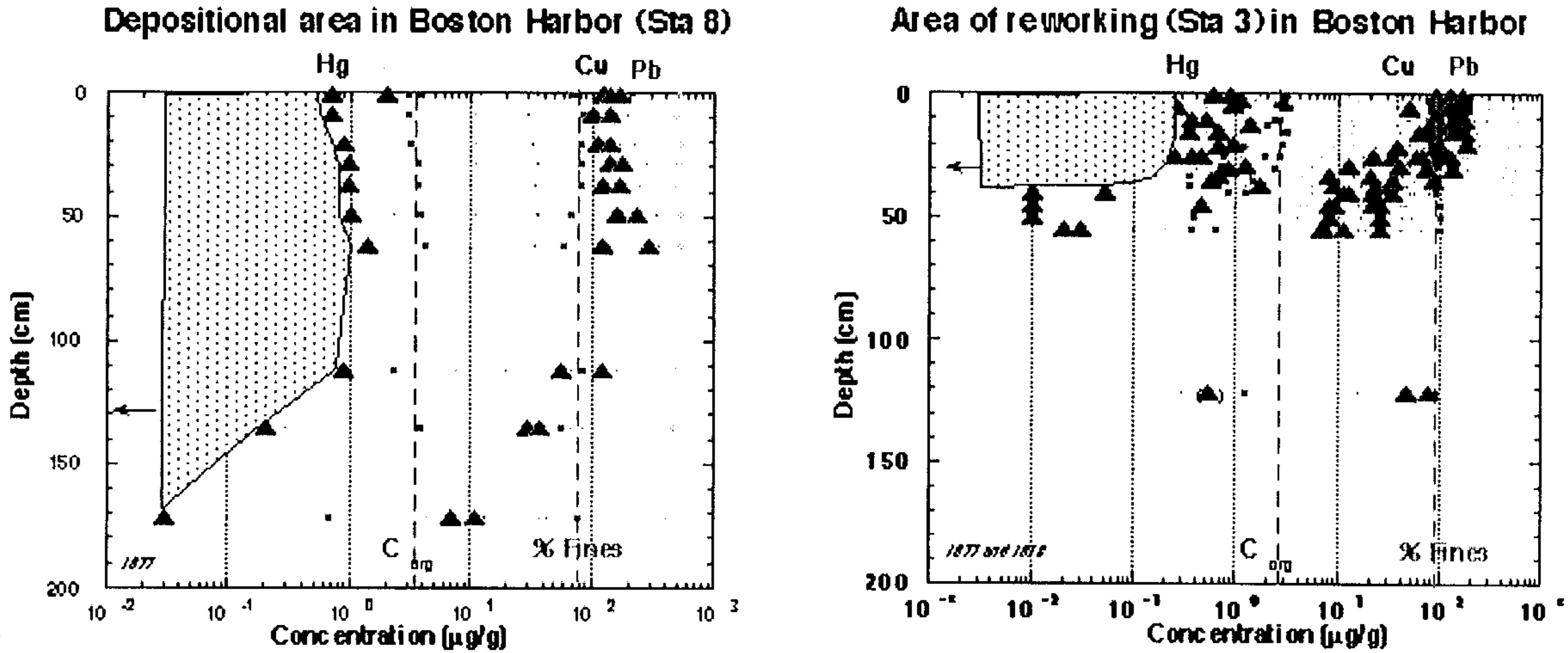


13. Silver (Ag) in Massachusetts Bay and Cape Cod Bay.(a) Ag concentrations (normalized to % mud (i.e., silt + clay)) in surface (0-0.5 cm) sediments collected at 10 locations with a hydraulically-damped gravity corer. (b) total amount of Ag in each core (net inventories) (from Bothner et al., 1993).



14. World synthesis of sediment contamination profiles (from Vallette-Silver, 1992) illustrates the increase in heavy metals (such as Pb, Cu, Cd, Ag and Hg), and man-made organic compounds (such as PAHs, PCB, DDT and others) in the environment that has occurred during the last 100 years.

Depth of contaminants in sediments



15. Profiles of metal contaminants in Boston Harbor sediments (from Bothner et al., in prep.). Concentrations of Hg, Cu and Pb are elevated above pre-industrial values (at core bottom). The greater thickness of the contaminated layer in depositional areas reflects a higher sedimentation rate.

such as pollution, on the ecosystem. Establishment of a link between sediment/water quality and degraded ecosystems is the greatest information need from the viewpoint of resource management. There is also a need to establish better cause and effect at all scales (EPA, 1995a; Langton, et al., 1994). A sampling of toxic effects observed in the Gulf of Maine ecosystem follows.

Table 5. Resource use or activity of value (from Buchholtz ten Brink & others, 1994).

Resource Use or Activity of Value

Living resources	***Waste disposal**
(primary concern is about stock replenishment	(need to determine assimilation capacity of the system)
*fish: *bottom feeders & *juvenile stages	*intentional (i.e. sewage and dumping)
*birds: shore & sea	inadvertent
*mollusks	water column
*crustaceans	sediment
*invertebrates	location
phytoplankton	**-Mineral**
zooplankton	sand and gravel
echinoderms	hydrocarbons
eel grass	**Commercial**
marine mammals	*aquaculture
rockweed	land creation
	transportation

** asterisk indicates priority needs for research/ and information - dash indicates low priority*

Table 6. Indicators of toxicity and effects in organisms and populations (from Buchholtz ten Brink & others, 1994) .

Indicators of toxicity and effects in organisms and populations

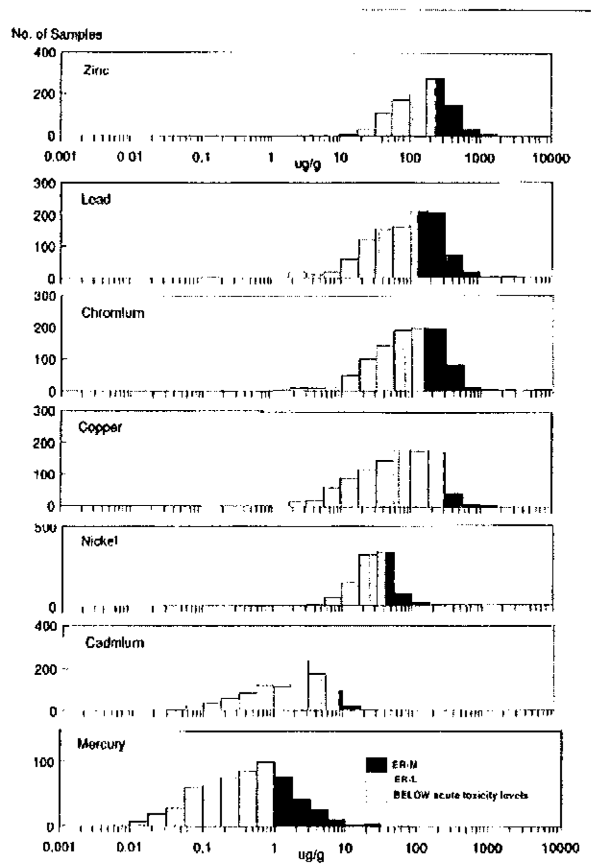
*Disease and/or individual health: sublethal effects and indicators of stress	
Population distribution and population range, changes in.	*Reproduction
*Market quality	Endocrine alteration
Population size	*Mortality
*Community structure	Biodiversity
*Nutrient enrichment / fertilization	Stability (dynamic response)

** asterisk indicates priority needs for research and information, - dash indicates low priority*

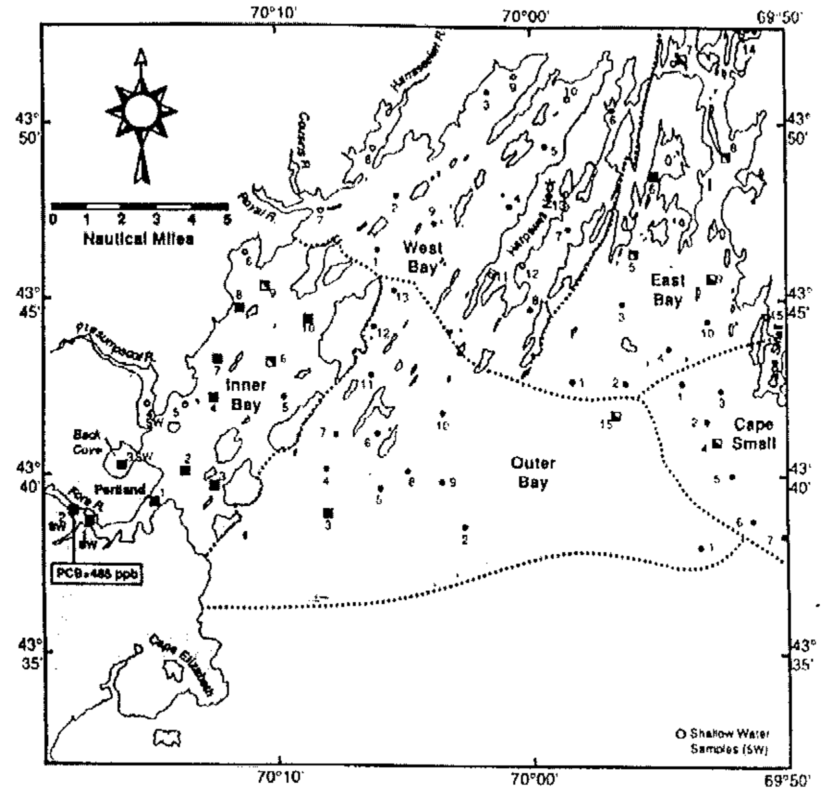
Toxicity is a broad term used to encompass detrimental effects of contaminants on living organisms (e.g., Long & Markel, 1992). Currently, criteria for defining chronic or acute toxicity for sediments or most marine organisms are in a state of development (Long, et al., 1995; MacDonald, et al., 1992, see also EPA 1995a). The Long and Morgan (1990) effects-based toxicity levels for sediments are one approach (applicable to bulk chemical analysis) being used to predict the potential for contaminated sediments to cause deleterious effects (EPA, 1992). Histograms of selected metal concentrations in Boston Harbor (e.g., Fig. 16, Manheim & Hathaway, 1991) show that 1) within a given geographical area, there is up to a three order of magnitude variability in the concentration, and 2) more than half the sediments sampled were likely to cause some toxic effect given the metal contaminant load. It is probable that the cumulative impact of multiple stressors is even greater.

The National Status and Trends (NS&T) program monitors a suite of contaminants in coastal sediments around the nation; however, its stations are too widely spaced (about 300 stations nationwide) to meet the the management needs for most individual waterbodies. The Gulf of Maine region has both some of the highest and the lowest contaminant concentrations in the nation . For example, mercury (Hg) values in benthic surveillance sites nationwide in 1986-1987 (O'Conner & Ehler, 1991) range from .007 to 4.3 µg/g while Gulf of Maine stations in the database (approximately 5000 samples) range from <0.01 to 30 µg/g. Completion of the Contaminated-Sediment Database will provide additional data points and allow better definition of the ranges of concentration found in the Gulf.

Casco Bay, a national estuary located near the city of Portland, Maine, has been extensively sampled and has been shown to have elevated metal and organic contaminants in its sediments (Kennicutt et al., 1993). Stations having the highest 25% of organic and inorganic contaminants (Fig. 17) tend to fall in the inner Bay and East Bay regions, near land-based sources. Unlike Boston Harbor, though, the potential for toxicity is limited to a fairly small area, and few toxicants. Metals are all below concentrations likely to cause toxic effects in test organisms while PCB, DDT



16. Histogram of selected metal concentrations in Boston Harbor sediments (from (Bothner et al., 1994)). Histograms of partially validated metals data show the number of samples and their concentration values. The data are color-coded by toxicity screening levels: ER-L and ER-M refer to "effects range" of low and medium, respectively (Long and Morgan, 1990). Light gray values exhibit no toxic effects. These acute toxicity screening levels were established by determining the lower 10 and 50 percentiles of sample populations for which both bulk chemical concentrations and acute animal toxicity data were available. Toxicity criteria derived by MacDonald (MacDonald, 1993) and by the New England River Basin Commission (EPA, 1995b) have similar values.



17. Location of the 25% highest organic and inorganic concentrations in sediments of Casco Bay (from Kennicutt et al., 1993). The highest concentrations of contaminants occur nearest the urban area around Portland, Me.

and Chlordane are mostly below levels suspected of evoking toxic biological responses. Only sediments in the inner Casco Bay harbor have concentrations of PAHs above the level thought to produce toxic responses, and these may be in forms of coal or soot that have low bioavailability.

Cumulative percentages of contaminants in sediments, mussels, and fish for Gulf of Maine NS&T sites (Fig. 18; Gottholm & Turgeon, 1992) of the Gulf of Maine show that sediments along the northern coast are relatively pristine and that contaminant concentrations increase towards the more urban southern coast. The sediment concentrations tend to reflect nearshore sources; contaminant concentrations in mussels are indicative of the integrated Hg values in the particles and water that passes by the mussels, while the incidence of liver neoplasms in flounder reflect the Hg values in the sediments and food sources of their habitat. As might be expected, the correlation between latitude and contaminant concentrations decreases as the mobility of the indicator species increases. Living resources in the Gulf of Maine are exposed to pollutants at locations which are different from those at which they are harvested or observed.

Another indicator of ecosystem health is the extent of shellfish bed-closures. In the 1980s, the North Atlantic region (ME, NH and MA) experienced the largest decrease nationwide in percentage of approved estuarine shell-fish growing waters: from 88% in 1985 to 69% in 1990 (NOAA-NOS, 1991). During that period, eight of the 15 estuaries in the region were down-graded in classification of shell-fish growing waters, while five were upgraded. Efforts to improve water quality by various municipalities in the Gulf has resulted in some reopenings since 1990. Shellfish closures are most directly attributed to sewage pollution (Table 7), either from sewage treatment plants or septic systems. Proximity to urban nonpoint sources also contributes significantly to adverse effects on shellfish.

Table 7. North Atlantic Pollution Sources Affecting Harvest-Limited acreage, 1990 (from NOAA-NOS, 1991)

North Atlantic Pollution Sources Affecting Harvest-Limited Acreage, 1990

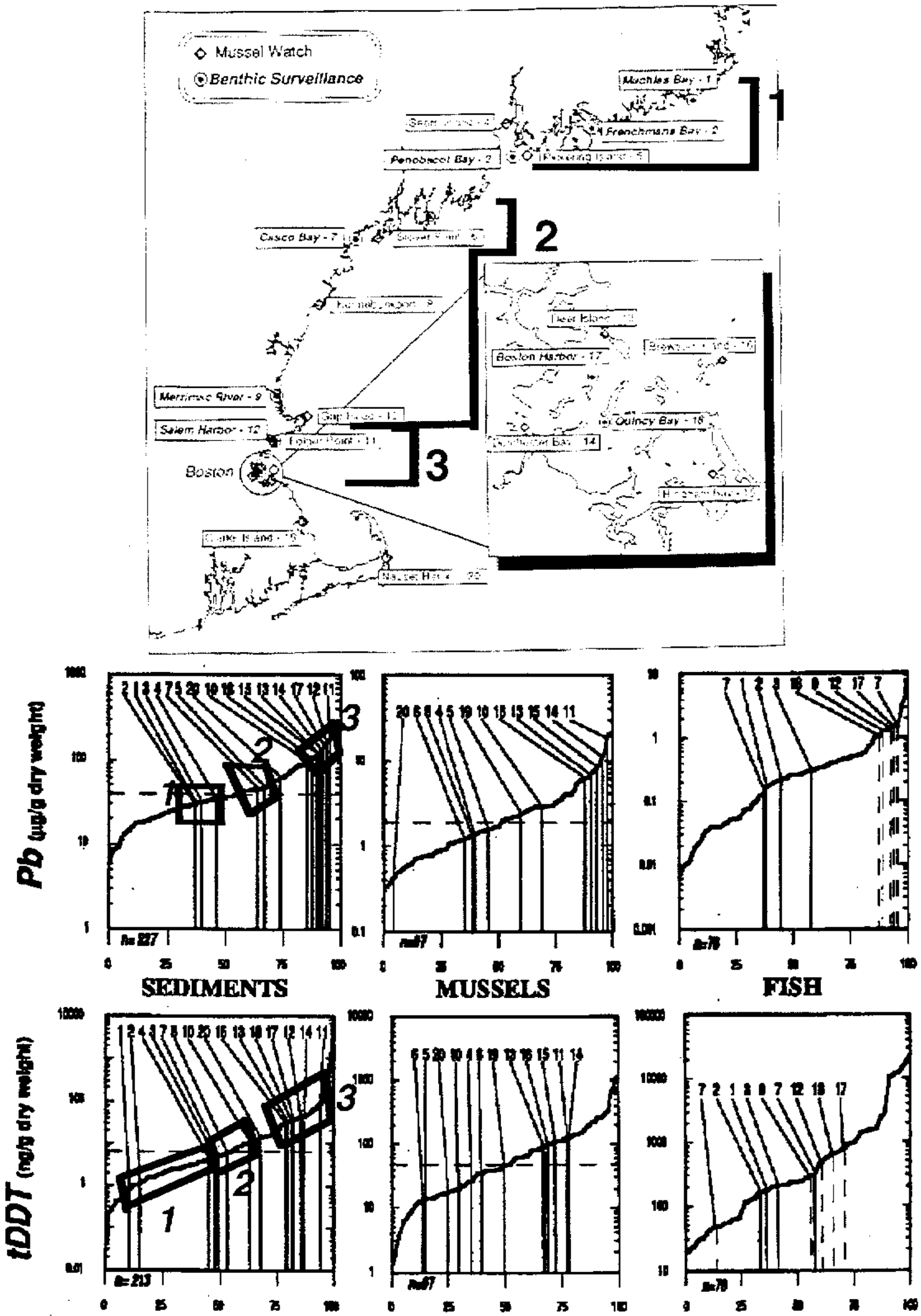
Sources	Maine		New Hampshire		Masschusetts	
	Acres*	%	Acres	%	Acres	%
Point Sources						
Sewage treat plants	115	57	9	100	120	85
Combined sewers	0	0	1	11	21	15
Direct discharge	0	0	0	0	1	1
Industry	11	5	4	44	9	6
Nonpoint Sources						
Septic systems	82	40	2	22	7	5
Urban runoff	24	12	6	67	50	36
Agricultural runoff	0	0	6	67	5	4
Wildlife	0	0	6	67	19	14
Boats	17	8	5	56	38	22
Upstream Sources						
Sewage treat plants	0	0	0	0	2	1
Combined sewers	0	0	0	0	0	0
Urban runoff	0	0	0	0	3	2
Agricultural runoff	0	0	0	0	0	0
Wildlife	0	0	0	0	0	0

*Acres are times 1000; %is percent of all harvest-limited acreage in state

circled are ≥ 40%; underlined are15-40%

From NOAA 1991. National Shellfish Register of Classified Estuarine Waters.

Currently, there are questions about the magnitude and scope of investigations necessary to provide the best understanding and assessment of pollution effects. The health of individual organisms, i.e., presence or absence of toxic effects, is one indicator of ecosystem health. Others (Table 6) are effects on habitats and on ecosystem diversity. There have been reductions in the size



18. . Locations of NS&T Program monitoring sites within the Gulf of Maine and the cumulative % of Pb and tDDT in sediments, mussels, and fish for these sites compared to sites nationwide (modified from (Gottholm & Turgeon, 1992)). Data is grouped by areas of 1) northern Maine, 2) the central coast, and 3) the southern metropolitan area to show that contaminant levels in surface sediments primarily reflect nearby sources and range from relatively pristine (Gulf background for Pb is approximately 30 μg/g) in the north to heavily contaminated in the south. Biota, however, may accumulate contaminants introduced at locations other than those at which they were collected.

of eelgrass beds in Boston Harbor and Great Bay, for example, and increases in the population of opportunistic organisms in impacted areas. There are difficulties setting priorities because a balance is needed between 1) expense, 2) uncertainty, and 3) differing scales of study that are required for different problems. Most indicators of health result from exposure or impacts that occur over a period of time rather than as the consequence of a single event. There are surely effects that are currently unknown because scientists have either not looked for them or not yet linked observations to causal factors. One class of compounds in this category that has received attention lately (Raloff, 1994) are those materials having reproductive and endocrine-disrupting effects. New chemicals that are not tested on marine organisms prior to approval (few are) pose a continuing unknown threat.

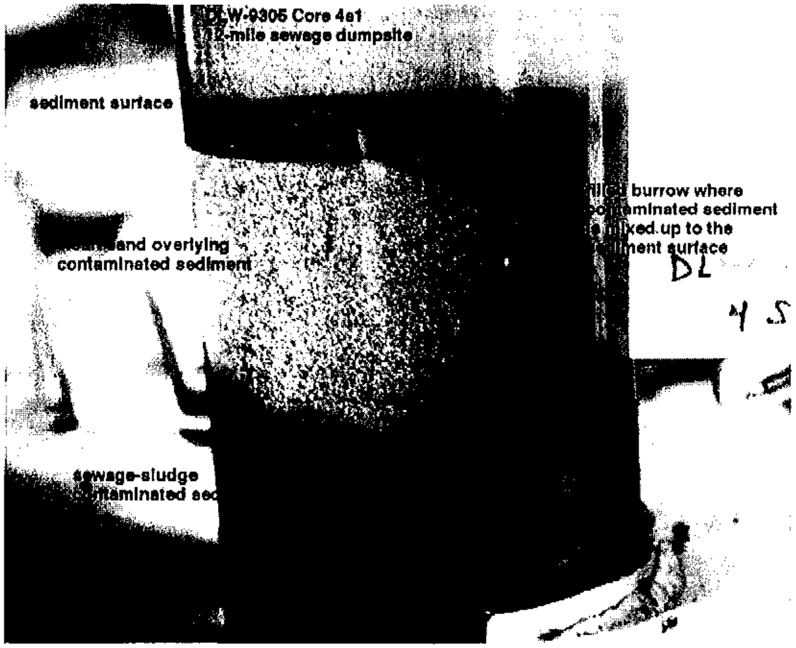
Uncertainty in observations of toxic effects is compounded by changes in the distribution of pollutants that occur in space and time as a result of both human activity and natural processes. Models of current transport, biological utilization, burial, and so forth that are used to predict the fate of various contaminants in the ecosystem have much uncertainty but are beginning to generate projections that are useful for environmental management. The decrease in metal contaminants in Boston Harbor surface sediments is a result of legally and administratively mandated source reduction aided by natural processes of burial and sediment mixing. Surficial reductions in contaminants are observable, but may be slow and spatially heterogeneous, with the consequence that sediments having elevated contaminant concentrations will remain accessible to the biota for considerable periods of time. A core from the historical New York City sewage -sludge disposal site (Fig. 19) illustrates the ability of benthic organisms to disperse anthropogenic deposits. Active burrows and tubes have also been observed to extend to 30 cm in sediments of Massachusetts Bay, where they intersect high metal concentrations from mid-century industrialization. There also are dynamic physical processes that result in water and sediment movements. Currents, storm and tidal wave action cause physical remobilization or focusing of sediments, as shown in a map of the sedimentary environment (Fig 20). Contaminants are more likely to accumulate in areas where fine-grained sediments are deposited. Maps similar to this one have been created for the coast of Maine and New Hampshire (Barnhardt, et al., 1995).

Pollutants may have far-reaching effects on the ecosystem as sources increase or as the passage of time allows for dispersal of contaminants away from the source. The dumping of sludge in the New York Bight Apex from 1923-1987 and its migration down the Hudson Shelf Valley is an extreme case of contaminant mobility . Chemical tracers of sewage input can be identified for tens of kilometers from the primary dumpsite (Fig. 21; Buchholtz ten Brink et al., 1996) when input is sufficiently high--but at what distance can an impact on the ecosystem or resource species be identified and correlated with the contaminants or anthropogenic activities?

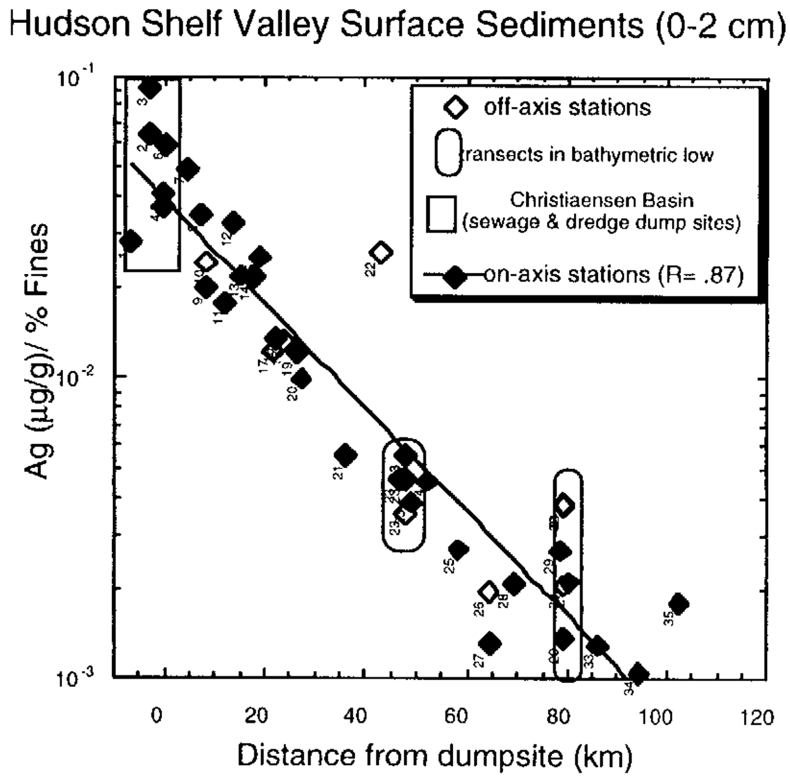
The chemical form of a contaminant in the environment affects its bioutilization (e.g., Farrington, 1991). Individual and population effects depend on factors like chemical speciation, cellular uptake, and routes of metabolism. Source reduction is especially important in the water column where dynamic processes function on a relatively short time scale. State and federal agencies are trying to identify linkages between cause (pollution, contaminants, human activities) and detrimental effects in order to make better predictions of the behavior of the ecosystem; however, there is much that we still don't know. The setting of research priorities in this and other workshops (Table 8; EPA, 1992; RMRP, 1995) helps provide the needed information.

Conclusion

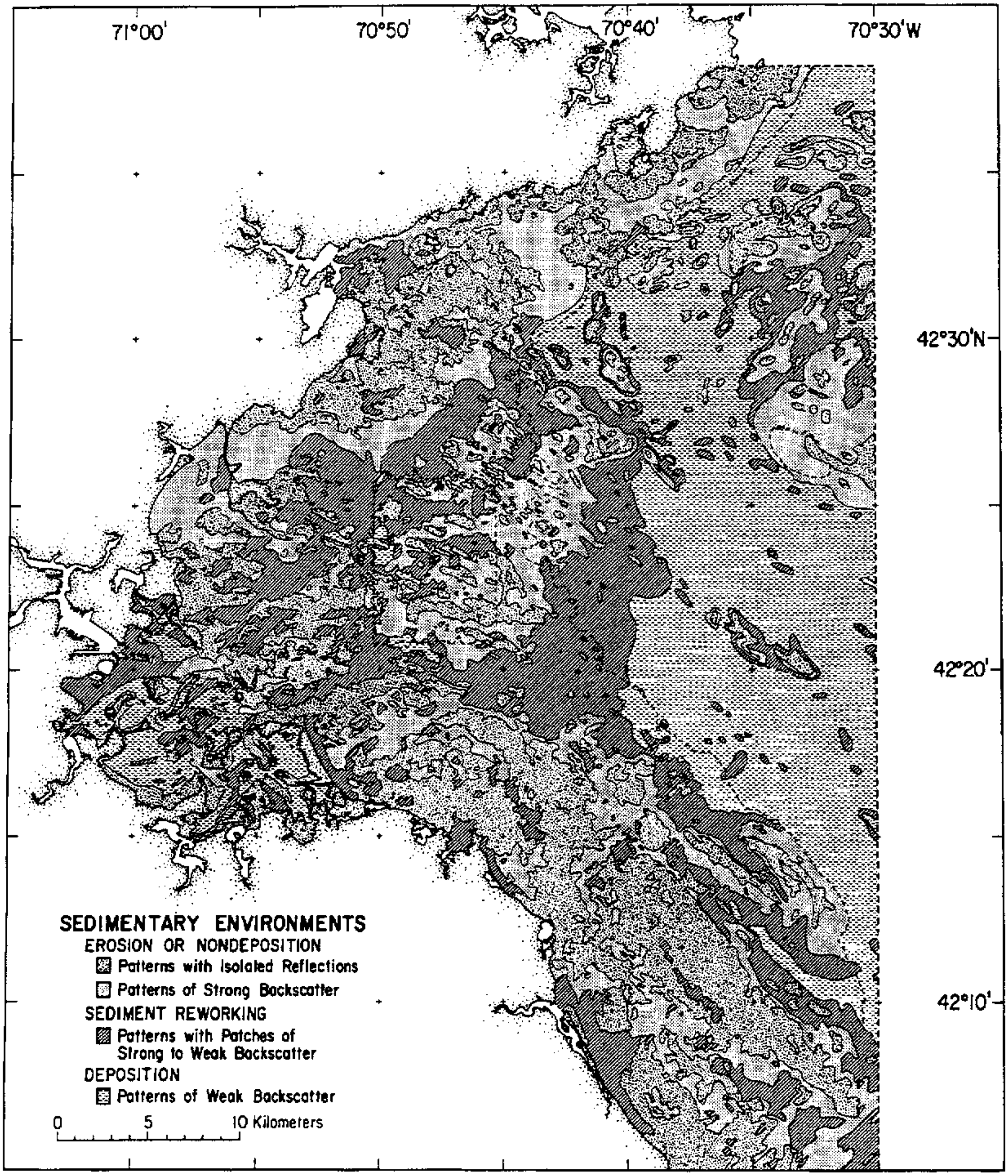
The Gulf of Maine is a heterogeneous and dynamic environment with significant spatial and temporal variations at many scales. In order to identify "pollution", i.e., detrimental effects due to human activity, we must know the baselines and natural variability of both contaminants and indicators of toxicity well enough at all scales to see a signal. In the Gulf of Maine, we have large urban centers that adversely affect the marine ecosystem well offshore through a variety of human activities.. We are also in the fortunate position of still having many relatively pristine marine areas. It is unlikely that we will reach an endpoint of "zero toxic effects" in the ecosystem, and in fact, societal decisions and trade-offs may decree that to do so is undesirable. Achieving a sustainable ecosystem is probably attainable if we apply our best efforts to identify rate-limiting



19. Photograph of a sediment core collected in 1993 at the site where sewage sludge was dumping by New York City until 1988. Benthic organisms (probably a burrowing shrimp here) can access and mix buried contaminated materials with the result that sediment recovery lags behind source reduction (Buchholtz ten Brink et al., 1996).



21.Silver concentrations (a tracer for sewage contamination in the sediments) vs. distance from the dumpsite for stations sampled in 1993 in the Hudson Shelf Valley (offshore from NY and NJ) illustrate the potential for dispersion of contaminants in the marine ecosystem. Sewage-derived material is present in surface sediments up to 80 km away from the primary source (New York sewage sludge dump until 1998) and occurs at higher concentrations below the surface within 26 km. of the dumpsite (from Buchholtz ten Brink et al., 1996).



20. Map showing the distribution of sonograph patterns and sedimentary environments across the Boston Harbor-Massachusetts Bay sedimentary system. Dashed 50-m isobath delineates the offshore limit of the inner shelf in Massachusetts Bay. White areas (shallow inlets) were not surveyed (from Knebel and Circe, 1995). Fine-grained sediments may be winnowed from erosional areas and redeposited in depositional areas; resulting in the focusing of contaminants that are associated with the finer-grained sediments.

processes and key linkages along with identification and implementation of effective public education and regulations. Our task as scientists is to document the present health of the ecosystem and provide sound advice for management practices that will preserve long-term ecosystem viability. Public education and outreach led by scientists will be a required component of this effort.

Table 8. Three primary research goals/tasks identified in the sediment and water quality working group of the Gulf of Maine Habitat Workshop (Buchholtz ten Brink & others, 1994) .

Research Priorities

In setting research priorities, identify the endpoint and keep goals continuously in mind.

Ultimate endpoint is zero toxic effects.

Goals

- most, if not all, waters to be fishable and swimmable
- maintain ecological diversity and multiple human use in the Gulf of Maine.
- maintain healthy ecosystems
- manage the Gulf of Maine in a way that we progress towards pristine ecosystems.
- **The links between potentially toxic contaminant concentrations and biotic effects must be better established.**
- **Transport paths must be studied to determine how contaminants move and become mobilized in the environment, and subsequently accessible to organisms.**
- **The effectiveness and net costs of remediation practices in meeting goals needs to be more clearly established** (and more effective approaches developed if needed).

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Working Group Reports

Anthropogenic Impacts Working Group Report

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Introduction

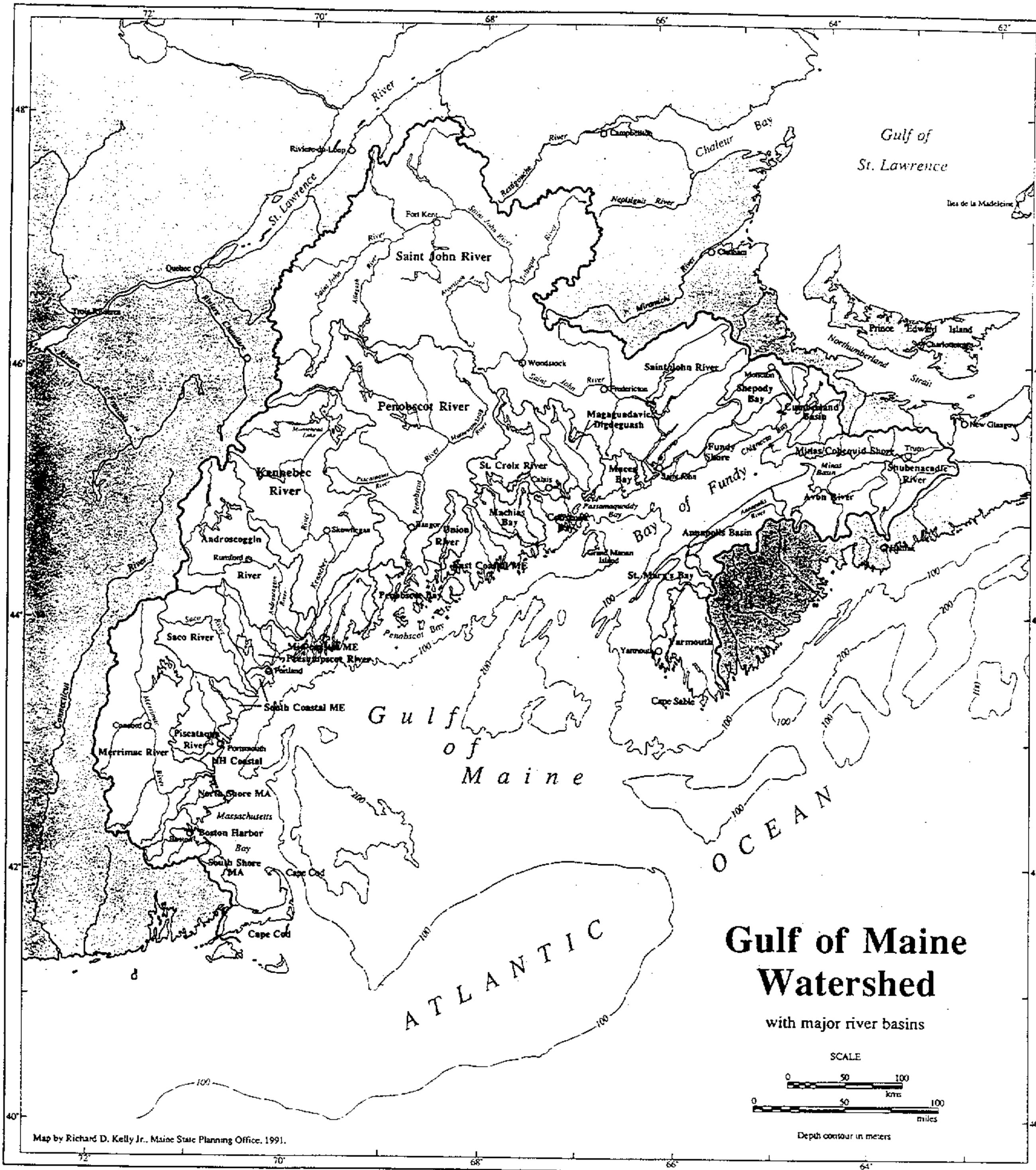
Anthropogenic activities in the Gulf of Maine have resulted in the introduction of chemical contaminants and physical alteration of the ecosystem (Loder and Becker 1989; Gottholm and Turgeon 1992; Dionne 1994; Gordon 1994; O'Reilly 1994; Pederson 1994). The working group elected to consider anthropogenic impacts within the context of several subsystems within the Gulf of Maine system. Subsystems were identified to reflect distinct differences in the magnitude and type of anthropogenic stresses exerted on each. The subsystems identified were: 1) watersheds and their associated estuaries, 2) the near shore coastal zone, 3) and the open Gulf. All of these subsystems receive contaminants and are impacted by physical alteration resulting in the loss of habitat and the degradation of resources (Figure 1).

A series of watersheds which drain into their associated estuaries comprise the overall Gulf of Maine watershed (Figure 1). Point and non-point introductions of contaminants into a watershed reflect land-use patterns in the watershed. Ultimately some fraction of those contaminants is conveyed to estuaries. In addition to the introduction of chemical contaminants, a variety of human activities have also physically altered habitats. Within the Gulf of Maine the degree of anthropogenic impact on watersheds and their estuaries ranges from relatively pristine to heavily impacted and largely reflects the population densities within the particular watershed.

A portion of the chemical contaminants entering estuaries are removed within the estuaries. The remainder is introduced into the near shore coastal zone primarily through tidal flushing, but also may be mediated by migration of organisms offshore. The near shore coastal zone is defined here by physical circulation patterns within the Gulf of Maine. The coastal current transports contaminants, exported from the estuaries or discharged directly into the near shore zone, into the offshore regions of the Gulf of Maine. The large water volume of the offshore regions dilutes contaminant inputs, reducing their impact. Atmospheric deposition may represent the most important source of contaminants to the offshore regions of the Gulf.

Future increases in population density and changes in land use practices are predicted to increase anthropogenic impacts in the Gulf of Maine. There is an urgent need to prevent further degradation of the relatively pristine regions of the Gulf, and restore those which are impacted. A first step toward this goal is to systematically assess the sensitivity of these relatively unimpacted subsystems to further anthropogenic impacts. The "sensitivity " of these subsystems is a function of the nature of the ecosystem dynamics within the system, the physical characteristics of the system, and the particular array of stressors unique to the system. Rigorous definition of ecosystem function is in many cases quite difficult and requires some degree of individual assessment. In many cases such assessments may be impractical.

The working group adopts the basic tenet that where uncertainties in such assessments are large, conservative management practices should be adopted. This however may compromise wise socioeconomic use of resources. Optimal "use" of these systems will require a firm understanding of the sensitivity of each to the cumulative effects of stressors, both natural and anthropogenic, acting on them. Preservation of the quality of these systems will require the concerted and integrated efforts of scientists, citizens and resource users. It will require carefully planned and coordinated research, monitoring, educational and management efforts to succeed.



The Gulf of Maine Watershed map was created by the
Gulf of Maine Council on the Marine Environment Public Education and Participation Committee
and produced by Richard Kelly Jr.

Priority Anthropogenic Impacts

The Working Group was given the following terms of reference: 1. identify the major anthropogenic impacts to the Gulf of Maine Ecosystem; 2. recommend priority research and management options to address these impacts. It was decided that although issues such as over fishing constituted anthropogenic impacts, these would be covered principally by the Fisheries Harvesting working group. However, this group did consider how fisheries harvesting may impact trophic relationships and how fishing may act synergistically with other anthropogenic impacts such as contaminants to effect the health of the ecosystem.

The following were identified as the major, non-fisheries harvesting anthropogenic stressors to the ecosystem (in no order):

Nutrient over enrichment
Introduction of toxic compounds
- metals
- toxic organics

Physical habitat disruption and degradation
- freshwater diversion
- tidal restriction
- dredging

Alteration of natural processes
- changes in ecological structure due to harvesting
- impacts to benthic structure

Aquaculture
Toxic/nuisance algal blooms

Working group participants developed background information on these major issues. A standardized format was adopted to facilitate integration of the information. The following section provides this information for each of the major issues. Each section was drafted by individuals in the working group with expertise on the particular issue.

Nutrient over enrichment

Statement of Problem

Many estuaries and coastal marine ecosystems are receiving increased nutrient inputs (nitrogen, phosphorus, and organic matter) from a variety of anthropogenic sources located throughout their watersheds (Smith et al. 1987; Larsson et al. 1985; Hinga et al. 1991; Boynton et al. 1995) . These sources include, inter alia, non-point inputs from agricultural, forest and urban runoff, and atmospheric deposition, and point source inputs from wastewater treatment plants and industry (NOAA/EPA 1989). A portion of nutrients originating from various land use activities in the watershed are transported to estuaries by rivers, or are discharged directly into estuarine and coastal waters. These increased nutrient inputs lead to eutrophication of the estuarine and coastal waters (National Research Council 1993). Eutrophication is defined here as an increase in the rate of supply of organic matter to an ecosystem (Nixon 1995). In addition to increases in organic matter production by phytoplankton and macroalgae, increased nutrient inputs can directly or indirectly result in a variety of environmental problems including decreases in seagrass beds which are important habitats for some finfish and shellfish, changes in species composition and abundance, and depletion of dissolved oxygen, among others (Boynton et al. 1995). However, quantitative relationships between nutrient loadings and degradation of estuarine ecosystems are poorly understood (Kemp et al. 1983).

Status of Knowledge

Natural inputs of nutrients to the Gulf of Maine as a whole are dominated by ocean inputs through the Northeast Channel (Schlitz and Cohen 1984; Townsend 1992; Christensen et al.

1992). Nitrogen is the primary limiting nutrient for phytoplankton production in many marine and estuarine waters. Nitrogen inputs from the Northeast Channel and Scotian shelf have been estimated at approximately 2 million MT/y (Schlitz and Cohen 1984) compared to terrestrial and atmospheric inputs (both natural and anthropogenic) of approximately 0.1 to 0.2 million MT/y (Schlitz and Cohen 1984; Loder and Becker 1989). While open waters receive the majority of the nutrients, they are dispersed over a large region. Thus, the nutrient inputs per unit area to the open waters are low. There are no documented eutrophication problems in the open waters of the Gulf of Maine (Loder and Becker 1989; O'Reilly 1994).

Nutrient problems are most likely to exist in estuarine and coastal embayments, where nutrients originating from non-point and point sources throughout the watershed first enter the marine environment, either through river transport or direct discharge (Loder and Becker 1989). The geographical distribution of anthropogenic nutrient inputs to Gulf of Maine estuaries circa 1982 was estimated in a report from the NOAA/EPA Team on Near Coastal Waters (1988). Data presented in that report suggest that: 1) nitrogen and phosphorus inputs generally increase as population increases, 2) both non-point and point sources of N tend to decrease in a gradient away from the highly populated metropolitan Boston area, and 3) non-point N sources are generally dominated by urban and agricultural runoff, and waste water treatment plants generally dominate point sources. More recent data are currently being synthesized to calculate nutrient and organic carbon loadings from Gulf of Maine watersheds (Jaworski, in prep.). Preliminary interpretation by Jaworski (in prep.) suggests that: 1) nutrient loadings decrease in a gradient away from the metropolitan Boston area; 2) anthropogenic nutrient inputs to a number of Gulf of Maine estuaries are relatively low compared to many other east coast systems; and 3) a considerable amount of the nutrient loading originates from sewage and is discharged into the tidal portions of the rivers.

While nutrient loadings to many Gulf of Maine estuaries can be estimated based on existing data, the effect of these loadings on particular estuaries within the Gulf of Maine is not known. This is due to a lack of environmental data and to the lack of a predictive relationship between nutrient loading and environmental degradation in Gulf of Maine estuaries. Few data exist on nutrient concentrations, nutrient recycling from planktonic or benthic communities, algal densities, or changes in the population structure of Gulf of Maine estuaries and near shore areas. Episodic low dissolved oxygen has been reported in Boston Bay/Charles River and some freshwater portions of the Merrimack River (Whitledge 1985). However, only now are systematic dissolved oxygen surveys of estuarine and near shore waters being undertaken in the Gulf of Maine, and these are of very limited scope.

There is a need for a predictive understanding of the relationship between nutrient loading and eutrophication in Gulf of Maine estuaries. This relationship likely depends on a number of factors, including flushing time, physical circulation patterns, temperature, and biological structure, among others. A preliminary assessment of pollution susceptibility for some Gulf of Maine estuaries has been developed (NOAA/EPA 1988). However, development of a more rigorous approach relating nutrient loading to environmental changes is critical to the development of future nutrient control strategies and effective land use management practices. As predicted for many other estuaries nationwide (Nixon 1990), nutrient inputs to the Gulf of Maine are predicted to increase due to continued population growth along coastal margins. Other stressors (e.g., toxic contaminants, physical alteration), in addition to nutrient loadings, likely compound the effects of eutrophication, and must be understood, as well.

Research Recommendations

- Design and implement a comprehensive monitoring program for estuarine and near shore coastal waters to identify and track the magnitude and location of eutrophication and environmental problems associated with nutrient over enrichment.

- Develop a comprehensive understanding of the relationship between nutrient loading and environment degradation in Gulf of Maine estuaries.

- Identify estuaries most sensitive to increased nutrient inputs.

- Develop a comprehensive understanding of the effect of multiple stressors on the health of Gulf of Maine ecosystems.

Management recommendations

- Determine changes in nutrient inputs to estuaries based on future predicted changes in land use throughout Gulf of Maine watersheds.
- Develop a data base management system for synthesis and integration of data and synthesis of information for making decisions about nutrient control strategies and regulations.
- Develop effective nutrient control strategies to minimize future increases in nutrient loading to the near shore waters of the Gulf of Maine.

Introduction of toxic compounds

Statement of problem

A suite of anthropogenically-derived organic and inorganic compounds have been inadvertently or intentionally released to the marine environment where they can, if above certain threshold concentrations, have deleterious effects on the viability of component species of the ecosystem. These contaminants include metals (Hg, Pb, Cd, etc.), organo-metals (methyl mercury, butyltins), and organo-chlorines (OC) (polychlorinated biphenyls, chlorinated hydrocarbons pesticides, and polyaromatic hydrocarbons [PAHs] including dioxins), among others. The major sources of some trace metals (e.g Hg) and dioxin-like compounds are incinerators and coal burning plants. PAHs and other by-products of fossil fuel combustion have many sources including automobile exhaust, power plants, home heating, and oil spills (Pederson 1994). Major sources of copper and trace metals are effluent and waste streams (Peterson 1994). Many of these contaminants become particle associated in the environment, and as such become concentrated in fine grained sediments. There is a considerable amount of data documenting the concentration of various toxic compounds in the environment and in biota. However, there is a great deal of uncertainty in relating environmental concentrations to biotic effects at the organismal or ecosystem level (Pederson 1994; McElroy et al. 1994).

Status of knowledge

There is a considerable amount of information on contaminant loadings to various regions in the Gulf of Maine, and concentrations of certain groups of contaminants in the sediments and sentinel or indicator species of the Gulf of Maine (Pederson 1994). A chief controllable source of metals and of many organic toxicants is sludge from domestic sewage. Heavy metals, OCs and PAHs have been monitored in sediment, mussels, fish (livers), marine mammals (blubber) and birds (eggs) from the Gulf of Maine by various agencies and individuals (e.g., Pederson 1994; Gottholm and Turgeon 1992; O'Connor and Beliaeff 199x; Schwartz et al. 1991 and 1993). Metal concentrations in Gulf of Maine estuarine sediments and mussel tissues show considerable spatial variability. However, concentrations generally decrease in a gradient away from Boston Harbor. Highest metal concentrations occur at sites in Boston Harbor, Salem Harbor and Folger Point (Gottholm and Turgeon 1992). Concentrations of Cd and Cr in Salem Harbor were some of the highest reported nationally for National Status &Trends sites (Gottholm and Turgeon 1992).

Cupric ion concentrations were found to be at potentially toxic levels in Boston Harbor surface waters (Sunda and Huntsman 1989 cited in Gottholm and Turgeon 1992). Metal concentrations in mussel tissue from the more polluted waters near Boston have been observed to approach levels considered to be unsafe for human consumption. These levels, however, are not believed to be deleterious to the health of the mussels themselves. As with metals, highest organic contaminant concentrations in sediments and biota occur in the Boston Harbor area (Gottholm and Turgeon 1992). There is indication that concentrations of various organic contaminants are decreasing at several sites throughout the nearshore Gulf of Maine (O'Connor and Beliaeff 199x). PCB concentrations are higher in livers of spawned fish from Boston Harbor sites and spawned eggs were smaller from Boston Harbor winter founder relative to those from Long Island Sound (NMFS 1990).

The concentration of both inorganic and organic contaminants is generally highest in estuarine and near shore areas, given that their sources are from anthropogenic activities in the watersheds. However, organo-chlorines emitted from a particular location can be widely distributed because they are transported by atmospheric processes and because they bioaccumulate in the food chain. For example, organo-chlorines bioaccumulate in the marine food web such that whales are known to contain 100x that found in fish whereas fish in turn contain 1000x that in plankton and plankton contain 1000x that in seawater. However, local hot spots have been identified in sediments and mussels in waters neighboring human population centers. Legislation restricting organochlorine use in the late 1960s (eg DDT) and 1970s (PCBs) has resulted in marked reductions in contaminant levels found in Harbor porpoise.

New contaminants of environmental concern are continually being identified. For example, in the last decade the presence of highly toxic dioxin has been documented in pulp mill effluents. Potential problems associated with environmental estrogens is a growing area of concern. The effects of these contaminants on the ecosystem are generally poorly understood. There is a need to continue to identify, evaluate and quantify newly identified or introduced toxic compounds.

As indicated above, the concentrations of various inorganic and organic contaminants in sediments and some biota of nearshore regions of the Gulf of Maine are reasonably well documented. There is also a considerable amount of information on the acute toxic effects of contaminants on various organisms. However, there is an urgent need to understand the long-term and chronic effects of each category of contaminant on both mobile and sentinel species, and at the organismal and ecosystem scale. This knowledge must be expanded to include the cumulative effects of multiple contaminants and stressors (e.g. physical habitat alteration, eutrophication) on key species and at the ecosystem level.

Research Recommendations:

- Determine the long-term and chronic effects of each category of contaminant on sentinel species.
- Determine the long-term and chronic effects of each category of contaminant at the ecosystem level.
- Investigate the cumulative effects of multiple contaminants on key species.
- Identify, evaluate and quantify newly developed toxic compounds.

Management Recommendations

- Establish and maintain a monitoring system of known contaminants.
- Periodically upgrade monitoring system to include new contaminants of concern.

- Increase the efficiency of sludge removal in domestic sewage, thereby reducing the chief controllable source of metals and many organic toxicants to the Gulf of Maine.
- Reduce contaminant release by industry to the atmosphere and hydrosphere (requires new legislation).

Alteration of Nearshore Hydrology and Habitats

Statement of the problem

A large percentage of the human population in Maine, New Hampshire and Massachusetts is located within the watersheds of the Gulf of Maine estuaries. Human activities have influenced estuarine ecology through changes in hydrology and physical habitat alteration. Hydrologic changes in watersheds and estuaries include: diversion of freshwater for municipal and agricultural purposes; damming of freshwater flow for energy and flood control; restriction of tidal flows via roads, causeways and fill; and changes in quantity and quality of surface water runoff from shoreline development. Physical alteration of habitats is primarily related to dredging activities and erosion of sand barriers resulting from hard stabilization (eg., sea walls and jetties).

Hydrologic modifications lead to loss of estuarine habitat via changes in discharge, salinity regime and sediment transport. For example, wading bird feeding habitat in the Bay of Fundy has been reduced through freshwater diversion. The delivery of freshwater, sediments and contaminants is increased by shoreline development. Eelgrass habitats become more susceptible to wasting disease with reduced freshwater inputs. Salt marshes degrade and subside due to partial or total restriction of tidal flow. Structures that modify hydrology also impede fish passage and have lead to a near complete demise of anadromous fish populations. Also, dredging and hard stabilization alters flow patterns and sediment distribution and transport, directly affecting soft sediment habitats and contributing to erosion of barrier beaches and salt marshes.

Status of Knowledge

Habitat refers to the biological, chemical, and physical/geological characteristics required by a species to survive and thrive in the aquatic environment. In nearshore wetland, subtidal seagrass, beaches, mudflat, hard substrate intertidal/subtidal regions, and soft sediment subtidal systems, the physical/geological nature of the environment plays a crucial role in determining habitat features. In open water environments the chemical and physical characteristics of water masses determine the temporally variable nature of the habitat features. Superimposed upon these habitat features are biological interactions, such as competition and predation, that help determine the success of a species in time and space. Habitat alteration can be due either to habitat loss (quantitative) or habitat degradation (qualitative). For many species in the Gulf of Maine, critical life history requirements are poorly known, so that their essential habitat requirements cannot be specified. However, it is clear that in other coastal wetland regions, such as the Chesapeake Bay, habitat alteration has led to dramatic declines in many species that support important fisheries.

In many instances, the seasonal distribution of a species is used to infer its habitat characteristics. This approach ignores the fact that for many intertidal organisms physical factors define the upper limits of an organism's distribution, while biological factors often determine the lower limits of distribution. Biological competition and physical stress from desiccation/salinity/temperature can interact, forcing an organism to occupy a distribution that is non-optimum for that species. Even though the emphasis in this discussion is on the forcing functions of hydrologic alteration, habitat loss/change, and habitat degradation, it should be borne in mind that there is a biological component to these interactions that may be critical. The critical qualitative characteristics that cause an organism to choose an occupy a given habitat are poorly understood and require adequate knowledge of the species' natural history characteristics.

Hydrological alteration can include the impacts of potential sea level rise; changes in flow patterns due to channelization, construction of seawalls and jetties, or dredging activities; altered drainage patterns in coastal wetlands; or secondary impacts resulting form sediment erosion/deposition. The altered hydrology not only causes a direct physical impact, but it can change the transport of pelagic larvae of marine species and later sediments that support wetland plant species. For example, inundation of wetland areas can cause water logging in the soils and the buildup of hydrogen sulfide, toxic to many plants. Loss of barrier beaches can result in erosion of the soil that supports many wetland plants. As sea level has risen many barrier beach/wetland complexes are already retreating landward, where they encounter the fixed barrier of human development which restricts their migration, while at the same time removing the buffers that protected the human habitations from flooding and storm events. Human build-out in coastal areas has also provided impetus for the construction of seawalls, jetties, rip/rap construction on coastal dunes, and other physical structures. Those structures have altered the flow of water with its accompanying effects on sediment erosion/deposition critical to maintaining coastal habitats in the face of sea level rise.

Human construction activities have greatly changed the pattern of sediment input to the marine environment with its accompanying load of non-point contaminants (especially nutrients). Many benthic animal populations are restricted to given types of sediments and increased or decreased sediment input can change the essential habitat features for these species. For example, juvenile lobsters occupy burrows under rock and rubble regions at the subtidal/intertidal interface, with these habitats being lost if excessive sedimentation occurs. Many benthic species are also important elements in the diets of finfish species. Sediment input reduces the oxygen available in the water column that is used by animals to ventilate and respire.

Anthropogenic activities in the near shore coastal waters and estuaries in the Gulf of Maine are the major stressors resulting in habitat alteration. These anthropogenic activities include: urbanization, aquaculture operations, impacts on the benthos from mobile fishing gear, drainage of wetlands, armoring of the coast to protect human habitation, construction of dams in coastal rivers, and gravel mining/oil and gas development. Because many Gulf of Maine fish species depend on estuarine habitats during some portion of their life cycle, these activities have a considerable potential to influence coastal fisheries. However, the basic data necessary to adequately characterize the anthropogenic stressors in space and time, and to delineate their individual and cumulative contributions to habitat alteration, are lacking.

<u>Research recommendations</u>

- On a Gulf wide basis assess habitat loss and degradation due to hydrologic alteration.
- Develop criteria for habitat restoration through hydrologic restoration at select sites.
- Design shoreline buffer zones to reduce the quantity and improve the quality of surface water runoff.

<u>Management recommendations</u>

- Restore hydrological regimes at select sites to restore ecosystem structure and function.
- Reduce contaminant inputs from non-point sources through the use of shoreline buffer zones.

Alteration of Natural Processes

<u>Statement of the problem</u>

There are real and observed changes in the ecological structure and productivity within the Gulf of Maine ecosystem (especially at higher trophic levels). For example, at higher tropic levels, species compositions have changed dramatically, while the total biomass has remained relatively constant. The implications of this are likely to be cascading trophic effects that alter species abundance, distribution and species interactions at all trophic levels. Most importantly, we do not know the long term impacts on the functions of the ecosystem as a whole, nor do we know whether any of these impacts are reversible within human time scales. Because we do not fully understand the trophic relationships, we can not fully predict the results of various management options.

Status of knowledge:

It is clear that species distribution and abundance has been affected by fish harvesting and management practices and policies. However, the relationship between the severe shifts taking place at higher tropic levels with other trophic levels is not clearly understood. The resilience of the system is unknown at both local and Gulf-wide scales. Therefore, we do not know whether these shifts are reversible (with human intervention). We also do not know the cumulative impacts of multiple stressors in a complex biological and physical system.

Research Recommendations:

- Develop a clear understanding of the resilience of the ecosystem. This will depend upon an understanding of trophic dynamics (interactions), biological community structure and "keystone" trophic relationships.
- Test novel approaches to interdisciplinary research.
- Establish a system-wide, hypothesis-driven monitoring initiative.

Management Recommendations:

- Clearly state assumptions about resilience of the ecosystem (i.e. its ability to return to former/ natural character) before developing management options.
- Employ adaptive management approaches wherever possible (ie., management approaches should be employed under a test basis).

Aquaculture

Statement of problem

The aquaculture industry, if improperly managed, can have several adverse effects on the ecological integrity of a marine system (e.g., Hastings and Heinle 1995; deFur and Rader 1995; Hopkins et al. 1995). Such impacts include:

- Genetic interactions between cultured and wild stocks through escapement.
- Spread of disease from cultured to wild fisheries.
- Benthic impacts from excess food accumulation, drug (antibiotics, therapeautants) application, and fecal matter.
- Water column impacts from antifouling paints (TBT), ammonia, etc.
- Introduction of exotic species.
- Exacerbated environmental degradation through inappropriate siting of aquaculture facilities.

- Aquaculture facilities provide artificial food sources for pinnipeds and sea birds, thus altering the food web and raising public policy issues relating to the "ethical" treatment of wildlife.

- Multiple user conflicts including marine mammal entanglement, conflicts with the wild fishery, aesthetic issues, land-use conflicts and recreational users.

Status of Knowledge

This problem is fairly well understood. We can learn from countries with advanced and intensive aquaculture such as Norway, United Kingdom, Ireland, Canada, and Chile, and other states such as Washington. There are few data on finfish aquaculture site degradation in Maine or New Brunswick. It appears that due to adequate regulation, good site selection and good husbandry, few adverse effects have resulted (or been identified) to date.

Research Recommendations:

- Increased research leading toward FDA approval of a wider range of drug treatments needed by aquaculture industry to control disease and parasitism.

- Develop effective, but ecologically benign, predator exclusion devices.

- Identify natural biological controls of fish disease to obviate the need for chemical treatments.

- Develop aquaculture facility designs which would minimize potential of whale/marine mammal/sea bird entanglement.

Management Recommendations

- Develop generic environmental impact statements (EIS) for finfish net pen aquaculture facilities, to objectively review general impacts of finfish facilities.

- Establish standards for facility design and operation which avoid site degradation, disease and escapement.

- Adopt Gulf -wide exotic species protocol detailing species both approved and not approved for culturing.

- Consider re-evaluation of the "take" provisions of the ESA and Marine Mammal Protection Act in light of increasing conflicts between seals and aquaculture facilities and increases in seal populations.

- Develop aquaculture education and outreach programs directed at improving public understanding and perceptions of aquaculture.

Toxic/Nuisance Algal Blooms

Statement of the Problem

High densities (blooms) of certain phytoplankton species commonly occur in the marine environment. Some bloom species produce toxins (e.g., PSP and domoic acid) that can be accumulated in higher trophic level species, particularly filter-feeding shellfish. While the toxins have relatively little effect on shellfish, ingestion of the shellfish can cause illness or death in vertebrates, including humans and marine mammals. For example, Paralytic Shellfish Poisoning (PSP), caused by eating shellfish containing neurotoxins from the dinoflagellate Alexandrium tamarense, has resulted in over two dozen human deaths and illness in hundreds more in eastern Canada and New England (White 1992). Mass kills of Atlantic herring, menhaden, and sand lance have also been attributed to PSP (White 1992). Other examples of shellfish poisoning due to toxic algae include Diarrhetic Shellfish Poisoning (DSP) and Amnesiac Shellfish Poisoning (ASP). To avoid human health problems shellfish beds are often closed, resulting in the loss of harvestable resources. The conditions or causes triggering bloom events are poorly understood, although anthropogenic nutrient enrichment and hydrography are believed to be possible contributing factors. While toxic events are known to have occurred throughout recorded history, their frequency has increased in recent decades.

Status of Knowledge

Toxic phytoplankton blooms occur primarily in the estuarine and coastal waters throughout the Gulf of Maine, but have influenced the offshore areas including Georges Bank. The plankton species responsible for the toxic and nuisance blooms are known. A bloom of the red tide dinoflagellate Alexandrium tamarense resulted in the closing of shellfish beds for the first time in 1989 on Georges Bank (White 1992). While this organism has been present in the Gulf of Maine for at least the past 30 years, its abundance has increased recently. Since 1989 red tide blooms have resulted in the closing of shellfish beds frequently in the Gulf of Maine. A combination of factors likely contribute to the development and distribution of the blooms. There is evidence that the waters near and around Casco Bay, Maine, may provide seed populations that become transported southward along the coast by wind driven coastal currents (Anderson and Keafer 1992; Anderson et al. 1995). In the fall of 1988 a bloom of the dinoflagellate Gyrodinium aureolum was associated with high mortalities of shellfish and benthic worms in Maquoit Bay near Brunswick, Maine (Heinig and Campbell 1992). This was the first known occurrence of a G. aureolum bloom resulting in shellfish kills in U.S. waters. The shellfish mortality was attributed to low oxygen concentrations and mucous and toxin production associated with this bloom (Heinig and Campbell 1992). Diarrhetic Shellfish Poisoning (DSP) and Amnesiac Shellfish Poisoning (ASP) have been reported in coastal waters near the Gulf of Maine, indicating a potential future threat to the Gulf of Maine (White 1992).

Research Recommendations

- Identify the physical, chemical and biological factors that initiate, sustain, and lead to the cessation of toxic algal bloom events

Management Recommendations

- Continue dockside monitoring of shellfish resources to protect human health and to insure product safety.
- Use future research results that identify the factors triggering blooms to develop appropriate management practices to decrease bloom occurrence

Research and Management Priorities

Priorities for research and management in the Gulf of Maine Ecosystem vary widely depending on depth and proximity to the coast. Therefore, this report focuses these recommendations on four categories: overall, estuarine, coastal, and open water. (in no order of priority)

A. Overall

Research

- Develop a clearer understanding of ecosystem resilience in the Gulf of Maine in order to direct management efforts - can the ecosystem return to its former state after significant perturbation?
- Identify sources, transport mechanisms, fates and effects of nutrients and toxic contaminants

- Increase research focus on ecosystem response, trophic interactions and dynamics, community structure and keystone species.
- Investigate the effects of multiple stressors on Gulf of Maine ecosystems
- Identify and implement novel approaches to interdisciplinary research.

Management
- Develop watershed-based management approaches.
- Recognize and account for linkages between near shore and offshore populations and habitats when making management decisions.
- Implement novel approaches to interdisciplinary management, and use adaptive management principles.

B. Estuaries and Coastal Embayments Subsystem

Research
- Assess Gulf-wide habitat loss and degradation due to hydrological alterations.
- Identify opportunities for habitat restoration that benefit living marine resources.
- Integrate knowledge of physical processes, ecology and nutrient and toxic contaminant sources and other stresses to understand the relative susceptibility of various estuaries and embayments.
- Increase efforts to understand contaminant effects on living marine resources.
- Investigate the effects of changing land cover on living marine resources.
- Document changes in coastal watershed, land cover, habitat, and land use.
- Develop a better understanding of the role estuaries play as buffers and filters.
- Determine linkages between inshore and offshore systems.

Management
- Assess and mitigate impacts of increasing urbanization on marine resources.
- Manage aquaculture carefully to avoid the numerous potential impacts.
- Reduce nutrient, metal and organic pollution loads to the system through better land-use management, careful control of urban non-point sources, and reduction of aerosol nitrate depositions.

C. Coastal Current Subsystem

Research
- The cumulative impact of stressors that effect downstream ecosystems (along-shore) must be better understood.

- Aquaculture research needs: - research on FDA-approved disease control methods - develop effective but ecologically benign predator control methods - determine impacts of aquaculture on surrounding ecosystem

- Continue support for a Gulf-wide data base.

- The factors triggering toxic blooms are unknown.

- Transports in the coastal current should be better understood.

- The effects of benthic habitat alteration on marine populations should be better understood.

D. Open Water Subsystem

Research

- The impacts of mobile fishing gear on target species and their food webs must be better understood if fisheries ecosystem management is to be implemented.

- The effect of disturbance on benthic systems (ie. turnover events/yr) is unknown and should be studied.

Summary

Non-fishing anthropogenic impacts to the Gulf of Maine ecosystem are still relatively minor compared to many coastal ecosystems worldwide. Problems such as eutrophication, introduction of contaminants and physical habitat alteration are limited primarily to estuaries and harbors. However, as populations increase and coastal impacts intensify, the potential to impact the Gulf of Maine ecosystem as a whole increases significantly. Also, not only do individual impacts intensify, but the potential for interactions between stressors increases in ways that are difficult to predict.

There is yet an opportunity in the Gulf of Maine to avoid the problems encountered in other regions as the coastal population increases, but enhanced research and management efforts are required. One key to these efforts is better coordination among disciplines, institutions, jurisdictions, and agencies as well as international cooperation.

Another key to protecting the health of the Gulf of Maine is the application of precautionary management approaches. Workshop participants stressed that in situations where uncertainties are large, conservative management practices should be adopted even though these may reduce short-term economic benefits. Given the lack of information on individual stressors in the Gulf of Maine, and the absence of information on cumulative impacts, such a precautionary approach is necessary.

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Fisheries Harvesting Working Group Report

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Abstract

The Working Group on Fishery Harvesting in the Gulf of Maine included 15 participants, representing government and academic scientists, fishers, and technical staff of various regulatory bodies. Participants 'brain stormed' a list of 65 issues, which , to varying degrees, influence fishery production (Appendix 1). These issues are broadly classified into: a). direct fishery effects, b). non-fishery effects, and c). uncertainty.

Direct harvesting effects on Gulf ecosystems include overcapacity-overharvesting of economic species, biological effects of high harvest rates on the productivity of species, ecosystem effects of the harvesting process, bycatch of non-target species, and conflicts between various gear sectors of the fishery. Solutions to the problematic issues of harvesting effects include reduction in the harvest capacity overall, and re-direction of the fishery to achieve more complete and proportional utilization of the Gulf's fishery resources. Methods of fishing which reduce bycatch and discards of small fish, unmarketable fish and prohibited species should be encouraged through regulatory actions. More complete knowledge of the spawning, migrations and stock structure of species is needed to design management systems which regulate the 'where and when' of fishing.

Non-fishery effects on harvesting include local, 'watershed' and global scale environmental change, and political, economic and regulatory conditions and decisions. Local-scale habitat changes include effects such as contamination, natural environmental variation, effects of alternate economic activities such as location of aquaculture facilities, and the effects on regional ecosystems of local regulations such as 'fish reserves'. Watershed-level activities include population and community-level contaminant effects, coastal development, introduction of non-native species, effects of watershed development on anadromous fishes, and bioaccumulation and availability of contaminants to humans. Global-scale effects on harvesting include potential world climate change effects on the distribution, interaction and productivity of economic species. Political activities which may influence Gulf harvest fisheries include geopolitical jurisdictions and their regulation of fisheries, national, regional, state and local laws governing the harvest of resources, and the interaction of statutes that dictate preservation of some components of the ecosystem (e.g. Marine Mammal Protection Act, Endangered Species Act), and full utilization of others (Magnuson Fishery Conservation and Management Act, MFCMA). Economic conditions influencing the Gulf's fisheries include the demand for fish, the role of imports, social values vs. public perceptions regarding the 'best use' of the resources, the relative valuation of recreational and commercial fishing, the role of aquaculture in meeting market demand, and the issue of

property rights and relationships. A key element in designing effective strategies for resource sustainability is the inter-generational social discount rate applied to benefit/cost evaluations of management programs intended to rebuild depleted resources.

Uncertainty is a critical element influencing the Gulf's fisheries. Uncertainty of the effects of fishing effort reductions on the rate of resource recovery of depleted groundfish stocks is a central issue in designing and selecting effective resource recovery plans. Uncertainty in the effects of local- regional and global scale environmental conditions on fish production results in these issues being considered secondary to the direct influences of harvesting. Uncertain future economic, management, and political conditions currently place a premium on resource extraction policies which generate short-term rather than long-term benefits from harvested populations.

The Working Group reached a series of conclusions emphasizing: (1) Fishing is a dominant factor influencing the abundance and species composition of exploited resources in the Gulf of Maine. (2) Some resources are at/near record low levels of abundance (e.g. groundfish, bluefin tuna), while others are abundant and lightly exploited (e.g. mackerel and herring). International markets have developed for some species, rather than being consumed locally (e.g. urchins and dogfish). The cumulative harvesting capacity in the Gulf exceeds that necessary to harvest the aggregate finfish resource at its maximum sustainable level. (3) Capacity reduction programs are considered crucial to the development of long-term fishery sustainability on the Gulf. (4) Increased fishing effort, declines in traditional species, and development of new alternative fisheries have all exacerbated gear conflicts. (5) The extensive use of mobile fishing gear has likely had significant impacts on benthic habitats of the region, but these effects are poorly understood. (6) Local, watershed and global environmental changes have variable consequences for the fisheries. These linkages are as yet poorly understood, but will become more influential as stocks are rebuilt, and (7) increased communication with fishers and the public is essential to the establishment of effective resource conservation and stewardship programs. In particular, appropriate involvement of fishers in research programs could help to increase the body of knowledge needed as a basis for decision making, and improve the credibility of those decisions in the eyes of the regulated populations.

Introduction

Fisheries resources off the Northeast U.S. have been described as being in 'crisis'. Landings and abundance data for many species of traditional commercial importance have shown consistent declines over the last decade or longer (NEFSC 1995). The spawning stock biomass of many of these species has declined, often reaching record low levels (Figure 1). Such declines have given rise to a heightened public awareness of fishery resource problems and have ultimately lead to changes in the management approach for these resources. In particular, the Northeast Multispecies Fishery Management Plan, Amendment #5, instituted a moratorium on new entrants to the fishery and substantially reduced the amount of time the existing fleet was allowed to fish. This amendment was followed by Amendments #6 and #7 which closed large areas and set goals of an 80% reduction in fishing mortality rates by 1997.

In contrast to the crisis for traditionally important groundfish species, the ecosystem itself might be best described as in a state of replacement. Although some commercially important stocks have experienced major declines in abundance (Figure 2), the total biomass of finfish has not. There have been well documented increases in lower valued species such as dogfish and skates. There has also been a recovery in the biomass of pelagic species including mackerel and herring. New fisheries for species including goosefish, urchins, sea cucumbers and others have been developed. Thus, to some extent, Gulf of Maine fishers have coped with the decline in groundfish by developing alternative targets. Questions exist, however, regarding the sustainability of the alternative resources. Are these fisheries liable to follow the downward trajectory of more traditional resources?

There are vigorous ongoing discussions regarding the appropriate management steps to rebuild the depleted stocks. There is little question that these resources can recover. More uncertain is how long will their recovery take. Corollaries to this question are: how large should the stocks be to attain the desired yield, and what are the requirements for developing sustainable fisheries in the Gulf of Maine? This Working Group, consisting of scientists, regulators and fishers (Appendix 1) identified a long list (Appendix 2) of potential factors that influence the productivity of fishery resources and their management in the Gulf. The issues were classified into broad categories: (a) direct fishery effects, (b) non-fishery effects, and © the effects of various uncertainties as they influence decisions by harvesters, regulators and scientists. This report reviews issues considered in the workshop, and provides conclusions regarding key aspects of fishery resource issues in the Gulf of Maine.

Conduct of the Workshop

Participants (Appendix 1) first introduced themselves, and gave brief summaries of their current interests and duties and perspectives on Gulf of Maine fishery harvesting issues. Next, an unedited list of issues was developed for later consideration by the working group (Appendix 2). The various issues were categorized into three major areas: (a) direct fishery effects, (b) non-fishery effects, and (c)uncertainty. The working group then discussed for each of the major categories, the nature of problems, status of knowledge, management recommendations (where appropriate), and research recommendations.

A -DIRECT FISHERY EFFECTS

Direct fishery effects on Gulf of Maine resources were separated into five specific issue areas: (1) overcapacity and overharvesting, (2) biological effects on target animals, (3) selectivity/bycatch/directivity, (4) ecosystem effects of harvesting, and (5) gear conflicts.

Issue (1): Overcapacity/Overharvesting

1. What is the Problem?:

A number of stocks of commercially important species (notably groundfish) have been severely depleted due to years of overfishing (Figure 1 and 2). Fishing effort, primarily targeting species such as cod, redfish and flounders, increased dramatically after the adoption of the Magnuson Act (Figure 3). Otter trawl effort doubled between 1976 and 1987, and has remained stable and high. Recent management actions have been taken to reduce the amount of effort in New England groundfish fisheries, to about 50% of the level in the early 1990s. However, this measure alone will be insufficient to reduce mortality rates on principal stocks to sustainable levels, let alone allow for stock recovery.

Stock depletion and the coincident increase in elasmobranch abundance are some of the most obvious anthropogenic impacts on the GOM ecosystem. The reduced yields from the depleted stocks are causing serious economic and social repercussions in the region.. The excess harvesting capacity that has driven recruitment overfishing in groundfish and some other species has also caused growth overfishing in some species, like lobsters, that haven't yet shown reduced recruitment. Declining landings of some stocks, coupled with increased demand, resulted in increasing prices to fishermen, partially offsetting negative impacts of lower catches on fishermen's incomes, and enabling effort to remain high on the stock, in spite of lower catches. In fact, net profits to harvesters peaked well after the landings declined in the late-1980s.

The USA fishery for the pelagic stocks has not expanded after the cessation of foreign fishing, as it did for groundfish. Atlantic herring and Atlantic mackerel stocks remain under-exploited, and stock biomass has increased to near-record levels for both species (Figure 4; NEFSC 1995). Overall, however, there are few offshore fishery resources that can be so-classified. Of 50 northeast fishery resources routinely assessed, about 2/3 are now classified as over-exploited (based on the rate of harvest as compared to long-term overfishing definitions) and 2/3 are at historically low levels of abundance (Figure 1). Of the resources considered over-exploited, only American lobster remains at a high level of abundance. Approximately 1/5 of the resources are fully-exploited, and only 1/6 are under-exploited, including herring, mackerel, red hake, butterfish and short-finned squid (NEFSC 1995).

Exploitation Rate

1994	Underexploited	Fully Exploited	Overexploited	
Abundance Level High	Atlantic Herring Atlantic Mackerel Skates 6%	Spiny Dogfish Striped Bass 4%	American Lobster 2%	**12%**
Abundance Level Medium	Red Hake-N. Butterfish *Illex* Squid 6%	Pollock Ocean Pout White Hake *Loligo* Squid Northern Shrimp Surfclam Ocean Quahog 14%	Summer Flounder American Plaice Black Sea Bass 6%	**26%**
Abundance Level Low	Red Hake-S. 2%	Silver Hake-N. Atlantic Salmon 4%	Cod-GM, GB; Haddock–GM,GB Redfish, Wolffish, Tilefish, Shad,Silver Hake–S, Atl. Sturgeon, Yellowtail–CC,GB,SNE,MA Witch Flounder Sea Scallop–GM,GB,MA Winter Flounder–GN,GB,SNE Bluefish, Windowpane–N,S Cusk, Scup, Goosefish, River Herrings 56%	**62%**
	14%	**22%**	**64%**	

Figure 1. Summary of status of 50 finfish and invertebrate stocks off the northeast USA. Stocks are classified by current exploitation rate (underexploited, fully exploited, and overexploited), and current abundance level (low, medium, high). Percentages of stocks in various categories are given.

LANDINGS & ABUNDANCE NORTHEAST USA

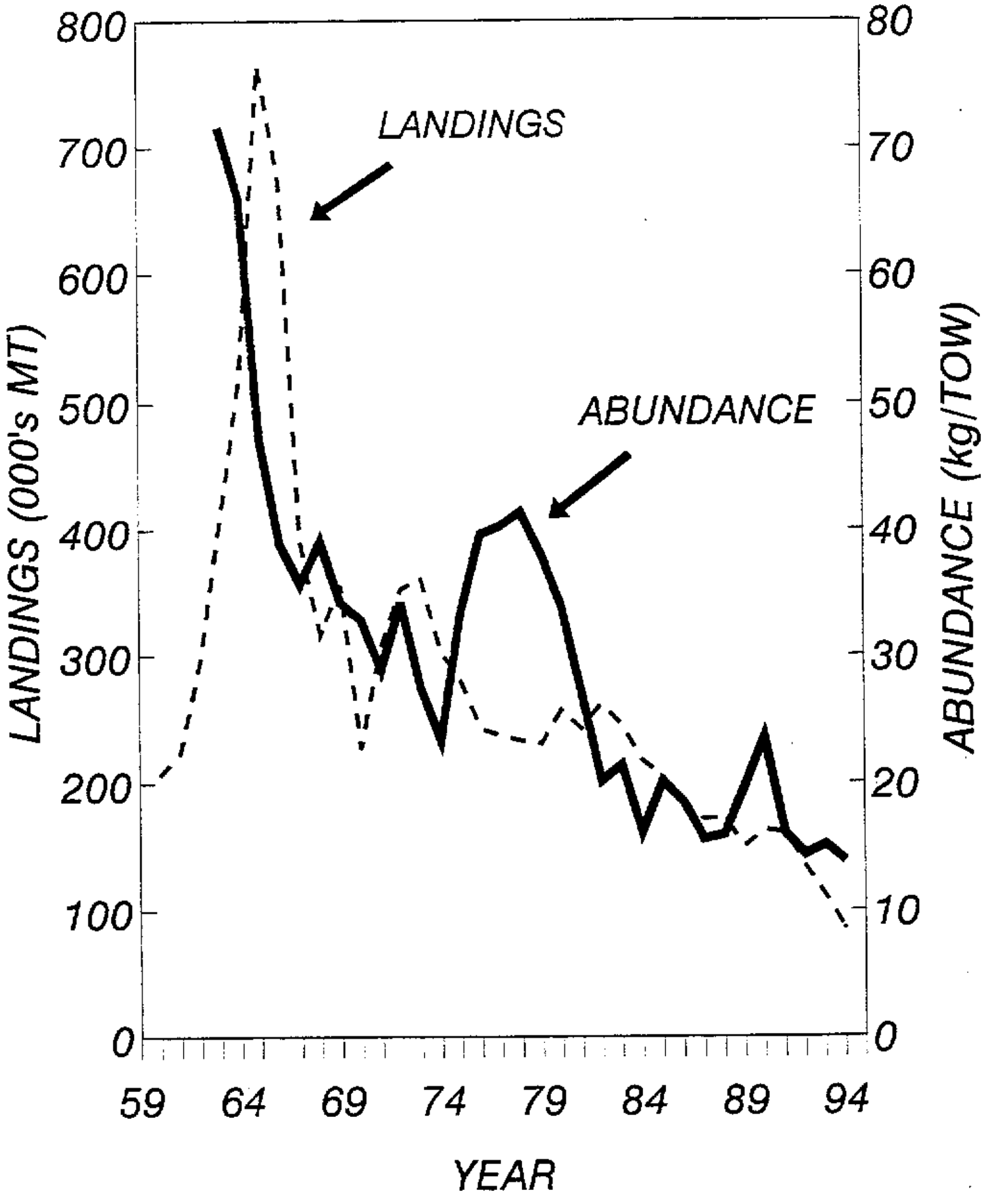

Figure 2. Landings and abundance (kg/tow in USA research vessel surveys) for principal groundfish and flounder resources, Northeast shelf, 1960-1994.

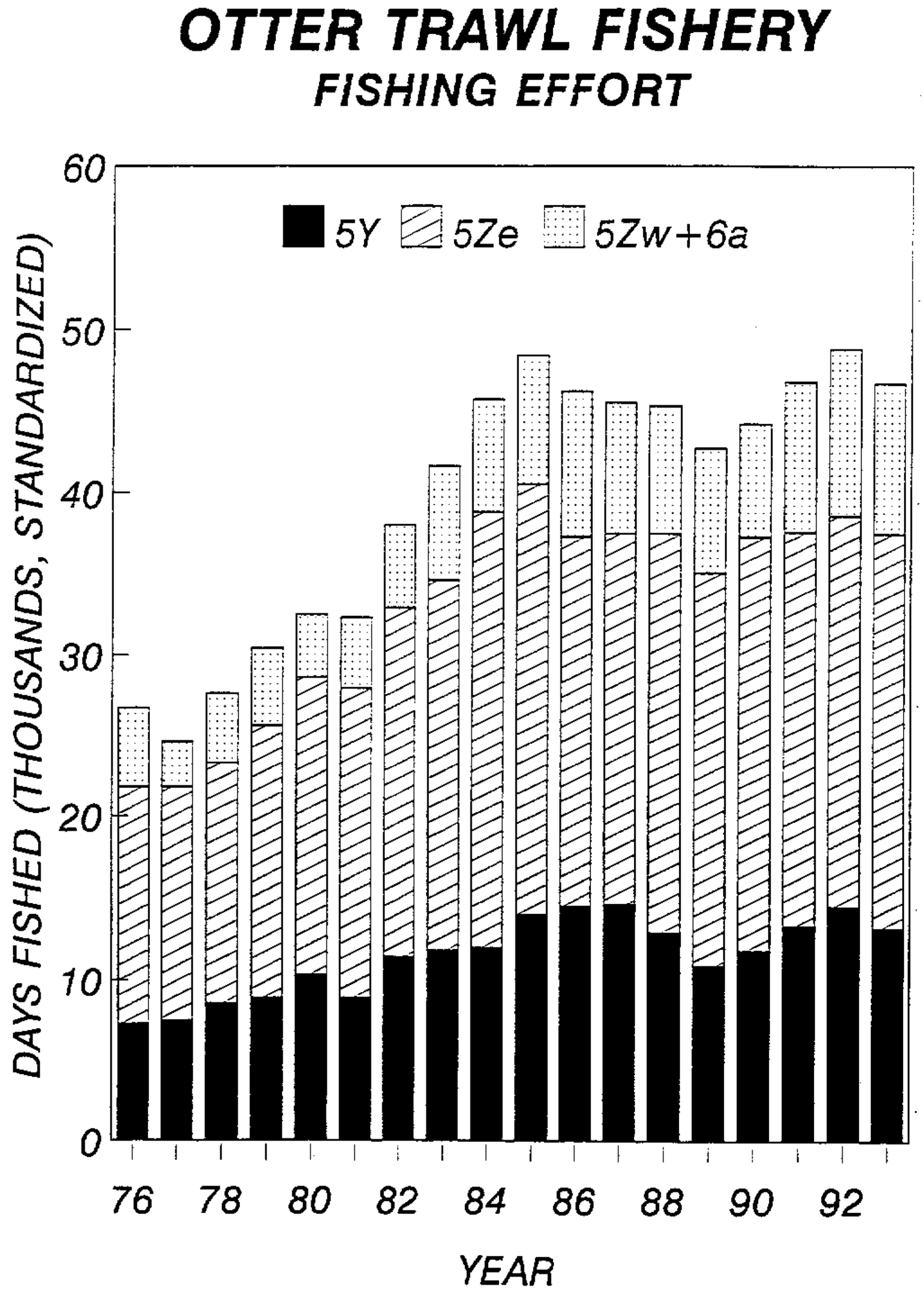

Figure 3. Trends in U.S. otter trawl fishing effort (standardized days fished) in three New England assessment regions, 1976-1993. Data are adjusted for different otter trawl vessel sizes, and are presented for the Gulf of Maine, Georges Bank and Southern New England.

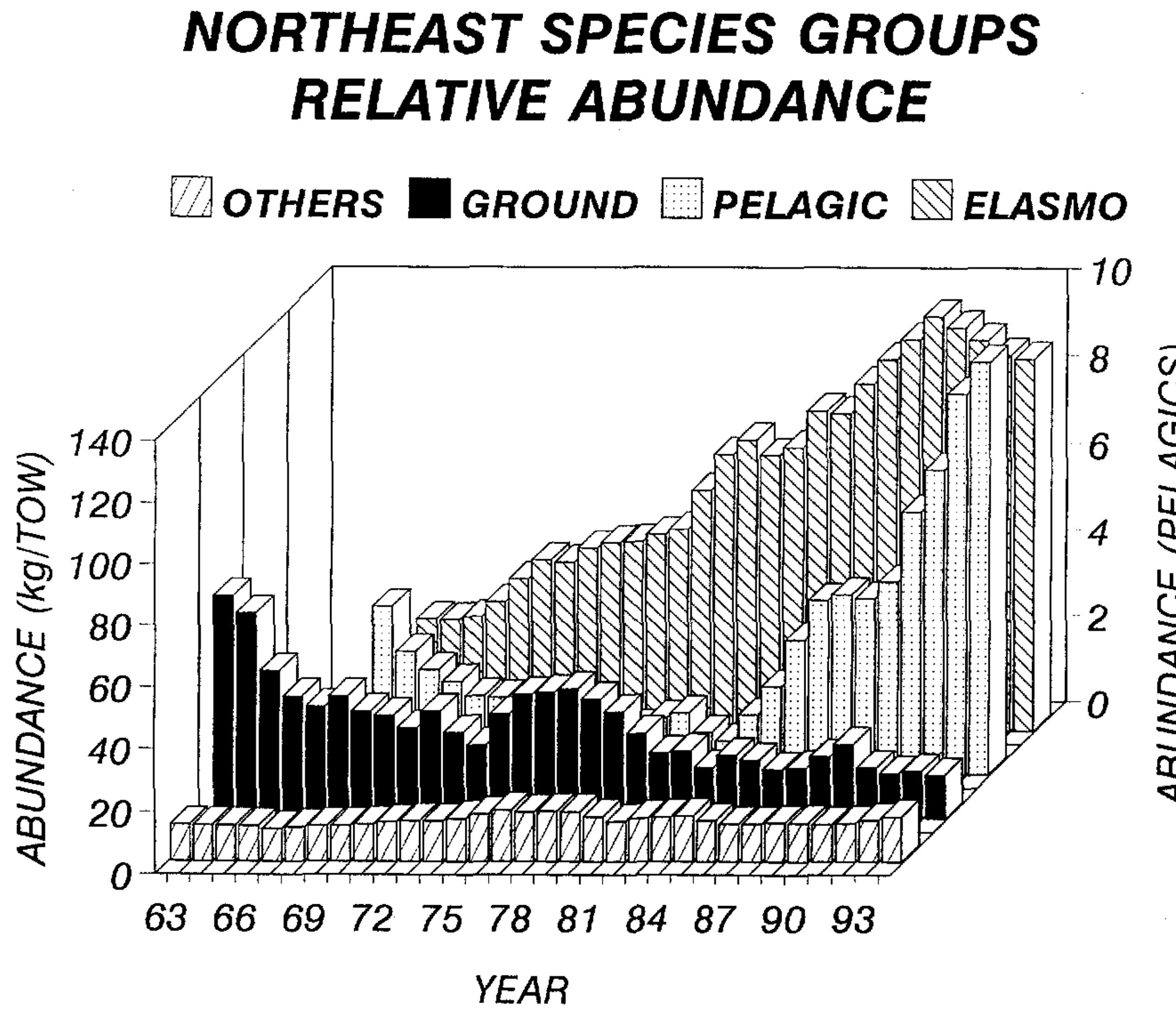

Figure 4. Changes in the relative abundance of four species groups in spring and autumn bottom trawl surveys in New England and the Middle Atlantic, 1963-1994. The four species groups are: (1) principal groundfish and flounders (Autumn index), (2) principal pelagics (herring and mackerel; Spring index), (3) elasmobranchs (skates and dogfish, Autumn index), and (4) other species (e.g. goosefish, scup, cusk, weakfish, etc, Autumn index). Data are smoothed with an autoregressive moving average procedure.

Where fishing mortality has remained very low, stocks have recovered to high levels (e.g. herring, mackerel and dogfish). For heavily regulated resources such as striped bass, surfclam and northern shrimp, the resource has improved significantly, as have fishery yields.

Marine fishery resources in the offshore Gulf of Maine region have varied considerably in abundance and landings during the last three decades, primarily due to their exploitation history. Dramatic reductions in most offshore stocks occurred at the hands of the distant water fleets, who pulse-fished the wide array of species available. Subsequent to the end of distant-water fleet fishing, some stocks have rebounded to very high levels. The Atlantic herring stock on Georges Bank was virtually extirpated in the 1970s, but has returned to relatively high abundance, and is now occupying historically important spawning areas. The Atlantic mackerel stock has, as well, increased in abundance following intensive overfishing in the early 1970s. Other offshore stocks such as squids, butterfish, skates, red hake and dogfish are at medium or high abundance levels and are not overfished.

The rapid increase in fishing effort during the late 1970s and early 1980s resulted in increasing fishing mortality rates. Improved juvenile survival in the 1970s and 1980s, and the expanding fishing effort temporarily increased landings, but these levels could not be sustained. Fishing practices during much of this period reduced the inherent resilience of the populations by removing many of the older (breeding) fish and resulting in the fisheries depending almost completely on the strength of incoming year classes ("recruitment fisheries"). At lower exploitation rates, the population would be comprised of a greater diversity of age groups, and thus, if recruitment of the incoming cohort is low, the fishery could concentrate for a while on the accumulated stock of older animals. In the case of Gulf of Maine groundfish, however, high rates of exploitation obviated this option. The dependence on the recruitment of young fish resulted in great economic incentives to target animals at or near legal sizes. Retention and discard of juveniles became more problematic.

In recent years, fishing mortality rates have exceeded recruitment overfishing levels by a factor of 2 or more. The recent declines in these offshore resources is attributable to persistent, gross recruitment overfishing. Although environmental variability has had a role in fluctuating survival rates for groundfish, declines in stock sizes and landings could have been averted or at least mitigated if the stocks had not been significantly recruitment overfished.

The rebuilding of many of these resources will require a recruitment event of very unusual (and improbable) survival, or a significant period of fishing mortality rates at or near zero, resulting in gradually increasing spawning stock biomass and recruitment. Some stocks (e.g. yellowtail flounder) could rebound relatively quickly (about five years), whereas others will take a decade or more (Georges Bank haddock).

Because of the low fishing mortality rates necessary to rebuild the stocks, monitoring the recovery will require increased reliance on research vessel surveys, conservative and carefully planned 'sentinel' fisheries, and an increased cognizance of basic life history processes and parameters.

Along with improved monitoring, there must be a substantial change in management approaches, with more emphasis on protecting the resource, and less on short-term economic and sociological concerns.

Even though the emphasis in this discussion is on the biological condition of the stocks, causes of overfishing include the behavior of fishers in a declining socioeconomic scenario; the number, size, and fleet composition; influences of new technology on increasing the effectiveness of fishing effort; the lack of selectivity of otter trawls; and market demand for underutilized species (mackerel, herring, sea cucumbers, sea urchins, skates, monkfish, and dogfish).

2. Status of Knowledge

The status of most commercially harvested stocks in offshore waters of the Gulf of Maine is quite well-known, except for some species which have only recently become primary targets of fisheries, including dogfish and monkfish. The primary cause of groundfish stock depletion is well-established to be persistent recruitment overfishing. For many of the New England and Mid-Atlantic groundfish stocks, current harvest rates are well beyond F_{max} and the point at which recruitment overfishing is defined. From 1976 to 1993 mortality rates for most stocks increased, and most have exceeded the overfishing definition for many years (NEFSC 1995). Persistent harvest rates considerably above the level of long-term replacement have had several important impacts on the groundfish resource. When good recruitment occurred (e.g. in the mid-late 1980s), these year classes attracted intense fishing pressure. Rather than 'stock-piling' fish to increase the spawning reserve of the populations, the high harvest rates quickly diminished the numbers of adult fish. Age compositions became increasingly truncated (to younger age groups), and the fishery and spawning populations became increasingly reliant on recruits. Thus, the New England groundfish fisheries in the MFCMA era became 'recruitment fisheries'. Recent dramatic reductions in these resources cannot be attributed to unusually poor recruitment survival (e.g. implying poor climatic conditions or increased predation on juveniles). Although survival rates of recruits for some stocks have declined in recent years, if the stocks had not been recruitment overfished, the trajectories of stock size and yields would have been very different, and it is likely stock sizes and yields would not have decreased so sharply.

In contrast, Atlantic mackerel and Atlantic herring stocks are at near-record-high levels of abundance and are fished at very low rates, considerably below those that would result in recruitment overfishing (NEFSC 1995). The contrast between the recent trajectories of the pelagics and demersal (groundfish) resources is striking, and further points to recruitment overfishing as the primary cause of declined in heavily fished resources.

On the whole, the total harvesting capacity is considered to exceed the Gulf's production capacity. However, many details are lacking about fishing power in specific fisheries and gear types, and the comparability of vessels and gears as related to fleet reductions in days at sea. For example, in the U.S. groundfish fishery, there were about 4,300 valid permits in 1995, but only about 1,000 active vessels. Rules aimed at reducing effort may not have a proportional effect on fishing mortality rates, due to the differing potentials of fleets to increase their fishing powers, in the face of reduced fishing time.

3. Management Recommendations

- Harvesting rates of depleted stocks must be reduced dramatically in order to allow for stock rebuilding.
- Markets for highly abundant species like mackerel and herring should be developed to provide some fishing alternatives.
- The overall fishing capacity in the Gulf should be reduced to a level that it is appropriate for the biological limits of the region. Excessive effort on other species from redirected groundfish vessels should be prevented.
- Communication between scientists/managers and harvesters should be improved, and public education about the long term benefits of stock rebuilding should be undertaken. Ways to expand a collaborative approach to fisheries management should be explored in order to improve the efficiency of and compliance with fishing regulations. The ability to evaluate and adapt fisheries management measures should be improved.
- Managers need to consider the development of adaptive management approaches with a policy of risk aversion (to account for scientific uncertainty or lack of knowledge).
- The level of communication and understanding between American and Canadian fishermen and industries needs to increase, if depleted transboundary resources are to be rebuilt. A number of the region's fishery resources range across the international boundary between the USA and Canada. Informal mechanisms exist for collaboration on the assessment and management of transboundary stocks, but communication and coordination of fishery management goals and approaches should be. The recent accession to the Northwest Atlantic Fisheries Organization (NAFO) presents another venue for potential cooperation, and this option should be explored.

4. Research Recommendations

- Fishing capacity and power should be better defined, especially in relation to gear type.
- Socioeconomic studies of fishing capacity, ability to switch fisheries, and consequences of

effort reduction on fishing behavior are needed to evaluate the biological and economic consequences of alternative management scenarios.

- Fishermen should be involved more in fisheries and environmental research, and collaborative opportunities for research should be identified.

- The existing sea sampling program should be augmented with a feedback mechanism to make information more readily available .

- Food products should be developed to stimulate domestic markets for and harvest of highly abundant species with the goal of developing sustainable fisheries.

Issue (2): BIOLOGICAL EFFECTS ON TARGET ANIMALS

1. What is the Problem?:

Apart from the high overall exploitation rates of many traditional stocks, there is great concern over the impacts of fishing on the vital rates (growth, onset of maturity) and stock structure within species. Limited information exists that documents increased growth, and especially earlier onset of spawning in some exploited stocks (e.g. Trippel 1995). Although these shifts in vital rates partially offset the effects of high harvest rates (e.g. through faster growth at age), the implications for stable populations are equivocal. For example, the shift to younger age at first reproduction, although allowing more quantity of eggs to be spawned, may actually result in poorer egg and juvenile survival per capita than in populations that spawn later in life.

Stock structure of exploited species is not know definitively. Thus, if a species is composed of a number of more-or-less discrete breeding groups, high harvest rates and the lack of specific protection for unique populations may act to reduce the overall resiliency of the population. Although speculative, such mechanisms may have important implications for our ability to restore depleted fishery resources. Likewise, highly species selective fishing has been a contributing factor to the decline in landings of traditional groundfish species.

2. Status of Knowledge:

The shift in species composition of the fish component of the ecosystem is well documented (Figure 4). Monitoring of the relative abundance and species composition of the resource, fishery catches, and fishery landings is accomplished through fishery independent surveys, vessel and dealer logbooks, biological sampling in the ports, and at-sea observer programs (NEFSC 1995). Additional information on the biological condition of the stocks is derived through the Marine Recreational Fishery Statistics Survey (MRFSS) program (NEFSC 1995). Biological characteristics such as growth and maturity are routinely monitored through these programs, although the intensity of sampling of commercial catches has declined significantly in recent years.

Nominal stocks for most Gulf of Maine fishery resources were identified many years ago. Most of these stock definitions were based upon information on movement patterns (e.g. through tagging studies), variation in growth and other biological characteristics, and patterns of strong and weak year classes. There is little knowledge of sub-stocks or unique spawning aggregations, or the effects harvesting may have had on the diversity of biological characteristics such as spawning date and location, or other physical attributes of species. Fishery management measures have generally applied over large areas (e.g. closures, quotas, mesh sizes), and were not necessarily dictated by the spatial variation in biological characteristics of the animals. Little can be done to change the situation until more information on the within-species variation in the biology of animals is better understood. There is a critical need to increase our emphasis on basic fishery biology, spawning, stock structure and species interactions. Without such information, we can only speculate on the implications of various policies for restoring biological diversity of exploited stocks. Likewise, the potential for enhancing stock restoration through enhancement efforts is critically dependent on improved information on stock structure and spatial variation in biological characteristics.

3. Management Recommendations

Apart from reducing overall effort on some components such as groundfish, management efforts could be directed so as to fine-tune the exploitation of individual stocks and breeding components, when such information becomes available. Reduced fishing on breeding aggregations, rebuilding of age structures, protection of migration routes and other measures are potentially available to managers, in order to augment protection of the reproductive capacity of fished populations. Recent research has emphasized the importance of older spawners in the population, and improved age structure is a direct result of the overall exploitation rate, and its pattern by age.

4. Research Recommendations

- Increased research emphasis on the spatial variation in biological characteristics is needed. Information on growth rates, onset of sexual maturity, sub-stock structure, movement patterns, and distribution in relation to environmental variation should be improved.

- Historical and recent information on spawning areas need to be collated to improve spatial control of the fishery.

- The viability of reproductive products of various sizes, ages, and substocks is a critical component of calculations of spawning stock biomass per recruit -- the basis for overfishing definitions for most species. This information should be collected.

Issue (3): SELECTIVITY/BYCATCH/DIRECTIVITY

1. What is the problem?:

Current fish harvesting technology is not sufficiently selective so as to avoid the capture of juveniles of target species. In particular, mobile fishing gear, regulated by minimum mesh sizes, continues to result in mortalities of juvenile and undersized animals. This is due partially to the relatively 'dull' selectivity properties of the gear, and because of compliance with regulations. Other gears also can take significant quantities of juvenile fishes as well. Apart from the selection of juveniles, fishing gears also catch non-target species which, if non-marketable, are discarded. Because of the patterns of species distributions, and existing fishing patterns, it is difficult to design regulations which afford a high level of protection to some critically depleted stocks, while allowing significant fishing on others. This will slow the stock rebuilding process, because each species will rebuild at different rates.

2. Status of Knowledge:

Bycatch rates in various fisheries are reasonably understood. Discards are generally accepted to experience poor survival, and limited studies of escapee survival indicate minimal mortality with single encounters. Effects of chronic or multiple encounters are unknown. Selectivity characteristics of existing gears are reasonably understood. Additional research is needed in the development of fishing gears which can effectively sort species while deployed, thereby enhancing survival of non-target sizes and species. The effects of these gear encounters on escaping animals needs to be evaluated, in order to determine net survivorship and selectivity of fishing gears. Lack of information on the ability of fishermen to target species or species groups or particular sizes of animals hinders the development of regulations to ameliorate the problem.

3. Management Recommendations:

- Regulatory discards (e.g. those attributable to management measures) should be minimized in the rebuilding process using time/area closures and selective gear when possible.

- Continued support for conservation engineering research is needed in order to continue the development and evaluation of selective fishing gears.

- Education programs for fishermen and public are needed to appraise these groups of the potential benefits of selective harvesting.

4. Research Recommendations:

- Extend sea sampling program to all fisheries- monitoring stocks, selectivity experiments, etc.

- Train displaced fishermen as observers.

- Evaluate directivity of fishermen by gear to minimize bycatch and target selected species. Compare gear types for bycatch rates, and secondary impacts. Selectivity (reduced bycatch and less retention of undersized target species) of mobile fishing gears needs to be improved through research in the area of conservation engineering. Continue development of selective fishing methods that minimize bycatch, and habitat destruction, utilizing fishermen and scientists in collaborative research. Increase intensity of sea sampling programs carried out on fishing boats at sea to estimate bycatch mortality of nontarget species and harvest rates for targeted species should be augmented with a feedback mechanism to make this information more readily available.

Issue (4): ECOSYSTEM EFFECTS OF HARVESTING

1. What is the problem?:

Recent reports (NEFSC 1995) suggest that trawling in the Gulf of Maine has increased dramatically since 1976. A significant portion of the area is trawled annually, with the distribution of this effort being quite variable. This level of trawling is likely to have strong direct and indirect effects on certain populations and communities. Conversely there are areas where intensive trawling are likely to have minimal impact while producing commercial quantities of fish. Identifying these habitat types and using gear appropriate to the habitat is currently problematic. Heavy fishing pressure in the Gulf of Maine extends beyond the targeted species to other components of the ecosystem. There are likely to be strong effects of fishing gear disturbance on benthic populations and communities. These effects may feedback to further depletion of fisheries stocks by destroying benthic nursery habitats of commercially important species.

In addition to the direct effects of overharvesting, there are many indirect effects of fish harvesting, such as bycatch of nontarget species, impacts of trawling on the benthic prey of groundfish, and increases in pelagic species (herring and mackerel) and elasmobrachs (skates and dogfish), which have altered the ecosystem on which the commercial groundfish depend. The increased abundance of pelagic predators and elasmobranch predators coincident with intensive harvesting of the targeted groundfish species may impede the recovery of fisheries, even if fishing mortality is reduced. The groundfish also compete with marine mammals and seabirds for prey species, so that as the marine mammals and seabird populations increase there are issues regarding the adequacy of the prey base.. Thus the ecosystem effects from the direct and indirect effects of fishing activities will need to be considered in the plans to rebuild the depleted groundfish populations.

2. Status of Knowledge:

The dramatic decline in groundfish abundance has been accompanied by a variety of changes in other fish components of the ecosystem (NEFSC 1995; Figure 4). In particular, there have been rapid and significant increases in principal pelagics (Atlantic herring and Atlantic mackerel), as well as small elasmobranchs (spiny dogfish and skates). Most of the increase in elasmobranch abundance is due to the increase in dogfish, particularly since 1980. Skate abundance, although near record high levels (for the aggregate of 7 species) had remained relative stable since the late 1980s (NEFSC 1995). Increases in pelagic and elasmobranch stocks, coincident with the declining trend in groundfish raise the question of potential biological interactions among the species. Feeding ecology studies indicate that although spiny dogfish consume relatively large quantities of finfish, but most of this is of pelagic species. Diet data collected on Georges Bank during the summer in 1984-1987 indicate that gadoids and flatfish accounted for only about 6.7% of the food consumption (by volume; 4.2% gadoids, 1.5% flatfish) of dogfish (NEFSC file data). It is concluded therefore that given the relatively low per capita consumption of groundfishes, and their variable co-distribution with groundfish stocks, that dogfish predations is probably not a significant factor influencing juvenile survival of important groundfish. Elasmobranch abundance increased steadily from the mid-1970s until the early 1990s (Figure 4). During this period of increase, many instances of high groundfish juvenile survival occurred. Total elasmobranch abundance has, in fact, stabilized and declined somewhat in the 1990s (Figure 4). Thus, the timing of abundance changes in elasmobranch population size are not correlated with recent declining trends in groundfish abundance and landings.

To what extent will these abundant species impede the recovery of groundfish? Competition by skates and dogfish with the groundfish stocks is apparently weak, since growth rates of depleted groundfish resources are currently at or near record levels for many stocks. Diet overlaps do not tend to be high, and most demersal species are opportunistic feeders. Predation by dogfish may include some mortalities of depleted gadoids and flatfishes. However, this predation is likely highly seasonal (owing to the extensive migrations of dogfish), and limited to a short duration, since gadiods such as cod and haddock rapidly grow out of the size range consumed by this predator. Given these considerations, it is unlikely that initial recovery of the groundfish resource will be impeded by the elasmobranch stocks, although the degree to which the ecosystem can support high biomasses of elasmobranchs and other groundfish resources remains conjectural. Thus, the case for ecosystem replacement by these species is weak, and initial recovery of the groundfish resources does not appear threatened by the abundance of elasmobranch stocks. However, the rate and level to which depleted stocks can recover may be influenced by the presence of these potential competitors and predators.

Knowledge of the linkage between benthic productivity and fish production is unclear in the Gulf of Maine system although in fresh water and coral reef systems the interactions are more fully researched and better understood. Generally, information is fairly poor with many clear gaps in:

(1) direct and indirect effects of the removal of key predators in the food web (i.e.,

cod, urchins, other benthic feeding fish), (also more info needed on what the keystone species are)

(2) overall <u>potential</u> influence of fishing gear disturbance has been elucidated in a few studies, but there is a general lack of information on the large scale effects of fishing gear disturbance.

(3) What is the <u>frequency</u> of the disturbance with regard to the time scale required for recovery? This is a critical info gap that needs to be bridged to build predictive knowledge and link to ecological theory.

3. <u>Management Recommendations:</u>

An ecosystem-based management approach should be adopted to optimize ecosystem yield, -- considering both the volume of catches and their economic returns --, with the fishery yields based upon an understanding of the limits to ecosystem productivity. Risk-averse management principles should be adopted in the face of uncertainty about how species interact. Juvenile fish habitats and nursery areas should be protected from obvious negative interactions. The potential utility of reserves (No Fishing Areas/Refuges) should be evaluated to test their potential as a fishery management measure for allowing overfished stocks to recover and to test hypotheses about controlling (cascading) effects of predators (Auster and Malatesta, 1995). Existing closed areas should be intensively monitored to evaluate their contributions to fish conservation and as long term measures for management.

4. <u>Research Recommendations:</u>

Acute and chronic effects of trawling events need to be definitively evaluates and related to the sensitivity of the fauna. The workshop recommends the development of a research program to evaluate habitat/gear specific impacts. Conservation engineering programs should be encouraged to develop less destructive harvesting methods. Current closed areas should be used as controls to research trawling impacts. Critical habitats for juvenile fish need to be evaluated, as a basis for protection of these nursery areas.

Issue (5): GEAR CONFLICTS

1. <u>What is the Problem:</u>

The reduced yields from the depleted stocks are causing serious economic and social repercussions in the Gulf of Maine/Georges Bank region. This situation has lead to gear conflicts between otter trawls, gill net fisheries and set line fisheries; resource allocation controversies between inshore and offshore fishers and between the recreational and commercial users of these resources; and political jurisdictional issues between the state and Federal governments in the U.S. and for transboundary stocks between the U.S. and Canada (especially in relation to the Hague Line on Georges Bank). Gear conflicts include mobile gear fishermen who are displaced from traditional grounds, into areas occupied by fixed gear. Thus, conflicts arise between 'traditional' and new users of fishing areas. There is concern over the relative habitat and bycatch characteristics of various gear types, and the appropriateness of gears for particular fishing grounds.

2. Status of Knowledge:

Gear conflicts are generally well documented. What is not well understood is the behavior of fleets in relation to various regulations such as closed areas and days-at-sea reductions. The requirement for mandatory logbook submissions should supply data on the fishing patterns by vessel, gear, port, etc. Based upon these data, models of fleet interactions could potentially be created.

3. Management Recommendations:

Minimizing gear conflicts will be difficult in the near-term, since available fishing grounds are becoming fewer (owing to area closures), and because declining stock sizes have, in some cases, resulted in a contraction of the geographic ranges of species. Allocation of specific fishing grounds to gear sectors is one option, but it has not generally been used heretofore, because of the equity issues involved. An approach that has been used is structured conflict resolution between conflicting groups. Agreements between fixed gear fishermen and monkfish trawlers were achieved in this manner. Increased use of mediation processes such as these are likely to be the most successful method to alleviate gear conflicts, since communication is obviously a prime requisite. Additionally, increased knowledge of fishing practices by all parties is important in minimizing the potential for conflicts.

B-NON-FISHERY EFFECTS

Non-fishery related effects on Gulf of Maine resources were separated into four issue areas: (1) local-scale effects, (2) watershed-scale effects, (3) global-scale effects, and (4) political/economic/management effects.

Issue (1): Local-scale Effects

1. What is the problem?

What are the implications of small-scale environmental changes on region-wide populations including fishery resources? Point-source pollution, activities such as aquaculture facilities, and physical habitat alterations such as mineral extraction, dredging, hydrocarbon extraction and land use changes clearly can have major effects in the immediate areas where these activities occur. Quantifying the impacts of incremental increases in these activities on the population rate of change of fishery resources has yet to be accomplished. Nevertheless, large-scale increases in any of these activities, and the cumulative effects of moderate levels of all of them have had detrimental impacts on some resources. Better information on the population consequences of these activities is needed in order to determine the ecosystem's capacity to absorb these changes without significant detrimental consequences.

2. Status of Knowledge

The population consequences of local-scale effects are poorly understood. For example, contaminant effects on genetics, bioaccumulation on population dynamics, and locations of critical habitats to one or more life-stages. But local effects probably are significant in more regional contexts in populations (i.e. critical habitats being affected in certain municipalities). Any potential effects might be masked by overfishing. Stock structures are not known very well and could be much more heterogeneous than currently thought. In this instance, local effects could be important. Population migrations could be significantly affected by a single local change. If a population is low enough, then local effects could be exacerbating to population change. Lack of process-oriented studies of critical habitats (no dynamic understanding) is a major gap in current knowledge. Presence-absence definitions may not be sufficient, for example, in definition of nursery areas.

Lack of historical records on critical habitat loss (i.e., traditional spawning or juvenile grounds) complicates the interpretation of local vs. Stock area or species changes. Similarly, there has been no systematic attempt to map fine-scale sea floor structure to juvenile fish habitats or generally critical habitats.

Activities such as aquaculture could have many local-scale effects on population consequences such as: displacement of traditional fishery activities, genetic pollution of escapees, introduction of parasites to natural populations, influx of nutrients into the ecosystem, and introduction of chemicals and antibiotics. Other local-scale alterations could have major consequences, depending on their specific location relative to critical habitats. The cumulative effects of many small-scale alterations have not generally been evaluated.

3. Management Recommendations

Siting of activities with clear local-scale impacts on the marine environment must be done in a cautious and risk-averse manner. Because we do not have definitive answers to many of the questions posed above, we cannot risk large-scale population consequences for fishery populations already stressed due to overexploitation.

4. Research Recommendations:

A major effort is needed to evaluate critical habitats and their characteristics for fishery populations. These studies should include better mapping of the features of the physical environment, and quantitative determinations of relative habitat use by various species/life stages. Additional experimentation is needed to determine the criticality of the various habitat attributes (e.g., how much better is one habitat type for survival of a species as opposed to alternatives).

Issue (2): Watershed-Level Effects

1. What is the Problem?

Regional or watershed-scale effects are those that occur at the population and community level (e.g. at the scale of the Gulf of Maine). Processes operating at this level include non-point source pollution, regional habitat changes, large-scale fishery closure areas, coastal and urban development, introductions of non-native species, watershed development effects on anadromous species, and 'upstream' effects of water management. Examples of the effects of regional-scale non-fishing effects on resources include the catastrophic declines of anadromous fish. Smelt runs in the N.E. region have been affected by acid rain. Coastal land use practices are implicated in the decline of Atlantic salmon. Coastal eutrophication may be responsible for shifts in the distribution of species such as Atlantic herring.

2. Status of Knowledge

The effects of regional-scale non-fishery effects are generally poorly understood. Direct habitat alterations at this scale are generally less severe than at the local scale, but the chronic effects of pollution, use of fishing gear, and other alterations to the environment may well have greater impacts than localized changes of greater insult to the environment. There are major gaps in our knowledge of these impacts on fishery productivity.

3. Management Recommendations

For anadromous species, management measures aimed at improving survivorship are necessary. The effects of large-area closures as an aid to fishery management should be evaluated. Specific recommendations on regional-scale habitat issues are given elsewhere in this document. In general there is a need to weigh coastal vs. marine habitat protection in terms of impact, for example many nursery areas are sub tidal, vs. salt marsh.

4. Research Recommendations

Process-oriented research to identify critical habitat areas and characteristics for adequate survival is urgently needed.

Issue (3): Global-Scale Effects

1. What is the problem?

Climate and global habitat change effects distributions, interactions and invasions of species, and their overall productivity. Global changes have long term implications for changes/disappearance of spawning grounds, ranges extension/restriction and other attributes of fishery resources. For the most part, these potential changes cannot yet be predicted.

2. Status of Knowledge

The potential sensitivity of the Gulf of Maine system to global-scale change is well recognized. Because the area is a convergence region for various characteristic faunas, dramatic changes in the productivity and species composition of resources will likely occur a climate change scenario. The area is recognized as an important region to monitor for signs of global change, and considerable resources are currently allocated to appropriate monitoring and related scientific study.

3. Management Recommendations

The link between anthropogenic effects and global environmental change provides the opportunity for management actions. Management recommendations are provided elsewhere in this document.

4. Research Recommendations

Research linking habitat characteristics and their variation to resource productivity and distribution are the highest priorities for understanding the potential effects of global change. Fishery resources react differentially to seasonal and annual variations in, for example, temperatures (Murawski 1993). There may well be major trophic and productivity changes associated with the rapid changes in marine temperatures and associated oceanographic phenomena.

Issue (4): Political/Economic/Management

1. What is the problem?

Fishery resources of the Gulf of Maine are influenced by a variety of political (jurisdictional), economic and resource management events and policies which determine the overall rate of harvest and the allocation of benefits to user groups, states and countries. Generally, these policies are poorly coordinated, and there is little effective balancing of interests, so as to assure that their cumulative impacts do not negatively influence the resource. Recent history has shown that competitive interactions between user groups and political jurisdictions have exacerbated over fishing, and resulted in overcapitalization, a 'race for fish', and poor overall resource conservation. The rising demand for fish, in the face of dwindling supplies, has resulted in higher unit prices to harvesters, thereby allowing stable or even increased effective effort. Although some coordination between states and nations occurs, in many cases the lack of overall control on harvest rates has resulted in declining populations. The enactment of fishing rate reductions and the response of the stock. Because of the length of the valuation period (e.g. 10 years), and the fact that these assessments require the use of social discount rates, the economic value of conservation to future generations may be severely underestimated. It is recommended that such studies do not employ discount rates, and that in evaluating such measures, the inter-generational impacts be given appropriate weight. The relative value of commercial and recreational fisheries as well for particular resources should also be considered more explicitly when determining allocations of fishery resources.

The issue of property rights to marine resources in the region remains controversial. There is a need to emphasize to the public and users that fish resources in EEZ areas are a national resource, rather than the property of harvesters. The issue of the nation renting or permanently allocating those rights needs to be considered, particularly if such systems can result in effective resource management. Similarly, the property right implications of aquaculture operations needs to be resolved.

Geopolitical boundaries/ and inter-jurisdictional issues continue to be problematic to the effective conservation of fisheries resources. Clearly, jurisdictions need not enact identical management programs, but where transboundary stocks are involved, the programs should provide *equivalent* conservation benefits. Measuring this equivalence is generally feasible for most fished resources. Informal meetings between governments, industries, and scientists should be encouraged between USA and Canada. The recent accession of the USA to NAFO (North Atlantic Fisheries Organization) should result in enhanced cooperation on scientific issues, and greater understanding of mangement approaches. There is a general need also for closer state/federal cooperation.

Managers should carefully consider the introduction of non-native species as related to both aquaculture escapees and the introduction of new wild species to the ecosystem.

4. Research Recommendations

Research on the behavior of fishermen in relation to management measures, economic conditions and other external influences is urgently needed.

C- UNCERTAINTY

1. What is the problem?:

Uncertainty currently plays a major role in the way fishery systems operate in the Gulf of Maine, from biological production to management and harvesting decisions. Overfished stocks in the Gulf of Maine contain few age classes, and as a result, stock abundance depends significantly on each year's incoming recruitment. Recruitment is the most unpredictable element in stock dynamics, however. This leads to uncertainty in fishery predictions, and to fishers who tend to focus on harvesting the few certain resources today rather than waiting to harvest uncertainly more resources tomorrow (Smith et al. 1993). As stocks are rebuilt, however, total stock abundance will fluctuate less from year to year, because a stock with many age classes will combine the effects of multiple years of both good and poor recruitment. This buffer would in turn provide stability and certainty to the fishery from year to year. This is especially feasible in the Gulf of Maine, because stocks occurring here tend naturally toward long-lived species with many age classes. (This potential benefit becomes difficult to identify under current regulatory time frames, however: the natural life span of many Gulf of Maine species exceeds 15 years, and can be as old as 50, although net benefits must be shown within only 10 years).

If stocks continue to decline to ever-lower levels, ecological interactions could be stretched to their breaking points, and species compositions and interactions could take on different and potentially irreversible forms or disappear entirely. A series of several small-scale disruptions may lead to a major disruption on a wider scale. Ecological theory shows that in stressed ecosystems, however, the breaking points and triggers of major disruptions cannot be predicted beforehand. This is one of the potentially most dangerous uncertainties inherent in present conditions in the Gulf of Maine

2. Status of Knowledge

Uncertainty in the likely recovery trajectories is a major impediment to the development of comprehensive fishery management plans. The selection of overfishing thresholds remains controversial. In particular, for stocks that have not undergone dramatic declines in abundance, selection of overfishing thresholds neat the biological limits to productivity remains somewhat subjective. Likewise the adequacy of management programs for stock rebuilding/sustainability are uncertain. In general, however, there has been great pressure toward overexploitation under uncertainty. The Gulf of Maine system might be more stable system than others (e.g., upwelling areas), but at this point has been made unstable because of overfishing.

3. Management Recommendations

Management programs should adopt risk-averse decision making in the face of these uncertainties. In particular, the selection of overfishing and target reference points should consider the consequences of failure to achieve management goals.

4. Research Recommendations

Scientists should strive to more explicitly quantify the degree of uncertainty, so that it can explicitly be dealt with by managers.

CONCLUSIONS

1) Fisheries are the dominant factor influencing the abundance and species composition of exploited resources in the Gulf of Maine.

2) Many important resources are at or near record low levels of landings and abundance (e.g., groundfish).

3) Alternative fisheries have recently developed coincident with the decline of traditional resources. Many of the new resources are intended primarily for international markets (e.g., urchins, dogfish), rather than being consumed locally.

4) Other resources for which few markets now exist remain at high levels of abundance (e.g., herring and mackerel).

5) The cumulative harvesting capacity of GOM fishing fleets (numbers of vessels and their size) exceeds that necessary to harvest the annual sustainable production of the Gulf resources. Fishery capacity reduction programs are considered critical to the rebuilding and maintenance of resources and their habitats.

6) Rates and levels of recovery of severely overfished stocks may be influenced by uncertain trophic links between abundant and depleted species.

7) Increasing fishing effort, declining stocks and more restrictive management programs have exacerbated gear conflicts, bycatch and discarding.

8) The extensive use of mobile fishing gear (e.g., otter trawls and shellfish dredges) has had significant impacts on the benthic communities of Gulf ecosystems. The effect on the production and diversity of these communities is poorly understood. Research in this area is critical to the establishment of sustainable and productive fisheries for the future.

9) Local, watershed and global environmental changes have variable consequences for the fisheries. These linkages are generally poorly understood, but will become more influential to fish species as they are rebuilt.

10) Increased education efforts aimed at the public and fishers is deemed crucial to the establishment of effective resource conservation programs. Participation by fishers in research activities could increase the level of understanding of the Gulf's resources, and increase support for management programs. Such an effort would necessarily include specific training in measurement and record keeping, periodic feedback, and continuous data exchange.

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Appendix 1. Brainstorming list of issues potentially influencing fisheries harvesting in the Gulf of Maine. Items are classified into three categories: A = Direct Fishery Effects; B = Non-Fishery Effects (e.g. environmental and political/economic/management); C = Role of Uncertainty.

1 Growth & Recruitment Overfishing A
2 Methods, Evaluation, Time Frame C
3 Spawning where/when C
4 Habitat Changes/Env. B
5 Competition MM/Fish C
6 Removal of Key Predators C
7 Bycatch effects A
8 Econ. Effects of Gear Conflict A
9 Selective Harvesting Species/size A
10 Biology of Fishes (Migration) C
11 Geopolitical/Interjurisdictional Borders B
12 Contaminant Effects at Pop. level B
13 Physical Habitat Alteration/gear A
14 Discarding A
15 Excess Capacity A
16 Economic Alterations C
17 Management processes & Compliance C
18 Re-designing fleets A
19 Fish Reserves B
20 Stock Structure w/species A
21 Coastal/Urban Development B
22 Fishing Effects on Benthic Habitat A
23 "Green" Methods of Fishing A
24 Harvesting Reflects on sediments A
25 Market Demersal C
26 Social Value vs. Public Perceptions C.
27 Effects of harvesting on Food webs D
28 Other than Assesmt. Info. in Fishery Mgmt. B
29 Phenotypic Shifts A
30 Watershed Development on Anadromous Fish B
31 Juvenile Habitat Requirement B
32 Fishermen participating in research C
33 Species Composition in mix of overfishing A
34 Non-native species (Aquaculture) B
35 Aquaculture B
36 Definition/Perception of sustainability B
37 Dual Management on Transboundary Stocks B
38 Non-Capture encounters A
39 Harvesting vs. food web Characteristics A
40 Laws, Mgmt., Progress, etc. C
41 Harvesting, Bioaccumulation & Avail. to humans C
42 Climate change on dist'n/interactions/invasions B
43 "Upstream" effects of H_20 mgmt. B
44 Gear competition grounds/size A
45 Unpredictability of resources vs. decisions by managers/fishers C
46 Adequacy of Mgmt. for stock rebuilding B
47 Better quantification - natural mortality/morbidity B
48 Uncertainty on Fishery Prediction C
49 Relative valuation of alternative uses B
50 Unpredictability of Env. B
51 Changes in species mix- of "new fisheries"
52 Property rights/Relations (ownership) C
53 Non-linear behavior near thresholds C
54 Conflicting objections in legislation C
55 Rebuilding rates in multispecies fisheries C
56 Scaling effects C
57 Interactional Activities C
58 Rate-limiting effects C
59 Recognition of Multispecies Processes C
60 Harvesting Sector Attitudes/Behavior A
61 Conflict between Innovation/Tradition in approaches to harvesting/mgmt. A
62 Interest group lobbying C
63 Recreational/Commercial A
64 Institutional change (Political) B
65 Maintaining Progress B

Protected Species Working Group Report

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Introduction

For the purposes of discussion, the Working Group defined protected species as species and populations of marine mammals, birds, sea turtles, and anadromous fish that are part of the Gulf of Maine ecosystem and that are afforded special protection by international agreements such as the Convention for the Protection of Migratory Birds; by the U.S. Marine Mammal Protection Act and/or Canadian statutes and regulations; or by the U.S. Endangered Species Act or similar statutes in Canada.

Areas within the Gulf of Maine provide important feeding, resting, nesting/breeding sites, and/or migratory corridors for many of these protected species. However, most protected species that occur in the Gulf of Maine are highly migratory and occur outside the Gulf of Maine at least sometime during the year. Restoring and maintaining healthy populations of those species that occur in the Gulf of Maine during only part of the year will require conservation efforts outside, as well as in, the Gulf of Maine.

Many of the species and populations of marine mammals, birds, sea turtles, and anadromous fish that occur in the Gulf of Maine have been adversely affected by human activities. Most species of large whales have been overharvested and reduced to very low levels. Many seabirds and shorebirds have been reduced to very low levels as a result of hunting, primarily for plumage, early in this century. Virtually all species and populations of sea turtles have been reduced to very low levels due to over harvesting of eggs and later life stages.

Threats posed by overharvesting have been generally recognized and intentional taking recently has been prohibited or strictly limited. At present, unintentional taking and habitat loss and degradation pose greater threats than intentional taking (see, for example, Nettleship 1991).

Marine Mammals

Introduction

More than 30 species of marine mammals are known to occur, at least occasionally, in the Gulf of Maine (see Table 1). Most of these are far-ranging and/or migratory, and spend part of the year outside the Gulf of Maine. Thus, effective conservation of the marine mammal component of the Gulf of Maine ecosystem will require conservation efforts outside, as well as inside, the Gulf of Maine.

Nature of the Problem

The marine mammal conservation problems of greatest importance in the Gulf of Maine are:

1. death and injury of severely endangered northern right whales and, to a lesser extent, humpback whales (see NMFS 1991a) from ship strikes and entanglement in fishing gear; and
2. incidental take of harbor porpoises in the sink-gillnet fishery.

Status of Knowledge

The Northwest Atlantic right whale population numbers about 300 individuals. Harvesting of these has been prohibited since the 1930s yet the population has grown little, if at all. The causes of lack of population growth have not been documented unequivocally, but appear to include mortality and injury from ship strikes as well as entanglement in fishing gear (see NMFS 1991b for more information concerning the status of and threats to this population).

Because of small population size, the loss of even one animal may increase the risk of extinction. Consequently, both Federal agencies (e.g., the National Marine Fisheries Service and the U.S. Coast Guard) and private organizations (e.g., the Center for Coastal Studies, the New England Aquarium, and the Memorial University of Newfoundland) have taken steps to minimize mortality from ship strikes and entanglement.

The second greatest marine mammal conservation problem in the Gulf of Maine is the incidental take of harbor porpoise in the sink-gillnet fishery. Although not unequivocal, best available data suggest that the level of incidental take may be greater than the annual recruitment level. Further, while trials done in October-December 1994 suggest that attaching acoustic pingers at regular intervals along net strings may reduce substantially the incidental take of harbor porpoises (Kraus *et. al.* in prep.), it is not known whether pingers will have similar effects in other areas and at other times of the year, or whether porpoise eventually will become accustomed to and stop avoiding the sounds produced by the pingers. In addition, area closures instituted in accordance with Amendment 5 of the New England Groundfish Fisheries Management Plan appear to have had little or no effect in reducing the incidental take of harbor porpoise in the U.S. portion of the Gulf of Maine. Seasonal closures instituted by Canada in the summer of 1995 to prevent cod catches from exceeding established quotas appear to have had the secondary effect of reducing harbor porpoise bycatch substantially because fisheries were closed during much of the summer when harbor porpoises frequent the Bay of Fundy (Trippel *et. al.*, in review). At the time of the workshop, it was not known whether Canada would institute similar quotas and closures in 1996 or beyond. Also, experiments are being done in Canada to evaluate the possible use of acoustic pingers to reduce incidental take but, at the time of the workshop, the results of these experiments were not yet available.

Harbor porpoise in the Gulf of Maine/Bay of Fundy have been designated a "strategic stock" as defined in the Marine Mammal Protection Act, amended 1994 (Blaylock *et. al.* 1995). At the time of the workshop, the National Marine Fisheries Service was in the process of establishing a Take-Reduction Team to develop a recommended Take-Reduction Plan as required by section 118 of the Marine Mammal Protection Act, as amended. In addition, the New England Fishery Management Council had initiated a review to determine additional measures that might be necessary and useful to reduce the incidental take of harbor porpoise in the New England sink-gillnet fishery, pending development of the recommended Take-Reduction Plan.

Entanglement of marine mammals in fishing gear is a well-documented mortality factor for many species, as discussed in other sections of this document. The entanglement of large whales, including right whales, fin whales, humpback whales, and minke whales in various kinds of fishing gear often results in the animal found towing such gear. The methods for mitigating entanglement caused mortality includes fishing area closures, gear modification, acoustic markers, and disentanglement. Among the mitigation efforts disentanglement has been successful in rescuing entangled whales of all species which are subject to entanglement. As a result, a disentanglement protocol has been developed for use the southern GOM which involves coordination between NMFS, USCG, Stellwagen Marine sanctuary, and the Center for Coastal Studies . The plan outlines lines of communication, a prioritized set of criteria for response, and a plan for initial monitoring of the entangled animal, followed by methods of rapidly responding to the entanglement with trained personnel and equipment. The Plan will also call for training of additional personnel if necessary, and equipping of those additional teams as needed.

The marine mammal conservation issues described above are the product of direct, human-caused mortality and injury. Looking to the future, there are likely to be a number of additional and possibly greater problems due to anthropogenic contaminants and habitat degradation and loss.

For example, both direct exposure and indirect exposure -- through the food chain -- to potentially harmful environmental contaminants is likely to increase as the human population and urban development increase, unless more effective steps are taken to limit both point and non-point source environmental contamination (i.e., limit the types and quantities of potentially hazardous substances allowed to enter rivers, estuaries, and the ocean through sewage outfalls and runoff of herbicides, pesticides, etc. from land).

In some areas, noise from commercial, recreational, and military vessels, offshore dredging and construction, and use of acoustic devices to try to keep pinnipeds and cetaceans away from aquaculture facilities and fishing nets interfere with cetacean communications and cause some species of pinnipeds as well as cetaceans to abandon or avoid traditional feeding areas, breeding/resting areas, and migratory routes (see, for example, Richardson *et. al.* 1995, Advanced Research Projects Agency 1995, and Strong *et. al.* 1995).

Further, terrestrial export of fertilizers and other nutrients may be causing or contributing to the development of toxic algal blooms and increasing the risk of marine mammals being exposed to naturally occurring biotoxins (Anderson and White 1989; Geraci et. al. 1989). Uneaten food pellets and fecal material from aquaculture facilities may create ideal environments for growth of bacteria, viruses, and other organisms that can infect and kill or debilitate marine mammals.

Increasing populations of harbor seals and gray seals, coupled with growth of the aquaculture industry in the Gulf of Maine, are resulting in increasing interactions and requests from industry representatives to authorize shooting or other measures to reduce fish loss and pen damage caused by seals. The increasing populations of harbor seals and gray seals, coupled with the decline in groundfish stocks in the Gulf of Maine, also has led some fisherman to conclude that there is a cause-effect relationship and to advocate culling seal populations to reduce competition with fisheries.

Research Recommendations:
- Almost nothing is known about the feeding habits and the food and other habitat requirements of marine mammals that inhabit the Gulf of Maine.

- Also, little is known about essential marine mammal habitats or the critical components of those habitats in the Gulf of Maine.

- Likewise, essentially nothing is known about how the various species and their critical habitat components have been and might be affected by point and non-point source pollution, commercial fisheries, and other human activities.

- Better information on the natural history and demography of marine mammals and their numerical and functional relationships with other components of the Gulf of Maine ecosystem is needed to develop an effective strategy for conserving the Gulf of Maine ecosystem as a whole, as well as its marine mammal constituents.

- Determine whether harbor porpoise will habituate to the acoustic signals produced by pingers attached to net strings and, if not, whether routine use of pingers would reduce incidental mortality to biologically acceptable levels and have no ill-effects on other species.

- Determine whether additional time/area closures under Amendment 7 are needed to ensure that the level of incidental take of harbor porpoises is not greater than can be sustained without causing the affected population(s) to be reduced or maintained below its (their) maximum net productivity level.

- To minimize the rish of making management decisions which will allow further depletion of the affected harbor porpoise population(s), or restrict fisheries unnecessarily, further studies also are needed to better determine -- (i) the size, productivity, and discreteness of the affected harbor porpoise population or populations; and (ii) the level, age-sex composition, and temporal and spatial distribution of incidental mortality throughout the range(s) of the affected population(s).

- Research needs for Northern right whales:
  a. continue and expand efforts to determine when and where right whales are most vulnerable to ship strikes and to alert transiting ships to avoid or exercise special care when transiting these areas;

  b. continue and expand efforts to locate and free right whales and humpback whales entangled in fishing gear; and

  c. conduct a review of available information to determine when, where, and in what kinds of fishing gear right whales and humpback whales are most likely to become entangled, and measures that might be taken to reduce the risk of entanglement (e.g., institute time/area closures to prohibit deployment of certain types of fishing gear at times and in places where right whales or humpback are likely to be present).

- Once adequate baseline data are obtained, surveys should be carried out at pre-determined intervals to detect and monitor trends in populations of concern. a). For example, the harbor porpoise population subject to incidental take in the sink- gillnet fishery in the Gulf of Maine should be surveyed at intervals no greater than three years, until there are adequate data to be confident that the population is increasing or has stabilized at or above its maximum net productivity level. b). Likewise, parts of the Years of the North Atlantic Humpback Whale (YONAH) Project, nearing completion, should be repeated at five- to ten-year intervals to ensure that there are no unexpected reversals in the recovery of this endangered whale population .

- To encourage thinking from an ecosystem perspective, the Working Group recommends that conceptual and mathematical simulation models should be developed and used to:
  a. help identify critical uncertainties and research needed to resolve critical uncertainties concerning the numerical and functional relationships among various ecosystem components; and
  b. help identify and evaluate the pros and cons of both past management practices and possible future management options.

- The Working Group noted that many different federal, state and provincial government agencies, and private institutions are conducting research and collecting and archiving data relevant to conservation of the various components of and the Gulf of Maine ecosystem as a whole. The Working Group further noted that there currently is not a central listing or directory indicating the types of research that have been and are being conducted or the types of data being compiled and archived by different organizations; or how the existing data can be accessed and used. The Group also noted that lack of any knowledge concerning the existence of, and how to access, data may mean that management policies and programs are not being based upon the best available data. Additionally, the Group noted that recent advances in electronic communications and geographic information systems (GISs) could be used to make existing data more accessible and useful.

- The Working Group recommends that, if not already underway, steps should be taken immediately to:
  a. develop and make available a directory listing relevant datasets being compiled and maintained by federal, state and provincial government agencies, and private institutions, and how those datasets can be accessed and used; and
  b. determine whether archiving, exchanging, and analyzing the various datasets might be enhanced through development of a common or coordinated geographic information system (GIS) (see, for example, Reynolds and Haddad 1990).

Management Recommendations:

- The Working Group concluded that high priority should be afforded to reducing the incidental take of harbor porpoise in fisheries in the Gulf of Maine and elsewhere in the range of the affected harbor porpoise population(s). Towards this end, the Working Group recommends that a Take-Reduction Plan should be developed and implemented as soon as possible.

- The Working Group emphasized that adaptive management and long-term monitoring programs, as well as basic research, are essential to resolve uncertainties and validate assumptions, and to detect unanticipated consequences of management policies and programs while they can yet be reversed. The Working Group also noted that monitoring programs must be sufficient to distinguish between natural and anthropogenic change. The Working Group concluded that available data must be evaluated, as a matter of priority, to:
  a. identify system variables most likely to change in detectable ways in response to human activities in the Gulf of Maine, adjacent watersheds, and adjacent ocean areas; and
  b. determine the experiments and long-term monitoring programs that would be most useful for resolving uncertainties and validating assumptions concerning the numerical and functional relationships among various ecosystem components and for detecting any unanticipated consequences of management [conservation] policies and programs.

- continued support of inshore disentanglement programs in the US.

- establishment of lines of communication and mechanisms for a similar quick response effort in Canada.

- support for offshore rapid-response rescue program in collaboration with USCG and DFO

- training and equipping of a team in Canada

- With regard to ecosystem simulation models, the Working Group recommends that critical data gaps, assumptions and uncertainties concerning system variables and links, and the possible consequences of incorrect assumptions and uncertainties concerning those variables and links, should be identified clearly and called to the attention of the individuals and organizations responsible for deciding conservation management policies and practices.

Birds

Introduction

Table 2 lists the species of waterbirds including seabirds, shorebirds, wading birds, and waterfowl which use the marine and/or estuarine environments of the Gulf of Maine for at least part of their life cycle.

Certain terrestrial birds use coastal islands and upland habitats along the shores of estuarine and marine waters. For example, islands and uplands adjacent to coastal wetland habitats are primary nesting habitats of the bald eagle, a threatened species, as well as ospreys. Both feed in the estuarine and marine environments of the Gulf of Maine. Other neotropical birds use terrestrial habitats associated with islands and coastlines and feed in estuarine and marine wetland habitats. Terrestrial birds were not considered by the Working Group.

Several species of waterbird are of special concern in the Gulf of Maine because of their very reduced populations, and have been designated an endangered or threatened species by Federal and State governments. These "listed" species include roseate terns, piping plovers, least terns (state listed only), and harlequin ducks.

Other species or groups of species of waterbirds are of concern for management in the Gulf of Maine because of widespread threats to nesting, feeding and/or roosting areas. These include seabirds, wading birds, waterfowl and bald eagles which nest on islands in the Gulf of Maine. They are of concern because of threats to their island breeding habitat due to development and disturbance. A relatively small number of islands support a large percentage of these species' populations in the Gulf of Maine. The loss of a major breeding colony could have significant effects on a species' population in the Gulf. The Great Auk, a flightless seabird extinct in the Gulf of Maine since the last century, is a testament to the vulnerability of island nesting seabirds.

Nature of the Problem

Principal current threats to waterbirds and fowl in the Gulf of Maine are human disturbance in feeding, roosting and nesting areas, and damage and destruction of such essential habitats as a result of recreational use and development (homes, piers, boat houses, etc.) (S. Fefer, this workshop). In some areas, increasing levels of environmental contaminants from river discharge, land based run-off, oil spills, and sewage disposal may affect survival and productivity (Nisbet 1994, Pearce *et. al.* 1979). In some areas, seabirds are caught and killed incidentally in gillnets, or entangled and killed in discarded net fragments and other types of persistent marine debris (Brown and Nettleship 1984, Nisbet 1994). Artificially large populations of gulls are a threat to other species, particularly terns and alcids, which gulls prey upon or compete with for nest sites. In addition, competition for prey with humans is a continuing threat to seabird populations in the Gulf of Maine. The interactions of capelin and seabirds in the Northwest Atlantic, and sand lance and seabirds in the Massachusetts and Cape Cod Bays within the Gulf of Maine, have been described (Brown and Nettleship 1982, Veit and Peterson 1993). Dragging in intertidal and subtidal areas may effect food availability in important migrating and wintering habitats. Disturbance of nesting colonies of waterbirds, where in close proximity to large aquaculture operations, may be of growing concern (S. Fefer, this workshop). Large oil spills have had catastrophic effects on seabird populations.

Status of Knowledge

Of special note are the four species of nesting terns (common, arctic, roseate and least). Roseate terns are the rarest of the North American marine terns. Their population has declined dramatically during this century. The hunting of this species on its wintering grounds, disturbance/destruction of nesting habitat on islands, nest site competition with gulls and gull predation have played a role in the decline of roseate and other terns (Buckley and Buckley 1981, Kress *et. al.* 1983).

Leach's storm petrel, a procellarid with small burrow nesting has suffered from the introduction of cats, rats, and other ground nesting predators on islands (Drury 1973-74). Piping plovers and least terns are beach nesting species that declined in the beginning of this century due primarily to hunting. Since 1918, shooting of these has been prohibited. Habitat loss and degradation, disturbance by humans and pets, and increased predation are cited causes of the downward trend that began in the 1940's and continues to the present time.

Greater black-backed and herring gull populations have increased significantly in the Gulf of Maine as they have throughout their range in North America and Europe. Legislation protecting gulls and the ready availability of anthropogenic waste as food, facilitated observed increases. Garbage dumps and wastes from inshore fisheries are the most important sources of supplementary food. These gulls, however, compete with other species of seabirds for nest sites on islands throughout the Gulf of Maine and prey upon seabirds resulting in a serious threat to other species including terns and the Atlantic puffin (Nettleship 1972, Drury 1965, 1973-74).

Large numbers of shorebirds depend on coastal habitats of the Gulf of Maine for feeding and resting during their long migration from the Arctic breeding grounds to South American wintering areas. Shorebirds including semipalmated plovers and sandpipers, dowitchers, black-bellied plovers, and ruddy turnstones often concentrate in relatively small areas which make them especially vulnerable to habitat disturbance and contamination. In the Bay of Fundy, Canada has established National Wildlife Areas in several locations recognized as "internationally significant" because of their use by migratory shorebirds. However, disturbance of feeding and roosting birds and habitat destruction remain a problem for maintenance of shorebird habitat throughout the Gulf of Maine.

The red-necked phalarope has been an abundant migrant shorebird within the Gulf of Maine. The waters in the mouth of the Passamaquoddy Bay traditionally have supported an estimated one-half to two million phalaropes annually (Morrison 1977), though in recent years this sized congregation has not been observed. The status of this population, and the causes of these distributional changes, is not known.

Generally, waterfowl populations in the Gulf of Maine have declined since mid-century due primarily to continual loss of wetland habitats. Declines of black duck populations, measured by mid-winter waterfowl surveys since the 1950's, are of special concern in the Gulf of Maine. Recent surveys indicate relatively stable wintering populations within the Gulf of Maine. However, habitat alteration throughout its breeding and wintering range has affected these duck populations. Coastal areas of the Gulf of Maine including Cape Cod provide essential habitat for black ducks during migration wintering periods. Other waterfowl for which coastal habitats in the Gulf of Maine are especially important and whose populations may be in continuing decline include surf, white-winged and black scoters, and a U.S. candidate endangered species, the harlequin duck, which winters in nearshore marine habitats of the Gulf.

Research Recommendations

- Research is needed to determine what, how, and at what levels anthropogenic contaminants may affect the survival and productivity of birds, particularly those that feed in those estuarine and nearshore areas, that are part of the Gulf of Maine ecosystem.

- Additional research is also needed to obtain accurate estimates of species and numbers of birds killed or injured incidental to commercial fisheries, as well as by entanglement in, and ingestion of, marine debris in the Gulf of Maine. (see Wolfe 1987 and Laist, in press, and Pearce, 1995, for a more complete description of the types of conservation problems caused by lost and discarded fishing gear and other kinds of marine debris).

- Additional studies are needed to determine feeding habits, dietary requirements, principal prey species, and principal feeding areas of the various bird species that are part of the Gulf of Maine ecosystem.

- Long-term monitoring of essential habitats and habitat components, as well as observations of abundance and annual production (for nesting species), is necessary to detect and determine likely causes of future population changes and trends. Further, fisheries managers should take into account the food requirements and feeding ranges (locations) of seabirds when developing fishery management plans for important seabird prey species.

Management Recommendations

- To restore and maintain healthy populations of seabirds, shorebirds, wading birds, waterfowl, and eagles that are part of the Gulf of Maine ecosystem, essential nesting, feeding, and roosting habitats must be protected. Further, disturbance of nesting, roosting, and feeding birds must be minimized. Garbage dumps and other artificial sources of food responsible for the increases in gull populations should be eliminated in areas where gulls are displacing or otherwise impacting populations of other birds. Seabird restoration programs on islands in the Gulf of Maine should be continued and expanded to restore populations of nesting birds (e.g., roseate terns, Atlantic puffins, and garnets), to increase their distribution to historical levels, and decrease their vulnerability. Restoration efforts such as those of the partner organizations of the Gulf of Maine Tern Working Group should be continued and expanded.

- Conservation of important on-land nesting sites, roosting sites, and adjacent buffer areas will require continuation of the protection now afforded to such sites, additional land acquisition, and restriction of activities carried-out in and near such sites. Depending upon the specific situation, this will require voluntary protective measures by land owners and/or leasing or purchasing of land by private conservation groups, or local, state, and federal government agencies.

- Reducing disturbance of birds in nesting, roosting, and feeding areas will require continuing education programs to increase public awareness of the causes and possible consequences of disturbance. In many cases, it will require limiting public access to avoid nesting, roosting and feeding areas at those times of the year when birds are present or particularly vulnerable to disturbance.

- Fisheries managers should consider the food requirements of seabirds and availability of food for seabirds when developing fishery management plans for prey species.

Sea Turtles

Introduction

Four species of endangered sea turtles, the leatherback, loggerhead, Ridley, and green, have been seen and are caught occasionally in fishing gear in the Gulf of Maine. Live turtles sometimes are found on beaches suffering from cold shock. The fact that finding turtles suffering from cold shock is not an extremely rare event, while seeing and catching turtles incidentally in commercial fisheries in the Gulf of Maine are relatively uncommon, suggests that the Gulf of Maine is near or at the northern margin of each species' range and by and large the critical conservation problems are outside the Gulf.

The leatherback is the most common sea turtle in the Gulf of Maine. It builds and lays eggs in nests on remote beaches in the Caribbean. Adults move north in the spring along the Gulf Stream edge as far as the Grand Banks. Unknown numbers of adults forage, mainly on jellyfish, in the Gulf of Maine during the summer and early fall. Leatherbacks are commonly taken in pelagic longline fisheries along the Gulf Stream edge, although they are usually released with only a hook injury. This fishery does not take place in the Gulf of Maine. Leatherbacks often become entangled in fixed gear along the southern Gulf of Maine in the fall as they migrate south along the coast. Lobster gear is the main fixed gear involved. This entanglement phenomenon continues in a progression south along the East Coast to New Jersey.

Status of Knowledge

Not enough is known about the movement patterns, feeding habits, or food requirements of the leatherback turtle to determine whether any part of the Gulf of Maine may be critical to the survival and recovery of the species. Incidental take in commercial fisheries in the Gulf of Maine does not appear to be common or a significant threat to the species. Incidental take in fisheries elsewhere in the species' range is a greater problem. Destruction of nesting beaches and the illegal collection of eggs and killing of animals when they are ashore for nesting appear to be the greatest threats to all species.

The National Marine Fisheries Service and the Fish and Wildlife Service have developed recovery plans for all the endangered sea turtles that occur in areas under U.S. jurisdiction.

Research Recommendations:

- Determine the movement patterns, feeding habits and food requirements of the leatherback turtle in order to determine whether any part of the Gulf of Maine is a critical habitat for this species.

- Investigate how leatherbacks may be attracted to and entangled in lobster gear.

Management Recommendations

- Develop and implement mitigation measures to prevent the entanglement of leatherback turtles in fixed fishing gear.

Anadromous Fish Species

Introduction

One endangered fish species, the shortnose sturgeon, occurs in several of the larger rivers that empty into the Gulf of Maine. This species occurs in other major rivers along the U.S. east coast, south to Florida. Presumably it rarely ventures into the sea. In the St Johns River, the northernmost limit of species' range, a large population was last assessed in 1970's. In the Penobscot River, one fish was landed in a fishery; the population size is not known, while two seasons of research at Bangor caught nothing, (the status is uncertain). In the Kennebec/Androscoggin Rivers, a large population was last assessed in the early 1980's, while recent surveys at spawning sites found large numbers of spawning adults. Surveys were done in five New Hampshire rivers of the Great Bay System, in the late 1980's with no results. The Merrimack River had a small population (<100) in early 1990's.

Another fish, the Atlantic sturgeon (ATS), is a candidate for inclusion on the U.S. List of Endangered and Threatened Species. It is often found in the same rivers as the Shortnose Sturgeon, but little assessment data is available. Spawning, egg/larval development, and juvenile life stages take place in freshwater. Adults live in the lower portion of the river and spend considerable time foraging at sea as adults.

The Atlantic salmon has been nominated for listing as threatened under the U.S. Endangered Species Act. They spawn in Gulf of Maine rivers, which represent the westernmost extent of this species' range. Egg and fry develoment takes place in natal streams, smoltification occurs in the second year and fish move to the ocean to continue two to four yers of development outside the Gulf of Maine in the North Atlantic. They return as adults to their natal streams with very low straying rates. Wild stocks considered under one DPS are found in the Dennys, Machias, East Machias, Pleasant, Narragauagus, Ducktrap, and Sheepscot Rivers. Uncertain stocks in Tunk Stream, Penobscot, and Kennebec are proposed for candidate species. Restoration is ongoing for non-protected stocks in the St. Johns, St. Croix, Penobscot, Androscoggin, Saco, Merrimack, Pawcatuck, and Connecticut Rivers.

In each case, the species is or may be endangered or threatened principally because of habitat degradation or loss (e.g., construction of dams which prohibit or restrict movement to and from critical spawning and feeding areas). With three exceptions, threats relate to management of the rivers emptying into the Gulf of Maine, rather than management of the Gulf of Maine or any of its constituent elements. Blockage of passage to historic spawning areas for salmon has caused extirpation in many rivers, and affects conservation efforts for remaining wild stocks as well as restoration efforts. Losses occur at upstream and downstream passage facilities. Long-standing salmon restoration efforts for major rivers has resulted in passage plans for dams. New hydro licensing cycle is bringing new considerations to the forefront. Poor success in ongoing restoration efforts is making managers question the validity of restoration plans.

Changing flow conditions affect Shortnose Sturgeon spawning immediately below dams, although the ESA allows special consideration of concerns for Shortnose Sturgeon in dealings with FERC. Regular maintenance dredging is a problem with resident Shortnose Sturgeon species, and Atl sturgeon to a lesser extent. As with dams, the ESA allows special consideration of concerns for Shortnose Sturgeon in dealings with the COE. River-wide assessments have been conducted for some rivers, with specific seasonal restrictions in place.

Agricultural and forestry practices may affect ATS spawning habitat, but Status Review finds this to be a low priority factor in the DPS coastal rivers.

Point sources exist in most large rivers, but not in the seven DPS rivers. Largely an issue with resident species such as Shortnose Sturgeon, and to a lesser extent with Atlantic sturgeon

(ATS). Each river has its own special contaminant problem. River-wide assessment of point source affects with five-year NPDES permit reviews of each watershed are being explored by EPA.

One of the critical determinations in the Endangered Species Act (ESA) protection for Atlantic salmon is the designation of discrete subpopulations which may be associated with specific Gulf of Maine watersheds, but ESA protection to subpopulations requires adequate supporting knowledge of stock identification parameters. Since a number of Gulf of Maine watersheds (St. Johns, St. Croix, and Penobscot) are stocked with hatchery reared fish, there is also the issue of interaction between wild and cultured stocks, since the ESA only applies to the protection of wild species and not cultured species or hybrids between wild and cultured stocks. A similar problem may be encountered in salmon pen aquaculture operations in the Gulf of Maine which poses threats from potential disease transmission to wild stocks and genetic interactions with wild stocks. An added threat to wild Atlantic salmon stocks is that the adults or smolts may be the preferred prey of harbor and gray seals. Since these seal populations are increasing as a result of protection afforded under the Marine Mammal protection Act (MMPA), the seal predation may pose a threat to the recovery of Atlantic salmon populations. Not enough is known about the feeding habits of harbor and gray seals to judge the reality of this problem. The Canadian government allocates a quota on seal populations in the belief that these predators may inhibit the recovery of cod and haddock. There is controversy on the adequacy of the scientific evidence to support this policy.

Research Recommendations

- Population assessments have only been done once for most rivers for Shortnose Sturgeon, and in many cases have never been done for Atlantic's. A time series of assessments is necessary to determine population numbers and trends for responsible management or need for continued ESA protection.

- Stock differentiation should be completed for Shortnose Sturgeon as a priority, and eventually for Atlantic sturgeons to assist managers in the GOM.

- Addressing the genetic issues for the Atlantic Salmon will be a focus of the ESA listing process. Questions regarding the impacts of past stocking practices, and the role of ongoing and future restoration efforts in overall Atlantic salmon rehabilitation must be addressed.

Management Recommendations

- Major human affects from generic activities such as dredging and point source pollution control should be done on a watershed basis. This should be stressed for all GOM watersheds.

- NASCO protocols for genetic management, pen-siting and disease control should be implemented in US and Canada equally, and trade controls for imported fish should be considered. (GATT problem here).

Broader Ecosystem Considerations

In the course of its discussions, the Working Group identified a number of general principals or considerations that should be kept in mind and factored into the development of a long-term strategy for conserving the Gulf of Maine and its constituent parts. They are :

- Ecosystems are complex; understanding the numerical and functional relationships among key system components is essential to effective conservation of the system and its constituent parts;
- Both living and non-living resources are finite and cannot support increasing demands indefinitely;
- As a general rule, biological and ecological considerations must be given greater weight than socio-economic considerations and drive or constrain ecosystem management and resource use;
- Education is an essential part of conservation;
- Resource users (e.g., fishers and operators of whale-watching programs) have much knowledge of the resources and should be involved in determining research and management needs and priorities;
- Anthropogenic contaminants are of concern at all trophic levels. Studies are critically needed to determine the levels at which various contaminants may affect the survival or productivity of critical ecosystem components, both individually and collectively. Studies also are needed to determine whether effects occur gradually or at some threshold level;
- Marine mammals and seabirds that are long-lived apex predators may be good integrators and indicators of the types and levels of contaminants present in the ecosystem;
- Noise pollution from vessel traffic and other anthropogenic sources is of concern for marine mammals that use sound to communicate, to locate and capture food, or to sense their environment. Noise pollution and other forms of disturbance may also be problems for other species groups;
- Management programs should include appropriate experiments and periodic review and tuning (feedback loops);
- The institutions responsible for research and management should be given the resources necessary to meet their responsibilities. Their responsibilities should be articulated clearly;
- The data and assumptions upon which management policies and programs are based, and the possible consequences of data gaps, uncertainty and incorrect assumptions, should be made clear to the individuals and organizations responsible for formulating research and management policies and programs;
- Long-term monitoring programs should be designed and carried-out to verify assumptions and detect unanticipated consequences of management policies and programs. The monitoring programs should be sufficient to distinguish between natural and anthropogenic changes; and
- Based on past studies and data, research, monitoring, and management programs should have short-term (3-5 years), intermediate-term (5-20 years), and long-term (20+ years) goals and planning horizons.

Table 1

Marine Mammal Biota of the Gulf of Maine

Species	Stock area	Region	NMFS center	N_{min}	R_{max}	FR	PBR	Total ann. mort	Ann. fish mort.	stra-tegic status
North Atlantic right whale	Western North Atlantic	ATL	NEC	295	0.025	0.1	0.4	2.6	1.6	Y
Humpback whale	Western North Atlantic	ATL	NEC	4,848	0.04	0.1	9.7	1.0	1.0	Y
Fin whale	Western North Atlantic	ATL	NEC	1,704	0.04	0.1	3.4	N/A	0.0	Y
Sei whale	Western North Atlantic	ATL	NEC	N/A	0.04	0.1	N/A	0.0	0.0	Y
Minke whale	Canadian east coast	ATL	NEC	2,053	0.04	0.5	21	2.5	2.5	N
Blue whale	Western North Atlantic	ATL	NEC	N/A	0.04	0.1	N/A	0.0	0.0	Y
Sperm whale	Western North Atlantic	ATL	NEC	226	0.04	0.1	0.5	1.6	1.6	Y
Dwarf sperm whale	Western North Atlantic	ATL	NEC	N/A	0.04	N/A	N/A	N/A	N/A	Y
Pygmy sperm whale	Western North Atlantic	ATL	NEC	N/A	0.04	N/A	N/A	N/A	N/A	Y
Killer whale	Western North Atlantic	ATL	NEC	N/A	0.04	N/A	N/A	0.0	0.0	N
Northern bottlenose whale	Western North Atlantic	ATL	NEC	N/A	0.04	N/A	N/A	0.0	0.0	N
Cuvier's beaked whale	Western North Atlantic	ATL	NEC	N/A	0.04	N/A	N/A	34	34	Y
True's beaked whale	Western North Atlantic	ATL	NEC	N/A	0.04	N/A	N/A	34	34	Y
Gervais' beaked whale	Western North Atlantic	ATL	NEC	N/A	0.04	N/A	N/A	34	34	Y
Blainville's beaked whale	Western North Atlantic	ATL	NEC	N/A	0.04	N/A	N/A	34	34	Y
Sowerby's beaked whale	Western North Atlantic	ATL	NEC	N/A	0.04	N/A	N/A	34	34	Y
Risso's dolphin	Western North Atlantic	ATL	NEC	11,140	0.04	0.5	111	68	68	N
Pilot whale, long-finned (*Globicephala* spp.)	Western North Atlantic	ATL	NEC	3,537	0.04	0.4	28	109	109	Y
Pilot whale, short-finned	Western North Atlantic	ATL	NEC	457	0.04	0.5	3.7	109	109	Y
Atlantic white-sided dolphin	Western North Atlantic	ATL	NEC	12,538	0.04	0.5	125	127	127	Y
White-beaked dolphin	Western North Atlantic	ATL	NEC	N/A	0.04	N/A	N/A	0.0	0.0	N
Common dolphin	Western North Atlantic	ATL	NEC	3,233	0.04	0.5	32	449	449	Y
Atlantic spotted dolphin	Western North Atlantic	ATL	NEC	4,885	0.04	0.1	N/A	31	31	Y
Pantropical spotted dolphin	Western North Atlantic	ATL	NEC	N/A	N/A	N/A	N/A	31	31	Y
Striped dolphin	Western North Atlantic	ATL	NEC	9,165	0.04	0.4	73	63	63	N
Spinner dolphin	Western North Atlantic	ATL	NEC	N/A	N/A	N/A	N/A	1.0	1.0	N
Bottlenose dolphin	Western North Atlantic, offshore	ATL	NEC	9,195	0.04	0.5	92	128	128	Y
Harbor porpoise	Gulf of Maine, Bay of Fundy	ATL	NEC	40,297	0.04	0.5	403	1,876	1,876	Y
Harbor seal	Western North Atlantic	ATL	NEC	28,810	0.12	1.0	1,729	476	476	N
Gray seal	Northwest North Atlantic	ATL	NEC	2,035	0.12	1.0	122	4.5	4.5	N
Harp seal	Northwest North Atlantic	ATL	NEC	N/A	N/A	N/A	N/A	0.0	0.0	N
Hooded seal	Northwest North Atlantic	ATL	NEC	N/A	N/A	N/A	N/A	0.0	0.0	N

*Excerpted from Table 1 of the National Marine Fisheries Service's 25 August 1995 Federal Register notice announcing completion of final marine mammal stock assessment reports and guidelines required by the 1994 amendments to the Marine Mammal Protection Act.

Table 2

Common Seabirds, Shorebirds, Wading Birds & Waterfowl of the Gulf of Maine

Common Name	Taxonomic name
SEABIRDS	
Gaviiformes	
Common loon	Gavia immer
Red-throated loon	Gavia stellata
Podicipediformes	
Pied-billed grebe	Podilymbus podiceps
Red-necked grebe	Podiceps grisegena
Horned grebe	Podiceps auritus
Procellariiformes	
Northern fulmar	Fulmarus glacialis
Greater shearwater	Puffinus gravis
Sooty shearwater	Puffinus griseus
Manx shearwater	Puffinus puffinus
Leach's storm petrel	Oceanodroma leaucorhoa
Wilson's storm petrel	Oceanites oceanicus
Pelecaniformes	
Gannet	Morus bassanus
Great cormorant	Phalacrocorax carbo
Double-crested cormorant	Phalacrocorax auritus
Anseriformes	
Common eider	Somateria mollissima
Charadriiformes	
Pomarine jaeger	Stercorarius pomarinus
Parasitic jaeger	Stercorarius parasiticus
Skua	Catharacta skua
Glaucous gull	Larus hyperboreus
Iceland gull	Larus glaucoides
Great black-backed gull	Larus marinus
Herring gull	Larus argentatus
Ring-billed gull	Larus delawarensis
Black-headed gull	Larus ridibundus
Laughing gull	Larus atricilla
Bonaparte's gull	Larus philadelphia
Little gull	Larus minutus
Black-legged kittiwake	Rissa tridactyla
Common tern	Sterna hirunda
Artic tern	Sterna paradisaea
Roseate tern	Sterna dougallii
Least tern	Sterna albifrons
Black tern	Chlidonias niger
Razorbill	Alca torda
Common murre	Uria aalge
Thick-billed murre	Uria lomvia
Dovekie	Palutus alle
Black guillemot	Cepphus grylle
Common puffin	Fratercula artica

Common Name	Taxonomic name
SHOREBIRDS	
Semipalmated plover	Charadrius semipalmatus
Piping plover	Charadrius melodus
Killdeer	Charadrius vociferus
American golden plover	Pluvialis dominica
Black-bellied plover	Pluvialis squatarola
Ruddy turnstone	Arenaria interpres
American woodcock	Philohela minor
Common snipe	Capella gallinago
Long-billed curlew	Numenius americanus
WhimbrelNumenius phaeopus	
Upland sandpiper	Bartramia longicauda
Spotted sandpiper	Actitis maculariaa
Solitary sandpiper	Tringa solitaria
Willet	Catoptrophorus semipalmatus
Greater yellowlegs	Tringa melanoleucus
Lesser yellowlegs	Tringa flavipes
Red knot	Calidris canutus
Purple sandpiper	Calidris maritima
Pectoral sandpiper	Calidris melanotos
White-rumped sandpiper	Calidris fuscicollis
Baird's sandpiper	Calidris bairdii
Least sandpiper	Calidris minutilla
Dunlin	Calidris alpina
Short-billed dowitcher	Limnodromus griseus
Long-billed dowitcher	Limnodromus scolopaceus
Stilt sandpiper	Micropalama himantopus
Semipalmated sandpiper	Calidris pusillus
Western sandpiper	Calidris mauri
Buff-breasted sandpiper	Tryngites subruficollis
Marbled godwit	Limosa fedoa
Hudsonian godwit	Limosa haemastica
Ruff	Philomachus pugnax
Sanderling	Calidris alba
Red phalarope	Phalaropus fulicarius
Wilson's phalarope	Steganopus tricolor
Red-necked phalarope	Phalaropus lobatus
American oystercatcher	Haematopus palliatus
Clapper rail	Rallus longirostris
Virginia rail	Rallus limicola
Sora rail	Porzana carolina
Common moorhen	Gallinula chloropus
American coot	Fulica americana

Common Name	Taxonomic name
WADING BIRDS	
Breeding residents	
Great blue heron	Ardea herodias
Green heron	Butorides striatus
Least bittern	Ixobrychus exilis
American bitten	Botaurus lentiginosus
Black-crowned night heron	Nycticorax nycticorax
Snowy egret	Egretta thula
Non-breeding residents	
Little blue heron	Egretta caerulea
Cattle egret	Bubulcus ibis
Great egret	Casmerodeus albus
Louisiana heron	Hydranassa tricolor
Yellow-crowned night heron	Nycticorax violocea
Glossy ibis	Plegadis falcinellu
WATERFOWL	
Resident Waterfowl	
American black duck	Anas rubripes
Mallard	Anas p. platyrhynchos
Common goldeneye	Bucephala clangula
Common eider	Somateria mollissima dresseri
Hooded merganser	Lophodytes cucullatus
American merganser	Mergus merganser
Canada goose	Branta c. canadensis
Mute swan	Cygnus olor
Breeding Resident	
Wood duck	Aix sponsa
Ring-necked duck	Aythya collaris
Blue-winged teal	Anas discors
Green-winged teal	Anas crecca carolinensis
Northern Pintail	Anas acuta
American wigeon	Anas americana
Wintering Waterfowl	
Greater scaup	Aythya marila
Bufflehead	Bucephala albeola
Old squaw	Clangula hyemalis
Harlequin	Histrionicus histrionicus
King eider	Somateria spectabilis
White-winged scoter	Melanitta deglandi
Surf scoter	Melanitta perspecillata
Black scoter	Melanitta nigra
Red-breasted merganser	Mergus serrator
Barrow's goldeneye	Bucephala islandica

Common Name	Taxonomic name
WATERFOWL	
Migrant Waterfowl	
Whistling swan	Olor columbianus
Brant	Branta bernicla brota
White-fronted goose	Anser albifrons
Lesser snow (blue) goose	Chen c. caerulescens
Greater snow goose	Chen caerulescens atlanticus
Gadwall	Anas strepera
Northern Pintail	Anas acuta
European wigeon	Anas penelope
American wigeon	Anas americana
Northern shoveller	Anas clypeata
Canvasback	Aythya valisineria
Redhead	Aythya americana
Lesser scaup Aythya affinis	
Ruddy duck	Oxyura jamaicensis
Fulvous whistling duck	Dendrocygna bicolor

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Appendix A

White Paper

WHITE PAPER
Health of the Gulf of Maine Ecosystem:
Cumulative Impacts of Multiple Stressors
Dartmouth College, September 18-20, 1995

The U.S. Congress has mandated that a regional Workshop be convened to assess human-caused factors affecting the health and stability of the Gulf of Maine ecosystem, of which marine mammals are a part. This workshop will be convened by the Regional Association for Research on the Gulf of Maine on September 18-20, 1995. The following white paper was written to help set the stage for the Workshop. It lays out in very broad terms some things we know and do not know about human effects on the Gulf of Maine, and expresses some underlying assumptions, particularly with regard to the need for the involvement of all stakeholders, that will be important to bear in mind during the Workshop discussions.

The Gulf of Maine is a relatively well-studied body of water that is less severely affected by human activities than some coastal areas around the world. Nevertheless, human activities have altered the habitat, sometimes drastically. Boston and Salem Harbors are among the most polluted in the United States. Heavy fishing pressure has led to dramatic declines in groundfish stocks. Increasing development along the coasts has diminished habitat necessary for juvenile fish and diadromous fish such as Atlantic salmon. Agriculture, fossil fuel consumption, and population growth have increased the amount of nutrients entering the Gulf through runoff and atmospheric deposition.

The growing human use of the Gulf of Maine and its surrounding watersheds raise concerns that such events will become more common and more severe in the future unless there is a commitment to wise stewardship. Although human-caused impacts are often recognized easily in the Gulf of Maine, their effects are rarely well understood. For, example, nutrient over-enrichment can be measured, but its consequences are unclear. It is suspected to have several undesirable effects, including increased incidence and persistence of toxic phytoplankton blooms ("red tides") and alterations in the composition of the phytoplankton community, resulting in changes to the structure and productivity of the food chain. In addition, the introduction of sewage sludge and industrial wastes with heavy metals and organic contaminants into the Gulf have the potential of affecting the health and development of economically valuable fish stocks, but the magnitude of this effect is unknown. Declining groundfish stocks are associated with large increases in dogfish and skates, but the interrelationships between the species are not understood, nor do we know what steps would return the ecosystem balance to the previous, more economically valuable state. Comparisons with other ecosystems, such as the Great Lakes, in which extensive efforts have been made to control human-caused affects may be instructive.

The biggest gap in our knowledge is an understanding of the cumulative and synergistic effects of the host of human-caused changes and natural variability within the ecosystem. Interactions among effects may be multiplicative rather than additive in nature. Many of the key questions about the Gulf of Maine ecosystem involve the intersection of biological processes, environmental conditions, and human activities as they relate to maintaining biological diversity. For example, we do not know the effects of otter trawling and shellfish dredging on benthic habitats that produce much of the prey for many commercially important fish species in the Gulf of Maine and provide habitats for early life history stages. Also, increased harvests of sea urchins, especially if coupled with changes in nutrient or pollutant levels, could have a significant effect on algae upon which the urchins feed, which, in turn could affect the survivorship of juvenile fish. Also, the effects of long-term climate change on the ability of fishery managers to restore overfished stocks to "normal" populations levels remains difficult to predict.

Despite the large body of scientific literature concerning the Gulf of Maine, the predictive capacity of scientific advice remains low. As with all large, complex systems, a primary problem is the lack of data about the system itself. Long-term programs of regular sampling of strategic variables are key to understanding the natural variation within the system and to establishing a baseline with which to compare the possible effects of further environmental degradation. Such long-term monitoring programs are difficult to carry out through traditional academic research programs, since the continuous gathering of routine data is not generally conducive to publishing papers at the "cutting edge" of science (although there are notable exceptions in this region). A commitment to long-term data gathering efforts will yield great future benefits, provided, of course, that the data sets are made available to the general public. Experimentally-based (process-oriented) studies to elucidate cause and effect relationships are also required, as are theoretical studies aimed at developing a conceptual framework of sufficient detail and accuracy that it will be useful for predictive purposes.

Funding and other resources (e.g., ships, aircraft, research and enforcement personnel) necessary to design and carry out an integrated and fully effective ecosystem conservation program have been, and are likely to remain, a major limiting factor. Furthermore, regardless of the level of funding, those dollars that are available may not be used as efficiently as possible. Also, existing data collected by the federal, state, and academic institutions in the region may not be fully used. Identifying sources of data and preparing data to be used in common with other sources are difficult but may pay large dividends in terms of increasing our understanding of the Gulf of Maine.

Management actions must be based on assessments of risks and benefits, which are particularly difficult to determine when the extent or effects of human-caused changes are unclear. In the absence of clear scientific advice, assessments are often entirely subjective and are rarely clearly expressed by stakeholders. The debate on the consequences of an activity and what precautions are prudent tend to reflect differing values and perceptions of risks and benefits. This kind of debate is difficult to resolve to the satisfaction of all stakeholders. It is important to realize, however, that science will never be the sole factor in making management decisions. Even if we understood the ecosystem completely and could predict with surety the effect of our actions, there would be debate as to the best uses of our resources.

Therefore, effective management can only occur when all the stakeholders have an opportunity for input into the decision-making process. Constructive exchanges of views between stakeholders require an acceptance of the fact that we have differing value systems, backgrounds and economic needs, and that these lead to differing views and priorities on how aspects of the ecosystem should be managed. Unless all interests are heard and considered, management cannot be fully successful.

The Gulf of Maine region has an unusually high caliber of scientific expertise and a high level of public interest and involvement in conservation and management issues. There are many opportunities for cross-disciplinary interactions on a scientific level and for constructive collaboration between interest groups, and there have been numerous workshops, conferences and symposia on the Gulf of Maine over the past two decades.

To the extent possible, the current Workshop should not duplicate past efforts and discussions. Its specific charge is to develop advice for Congress by identifying human-caused factors affecting the health and stability of the Gulf of Maine ecosystem and recommending a program of research and management to restore or maintain that ecosystem. The participants will include scientists, resource managers and representatives of user groups and environmental organizations. It is hoped that the diversity of viewpoints will lead to a positive synergism that will give a balanced, well-considered product. The first priority will be to identify issues and concerns, and then to refine and develop those issues and concerns to the extent that time allows. Given the time allowed and the complexity of the problems, it is unlikely that there will be consensus on all concerns, although the Report to Congress will try to identify those points where there is consensus and to explain the nature of the controversy where there is disagreement.

The specific terms of reference, as mandated by Sec. 20 of the Marine Mammal Protection Act, are as follows: "The goal of the workshop shall be to identify [human-caused factors affecting the health and stability of Gulf of Maine], and to recommend a program of research and management to restore or maintain that marine ecosystem and its key components that

(A) protects and encourages marine mammals to develop to the greatest extent feasible commensurate with sound policies of resource management;
(B) has as the primary management objective the maintenance of the health and stability of the marine ecosystems;
(C) ensures the fullest possible range of management options for future generations; and
(D) permits non-wasteful, environmentally sound development of renewable and nonrenewable resources."

On or before 31 December 1995, the Secretary of Commerce is to submit to Congress a report containing the results of the workshop, proposed regulatory or research actions, and recommended legislative action.

Appendix I of this paper contains a preliminary list of human-caused factors that may be affecting the Gulf of Maine ecosystem, together with a brief statement illustrating some of the concerns about these factors. The list was drawn largely from issues and topics identified by a working group that met on 3 May 1995 to prepare for the Workshop. It is not intended to be a complete list of the impacts of humans on the Gulf of Maine, nor are the descriptions following each factor meant to reflect fully the range of issues under that topic. Rather, this paper is intended as a "strawman" draft to generate ideas and discussion in order to help the Workshop meet the first part of its mandate. The Appendix does not include a discussion of research or management needs, as that was felt to be the province of the Workshop itself.

Appendix II contains a draft conceptual model of the Gulf of Maine ecosystem. The Workshop Steering Committee felt that it would be beneficial to develp a conceptual framework that could identify the critical scientific uncertainties and provide a rationale for management recommendations. Again, this is not intended to be a complete or definitive model. Instead, it is meant to provide a starting point in efforts to identify the key factors in the ecosystem and the effects of human-caused stressors on that system.

Participants are encouraged to draft and submit written additions or corrections to these Appendices and to submit suggestions for research or management programs. Persons unable to attend are encouraged to submit written comments to the Workshop Chairman through the Regional Association for Research on the Gulf of Maine.

APPENDIX I

Preliminary list of human activities affecting the Gulf of Maine

(Not necessarily in order of priority)

APPENDIX
Preliminary list of human activities affecting the Gulf of Maine
(Not necessarily in order of priority)

1. Dredging

Dredging creates and maintains appropriate dimensions within navigable waterways, turning basins, harbors, and marinas. Dredging projects in the coastal zone are diverse in purpose and in severity of effects. Effects of dredging include: (1) increased turbidity; (2) altered sediment structure; (3) disruption and direct removal (covering) of sensitive habitats (e.g., eelgrass beds, bivalve mollusk beds, and spawning and nursery areas) and associated biological communities; (4) modification of natural water circulation patterns; (5) disruption of catadromous and anadromous fish migrations; and (6) resuspension of trapped nutrients, organic matter, and contaminants (including toxicants) from within the substrate. These in turn can affect living marine resources, especially early life-history stages and sessile forms.

Short-term effects on marine organisms include clogging and abrading gills and digestive organs, reducing light penetration, facilitating eutrophication, depleting dissolved oxygen (DO) supplies, and making heavy metals, pesticides, and other pollutants bioavailable by uncovering and suspending them in the water column. Toxic contaminants can accumulate in tissues of marine organisms, contributing to long-term, chronic, debilitating effects. Also, animals and plants can be displaced by excessive turbidity from dredging operations. If dredging and disposal are significantly curtailed or managed during sensitive life stages, adverse effects can often be minimized.

2. Use of Mobile Fishing Gear

There are a number of issues surrounding the use of mobile fishing gear such as trawls and clam and scallop dredges. First, there is often a large bycatch of unwanted species. In addition to the waste involved, there is a significant possibility that this would adversely affect the populations of incidentally-caught species, or change the composition of the community. Second, the degree of fishing for target species may exceed the capacity of those species to sustain a harvest. Third, dragging a large object over the bottom can change the benthic habitat and affect the species inhabiting the bottom, which could in turn change the composition or abundance of commercially valuable species. Likewise, churning up the bottom will cause at least temporary changes to the water column, as sediments and nutrients are re-suspended, and to the granulometry of the sea floor.

3. Use of Passive Fishing Gear

The use of passive fishing gear such as gillnets, longlines, and lobster traps often results in bycatch. Some types of gear entangle significant numbers of marine mammals, sea birds or turtles. As with other fishing gears, there are concerns that passive gear may also be taking more of some target species than is sustainable. Nets lost at sea often continue to entrap fish and endangered species for long periods, thereby adversely affecting the ecosystem without any economic benefit to humans.

4. Anadromous Fish Restoration

Diadromous fish in the Gulf of Maine are affected by numerous human-caused factors, including fishing, changes in water quality, changes in the river structure due to dams, increased erosion due to logging, waste discharges, or coastal development. In the United States, the Atlantic salmon were native to at least 34 rivers but naturally reproducing populations are now found in only seven. These populations do not appear to be self-sustaining. However, efforts are underway to protect the species and to assist in its recovery.

5. Pollution

A wide array of human activities increase pollution within the Gulf of Maine. Broadly speaking, these fall into two types -- "point source pollution", in which an identifiable location such as a factory, power plant or sewage treatment plant generate pollutants that enter the Gulf of Maine, and "non-point source pollution", in which the total pollutant level is the result of many sources, such as automobile emissions or run-off contaminated by fertilizers or pesticides used by homeowners and agriculture.

The term "pollution" covers a multitude of contaminants and a variety of potential problems. These include:

- nutrient loading and eutrophication: Inputs of nitrogen, phosphorus and other plant nutrients may be 10-50 times are great as in prehistoric times (Hinga et al. 1991) as a consequence of deforestation, sewage disposal, urban road runoff, fertilizer use, etc. Inputs are expected to continue to increase in the Gulf of Maine as demands grow in response to human population growth, as fields wear out and require greater amounts of fertilizers.

  There is considerable concern and some evidence that nutrient over-enrichment has resulted in several undesirable eutrophication effects in estuarine and coastal areas of the northeastern United States, including: (1) increased incidence, extent, and persistence of blooms of noxious or toxic species of phytoplankton. These blooms are associated with mortality or reduced productivity of economically or ecologically important marine species, as well as decreased fisheries harvests, sea food safety concerns, and reduced aesthetic value of coastal areas; (2) increased frequency, severity, areal extent, and persistence of anoxia and hypoxia, the condition of depressed concentrations of DO in bottom waters such as reported to occur during summer in Raritan-Hudson Estuary, western Long Island Sound, inshore New York Bight, and portions of Boston and Portland Harbors. Reduced oxygen results in mortality of benthic organisms, reduced growth and production of fisheries resources, and changes in resource distributions; (3) alterations in dominant phytoplankton species and size compositions, as well as in the nutritional-biochemical "quality" of the phytoplankton community, causing changes in structure, function, and productivity of the food chain culminating in the fisheries; (4) greatly increased turbidities of surface waters from planktonic algae leading to "shading" and consequent losses of bottom macrophytes such as eelgrass, to reductions in critical estuarine habitats for early life stages of fishes, and to reduced aesthetic appeal of recreational waters; and (5) viral/bacterial closures of inshore shellfish beds and swimming beaches.

° effects of toxic compounds: Humans generate a wide variety of toxic compounds, including heavy metals, pesticides, PCB's, and petroleum-based compounds, that have been shown to affect the health of individual fish and other marine and terrestrial species. The highest concentrations of chemical contaminants are to be found in coastal waters, especially near industrialized or heavily urbanized areas, and waste disposal areas. Such areas are also the spawning and nursery habitats for many important commercial fishes. The early life stages of these fishes are most susceptible to toxicants (Dethlefsen 1976; Mangor-Jensen and Fyhn 1985; Foyn and Serigstad 1988). Concerns have been expressed that high concentrations of toxic compounds may depress the immune system of marine mammals. It is difficult, however to attribute specific effects observed in the field to specific pollutants (Wolfe et al. 1982), and the overall effect of toxic compounds on the ecosystem or on any particular stock is not yet quantifiable. Contaminated fish and the fears of contamination have direct effects on the economic value of fish. The persistence of many of these compounds in the marine ecosystem is also unknown.

6. Sewage sludge and industrial waste dumping

Offshore disposal of domestic and industrial wastes normally involves barging sludge (solids that settle during sewage treatment) and either containerized or non-containerized industrial wastes to a designated, regulated site to dump. There are no designated sewage sludge dumpsites and only one designated industrial waste dumpsite in the Gulf of Maine. However, there are probably other, non-designated, unregulated sites in the Gulf of Maine where industrial wastes have been dumped. Given the multiple sources of contaminants (including discharge from combined sewer overflows, storm water discharges and liquid wastewater effluents, atmospheric deposition, and ocean dumping of industrial wastes), it has been difficult to isolate a specific cause-and-effect relationship between discharge of sludge and effects to the Massachusetts Bay/Cape Cod Bay ecosystem and its living marine resources, although Boston Harbor winter flounder livers exhibited a greater prevalence of neoplasms in the past and still have high levels of pre-cancerous lesions. A NOAA study of the 12-mile dumpsite in the New York Bight has shown an increase in lobster in the area after cessation of dumping in 1987 as well as a 50% decrease in benthic macrofaunal biomass (Reid et al., in review).

7. Seabed Mining for Sand and Gravel

Mining of the seabed for sand and gravel is usually done by surficial scraping or point excavation of materials to some greater depth. Suction dredges generally are used to lift materials to receiving barges. Environmental effects of such removal include: (1) "destruction" of existing benthic biota; (2) resuspension of fine sediments with subsequent effects on larval, juvenile, and/or adult fish or juveniles and larvae; (3) changes in profiles or surfaces of mined areas; and (4) consequences of entrained fine materials being carried tens of kilometers from the dredging site. Development of deep excavation or "borrow" pits can lead to depressions that later become anaerobic during certain periods of the year, with attendant effects on fish (Pacheco 1983). In many areas of the Gulf of Maine and in the New York Bight, there is concern that mining in one area may affect fish eggs, demersal larvae, juveniles, and adults some distance away.

8. Over-capitalization of the Fishing Fleet

Irrespective of the specific effect caused by the type of gear, there is evidence that the fishing pressure on a number of species is unsustainable--there are "too many boats chasing too few fish". Current methods of controlling harvests have had only limited success. The collapse of the groundfish stocks on George's Bank is the best known example in the Gulf of Maine, but over-fishing for scallops, bluefin tuna, swordfish and other species has also occurred. The decline in stocks of commercially important fish raises immediate economic issues and long-term ecological questions. Recent increases in spiny dogfish and skates correlated with declining groundfish stocks raise questions about the trophic interactions with the marine food chain and whether the gadoids and flounders can recover their former predominance. Further, the ecosystem effects of shifting fishing effort to these less-harvested species cannot be predicted. Such an effort might help restore finfish stocks or it might lead to yet another set of dominant species.

9. Coastal Urbanization

Tremendous development pressures exist throughout the coastal Northeast. Construction in and adjacent to waterways often involves dredging and/or filling activities which elevate suspended sediment levels. Excessive turbidities can abrade epithelial tissue in marine organisms, clog gills, decrease egg buoyancy, and reduce light penetration, thereby affecting photosynthesis and causing localized oxygen depressions. Suspended sediments may subsequently settle to the benthos and destroy or degrade productive bivalve mollusk beds, forage areas, and spawning sites such as eel grass meadows. Often, but not always, effects of turbidity and siltation are temporary and short-term (U.S. Department of Commerce 1985).

Accompanying the increased development of estuarine and coastal areas is the demand for potable, industrial, receiving, and cooling waters necessary for ever-increasing wastewater treatment and disposal, community development, industrialization, and electric power. Demands increase as groundwater becomes depleted or contaminated, and as freshwater is diverted via dam and reservoir construction, canals, or other methods. Reduced flows to estuaries can reduce nutrient levels and increase salinity, and thus decrease overall diversity and productivity of estuarine systems. Moreover, reduction of nutrient-rich oxygenated water in a large estuary can lower significantly the biological productivity of large areas of coastal water normally exposed to the seaward-flowing estuarine plume (Chambers 1991).

Water not lost through domestic and industrial consumption is returned to rivers as point-source wastewater discharges. Although generally treated, domestic discharges often contain suspended organic and inorganic compounds (including chlorine compounds), heavy metals, nutrients, and bacteria. Sewage treatment effluents produce local changes in biological communities due to chlorination and increased contaminant and organic loading. In addition to creating thermal plumes, industrial discharges may contain dissolved and suspended contaminants, including nutrients, heavy metals, halogenated hydrocarbons, petroleum products, and other organic substances. The EPA regulates industrial wastewater effluent through NPDES permits as a means of identifying, defining, and, where necessary, controlling point-source discharges. However, it is difficult to estimate the singular, additive, and synergistic effects of industrial and domestic wastewater discharges on estuarine and coastal habitats. Effects are cumulative and are the hallmark of intensively or extensively developed urban communities.

Associated with urban development are inevitable increases in nonpoint-source contamination of estuarine and coastal waters. Highways, parking lots, and removal of terrestrial vegetation and fringe marshes facilitate runoff of soil, fertilizers, biocides, heavy metals, grease, oils, PCBs, and other harmful materials. Atmospheric emissions from industrial processes may contain sulphurous and nitrogenous compounds that contribute to acid precipitation, a concern in some freshwater sections of tidal streams, and are also a source of lead, Mercury, PCB's and PAH's produced by combustion. Moreover, components of these nonpoint pollutants accumulate in water, sediments, and marine biota (U.S. Department of Commerce 1985).

10. Energy Production and Transport

Energy production facilities are widespread along Northeast coastal areas, and include land-based nuclear power plants, hydroelectric plants, and fossil fuel stations. Effects of these facilities on estuarine and coastal habitats include water consumption, heated-water discharges, temperature variations and thermal shock, entrainment (in cooling systems) and impingement (on intake screens) of organisms (especially of larvae and juveniles), discharges of heavy metals and biocides, destruction and elimination of habitat, and disposal of dredged materials and fly ash (U.S. Department of Commerce 1985).

11. Ocean Drilling

Although Congressional action has precluded outer continental shelf energy exploration in the most productive fishing grounds in the Northeast, future drilling, transport, and production facilities could affect biota and their habitats. These impacts could occur through deposition of drilling muds, cuttings, and other materials. Oil spills resulting from well blowouts, pipeline breaks, and tanker accidents remain a major concern. Seismic testing operations can interfere with fishing operations and damage or destroy fishing gear.

12. Agricultural Operations

Agricultural operations can affect fish habitats directly through physical alterations, and indirectly through chemical contamination and erosion and transport of suspended matter. Fertilizers, herbicides, insecticides, and other chemicals are carried into the aquatic environment via nonpoint-source runoff from agricultural lands. Such runoff can affect aquatic vegetation directly which will, in turn, affect the food web. Agricultural runoff also transports sediments and animal wastes which can affect spawning and nursery areas, and degrade overall water quality and benthic substrata.

One of the most serious consequences of erosional runoff is that it necessitates frequent dredging of navigational channels. The resulting dredged material requires disposal, often in areas important to marine biota (U.S. Department of Commerce 1985). This is of special consequence if high levels of contaminants become mixed with the sediments.

13. Coastal and Wetland Use and Modification

Increased demand for land suitable for homesites, resorts, ports and marinas, beach clubs, and industry has destroyed or altered large areas of New England's estuarine and coastal wetlands and subtidal habitats through dredging, filling, diking, bulkheading, ditching, erosion, and other forms of shoreline modification. As residential and commercial uses of estuarine and coastal lands increase, so does the recreational use of adjacent waters. Marinas, public access landings, private piers and beaches all vie with fish and other wildlife for space, and encroach upon essential, sensitive estuarine and coastal habitats.

Competing uses further contribute to destruction or modification of wetlands. Agricultural development, including wetland drainage to increase tillable acreage, can significantly affect wetlands. Flood control measures in low-lying coastal areas, including dikes, ditches, and stream channelization can also significantly affect wetlands. Wildlife management techniques that modify wetland habitats, such as construction of dredged ponds and low-level impoundments, can harm marine fishes since such freshwater habitats do not replicate the brackish or saltwater habitats they replace.

Each coastal state, as well as the Army Corps of Engineers (COE), regulates projects proposed for wetlands. Although these regulations have to some extent ameliorated wetland modification and destruction, construction that is judged to be in the public interest or to be water-dependent continues, as does illegal, unauthorized construction. Primary threats associated with such construction activities (e.g., agricultural runoff) have been discussed earlier in this section.

14. Aquaculture

Aquaculture holds the potential of supplying large and predictable high-quality protein at reasonable costs. However, unnaturally crowded conditions in aquaculture pens can lead to increased rates of disease, which can be transmitted to free-swimming populations. Individuals bred for captivity may escape, mixing their genes with animals selected for survival in the wild. Also, the constant addition of food and fecal material to a small area has at least local effects on bottom communities. Aquaculture nets may entangle marine mammals, and marine mammals may exploit the cultured species, affecting profits and increasing the marine mammal's reliance on artificial food sources.

15. Hydroelectric Dam Construction

Construction of dams changes sediment transport rates and usually decrease the amount of water flowing through downstream ecosystems. Changes in flow rates also affects the water temperature. Dams have had a major effect on the reproductive success of depleted Atlantic salmon, both through heavy mortality of young fish in water intake systems on the way downstream and through physical difficulties in bypassing the dam on their return to spawn.

16. Tidal Bore Power Schemes

Plans are being considered to develop and install large-scale machinery to harness power from the tidal fluxes in the northeast Gulf of Maine and Bay of Fundy area. There are concerns, however, that the equipment needed to do this could alter the physical habitat or could harm animals that come in contact with it.

17. Fish Waste Disposal

Dumping of wastes from fish and invertebrate processing operations generates much the same concern as sewage treatment effluent discharge and sewage sludge dumping. This concern includes increased biological oxygen demand (which may result in areas where oxygen levels are too low for some species to survive), algal blooms, and increased concentrations of pathogenic bacteria. Closure of land-based processing plants, because of their inability to meet federal (i.e., National Pollution Discharge Elimination System (NPDES)) or state pollution discharge effluent requirements, serves to enhance the appeal of at-sea disposal. While at-sea disposal of these wastes is exempt from regulation under the Ocean Dumping Act, the onus of proof of no environmental harm rests with the entity pursuing at-sea disposal.

18. Acoustic Pollution

The oceans are far noisier now than they have ever been. Sound travels much farther in water than in air, so much so that very loud sounds, if broadcast under the right conditions, can be heard around the world. These sounds, such as used in the Acoustic Thermometry of Ocean Climate (ATOC) experiment could theoretically damage the hearing of marine mammals if close enough. Also, the noise from ship engines, acoustic devices used to warn marine mammals away from nets, and other man-made sources can mask sounds that provide important biological cues. This may be particularly important for whales, which rely on long-distance acoustic communication for reproduction, navigation and other functions.

19. Vessel Impacts on Marine Mammals

Ships sometimes strike and kill large whales. This appears to be a major factor slowing the recovery of the highly endangered right whale. Whale watch boats may make it more difficult for the whales to find food or to communicate.

20. Marine Debris

Man-made materials discarded at sea cause a number of problems. Some species, particularly sea turtles, have died from ingesting plastic bags. Many species, including endangered marine mammals and seabirds, have become entangled in plastic six-pack beverage rings, packing straps, and other debris. Lost or discarded fishing nets or line may continue to "fish" for years.

21. At-Sea Fish Processing

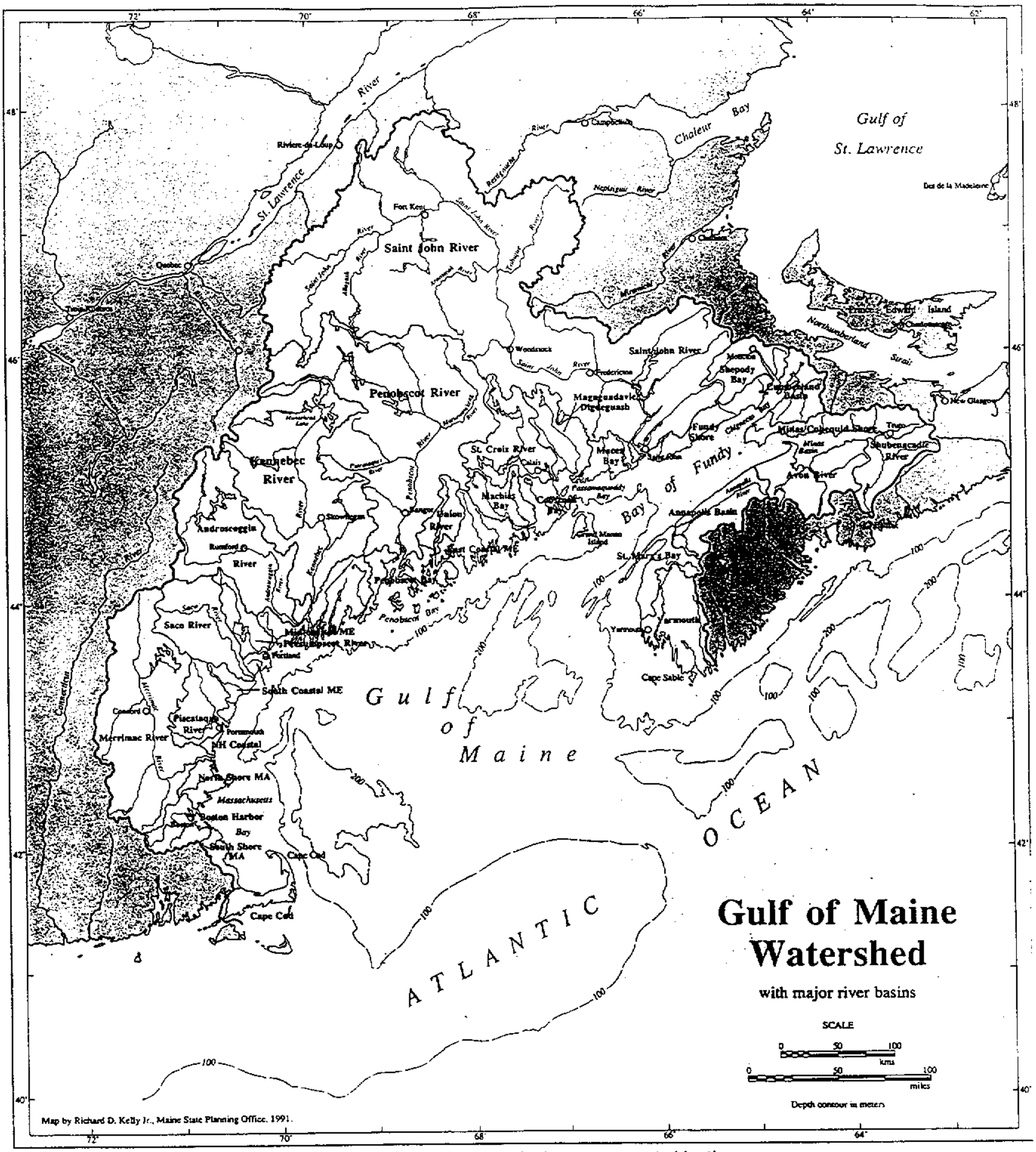
Waste from fish processed at sea is usually dumped back into the ocean. This minimizes the biomass extracted from the system, but may result in substantial changes in the species composition. Scavenger species may find food relatively abundant, while species that prey upon the fish may find a reduced food availability.

22. Exotic Species Impacts

The accidental or deliberate introduction of non-native species into an ecosystem can wreak havoc on the balance in the natural system. "Exotic" marine organisms can be carried from one area to another in the ballast tanks of vessels, attached to ships' hulls, or when two previously separate bodies of water are connected through canals. While non-indigenous species have not had the dramatic impact in the Gulf of Maine that has been seen in the Great Lakes with introductions of lampreys and zebra mussels, some historical invaders such as littorine snails and dog whelks are firmly established in the ecosystem.

23. Climate Change

Changes in climate could affect the physical characteristics of the Gulf of Maine such as water temperature, insolation, wind speed and circulation patterns. Such changes would have an impact on virtually all aspects of the ecosystem, from the species composition to the spawning times, larval migrations and growth curves of the inhabitants. Warmer air temperatures could lead to stronger thermoclines and reduced mixing of nutrients and reduced productivity. Increased wind stress could lead to increased turbulence in the upper waters. Increased evaporation and rainfall would change run-off and erosion rates, thereby changing estuary structures. If sea level were to rise rapidly, this could lead to substantial loss of wetlands.



The Gulf of Maine Watershed map was created by the
Gulf of Maine Council on the Marine Environment Public Education and Participation Committee
and produced by Richard Kelly Jr.

Appendix II
Draft Conceptual Model of the Gulf of Maine Ecosystem

In order to manage the Gulf of Maine (GMe) ecosystem in a more integrated and sustainable fashion, the steering committee for the September 18-20, 1995 workshop felt that it would be beneficial to develop a conceptual framework that could identify the critical scientific uncertainties (basis for research recommendations) and provide a rationale for the management recommendations. In the enclosed first cut at a conceptual model the Gulf of Maine proper is divided into a coastal component (estuaries and state jurisdictional waters to the three-mile offshore limit) and open water/benthic environment component (pelagic and benthic system in the Federal jurisdictional waters, including Georges Bank, Stellwagen Bank, Browns Bank, etc.). The Gulf of Maine ecosystem is subject to forcing functions from the landward side (coastal watersheds) and the seaward side (far field open ocean out to the 200-mile Federal Exclusive Economic Zone boundary).

Within the coastal component and open water/benthic component within the Gulf of Maine proper we have identified the state variables in each system, as well as the processes that influence these state variables. The state variables in this generic conceptual model represent the standing stock (as population numbers or abundance level in terms of carbon, organic matter, energy units, or concentration of abiotic components in the appropriate units). The flow of materials, energy, or population numbers between components is related to the level of these factors within the state variable compartment, with the flow controlled either by the donor compartment or the recipient (or receiving compartment) levels of these factors. For example, if the demersal fish component controls the production of the hard substrate benthic invertebrates, then this would be an example of recipient compartment control. An example of donor compartment control might be dissolved inorganic nitrogen levels limiting phytoplankton production.

The processes list the various types of anthropogenic impacts that might influence either the state variable compartments themselves or the flows/exchanges between the state variable compartments. Since the coastal component is coupled with the offshore open water/benthic environment, there will be a two way interchange between these two parts of the Gulf of Maine proper. The processes that represent the system can either be manifested in a straight forward linear fashion (direct effects or indirect effects) or there might be feedback effects or cumulative impacts that impact the system in a nonlinear fashion. Thus the conceptual model indicates two way arrows for either potential nonlinear effects or joint donor/recipient compartment flow control, but this will not always be the case, if the dominant

processes operate primarily in a linear fashion or the flows between state variables are controlled either by donor or recipient control. For example, plankton/nutrient interactions often involve bottom-up nutrient concentration effects on phytoplankton community structure and top down selective predation effects of zooplankton on phytoplankton.
The watersheds on land and the far field oceanic system are primarily viewed as external forcing functions to the Gulf of Maine proper, even though one could develop separate conceptual models for each of these. The forcing function inputs are likely to be represented by one way arrows, but there are components, such as the anadromous/catadromous transport of fisheries in the coastal watersheds and the organismal dispersal and exchange with the far field ocean in which two way exchanges actually occur, and these are represented by net transport in the forcing function inputs. The net transport of anadromous/catadromous fish between the coastal watersheds and the Gulf of Maine proper is a function of the loss of breeding habitat in coastal rivers, impacts of dams on fish migration, and effects of chemicals (salt and acid rain) on freshwater quality, while this net transport is impacted in the marine system by fisheries harvesting, seasonal migrations, and natural predation. Similarly for the far field ocean the physical coupling of temperature, salinity, momentum or water transport is critical to the circulation within the Gulf of Maine proper, as is the riverine input of freshwater and the exchange heat and moisture from the atmosphere to the water in the Gulf of Maine. The external forcing functions provide a driving force to the state variables within the Gulf of Maine proper and supplement the impacts related to the anthropogenic processes that occur within the Gulf of Maine. Thus anthropogenic factors influencing the Gulf of Maine can emanate either from the internal processes or the external forcing functions.

The coastal habitats within the Gulf of Maine itself could be visualized either in terms of state variables for each type of habitat (wetlands, mud/sand flats, benthic hard and soft substrate systems, and pelagic community) or could be simplified to represent the habitat support value and nutrient/pollutant transport functions that link the coastal component to the open water/benthic environment. If one desired to examine the impacts of the forcing functions from the coastal watersheds directly on the coastal habitats, then one would have to develop sub-models for each of the coastal habitat types. However if one's emphasis was on the open water/benthic environment, the coastal habitats could simply be modelled in terms of their habitat support value and nutrient/pollutant transport functions. From a research perspective it would make sense to develop sub-models for both the coastal habitats and the offshore open water/benthic environments in the hopes of identifying the critical choke points in the system and identifying the potential impacts of anthropogenic factors on the resources in the Gulf of Maine proper. It is possible, however, that in developing management recommendations it might make sense for areas in which there is primarily either state or Federal responsibility to treat the system in a simplified fashion.

For example, most states conduct testing programs for red tide toxins in inshore shellfish and one might want to treat this separately from a management perspective from the red tide contamination of offshore sea scallops on Georges Bank, where the adductor muscles are generally not contaminated with biotoxins and there is only a seafood safety concern if tomales are harvested for consumption. The Federal government has a different management approach than does the states for dealing with biotoxin contaminated surf clams and ocean quahogs, so that from a management perspective these might also be addressed separately. Obviously for the management of fish stocks that occur both in state waters and in Federal jurisdiction waters, the management regimes need to be coordinated for successful management of commercial fishery resources and the coastal habitats and open ocean/benthic environments need to be explicitly addressed.

The other jurisdictional issue of concern in the Gulf of Maine are transboundary stocks of commercial fish species and marine mammals between the United States and Canada that migrate across the Hague line. Since Canada has a Total Allowable Catch management regime for fisheries while the U.S. uses a combination of area closures and gear restrictions, the two approaches are not compatible. The two countries have made progress towards joint enforcement and penalties for violations of the Hague line by fishers from either country. The Hague line has prevented many U.S. fishers from fishing in areas that they utilized historically, which has exacerbated tensions associated with fishing violations. There are still areas inshore of 50 fathoms southwest of Grand Manan Island and offshore east of 65.5 longitude where the U.S. and Canada have not resolved their border disputes. The scallop resources on the Canadian portion of Georges Bank have been especially contentious and have been the source of numerous violations by U.S. fishers, who fished in this area historically and have depleted many of the scallop resources available in U.S. coastal waters. Since both the U.S. and Canada have depleted their common groundfish resources (cod, haddock and yellowtail flounder), they will need to work jointly on rebuilding these transboundary stocks and developing a complementary management approach after these stocks have recovered.

Transboundary stocks of marine mammals and protected species are also an area in which Canada and the U.S. need to develop an integrated approach for managing these common resources. This may be difficult for marine mammals in which the U.S. Marine Mammal Protection Act (MMPA) prevents the intentional lethal killing of marine mammals (only allowing incidental takes of marine mammals in conjunction with commercial fishing activities), while Canada pursues a policy of harvesting seals in order to reduce the natural predation pressure on commercial fish populations in order to expedite the recovery of depleted groundfish stocks. There are some potential areas of cooperation, such as developing joint approaches to reducing the incidental take of harbor porpoises in the sink gillnet fisheries in the Gulf of Maine. Another area of potential interaction is rebuilding the populations of Atlantic salmon in the Northwest Atlantic Ocean. There has been joint efforts between Canada and the U.S. to protect migratory bird species, between the breeding areas in Canada and the winter feeding areas within the U.S. The grey seals and harp seals appear to be expanding their range from excess populations within in Canadian waters to re-establish colonies within U.S. waters in the Gulf of Maine. Sea turtles and many whales are seasonal migrants into the Gulf of Maine and thus may be impacted by anthropogenic activities occurring in the far field region.

Many of the anthropogenic impacts from pollution (either by nutrients or toxic chemicals) involve jurisdictional issues between the states and Federal governments within the U.S. (acid rain may be an exception to this, as an area of concern about U.S. impacts on freshwater areas in Canada). Much of the enrichment of coastal waters with nitrogen, phosphorus, carbon, and silicon come from point or non-point sources on land that reach the Gulf of Maine via coastal watersheds (an exception may be the nitrogen input into the Gulf of Maine through the Northeast Channel, which is a large oceanic source area). Many of the toxic chemicals enter the Gulf of Maine from coastal watersheds, with the atmosphere being an important source for polychlorinated biphenyls (PCBs), combustion-derived polynuclear aromatic hydrocarbons (PAHs), mercury, and lead. Since most of the point sources of pollution are in state waters and they receive national pollution discharge elimination system (NPDES) from the states and the U.S. Environmental Protection Agency (EPA), this is an area requiring integration between the states and Federal government in their management regimes. The states are required to develop plans to manage non-point pollution sources under the Clean Water Act and Coastal Zone Management Act which would seem to offer an opportunity for Federal/state integration, however there is no mechanism to develop enforceable state regulations to implement the state non-point pollution programs and their has been no Federal funding available to act as a carrot to encourage the state's to develop such an enforceable program.

The primary responsibility for dredge spoil disposal lies with the Federal government in the Gulf of Maine (through EPA and the U.S. Army Corps of Engineers, with the National Marine Fisheries Service providing comments in relation to fisheries habitat concerns). The states have a role in evaluating the impact of dredging projects on inshore habitats. Since the Federal government needs to provide an exemption for the offshore disposal of contaminated dredge spoils (which is a critical problem in many harbors in the Northeast), the state and Federal governments need to develop management strategies for handling contaminated dredge spoils.

Another area which requires joint state/Federal coordination is the impact of state projects (such as the Massachusetts Water Resources Authority's ocean outfall) on Federal endeavors (such as the Stellwagen Bank National Marine Sanctuary). The Coastal Zone Management Act requires the consistency of Federal projects with state CZM plans, but the state activities do not have to be consistent with all Federal policies in areas where the state's have primacy. For example, the Clean Water Act NPDES permit has requirements on the levels of chemicals that the MWRA outfall pipe can discharge into the mixing zone around the outfall pipe, but it does not contain criteria on the biological integrity in the receiving system (much of which is in Federal waters, including the Stellwagen Bank National Marine Sanctuary). Some concerns have been expressed in regards to the outfall pipe changing the planktonic community structure which is the key food source for the endangered Northern Right whale.

The Federal government is primarily responsible for resource use issues and pollution concerns in the Federal jurisdictional waters (open water/benthic environment in the conceptual model). These concerns include ship strikes of endangered whales; pollution from commercial shipping activities; impacts from overfishing (direct impact on targeted resources, impacts on the benthic environment from otter trawls and shellfish dredges, and indirect effects on the pelagic/benthic food chain-fishing activities removing top predators or key benthic prey); dredge spoil disposal impacts on feeding, reproduction, and gas exchange in biota; eutrophication effects on aquatic food chain structure and noxious algal blooms (red tide events) from nitrogen, phosphorus, and silicon inputs/uptake; toxic pollutant impacts on the growth, reproduction, and behavior of marine biota; and potential impacts between aquaculture and wild fish stocks (disease and genetic exchange). Similar types of issues occur in the coastal habitats that require coordinated management or policies between the state and Federal governments.

The conceptual model should provide a framework for identifying the state of knowledge on the status of the resources in the Gulf of Maine system; the key anthropogenic processes impacting the state variables within this ecosystem; and identifying the choke points controlling the system. The research recommendations from the workshop should focus on the areas in which we need either more data or synthesis of existing information in order to understand how the Gulf of Maine ecosystem is structured and the key processes controlling its functioning. The identification or prioritization of these research recommendations need to be related to the management schemes utilized either by the state or Federal governments. Research recommendations should be related to either management information needs or the concerns of the non-government organization participants at the workshop. The managers involved in the workshop need to provide insight into how current management procedures could be better coordinated either between the state and Federal governments or between the U.S. and Canada. All of the workshop participants need to come up with suggestions about how we can manage the Gulf of Maine on a sustainable basis, incorporating not only activities within the Gulf itself, but also taking into account the forcing functions coming from the coastal watersheds and far field ocean. Over the longer term global climate change impacts from outside of the Gulf of Maine proper could change the nature of the system and its responses to the forcing inputs from land and anthropogenic impacts occurring within the system itself. Thus the management recommendations would include both better coordination of existing management schemes and suggestions for better ways to manage the Gulf of Maine on a more integrated basis across jurisdictional boundaries and on a sustainable basis.

REVISED GULF OF MAINE ECOSYSTEM CONCEPTUAL MODEL

<u>Watersheds on Land</u>

Forcing Functions: →
(may have feedback or two arrows)

- water flow
- land use changes - (point/nonpoint discharge -nutrients/pollutants) (sediment discharge) (habitat loss factor)
- anadromous/catadromous net transport species (function of breeding area loss, dams, salt, acid rain, organic/inorganic toxic pollutants, & eutrophication)
- atmospheric inputs: nitrogen toxics (PCBs, PAHs, Hg, Pb) heat/moisture

<u>Coastal Habitats</u>

State Variables: ⇄
(donor or receiving compartment control) primary producers/ consumers (grazing food chain) and detritus food web components in wetlands, mud/sand flats, beaches/dunes, seagrass beds, hard and soft sediment benthic, and pelagic community

<u>or</u>

alternatively the habitat support value and nutrient/pollutant transport function for these coastal systems

⇅ (linear or nonlinear interactions)

Processes:

- food chain interactions (top down/bottom up)
- dredge spoil disposal andhabitat change from dredging
- commerce impacts (pollution & exotic organisms)
- eutrophication effects (C, N, P, & Si) on food chain structure
- toxic pollutant impacts (growth, reproduction, behavior)
- aquaculture/fishing impacts

<u>Open water/Benthic Environment</u>

State Variables: ←
(donor or receiving compartment control) Plankton; micronekton; pelagic fish; demersal fish; marine mammals; hard bottom substrate; soft bottom substrate; temp. and salinity; nutrient conc. & toxic substances conc. (water & sediments);
Benthic organisms (epi- and infauna)

⇅ (linear or nonlinear interactions)

Processes:

- top down vs. bottom up food chain interactions
- direct and indirect effects of fishing activity
- dredge spoil disposal effects
- commerce impacts (ship strikes, pollution)
- eutrophication effects (C, N, P, & Si) on food chain structure
- toxic pollutant impacts (growth, reproduction, behavior)

<u>Far Field Ocean</u>

Forcing Function:
(may have feedback or two way arrows)

- physical oceanic coupling (temp., salin., momentum or water transport)
- nutrient exchanges
- organismal dispersal/exchange

Appendix B

Workshop Agenda

Agenda

The Health of the Gulf of Maine Ecosystem: Cumulative Impacts of Multiple Stressors

(note: program breaks will be held at 10:00 a.m. and 3:00 p.m. daily)

Sunday, September 17th

7:00-9:00	Workshop Planning committee meeting (Jack Pearce, David Dow, Gordon Wallace, Daniel Lynch, Eugenia Braasch, Working Group Chairs, Rapporteurs, Plenary Speakers)	Thayer School Conference Room

Monday, September 18th

7:30-8:00	All Workshop Participants Check in at Registration Desk	Thayer School Conference Room
8:00-8:30	Welcome & Charge to the Workshop, Jack Pearce	Thayer School Room 100
	Plenary Speakers:	
8:30-9:15	Physical Environment / Forcing Functions, Daniel Lynch	
9:15-10:00	Water Column, David Townsend	
10:15-11:00	Benthic Environments, Jon Witman	
11:00-11:45	Fisheries Resources, Richard Langton	
12:00-1:00	lunch	Thayer School Great Hall
	Plenary Session continued:	
1:00-1:45	Protected Species Resources, Andrew Read	
1:45-2:30	Sources / Fates / Effects of Pollutants, Marilyn Buchholtz ten Brink	
	Invited Comments and Discussion	
2:45-5:00	(NGO representatives, managers, scientists, other participants)	Thayer School Room 100
5:00-6:00	social hour	Dartmouth Outing Club, Occum Pond
6:00-7:30	dinner	Dartmouth Outing Club
7:30-9:00	Workshop Planning committee meeting	Thayer School Conference Room

Tuesday, September 19th

8:00-8:30	Charge to the Working Groups	Thayer School Conference Room
8:30-12:00	Working Group Discussion:	Thayer School
	Anthropogenic Impacts, Sybil Seitzinger, facilitator Ned Cyr and David Mountain, rapporteurs	Room 105
	Fisheries Harvesting, Steve Murawski, facilitator Solange Brault, Joseph DeAlteris, and Wendy Gabriel, rapporteurs	Room 135
	Protected Species/Marine Mammals, Bob Hofman, facilitator Ramona Haebler and Charles Hopkinson, rapporteurs	Conference Room
12:00-1:00	lunch	Thayer School Great Hall
1:00-4:30	Working Group Discussion:	Thayer School
	Anthropogenic Impacts, Sybil Seitzinger, facilitator	Room 105
	Fisheries Harvesting, Steve Murawski, facilitator	Room 135
	Protected Species/Marine Mammals, Bob Hofman, facilitator	Conference Room
4:30-6:00	Working Group Presentations	Thayer School Conference Room
6:00-6:30	Concluding Remarks & RARGOM Workshop Evaluation	Thayer School Conference Room
7:00-8:30	dinner	Hanover Inn, Wheelock Room

Wednesday, September 20th

8:00-12:00	Draft executive summary	Thayer School Conference Room
	(Jack Pearce, David Dow, Gordon Wallace, Daniel Lynch, Eugenia Braasch, Working Group Chairs, Rapporteurs, Plenary Speakers, Steering Committee members)	
12:00-1:00	lunch	Thayer School Great Hall
1:00-4:30	Edit Working Group reports	Thayer School

Appendix C

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