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Foreword

Foreword

The Gulf of Maine is a semi-enclosed sea covering an area of 90,700 km^2 with a total drainage area twice the size of the Gulf itself (179,000 km^2). The landward border of the Gulf is provided by 5,600 km of coastline in the states of Maine, New Hampshire and Massachusetts and the Canadian provinces of New Brunswick and Nova Scotia and seaward by the Scotian Shelf and Georges Bank. The coastal margin and submerged banks of the Gulf are highly productive and support a variety of important fisheries. Commercial fisheries in the region provided 650 million to fishermen in 1988 and generated about 2 billion in total revenue. Recreational fishing and aquaculture contribute additional revenue to the region. So do other recreational uses of the Gulf such as boating and whale watching. The coast is a major attraction for more than one billion tourists who visit the region annually; it also provides a home for more than five million people who live in the coastal counties bordering the Gulf. Population density is greatest in the southwestern portion of the Gulf, i.e., in Massachusetts, New Hampshire and western and mid-coastal Maine.

A recent summary of the environmental status of the Gulf of Maine describes it, on the whole, as clean, but reports the results of recent studies which show that certain nearshore areas are as polluted as other heavily populated and industrialized east coast sites (Thurston and Larsen 1994). This is true despite the fact that urban and agricultural land use in the region is minor compared to the amount of land that is forested. Compared to other coastal regions of the U.S., there are few industrial sources of pollution. Point source pollution, however, remains a problem. There are estimated to be several hundred industries that pump waste directly into the Gulf, but most industrial effluent in the U.S. flows into municipal sewage treatment systems (Van Dusen and Hayden 1989). Many sewage treatment facilities are either operating beyond their capacity or are not designed to provide adequate treatment for industrial effluents. Non-point sources of pollution (e.g., runoff from roads, farms, and parking lots, failing septic systems, shipping and boating activities, and deposition of air and river borne contaminants) are believed to represent the greatest threat to nearshore environmental quality because of their chronic and ubiquitous nature, their cumulative effect, and the difficulty of controlling them (Van Dusen and Hayden 1989). Concentrations of metals in fish livers in coastal waters downstream from the industrialized Kennebec River drainage basin are higher than those from Boston and Salem harbors (Larsen 1992). Contamination is not limited, however, to the coastal zone: hydrocarbons have been detected in sediments throughout the Gulf, including the deep offshore basins (Larsen 1992). Contaminants of greatest concern are those that persist in sediments and are slowly released into the food chain where they are accumulated by filter-feeding organisms and predators. Some of these were produced by industries that were common over a hundred years ago (e.g., tanneries and textile mills) or prior to recent improvements in the quality of industrial effluents.

Coastal marine habitats in the Gulf of Maine have been lost or altered as a result of various types of human activity. Approximately 65% of the tidal marshes and flats in the Maritime provinces and 20% of those in Massachusetts have been lost or altered since the arrival of European settlers. Degradation and loss of coastal wetlands is produced by filling, and the building of causeways and roads, railroad beds, and dikes. Barrier beaches in many areas are heavily developed and stabilized with seawalls. The inlets of tidal rivers are frequently stabilized with jetties or breakwaters and the inlet channels are regularly dredged. Commercial and residential development within the tidal and freshwater portions of estuarine watersheds, on beaches, and on the rocky coastline, is extensive in certain areas and commonly occurs close to the shoreline. Dams have blocked the upstream migration of an adromous species of fish like Atlantic salmon, shad and alewives. Large areas of productive intertidal shellfish habitat are closed to harvesting because of bacteriological contamination and seasonal outbreaks of paralytic shellfish poisoning, caused by a nerve toxin produced by single-celled planktonic organisms that multiply rapidly in the summer months, perhaps in response to higher water temperatures and elevated nutrient levels along the coast.

Threats to marine habitats in the Gulf are not limited to coastal waters or to the more obvious types of human activity. Certain commercial fishing practices, particularly the widespread and continuous use of bottom trawls and scallop drags, can cause major physical disturbance to inshore and offshore benthic habitats and communities and may reduce biodiversity. Oil spills represent an ever-present threat to nearshore benthic and pelagic habitats in the Gulf. Coastal ecosystems in the Gulf of Maine are also vulnerable to environmental changes such as increases in sea level which are predicted to result from global warming, and storms.

Habitat loss and degradation in the Gulf of Maine have been receiving more attention from environmental managers in recent years. The Gulf of Maine Council on the Marine Environment was created by the three states and the two provinces bordering the Gulf in 1989. The Council and its Working Group, which represents a partnership of several federal, state, and local agencies and organizations, developed a regional marine environmental quality monitoring plan and a ten year action plan "to maintain and enhance marine environmental quality in the Gulf of Maine and to allow for sustainable resource use by existing and future generations" (GOM CME 1991). Gulfwatch, a program designed to monitor the status, trends, and sources of risk to the marine environment, was implemented by the Council in 1991. Blue mussels were selected as the best environmental indicator for a number of reasons, including the fact that they are one of the indicator organisms in the Gulf that have been monitored for diseases and chemical contamination by the NOAA National Status and Trends (NS&T) Program for Marine Environmental Quality since 1986 (Gottholm and Turgeon 1992). The Gulf Council supports committees on habitat protection, coastal and marine pollution, protection of public health, and monitoring and research, among others. The Council makes recommendations to its member states and provinces concerning environmental management issues and attempts to set regional management policy and coordinate regional management activities by government and non- government organizations. The Habitat Protection Committee is currently engaged in a cooperative effort with the U.S. Fish and Wildlife Service to identify regionally significant habitats in the Gulf of Maine. Once they are identified, threats to those habitats will be identified and recommendations for their protection and restoration will be developed.

There are, in addition to NOAA's NS&T Program, other U.S. federal programs which are addressing environmental quality issues in the Gulf of Maine. One is the U.S. Environmental Protection Agency's National Estuary Program, which currently is supporting projects in Massachusetts Bay and Casco Bay, in partnership with the U.S. Fish and Wildlife Service, the Maine Department of Environmental Protection, and the Massachusetts Coastal Zone Management Office. The mission of the Casco Bay Estuary Project is "to preserve the ecological integrity of Casco Bay and ensure the compatible human uses of the Bay's resources through public stewardship and effective management" (Doggett and Smith 1992). Two of the four objectives for accomplishing this mission are: 1) "to take steps to prevent, mitigate and remediate impacts from existing and potential pollution sources and habitat loss; and 2) to support efforts to understand the Casco Bay ecosystem, including natural processes and the impact of human activities." Another EPA program, the Environmental Monitoring and Assessment Program (EMAP), recently completed a four year project in the Middle Atlantic region. Plans to extend EMAP into the Gulf of Maine region in 1995 are uncertain at this time due to funding problems. Preliminary field sampling was conducted at several locations in the Gulf in the summer of 1994.

Other U.S. federal programs that address marine habitat and environmental issues include a variety of activities conducted by NOAA's Strategic Environmental Assessment Division (e.g., inventories of estuaries and wetlands, analysis of coastal population trends, assessments of the susceptibility of estuaries to nutrient discharges, development of geographic information and mapping systems for nearshore waters, and inventories of estuarine living marine resources). The NOAA Coastal Ocean Program initiated an Estuarine Habitat Program in 1990 to conduct research on estuarine habitats important in the production of living marine resources. The Coastal Ocean Program, through its Coastal Change Analysis Program (C-CAP), is helping to develop the tools and the scientific information necessary to monitor changes in coastal wetlands in the Gulf of Maine as deduced from satellite images and aerial photographs. An assessment of wetlands habitat loss in coastal U.S. waters of the Gulf during the past ten years was recently conducted by the U.S. Fish and Wildlife Service as part of the C-CAP project. The Gulf of Maine Council's Data and Information Management Committee has developed an Electronic and Information Management System (EDIMS) at the University of New Hampshire which contains databases (e.g., daily satellite images) that can be accessed through Internet.

A number of habitat mapping programs are underway in Canadian waters of the Gulf of Maine. The Department of Fisheries and Oceans is conducting a habitat sensitivity mapping project for the Bay of Fundy and the Atlantic coast of Nova Scotia. Another project, called the FMG Project, has assembled a list of physiographic, oceanographic, ecological and infrastructure variables for the Bay of Fundy, the Gulf of Maine, and Georges Bank into a geographic information system (GIS). Other projects are being conducted jointly with U.S. agencies. These include the East Coast of North America Strategic Assessment Project (ECNASAP). The objective of this project is support multi-species management within an ecosystem context by identifying species assemblages and their relations with their habitats and with key exploited species.

Habitat protection recommendations are becoming more commonplace in fisheries management plans in the U.S. and Canada and there is growing pressure from marine conservation organizations and commercial and recreational fishermen in the U.S. for the federal fisheries management councils and the National Marine Fisheries Service to take a more active role in protecting and restoring essential fishery habitats. At the same time, state agencies charged with conserving marine fishery resources, and the Atlantic States Marine Fisheries Commission, which establishes and implements cooperative interstate fishery management activities, are becoming more involved with habitat and environmental management issues. In Canada, as a result of the adoption of a new fish habitat management policy by the Department of Fisheries and Oceans in 1986, the objective is to achieve a net gain of productive fish habitat.

Although there is a growing awareness of the importance of habitat protection and management in the Gulf of Maine region, and despite efforts to identify some of the key management and research issues at stake, there has not been much research done to provide the habitat-related information that is required to support effective environmental and fisheries management. Habitat and environmental quality issues were addressed in several oral presentations and by several working groups (including toxic contamination, eutrophication, and habitat and habitat loss) at the Gulf of Maine Conference held in Portland, Maine in December 1989 (Konrad et al. 1990). Recommendations from the various working groups at this conference were incorporated into the Gulf Council's Action Plan. Scientific aspects of various environmental issues were subsequently addressed at a Gulf of Maine Scientific Conference in Woods Hole, MA in January 1991 (Wiggin and Mooers 1992). A number of recommendations for future habitat-related research and monitoring were made at that meeting.

During 1991, the Regional Association for Research on the Gulf of Maine (RARGOM) developed a draft ten year research plan for the Regional Marine Research Program (RMRP). A final version of this plan was adopted by the RMR Board in 1992 (RMRP 1992). Two of the four priority scientific questions included in the plan relate to habitat. One of these was "What is the relative importance of natural and human-induced changes to the physical environment on ecosystem structure and function?" The other one was "What are the sources, pathways, fates, and effects on living marine resources, of contaminants in the Gulf of Maine?" Following each question was a list of associated information needs.

The Workshop

Given this situation, and perceiving the need for a workshop that would specifically and more comprehensively address habitat-related information needs and identify the research required to provide necessary information, the Regional Association for Research on the Gulf of Maine decided, in 1993, to organize a workshop at the Maine Department of Marine Resources Laboratory in Boothbay Harbor, Maine. This one was one of a series of workshops convened by the Association during 1993 and 1994 as part of its mission to coordinate, facilitate, and stimulate marine scientific research through better communication among scientists in the region. Funding for the workshop was provided by the Regional Marine Research Program and the National Undersea Research Center at the University of Connecticut. Four plenary speakers were asked to identify broad issues relating to the location and extent of marine habitats in the Gulf and the principal human impacts to those habitats, questions of physical and temporal scale as they relate to habitat-based fisheries management, the incorporation of habitat information in U.S. fisheries management plans, and the impacts of contaminants on habitats in the Gulf of Maine. Managers and researchers from the U.S. and Canada were invited to attend the workshop.

About fifty participants were divided into four working groups and asked to identify habitat-related management goals, management information needs, and research priorities as they related to fisheries resources, water and sediment quality, biodiversity, and coastal habitat alteration. The Proceedings of this workshop include the four working group reports, the four plenary papers (which were prepared subsequent to the workshop), and abstracts of posters which were prepared by some participants for display at the workshop. An executive summary of the workshop has been prepared to summarize the major conclusions reached by the four working groups and to identify some common themes and recommendations that emerged from the workshop.

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1. Executive Summary

Executive Summary

Each working group was asked to consider three primary questions as they related to their topic:

I. What are the management goals;
II. What information is needed for management? and
III. What research is required to provide the information needed for management?

Each group was also asked to prioritize research needs according to the urgency of the management issue being addressed and the availability of relevant information. What follows is a summary of the major conclusions and recommendations for each working group, in response to each of these questions. The reader is referred to the four working group reports for more detailed summaries of their deliberations and conclusions. In addition to management and research needs that were specific to each of the four topics, there were also several common themes which emerged during the workshop.

Common Themes

1. **The need for basic information on size, location, and distribution of Gulf of Maine benthic habitat types.** High resolution, spatially referenced data, compiled in detailed geographic data bases and displayed as maps and/or video images, are a fundamental need for both researchers and managers, especially when combined with similar information relating to the organisms that utilize those habitats collected at the same spatial scale. Similar data relating to water and sediment quality are also crucial, although the high cost of analyzing contaminants usually prevents the collection of these data at high resolution.

2. **The need to understand the functions and values of individual habitat types in sustaining selected Gulf of Maine living resources, biodiversity, and ecosystem structure and function.**

3. **The need to quantify the effects of individual and multiple human impacts on specific habitats and ecosystems.** This can be accomplished by comparing baseline data collected prior to, or during the early stages of, habitat degradation with data collected later on, as long as standardized data collection and analysis procedures are followed for each parameter.

4. **The need to develop habitat-mediated models of populations, species, and communities that could be used to predict changes in the abundance and/or distribution of living marine resources in the Gulf that would result from changes in habitat characteristics.** Such models would be of great value to environmental managers, especially if configured for visual (video) display.

Recommendations

Geographic data base development

Considerable field work is required to conduct resource inventories and survey benthic habitats in order to obtain the necessary information to incorporate into geographic data bases. Surveys of transient habitat features which are subject to natural or human-induced alteration should be conducted initially at different times of years and then repeated annually or every few years as conditions change. Once available, these data should be incorporated into a centrally located Geographic Information System (GIS) data base which can be accessed by researchers and managers throughout the region. Current environmental data base development and mapping efforts in the region need to be supported and expanded.

At the same time, efforts need to be made to compile all existing information for GIS use (some of it is still missing). There are currently two projects of this kind underway in the Gulf of Maine. One is the development of a contaminated sediment data base and the other is a bathymetric survey and mapping of nearshore coastal waters. Both are funded by the Regional Marine Research Program. Given its importance for habitat management, and its regional nature, geographic data base development is an activity which should be supported by the Gulf of Maine Council and by government agencies in the U.S. and Canada which have habitat protection and restoration responsibilities.

Before any new survey or resource inventory work is initiated, a group of experts should be convened to evaluate what additional data are needed (and for which habitats), to establish standardized data collection protocols, to design the necessary data collection methods, and, if necessary, to obtain funds for collecting and compiling the information, analyzing samples, and compiling the results. It is recommended that the Regional Association for Research on the Gulf of Maine and the Gulf of Maine Council on the Marine Environment collaborate in organizing such a meeting and in implementing its recommendations.

Establishing research priorities

There needs to be continued improvement in the process of establishing research priorities between scientists, managers, and the public. Optimally, managers would define what needs to be accomplished (with input from the public and affected user groups) and scientists would provide advice to them concerning what questions need to be asked and how to obtain the necessary information.

Communicating research results

It is not sufficient to perform and report results to research colleagues. Results of research projects should be summarized and made available in a usable form to a variety of audiences and user groups, including decision makers and politicians, agency managers, agency staff, resource users, general public, primary and secondary educators, and citizen volunteers.

Findings and Recommendations of Individual Working Groups

The following management goals, management information needs, and research priorities were identified by the four working groups.

I. Management Goals

Government agencies are charged with preserving and managing species or biotic assemblages within certain geographic boundaries (e.g., preserving habitat for endangered species), but are given no analogous authority to preserve **biodiversity**. Similarly, there is no functional ecosystem management, only management of single species or species groups. The information necessary to accomplish successful ecosystem management aimed at maintaining or restoring biodiversity does not presently exist.

The **coastal alteration** working group agreed that through the use of their regulatory authority, government agencies aim to protect, restore, and reduce the human impact on coastal and offshore habitats. This is accomplished through their permitting authority and by the monitoring of compliance and the enforcing of permits and regulations.

The **fisheries** working group acknowledged that fisheries management has traditionally focused on the conservation and restoration of exploited fisheries resources. At the same time, it is currently recognized that resource stability and product quality require a healthy environment and that the protection and restoration of habitats which are essential for population survival and production is also an important management objective.

The **sediment and water quality** working group identified the following nonprioritized goals when discussing the purpose of habitat management or restoration: to protect human health, maintain/improve quality of (human) life, promote/maintain multiple uses of the environment, e.g. recreation and fishing, protect/restore habitats used by living marine resources and for recreational use, and protect habitats for their own sake, e.g., to maintain biodiversity. The group then proceeded to establish four management goals for the Gulf of Maine:

1. for most, if not all, waters to be suitable for fishing and swimming;
2. maintain ecological diversity and multiple human use;
3. maintain healthy ecosystems
4. manage the Gulf of Maine in such a way that we progress towards pristine ecosystems, with no toxic effects as an endpoint.

II. Information Needed for Management

The **biodiversity** working group listed the most likely threats that would cause a loss of biodiversity in a range of marine habitats. These are: fishing activities, dam construction, seawalls and other coastal construction, land use practices and wetland alteration, contamination, dredging and mining, and aquaculture. A number of issues were listed for each item. Maps of habitat features, and baseline surveys of associated fauna and flora, are a high priority information need. Once the distribution and abundance of the biological components of an ecosystem, and their spatial and temporal variability, are known, changes in community structure (numbers of species and individuals of each species) can be tracked and related to habitat alterations that are caused by any anthropogenic or natural factor. It is also important to identify life history characteristics of key taxa and to identify the functional linkages (e.g., prey- predator) between different members of the ecosystem.

Success of management efforts depends in part on the quality of information that is available. Management decisions are often made in the absence of adequate environmental and ecological information. The **coastal alteration** group identified four types of habitat-related information that are required for managing coastal habitats in the Gulf of Maine, with a number of specific information needs in each category. These four broad types of information are ordered hierarchically since the end product -impact management or remediation - requires knowledge of human impacts and their ecological effects, which, in turn, requires some knowledge of natural ecological parameters and processes.

1. Ecological parameters and processes, e.g., inventories of existing habitat resources, knowledge of the functions and values of existing habitats, living resource habitat requirements, critical habitats for target species, linkages between coastal zone and offshore processes.

2. Human impacts, e.g., the extent of dredging, resource harvesting, dumping, etc., the identification of land use patterns in coastal watersheds, sources of point and non-point pollution.

3. Ecological effects of impacts, e.g., the identification of habitats at risk of degradation or loss through human impact, assessing the impact of different land uses on coastal habitat systems and the degradation rates for critical habitats for target species.

4. Impact management and remediation, e.g., the use of ecological indicators to detect change in habitat function and value due to natural processes and human action, monitoring the functions and values of restored and created habitats, and designing buffers sufficient to protect habitat functions and values from human land use practices.

Priority coastal habitats that are considered important to managers and/or in need of management are salt marsh, eel grass, and kelp/macroalgal habitat, and mud flats. Beach and sand dune habitat was also discussed, but considered to be well studied relative to other coastal habitats.

For many species, habitat-related information is inadequate for **fisheries** management purposes, particularly specific information relating to the habitat requirements of a given species at different life history stages. The identification of a species' essential habitat(s) is required before work can proceed to define its geographic extent and to evaluate its vulnerability to human impacts. The working group developed a generalized matrix to be used in determining the essential habitat(s) for any species, based on information regarding its large scale distribution patterns (e.g., distance from shore) and local habitat characteristics (e.g., substrate type) at different life history stages. The group also developed a logic flow diagram for assisting researchers and managers in making informed decisions leading to effective habitat conservation, restoration, and enhancement.

Five different information categories were established by the **sediment and water quality** group, and they recognized that the interactions between categories represent the processes that enable the ecosystem to function. It is important to understand the linkages between these categories. For example, what human activity introduces which contaminant in which location or habitat type, or, in a specific location or habitat, what are the toxic effects caused by any given contaminant and how are they produced?

1. Human activities which have significant detrimental impact on the marine ecosystem included: land use, point and non-point contaminant sources, waste disposal, marine construction, the marine industry in general (including fishing and aquaculture), and marine recreation. The group recommended that existing regulations need to be enforced and the public needs to be better educated regarding the effects of human activity on the marine environment. The group also noted that immediate improvements in water and sediment quality will result from stopping certain activities while, for others, the response time is long. Also, some human activities have local effects while the effects of others are more widespread. Some contaminants were introduced into the environment by industries that no longer exist. Managers need to know how different deleterious human activities have changed with time (are they more or less of a problem than they used to be?) and how long it takes the ecosystem to respond to changes in these activities.

2. Contaminants with priority needs for information and research are: metals (such as cadmium, mercury and lead), excess organic carbon, chlorinated hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), pesticides and herbicides, and pathogens. Nutrients, temperature and salinity alterations, and radioactive contamination were not judged to be as important. Those compounds which persist in the marine environment and produce a poorly understood response in organisms that are exposed to them are of major concern. Site-specific information on transport paths and cycling is needed for certain environments and organisms.

3. Habitat types and locations with priority needs for information and research are: areas of fine-grained sediment or deposition (because they tend to have higher contaminant concentrations or accumulation rates), any nearshore site that is in close proximity to where contaminants are discharged, fronts in the water column, and other areas where there are large fluxes of contaminants in the water column.

4. Resource, use, or activity of value: living resources that are linked to contaminated habitats are the juvenile stages of fish, bottom feeding fish, mollusks, crustaceans and other invertebrates. Uses of these habitats that require information and research are aquaculture and waste disposal (need to determine the assimilation capacity of the environment), particularly intentional waste disposal (i.e., sewage and dumping). Birds and marine mammals have high recreation value and also may be valuable as indicators of ecosystem health.

5. Specific effects or indicators of toxicity that are of high priority are disease and health effects, effects on reproduction, market quality of harvested resources, mortality, community structure, and nutrient enrichment. From the point of view of resource management, it is recognized that the most important information need is establishing the links between low sediment or water quality and degraded ecosystems. Effects studies can be ordered from the simplest systems (sub-organismal) to the most complex (ecosystems), with a need to establish cause and effect at all levels. It is also important to better understand synergistic effects between individuals, trophic levels, and populations and to study sub-lethal effects.

III. Research Priorities

Research required to provide knowledge for a habitat-based approach to managing for **biodiversity** includes:

1. Determine the appropriate scale for resolving features of habitat and communities suitable for management for each habitat type. (Selection of representative habitats is required for this research component.) This work requires determining the appropriate physical parameters needed for characterization of each habitat type.
2. Determine the role that biodiversity plays in maintaining ecosystem health vis a vis the functional role of biodiversity in carbon flow, contaminant cycling and sequestering of carbon/contaminants.

For each **coastal** habitat of concern, urgent management needs were defined and habitat-specific research priorities were identified. Primary management needs were determined by considering: 1) the degree to which habitat continues to be altered under existing management regimes; and 2) the degree to which ecological changes that result from habitat alteration are understood. Human impacts posing the greatest threat to habitat function, and for which the ecological effects are least understood, were given the highest priority. Management priorities and corresponding research needs common to all coastal habitats were identified. They are, for management:

1. Conduct Gulf- wide assessment of individual impacts, especially habitat loss.
2. Conduct Gulf- wide assessment of cumulative effects of combined impacts on habitat health.
3. Use indicators to monitor habitat health.
4. Assess the trade-off between different approaches to impact remediation.
5. Achieve comprehensive coastal watershed management and planning.
6. Determine impact of coastal zone habitat alteration on Gulf of Maine living resources (in coastal and offshore areas).

The corresponding research needs are:

1. Develop Gulf-wide, high resolution, habitat maps and inventories.
2. Determine the synergistic effects of multiple impacts on habitat health.
3. Identify and test the utility of potential indicator species, species groups, or multi-parameter indices of habitat health.
4. Determine the relative benefits to habitat functions and values of protection vs. restoration vs. creation.
5. Determine the relative impacts of different land use practices on coastal habitat functions and values.
6. Develop models to predict response of target Gulf of Maine resources (coastal and offshore) to coastal habitat alteration.

A series of research priorities were identified that address many of the issues identified by the **fisheries resources** working group in the process of developing the matrix and the flow diagram. These priorities were not intended to exclude other research initiatives, but are rather specific examples of the general approach taken by the working group.

1. Conduct process-level laboratory research to demonstrate the importance of physical environmental features for the survival of different life history stages and field work in order to determine the biological and ecological effects of natural and human induced habitat modification.
2. Create maps to identify habitats at spatial scales required for research purposes.
3. Link process studies, which are necessarily conducted on a small scale, to habitat mapping exercises, in order to address larger scale effects.
4. Identify information gaps in life history information and in habitat-life history interactions, and conducting necessary research to fill in those gaps.
5. Develop numerical models that describe known habitat-species interactions and define potential areas of research.
6. Develop geographic information systems for the display of human population patterns, location and extent of habitats and species populations, etc.
7. Evaluate the function of refugia relative to stock enhancement efforts and other management approaches to habitat conservation and protection.

The **sediment and water quality** working group identified a number of research priorities which fall into three broad categories, with a number of sub-categories in each.

1. The link between potentially toxic contaminant concentrations and biotic effects must be better established. A number of related issues should be recognized:
   a) bioavailability, efficiency of contaminant transfer and organism responses to contaminants;
   b) ways in which linkages can be made through physiological or community studies;
   c) need to understand how ecosystem and organisms' systems function;
   d) studies should include consideration of how to eventually establish sediment criteria for toxic contaminants;
   e) definition and study at various spatial and temporal scales and response times is needed (paleoecological techniques may be useful);
   f) links must be established between ecosystem effects and contaminants that may not be inherently toxic, such as excessive nutrient and organic carbon loadings.
2. Transport paths must be studied to determine how contaminants move and become mobilized in the environment and subsequently become accessible to organisms.
   a) routes and rates of anthropogenic and natural loading
   b) contaminant distributions and concentrations
   c) spatial and temporal variability and response times
   d) sediment, geochemical, and biological transport and transformation processes
   e) water circulation and dynamics of associated contaminants on macro and microscales
   f) biological uptake efficiency and bioaccumulation
   g) human physical perturbation
3. The effectiveness and net costs of remediation practices in meeting goals needs to be more clearly established.
   a) Does restoration or remediation work and should we do it?
   b) Can remediation strategies be developed based on manipulation to enhance transformation of toxic to non toxic contaminants and mitigate ecological effects?
   c) Can alternatives to existing activities or regulations that result in contamination (e.g. dumping) be developed?

2. Plenary Papers

Location, Extent and Importance of Marine Habitats in the Gulf of Maine

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Introduction

The purpose of this invited plenary paper is to provide a general overview of marine habitats in the Gulf of Maine, briefly review some of the pressures affecting them and offer some thoughts on the requirements for effective habitat management. Because of the broad scope of the topic, it has not been possible to go into much detail but selected references are provided for those who want more information.

For the purpose of this paper, the Gulf of Maine is defined as including the Gulf of Maine proper, Georges Bank and the Bay of Fundy. This unique marine system is shared by the United States and Canada and is bordered by the states of Massachusetts, New Hampshire and Maine and the provinces of New Brunswick and Nova Scotia.

As emphasized in the background material distributed before the workshop, habitat means different things to different people. We could probably spend a whole workshop debating exactly how habitat should be defined. However defined, I think we all agree that in general terms "habitat" refers to the ecological relationships that exist between organisms and their environment. The concept of habitat is probably best developed for terrestrial and freshwater environments. Only recently, have we started to apply it to marine environments.

Under the Canadian Fisheries Act, fish habitat is defined as those parts of the environment "on which fish depend, directly or indirectly, in order to carry out their life processes". This includes features such as spawning grounds, nursery areas, feeding areas, shelter/resting areas and migration routes that are essential to organisms at different stages of their life cycles. Organisms and their habitat can be viewed as a three-dimensional puzzle whose pieces fit together to create an intricate whole. The pieces can represent factors such as substrate type, temperature, light and food. Even if just one piece is missing or damaged, the habitat is incomplete and unable to support a given species at full capacity. As my habitat manager colleagues succinctly say, "No habitat, no fish".

More recently, it has been proposed that habitat should be more narrowly defined as the structural component of the environment which attracts organisms and serves as a centre of biological activity (Ryder and Kerr 1989). This more restricted definition separates structure from other environmental factors (such as light, temperature and nutrients) and thereby focuses attention on physical features of the environment which display a definite organizational pattern. Following this train of thought, my review of habitat types will be organized principally on the basis of physical features. However, it is clear that more work is needed in clarifying the concept of habitat as applied to the marine environment.

The marine habitat of the Gulf of Maine is of value to the citizens of the New England states and Maritime provinces for many uses including:

- Wild Fisheries
- Aquaculture
- Plants and Wildlife
- Flood Prevention
- Natural Treatment Systems
- Transportation and Energy
- Tourism and Recreation
- Research and Education

The value of the Gulf of Maine habitat was discussed at a recent workshop (ARGO-Maine 1988).

Review of Physical Habitat Types

While focus of this workshop is on marine habitat, I want to emphasize at the outset the importance of the associated freshwater habitat which is of similar geographic extent. There are a large number of rivers flowing into the Gulf of Maine which include the Merrimac, Saco, Kennebec, Penobscot, St. Croix, St. John, Petitcodiac and Shubenacadie. These and the associated lakes form important habitat for part of the life cycles of diadromous species such as salmon, gaspereau, shad and eel. Habitat disruption in the watershed area can also impact habitat in the coastal zone.

One of the unique physical features of the Gulf of Maine is the high level of tidal energy occurring throughout the system but especially prevalent over Georges Bank and in the Bay of Fundy. Efforts to develop numerical tidal models have indicated that the Gulf of Maine operates as a single tidal system (Greenberg 1979).

A. Intertidal

The 5600 km coastline of the Gulf of Maine has been influenced by many geological processes including faulting, glaciation, sea level fluctuations and erosion. The type of intertidal habitat found at a given location is determined primarily by the kind of substrate (e.g. bedrock or sediment) and the level of wave and tidal energy. The area of intertidal habitat is determined by slope and tidal range.

Tidal range is large in the Gulf of Maine. It averages 2-3 m along the coast of Massachusetts, New Hampshire and southern Maine. Tidal range increases eastward along Maine coast and up into the Bay of Fundy. The upper Bay of Fundy is world famous for its exceptional tidal range which can average 12 m and exceed 16 m under spring tide conditions. Tidal range varies daily due to various astronomical cycles of which the spring-neap cycle is the most pronounced.

For the purpose of this review, four major types of intertidal habitat are identified. A more detailed classification scheme has recently been devised by Brown (1993) for the coast of Maine.

- **Rocky shore** - Bedrock exposed to wave activity. Usually accompanied by dense macrophyte coverage (*Fucus, Ascophyllum* and other species). Most common at Cape Ann, along the coast of Maine and in the lower Bay of Fundy.

- **Beach** - Dynamic sediments exposed to wave activity. Grain size can range from fine sand up to boulders depending upon energy level and source material. Many different types occur. Most extensive along the coasts of Massachusetts, New Hampshire and southern Maine. Smaller beaches are found throughout the rest of the Gulf of Maine.

- **Saltmarsh** - Low energy depositional environments found in the upper part of the intertidal zone. Low marsh occurs at or just below mean high water (MHW), is flooded regularly, is sloped and is composed almost exclusively of the cordgrass *Spartina alterniflora*. High marsh occurs above MHW, is flooded irregularly, is flat and has more diverse vegetation but is commonly dominated by *Spartina patens*. Saltmarshes are found throughout the Gulf of Maine wherever proper sedimentary conditions exist. Major marshes are found on Cape Cod, the north shore of Massachusetts, along the Maine coast, in the upper reaches of the Bay of Fundy and around Yarmouth. Jacobson et al. (1987) estimate that there are approximately 158 km^2 of saltmarsh along the coastline of the Gulf of Maine distributed as follows:

Massachusetts	25 km^2
New Hampshire	1.51
Maine	78.9
New Brunswick	15.4
Nova Scotia	36.7

- **Mud and sand flats** - Depositional environments found in the middle to lower part of intertidal zone. Sediment grain size decreases with level of energy. Vegetation not readily visible but surficial sediments contain microscopic algae. Intertidal flats are found throughout the Gulf of Maine wherever proper sedimentary conditions exist. They are particularly extensive in Cape Cod Bay (where the slope is low) and upper reaches of the Bay of Fundy (where the tidal range is high).

B. Nearshore

Nearshore habitats can be defined primarily on the basis of freshwater runoff, coastal geomorphology and bathymetry. For the purpose of this review, two principal types are identified.

- **Estuaries** - Dynamic coastal systems with substantial freshwater input and free connection with offshore waters. Waters have a salinity gradient and tidal flushing is important. They usually have considerable intertidal area. Important subtidal features include eelgrass beds, kelp beds and shellfish reefs which provide biological structure as well as primary productivity. Estuaries are found throughout the Gulf of Maine at mouths of rivers. The largest ones are found along the coast of Maine and in the Maritime provinces where the major rivers enter.

- **Bays** - Inlets of the sea. Little or no salinity gradient but tidal flushing can still be important. Usually larger than estuaries. Less importance of intertidal habitat but increasing importance of subtidal habitat. Found throughout the Gulf of Maine. Examples include Cape Cod Bay, Casco Bay, Penobscot Bay, Passamaquoddy Bay and St. Mary's Bay.

The nearshore zone of the Gulf of Maine also contains over 3000 islands which increase the amount of intertidal habitat. They can be composed of both glacial deposits and bedrock and are particularly common along the coast of Maine.

C. Offshore

Offshore habitats can be defined on the basis of bathymetry and physical oceanographic features. There are three major basins in the Gulf of Maine that have water depths greater than 200 m (Georges, Jordan and Wilkinson Basins). Bathymetric highs include Georges Bank, Browns Bank and Stellwagon Bank as well as numerous ledges such as Jeffries, Fippennies and Cashes. Banks and ledges have coarse sediments because of tidal scouring and wave activity (Valentine and Lough 1991) while deeper waters tend to have finer sediments.

The physical oceanography of the Gulf of Maine was recently reviewed by Brooks (1992). Offshore water enters around Cape Sable and through the Northeast Channel, travels around the Gulf in a counter clockwise direction and exits through the Northeast and Great South Channels. A leaky gyre, which rotates in a clockwise direction, occurs over Georges Bank. Tidal energy keeps the water column well mixed all times of the year in numerous places where the depth is less than about 50 m. These include Georges Bank, Nantucket Shoals, southwest Nova Scotia, Grand Manan and most of the New England coast (Loder and Greenberg 1986). Such intense mixing results in colder surface temperatures that are reflected in satellite imagery. Well-mixed areas are separated from stratified waters by tidal fronts which have high levels of primary productivity because of ideal light and nutrient conditions (Townsend 1991). The biological communities on either side of a tidal front can be quite different (Perry et al. 1993).

Habitat Use by Species

From this brief overview of physical habitat types, it is clear that the Gulf on Maine has a large number of diverse habitats due to the pronounced variability in shoreline characteristics, water properties, bathymetry and composition of the sea floor. This diversity is further illustrated by examining how different species use habitat. Habitat use is not uniform but tends to be very patchy for reasons that are not well understood.

Major stocks of offshore **lobster** are restricted to deep water around Georges Bank. There is evidence of migration up onto the Bank for spawning during the summer months.

Although widely distributed throughout the Gulf of Maine, **sea scallops** are most abundant on Georges Bank and near the mouth of the Bay of Fundy where strong tidal currents prevail and sediments are composed primarily of sand and gravel. They are absent from areas with highly mobile sediments and appear to be intolerant of even low concentrations of fine sediment (Cranford and Gordon 1992).

Three distinct **herring** stocks are found in the Gulf of Maine. Each stock migrates over a well-defined area including an overwintering region along the southern New England coast. In late summer and early fall, herring home onto precise locations on the sea floor for spawning. These spawning beds are very restricted in area and the factors involved in their selection are not well understood but seem to include three dimensional structures for egg attachment and strong currents to supply oxygen.

Cod have clear preferences for depth, temperature and substrate type. A large amount of the subtidal habitat of the Gulf of Maine is capable of supporting commercial stocks. In late July and August on Georges Bank, juvenile cod are found on gravel habitat where they seem best able to find food and avoid predators (Valentine and Lough 1991). It has been suggested that undisturbed gravel habitat is essential for successful cod recruitment throughout the Gulf of Maine.

Right whales enter the Gulf of Maine from more southern waters during the summer and fall. They tend to concentrate in the Grand Manan Basin and the Roseway Basin areas, presumably because of the availability of prey.

The tidal flats in the upper reaches of the Bay of Fundy are of hemispheric importance for **semipalmated sandpipers**. Birds arrive in late July/early August after breeding in the Arctic and feed extensively on benthic invertebrates, doubling their weight in two weeks, before continuing their migration to South America.

The Gulf of Maine is home to many species of **seabirds** which range over large areas in search of food. Their breeding colonies are usually restricted to uninhabited coastal islands, such as Machias Seal Island, and can easily be disrupted by human activities.

It should be clear from these examples that marine habitat is not uniform and that different species use it in different ways. Proper management requires a sound knowledge of how all important species use habitat, both spatially and temporally. Habitat mapping is an important new area for research and numerous methods are now available including submersibles, ROVs, video-equipped sampling equipment and sidescan sonar. Many interesting features of the sea floor remain to be discovered.

Natural Impacts

Before discussing some of the human impacts on habitats in the Gulf of Maine, it is important to stress that habitats are also subjected to natural changes which operate over a wide range of temporal and spatial scales. Recent glaciation has caused long-term changes in sea level over the entire Gulf of Maine region. The shoreline was quite different 12,000 years ago when the ice last retreated. Sea level was about 100 m lower then now, both Georges and Browns Banks were exposed and the Gulf of Maine as a whole was much more estuarine in character. Since then the region has been subjected to rising sea level and increasing tidal range (Kelley 1992).

Storms play a major role in influencing marine habitat. They affect shoreline erosion and the transport of sediment in intertidal, nearshore and offshore habitats. Moving sediment alternately buries and exposes sea floor habitats. Yeo and Risk (1979) have documented the effects of storms on intertidal communities in the Bay of Fundy. Offshore habitats can be affected to depths more than 100 m. The Halloween storm of 1991 had a major impact on the coastline around the Gulf of Maine, especially on the beaches of Cape Cod.

It is important that this natural variability be taken into account when assessing the impacts of human activity on marine habitat because not all habitat changes observed are due to human activities.

Human Impacts

While the Gulf of Maine remains in a relatively healthy condition, it undoubtedly is showing stress from human activities. Summarized below are some of the current and potential stresses.

- **Coastal engineering practices** - Coastal engineering works are widespread throughout the Gulf of Maine and have destroyed a large amount of habitat, especially in the intertidal zone. These practices include the diking of high saltmarsh in the Bay of Fundy, infilling and drainage of wetlands, construction of barrages, seawalls and breakwaters and dredging. In some cases, these engineering activities have by chance led to the creation of new habitats, such as the formation of mudflats seaward of barrages constructed across estuaries in the upper reaches of the Bay of Fundy.

- **Industrial / commercial / residential development** - Development in the coastal zone occurs throughout the Gulf of Maine but is most intense in the more heavily populated southern regions. Construction of roads, parking lots, services and buildings often destroys natural habitat and stresses wildlife. Development often takes place in areas such as dunes, saltmarshes and floodplains that are not suitable in the longer term because of their highly sensitive and dynamic nature.

- **Dams** - Dam construction for the development of hydropower is widespread in the Gulf of Maine. Effective passage facilities are difficult to implement and so dams often result in barriers preventing anadromous fish (salmon, gaspereau, shad, etc.) from reaching their spawning habitat.

- **Mobile fishing gear** - Mobile fishing gear such as otter trawls, scallop rakes and clam dredges are widely used to harvest demersal and benthic species throughout the Gulf of Maine. Physical disturbance to surficial sediments is readily visible in certain regions with sidescan sonar (Jenner et al. 1991, Valentine and Lough 1991). There is also evidence that epibenthic organisms can be damaged (Langton and Robinson 1990). It has been suggested that physical disruption of essential benthic habitat may be one factor affecting the recent crash in demersal fish stocks but it is probably minor compared to environmental changes, overfishing, bycatch problems and seal predation. The impacts of otter trawling were found to be minor in the physically stressed intertidal zone of Minas Basin (Brylinsky et al. 1994) but these conclusions cannot be assumed to be true for subtidal habitats with more diverse assemblages of benthic organisms. This activity affects a large area of the Gulf of Maine and its potential significance is currently under active investigation.

- **Baitworm harvesting** - Baitworm (*Glycera dibranchiata*) harvesting is widespread, especially in Maine and Nova Scotia. Worms are dug by hand and concern has been expressed about the potential effects of digging activities on other intertidal organisms and the shorebirds feeding upon them. Baitworm harvesting is currently very intense in the Minas Basin.

- **Regulation of river runoff** - Regulation of river runoff for the production of hydropower alters the delivery of freshwater to estuaries which affects their physical oceanographic properties. This is most pronounced in Maine, New Brunswick and Nova Scotia.

- **Mariculture** - Mariculture is a growing industry throughout the Gulf of Maine with both shellfish and finfish species being grown. At the present time, it appears that the potential impacts of finfish culture are greater than shellfish culture because of the use of feed. Monitoring studies at salmon farms in Maine and New Brunswick indicate that ungrazed food pellets and feces can accumulate on the sea floor under cages and alter both physical and biogeochemical properties. The severity of impact depends upon water depth and current velocity. Work is underway to develop scientifically-based numerical management models to help minimize habitat damage as this important industry continues to expand (Hargrave 1994).

- **Rockweed harvesting** - *Ascophyllum nodosum* has been harvested in southwestern Nova Scotia since 1959. There is a proposal to expand this industry into the Passamaquoddy area of New Brunswick. The removal of the rockweed canopy changes the physical structure of the intertidal community but the impacts on other species are not well understood.

- **Tidal power** - A small scale pilot project has been operating at Annapolis Royal in Nova Scotia since 1983. Large scale tidal power development is probably still far in the future, if ever. Modeling studies have demonstrated that barrage construction in the Minas Basin would lead to widespread changes in tidal regime throughout the Gulf of Maine (Greenberg 1979, DeWolfe 1986). While these changes are small compared to natural variability, they could have important impacts on habitat and coastal communities (Gordon and Dadswell 1984).

- **Ocean mining** - There is no appreciable ocean mining activity at present in the Gulf of Maine but there is considerable potential for extracting sand and gravel for construction purposes. Such activity would be very disruptive of benthic habitat.

- **Sea level rise** - Sea level is currently rising in the Gulf of Maine and one of the contributing factors is thought to be an increase in "greenhouse" gases in the atmosphere due to human activity. This increase, which could be as much as 1 m over next century (Titus and Wells 1986), would undoubtedly impact on coastal habitat.

The above examples have illustrated how physical stresses have or could influence the **extent** and **structure** of habitat in the Gulf of Maine. Habitat **quality** can be influenced by wide variety of contaminants including sediment, nutrients, toxic chemicals and microorganisms. These enter from a variety of sources including urban sewer systems, industrial outfalls, ocean dump sites and the atmosphere. The habitat quality in the Gulf of Maine was recently reviewed by Larsen (1992). Hydrocarbon drilling on Georges Bank is likely to become an issue again when the current drilling moratoria are reviewed.

Another recent concern has been the apparent increase in the kinds and frequency of harmful algal episodes (PSP, ASP, DSP) that may be related to human activities such as eutrophication, shipping and shellfish transfers.

Habitat Management

The overall goal of habitat management is to ensure the long term sustainability and quality of habitats and the resources they support. To do this effectively requires a thorough scientific understanding of natural processes and a conscientious effort by scientists to apply this knowledge to practical management issues. In the past, much habitat management has been reactionary in response to problems and there clearly is the need in the future to take a more proactive approach based on sound ecological knowledge. This requires an effective and continuing collaborative effort between scientists and habitat (as well as fisheries) managers with input from other stakeholders including industry, environmental organizations and the public. An overview on the necessary links between science and habitat management has been prepared by Ducharme (1992).

Habitat management comprises three different types of activities:

- **Habitat protection** - Habitat protection involves managing existing habitat on a sustainable basis. To do this effectively requires a sound scientific knowledge of habitat type and distribution as well as how different organisms use it, especially species of high economic and social importance (Harding 1992). An important goal is to identify essential habitats that must be protected to assure a species survival at acceptable levels. This ultimately leads to controls on how habitat is used. National, state and provincial parks protect some coastal areas of particular beauty and importance. Wildlife and marine sanctuaries are widely distributed throughout the Gulf of Maine, including offshore areas such as Stellwagon Bank.

Fisheries management zones have been established to control fishing time and gear type. Regulations regarding habitat protection should evolve to improve their effectiveness as scientific knowledge increases. This will undoubtedly require more stringent control over the use of marine habitat in the future (i.e. marine zoning). Marine refugia can be effective tools in coastal fisheries management (Dugan and Davis 1993).

- **Habitat restoration** - Some habitat that has been lost due to past human activity can be recovered through restoration. For example, dams can be removed or fitted with fish passage structures to allow the passage of diadromous species. Dikes can be removed to allow pasture land to revert back to saltmarsh. Construction of sewage treatment plants could open up shellfisheries previously closed because of fecal coliform contamination. Banning trawling from heavily trawled areas could allow stressed communities to recover but there is no guarantee that they would return to their original condition.

- **Habitat enhancement** - Habitat enhancement refers to those activities that create new habitat and/or increase the productivity of habitat. The most widespread example in the Gulf of Maine is the construction of freshwater impoundments on high saltmarsh to increase wildfowl production. Recently, there have been numerous proposals to build artificial reefs in coastal waters using a variety of materials. There is also a plan to build a fish passage structure at Grand Falls on the St. John River which would open up significant new spawning habitat to diadromous fish.

Since the focus of this workshop is on research, it is important that we as scientists reflect upon how effective we are in establishing the necessary collaborative links with habitat and fisheries managers. Is our research targeted at the right issues? Are we producing the correct data products? Are the results of our research being incorporated into better management practices? If not, how can we assure that they are? These are important questions that should be addressed by the individual working groups at this workshop.

Importance of Data Management and Geomatics

Effective habitat management requires ready and easy access to available scientific information. Hence the importance of data management. The presentation and analysis of habitat data has been greatly facilitated by recent advances in geomatics. Listed below are some of the data management and geomatics projects currently underway in the Gulf of Maine.

- **FMG Project** - This project has assembled a long list of physiographic, oceanographic, ecological and infrastructure variables for the entire Bay of Fundy, Gulf of Maine and Georges Bank system into a geographic information system which contains 133 maps. It is now called FMG InfoATLAS™ and is available from Axses Information Systems. The system is now being further developed by MacLaren Plansearch and Axses to provide better access to the data.

- **DIMC/EDIMS Project** - This Environmental Data and Information Management System (EDIMS) for data management and exchange has been developed by the Data and Information Management Committee (DIMC) under the Gulf of Maine Council on the Marine Environment. The system presently resides at the University of New Hampshire and contains data bases that can be accessed through INTERNET. It can provide satellite imagery for the Gulf of Maine on a daily basis.

- **ECNASAP Project** - The East Coast of North America Strategic Assessment Project (ECNASAP) is a joint US and Canada pilot project involving NOAA, DFO, Environment

Canada and others. The spatial coverage is from Cape Hatteras to Labrador but includes the Gulf of Maine. The overall objective is to support multi-species management within an ecosystem context by identifying species assemblages and their relations with their habitats and with key exploited species.

- **DFO Habitat Sensitivity Mapping Project** - This project is mapping the inland, coastal and marine habitat of the Bay of Fundy and Atlantic Coast of Nova Scotia. Initial focus has been on assembling data sets for the approaches to Saint John, New Brunswick. The information will be used to help manage possible future oil spills as well as routine evaluation of impacts on aquatic habitat. The project includes a modeling aspect for generating habitat maps from resource information. The current system runs on a laptop PC so it can be used in the field.

Many other data management and geomatic projects are underway within the Gulf of Maine area and there is a critical need for cooperation, standard approaches and the sharing of data bases. A workshop on Gulf of Maine data and information needs was organized in late 1993 by the Regional Marine Research Program for the Gulf of Maine, the Regional Association for Research on the Gulf of Maine and the Gulf of Maine Council on the Marine Environment. A series of recommendations for future action are listed in the workshop report (Phelps et al., 1993). These include the development of a regional information management system following a distributed networking approach utilizing INTERNET.

Note should also be made of the priority habitats project currently being conducted by the Habitat Panel of the Gulf of Maine Council on the Marine Environment. This project, being led by the US Fish and Wildlife Service, is identifying priority species which characterize "regionally significant habitats".

Summary

The Gulf of Maine is a very special marine system. Its diverse and productive habitats provide many benefits to our society. Human activities are affecting both the extent and quality of habitat but there is still time for us to get our act together and take the corrective action necessary to ensure the sustainability of habitat over the longer term. We have the knowledge and tools needed to do the job. Let us hope that the recommendations coming out of this workshop get implemented.

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A Spatial and Temporal Perspective on Fish Distributions: Improving our Definition of Fisheries Habitat in the Gulf of Maine

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Abstract

Fish populations have been exploited along the northeastern coast of North American for over 500 years. During this period an extensive knowledge of fish distributions and habitat has developed both as anecdotal and scientific literature. Despite this knowledge, catches and stocks have fluctuated widely. As a result of a large decline in the fish stocks, that is primarily attributed to over fishing, the region is currently experiencing the implementation of extreme management initiatives to allow the exploited stocks to recover. As our scientific knowledge of fish populations increase, the question arises as to why management has been unsuccessful in maintaining the harvest at a sustainable level. This paper addresses that question by reviewing patterns and processes exhibited by both fishers and fish through a hierarchy of temporal and spatial scales. Large scale population surveys, for example, document the persistence of patterns in the structure and geographic range of fish populations. In contrast to regional scale patterns in population structure, both fish and fishers interact and react at the scale of a fishing ground. Similarly, the large industrial fleets concentrate on aggregations of fish since the profitability of larger trawlers depends more on the concentration of the resource than the distance from the home port. The impact of fishing and the behavior of animals at this scale is cumulative at the population level where current management plans are operative. Research has also demonstrated that fish distributions can be attributed to variability in small scale physical features so that distributional patterns are the cumulative result of animals individually reacting to small scale environmental cues. It is essential to integrate the different scales which operate throughout the fishery into our understanding of habitat and also into a management scheme that incorporates both the perspective of the fishers and the targeted resource.

Introduction

Exploitation of marine fish has continued along the North American coast by European and, ultimately, the American and Canadian fleets for over 500 years (Collins and Rathbun 1887) with resource harvesting by native Americans predating this period (Borque 1994). Many of the regions groundfish fisheries are currently overexploited (NMFS 1993) with Canadian Atlantic cod stocks, in particular, suffering a total biological collapse (Sinclair 1993). A two-year moratorium on fishing for Atlantic cod, *Gadus morhua*, was imposed in 1992 by the Canadian government and was recently extended to recreational and personal consumption, effectively ending the traditional basis of outport life along the coast of Newfoundland. In the United States, management councils are also imposing severe restrictions on the amount of fishing effort with the present goal in New England of reducing effort, and hopefully mortality, by 50% over a period of five years (New England Fishery Management Council 1994).

The over exploitation and ground fish stock collapse being documented in North America is not unique to the region (FAO 1988; Massachusetts Offshore Groundfish Task Force 1990; Sissenwine and Rosenberg 1993) and has not occurred without scientific advice on biologically sustainable rates of harvest. The total allowable catch (TAC) for the fishing banks east of Newfoundland, for example, was projected for 1987 at 380,000 tonnes (Kirby 1983). By 1986 the TAC had been revised downward to 286,000 tonnes using a management criterion that would allow continued growth of the stocks, rather than merely preventing over fishing. By 1989 the TAC was further reduced because of the observed lack of growth in the stock. In 1992 the TAC was set at 121,000 tonnes but this quantity of fish was not captured because a moratorium was declared in July of that year. A parallel effort has taken place in the United States. The Interim Groundfish Plan was implemented in New England in 1983; replacing a quota based system. The fishery was initially regulated through minimum fish size and codend mesh size regulations. Biological targets for a species spawning stock biomass were set in 1986 with the implementation of the Northeast Multispecies Fishery Management Plan. These biological targets were based on a species maximum spawning potential, as an index of the reproductive health of a stock, and represent a radical departure from traditional concepts for fishery management. This management plan was amended four times in the intervening years with Amendment # 4 recognizing the need to develop and implement strategies for rebuilding the over fished groundfish stocks in a subsequent revision to the plan. Currently, Amendment # 5 to the management plan is being implemented and its restrictions of fishing effort reflect a general and continuing decline in the status of the groundfish stocks.

What is unique about the collapse of the fishery stocks off Newfoundland and the overexploited condition of the stocks in U.S. waters is that these conditions have developed in regions that have sustained commercial fisheries for centuries. Explanations have centered on over fishing (Smith 1988 for an historical review), on the role of ocean climate (e.g. Serchuk et al. 1994), potential pollution, and our lack of knowledge in this area (Longwell et al. 1992; Schaaf et al. 1993), and the interactions between these factors. Our purpose is not to examine or evaluate the role of any particular factor, but rather to consider the need for a multiscale understanding of interactions between fishers and fish, and fish with their habitat.

Spatial scale is particularly important in defining fish habitat. In their review of fish-habitat relationships Peters and Cross (1991) adopted Ryder and Kerr's (1989) definition of habitat as "the structural component of the environment that attracts organisms and serves as a center of biological activity." Peters and Cross (1991) consider structure to be anything with a definite organizational pattern and they list a variety of such elements. There remains, however, great difficulty in determining the scale at which environmental factors affect the distribution of fish, or alter vital rates determining recruitment, mortality, and somatic growth. In addition, there is considerable uncertainty about how processes at one scale carry through to other scales (Kotlier and Wiens 1990). This paper outlines the different scales that have been the focus of fisheries research, through a review of the scientific literature and presentation of some original data, and then discusses the use of multiscale analysis in defining fisheries habitat and the need for incorporating this data into research and, ultimately, management of the resource.

Studies Demonstrating Pattern at Multiple Scales

Groundfish Species Assemblages

Over the last decade demersal fish assemblages, or areas with species having similar spatial distributions, have been identified along the northeastern coast of North America in a series of papers (Colvocoresses and Musick 1984; Overholtz and Tyler 1985; Mahon and Smith 1989; Gabriel 1992; Gomes et al. 1992). In all these studies a time series of fishery independent bottom trawl survey data, ranging from 9 to 21 years, has been analyzed for the existence of persistent groundfish assemblages over large geographic areas using cluster analysis or ordination techniques. The goal of all these papers has also been similar and is summarized by Overholtz and Tyler (1985): "...to begin to investigate the long-term temporal scale of communities so that ecologists and managers can begin to function in terms of ecological time instead of just a framework for short-term reaction."

Ecological time scales require the identification of persistent patterns which can be related to physical and/or biological features. Attempts at relating the identified groundfish species assemblages in the Gulf of Maine and on Georges Bank to the physical environment have been successful (Figure 1).

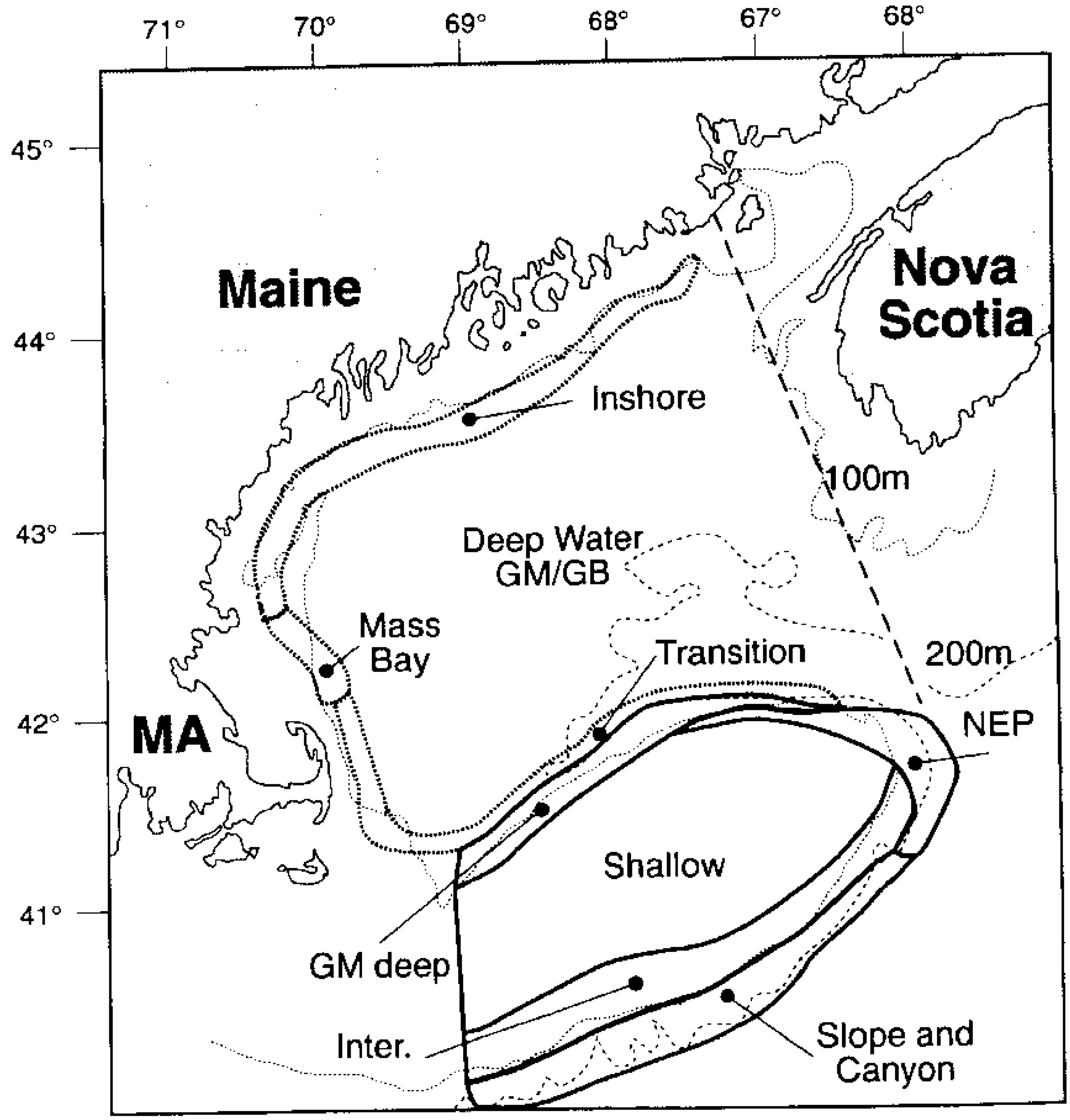

Figure 1. Groundfish species assemblages identified in the Georges Bank and Gulf of Maine regions. Figure is a composite from figures presented in Overholtz and Tyler (1985) for Georges Bank, solid lines, and Gabriel (1992) for the Gulf of Maine, fine dotted lines. Coarse dotted line represents the southern limit of a Scotian Shelf assemblage identified by Gabriel (1992). Deep Water GM/GB = Deep water Gulf of Maine Georges Bank; Mass Bay = Massachusetts Bay/Stellwagen Bank; Transition = Gulf of Maine/Georges Bank Transition; GM Deep = Gulf of Maine Deep Water; NEP = Northeast Peak; Inter = Intermediate.

On Georges Bank, Overholtz and Tyler (1985) found five, depth related, groundfish species assemblages persisting over both space and time, despite substantial changes in biomass and variation in numbers of fish between 1963 and 1978. In this case, seasonal shifts were relatively minor and only affected the shallower assemblage groupings. Depth and salinity were identified as the major physical forces explaining the assemblage structure. Interestingly, a number of species were in different assemblages depending upon their life history stage. Adults often occurred in the deeper assemblages while the juvenile were found on the shallow parts of the bank.

The assemblage structure in the Gulf of Maine was included in a study by Gabriel (1992) who took a broader geographic view of species assemblages than the previously discussed work. Based on National Marine Fisheries Service data, collected between Cape Hatteras, North Carolina and the Canadian Province of Nova Scotia for the years 1967 through 1988, Gabriel identified six major site groupings which corresponded to generally acknowledged geographic regions such as Georges Bank and Gulf of Maine. In the northern areas the site boundaries were correlated with depth differences while in the south, the Mid-Atlantic region, the boundaries showed a temperature dependence that was more sensitive to oceanographic features. Species assemblages showed a persistence over time but demonstrated some spatial shifts as southern, temperature-responsive, species showed some northern excursions as the northern stocks were being reduced from over exploitation. Within the Gulf of Maine per se, Gabriel (1992) identified a persistent Deep-Water Gulf of Maine-Georges Bank assemblage and a Gulf of Maine-Georges Bank Transition assemblage. Occasionally an Inshore Gulf of Maine assemblage as well as a Massachusetts Bay/Stellwagen Bank assemblage would also be apparent. Change in assemblage structure within the Gulf of Maine are reflected in changes in aggregate biomass, based on catch-per-tow data from the annual National Marine Fisheries Service groundfish surveys. There are three periods evident in the data with an initial biomass decline from 1963 through 1974, a recovery from 1975 through 1981, and a subsequent decline from 1982 through 1988.

Despite the recognition of persistent site groupings and species assemblages, intra-annual variability in these features does occur at large scales. Tyler (1971), for example, demonstrated that groundfish species can be separated into year-round, winter and summer residents, and occasional migrants. Areas with wide temperature fluctuations, like the Middle Atlantic Bight, are dominated by temporary residents while boreal systems such as the Scotian Shelf, which have narrow temperature fluctuations, are dominated by year-round residents. It is interesting to note that regional scale distribution patterns of finfish have been correlated with bottom type in boreal regions with a high percentage of resident species (Scott 1982, but see Mahon and Smith 1989) but not in temperate systems with a high percentage of temporary residents (Colvocoresses and Musick 1984, Phoel 1986).

Benthic Communities in the Gulf of Maine

The benthic invertebrate macrofauna and megafauna in the Gulf of Maine and on Georges Bank is relatively little studied. There are, however, several publications outlining fauna assemblages, or communities, together with discussions relating these groupings to the physical environment.

On Georges Bank, Theroux and Grosslein (1987) identify four assemblages of macrobenthic invertebrates which builds on the description of four communities described by Wigley and Haynes (1958). These assemblages are persistent over time and include a western basin assemblage, a Northeast Peak assemblage, and two separate assemblages on the central and southern part of the bank. The faunal composition reflects the composition of the sediments and current regime of the region.

The Gulf of Maine, like Georges Bank, is a physically complex environment and the wide variety of bottom types, when combined with the variation in the structure of the water column, results in a diversity of habitats with discrete invertebrate communities. Watling et al. (1988) identified six communities in the Gulf including a near shore shallow, a boreal mud, sand bank, rock ledge, boreal-slope transition, and upper slope community (Figure 2).

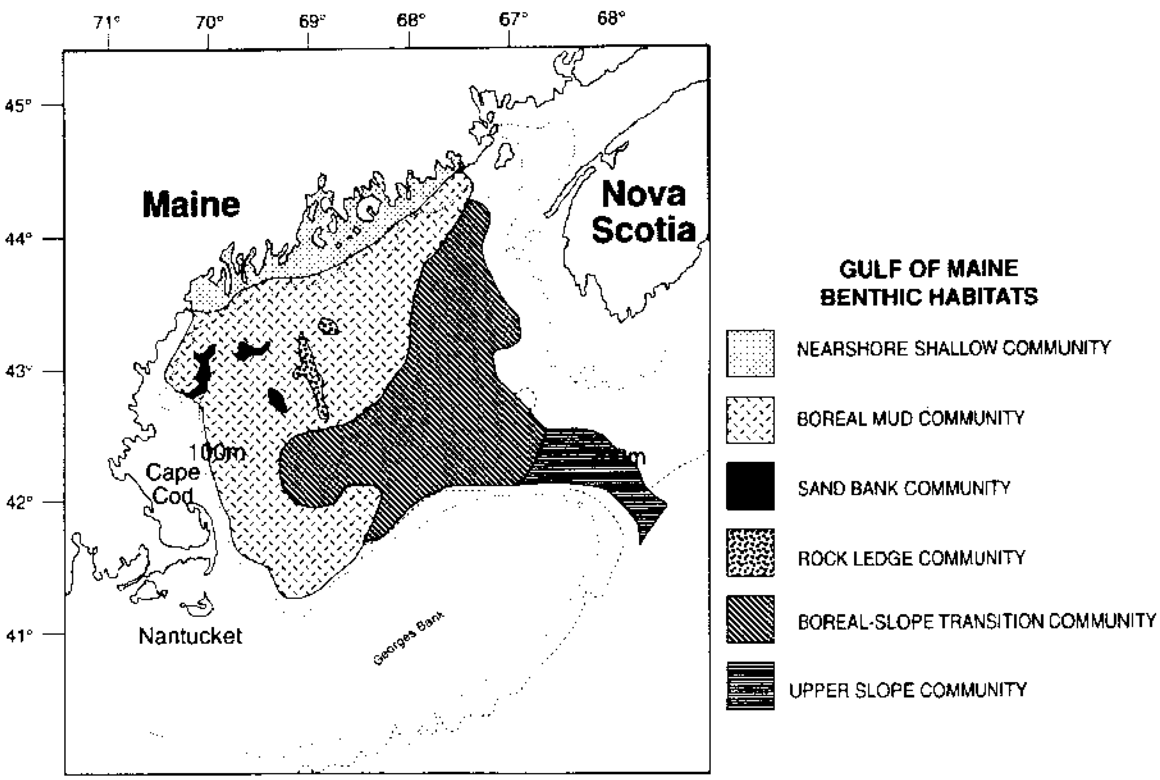

Figure 2. Map of Gulf of Maine showing approximate distribution of major macrobenthic and megabenthic communities. Modified from Watling et al. (1988).

Fishing Grounds

Within the geographic extent of the groundfish site and species assemblages, and benthic invertebrate communities, described above are discreet geographic areas that are best described as fishing grounds. These areas are usually physical feature on the sea floor, such as a bank or ledge, although they may be less clearly defined (Collins and Rathbun 1887; Rich 1929). In "Fishing Grounds of the Gulf of Maine" (Rich 1929) the known grounds were described and the charts depicting the grounds in the mid-coast region of the Gulf of Maine and on Georges Bank are reproduced here as an example of the information available for the entire east coast (Figure 3a and b).

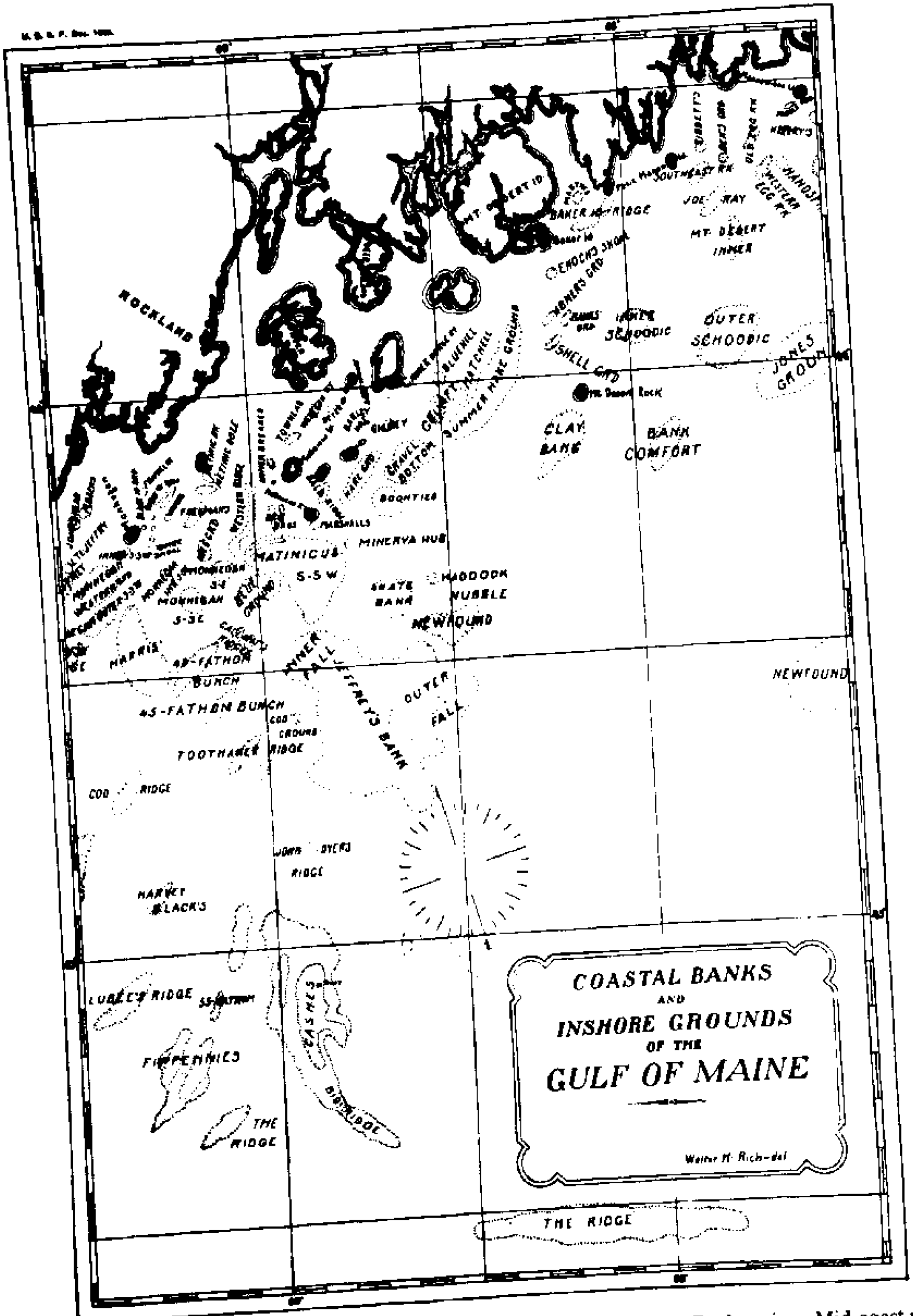

Figure 3.a Example of the extent of fishing grounds in the Gulf of Maine Georges Bank region. Mid-coast region of the Gulf of Maine. Figure is from Rich (1929).

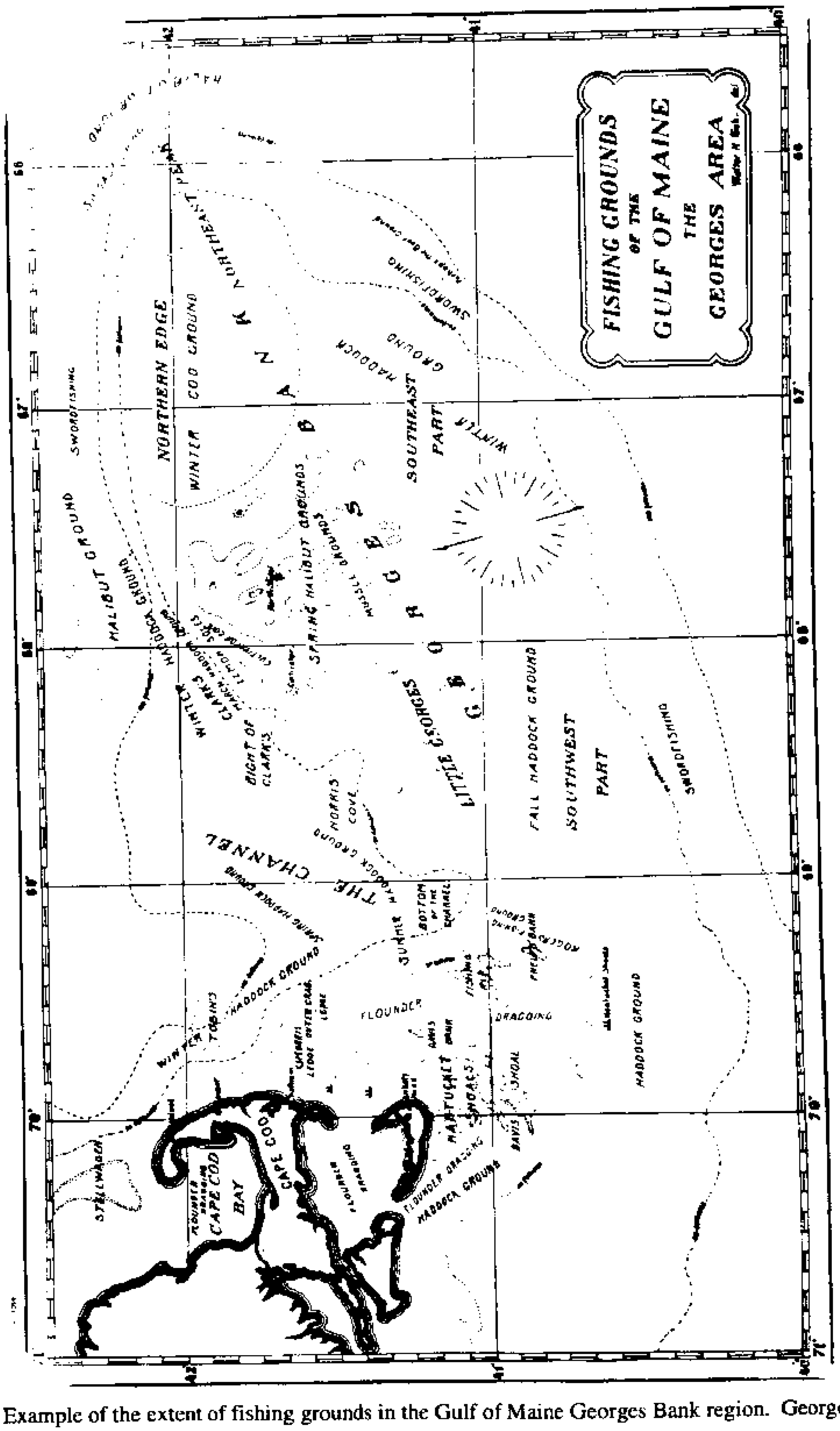

Figure 3.b Example of the extent of fishing grounds in the Gulf of Maine Georges Bank region. Georges Bank. Figure is from Rich (1929).

Rich's publication and Collins and Rathbun (1887) correspond to the days at the very beginning of, and prior to, the era of the otter trawl fishery when sail and dory fleets dominated the fishing industry (e.g.. Pierce 1989). Many of these grounds have continued to be important despite radical changes in fishing technology. The otter trawl was introduced into the American fishing fleet in 1905, for example, and is now the primary method of capture of groundfish species along the entire North American continental shelf.

Despite the early documentation of fishing grounds (Collins and Rathbun 1887; Rich 1929) and the call by Rathbun (1887) almost one hundred years ago to undertake a detailed study of the larger grounds that "may be profitably resorted to by our fishermen" research at this scale has been slow to evolve. Nevertheless, as technology has both developed and become available to the scientific community in the past several decades studies of banks and ledges, and the association between these physical structures and the fish and fisheries associated with them, have increased. Several case studies are illustrative of patterns and processes that can be attributed to this scale of research.

Brown (1987) describes the Georges Bank Atlantic cod stocks as a major component of the fisheries on the northeast coast of the U.S. while both Collins and Rathbun (1887) and Rich (1929) had previously identified the northern edge of the bank as an important winter cod ground. Research has shown that the northeastern portion of Georges Bank is an important spawning and nursery for young gadids with spawning for cod occurring in late winter and early spring (Lough 1984; Smith and Morse 1985). Eggs, larvae and young juveniles are pelagic and have a ubiquitous distribution over the bank. The pelagic juveniles assume a benthic life during the summer months. Lough et al. (1989) conducted a series of cruises over northeast Georges Bank, using both surface deployed sampling gear and occupied submersibles, to document the abundance and patchiness, relative to bottom type, of young cod and haddock. In addition to the biological sampling, Valentine and Lough (1991) conducted an extensive mapping program of the eastern region of Georges Bank to develop sedimentary maps that could be related to the distribution of commercially important species. Lough et al. (1989) found that pelagic juvenile cod, in the length range of 2 to 5 cm, were broadly distributed over eastern Georges Bank (Figure 4a). By the end of July or early August these fish had settled to the bottom and were restricted to the gravel pavement area toward the northern edge of the bank (Figure 4b). They hypothesized that the bottom structure played a critical role in protecting these young fish from predation mortality.

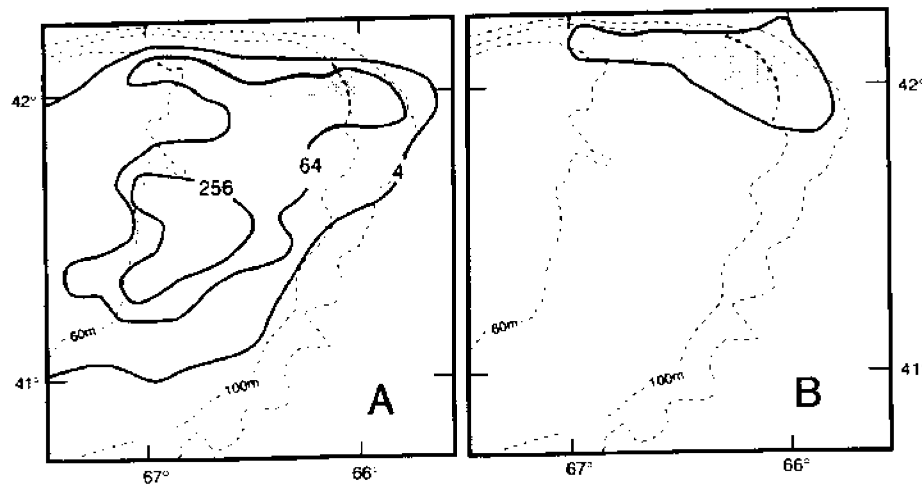

Figure 4.a) Distribution of pelagic stage larvae of Atlantic cod, in June of 1986 (numbers represent individuals per 1000 m^2) and 4b) generalized distribution of benthic stage postlarval of Atlantic cod and haddock, in 1986 and 1987, on northeast Georges Bank. Note the restriction of the postlarval gadoids to the gravel pavement (hatched area) on the northern edge of the bank. Modified from Lough et al. (1989).

Sheepscot Bay is a coastal fishing ground, along the mid-coast area of Maine, where Atlantic cod and other groundfish species are known to spawn in substantial numbers. Fishermen have exploited the stocks in this bay for years and, in 1981, the Maine Department of Marine Resources closed the bay to groundfishing during May and June in recognition of the importance of this area as a spawning ground for a discreet group of Atlantic cod. In 1990 Langton and Watling described the fish-benthos connection in Sheepscot Bay, as well as the Gulf of Maine in general, and evaluated the stability of predator prey relationships over space and time. Data from the Bay was derived from a series of trawls taken at three stations. In the 1990 report, fish food habits data was pooled by predator to characterize the food chain in the Bay. In this paper the fish catch and fish food habits from each station are compared to demonstrate mesoscale changes in these relationships and the importance of scale in investigations of fish predation studies. The data presented here demonstrates the tight linkage between predators, prey, and substrate type.

There are three potential tows in Sheepscot Bay for otter trawling. Two of these are on mud bottom in a drowned river valley (Stations A and C) while the third tow is over a sand/gravel paleo-delta extending out form the mouth of the Kennebec River (Station B) (Figure 5). Comparison of the length/frequency plots of the six dominant species of fish, accounting for 87% of all fish caught, at these three stations shows two distinct fish communities (Figure 6). Over a maximum distance of 3 to 4 nautical miles between tows there is limited overlap in species composition between stations. The catch at a stations A and C is similar and is dominated by American plaice, *Hippoglossoides platessoides,* and ocean pout, *Macrozoarces americanus,* while the catch at station B is dominated by longhorn sculpin, *Myoxocephalus octodecimspinosus,* winter flounder, *Pleuronectes americanus*, little skate, *Raja erinacea*, and yellowtail flounder, *Pleuronectes ferruginea*. Analysis of fish stomach contents further distinguishes these stations. At station B, for example, 60% of the six species listed above contained an amphipod, *Unciola inermis*, in their stomachs (Table 1).

Table 1. Percent occurrence of *Unciola inermis* in the stomachs of predatory fish in Sheepscot Bay. (N) = number of fish examined

	Station A		Station B		Station C	
	%	N	%	N	%	N
Longhorn Sculpin	1	(168)	61	(316)	1	(105)
Winter Flounder	0	(39)	51	(272)	0	(70)
Little Skate	2	(45)	58	(120)	0	(17)
American Plaice	0	(77)	40	(10)	0	(180)
Ocean Pout	0	(24)	71	(7)	0	(48)
Yellowtail Flounder	0	(8)	77	(52)	0	(10)
Totals	<1%	(291)	60%	(777)	<1%	(430)

In contrast, the average percent occurrence of this amphipod species was <1% for the same six predators at stations A and C. The finer scale distinction between stations within this bay is further magnified by a shift from a sand dominated to gravel dominated substrate over the tow that constitutes station B (Figure 5). This sand/gravel station was sampled using a Smith McIntyre grab and the infauna enumerated. The infaunal species composition was different and the maximum numerical densities differed by an order of magnitude between substrate types. What was most significant, however, was a complete absence of *Unciola* in the sand. Not only are the fish at station B preying heavily on this particular species of amphipod but it is logical to suggest that they are showing a preference for the gravel half of the station since fish stomach contents have recently been shown to serve as a good tool for describing prey distributions (Fahrig et al. 1993).

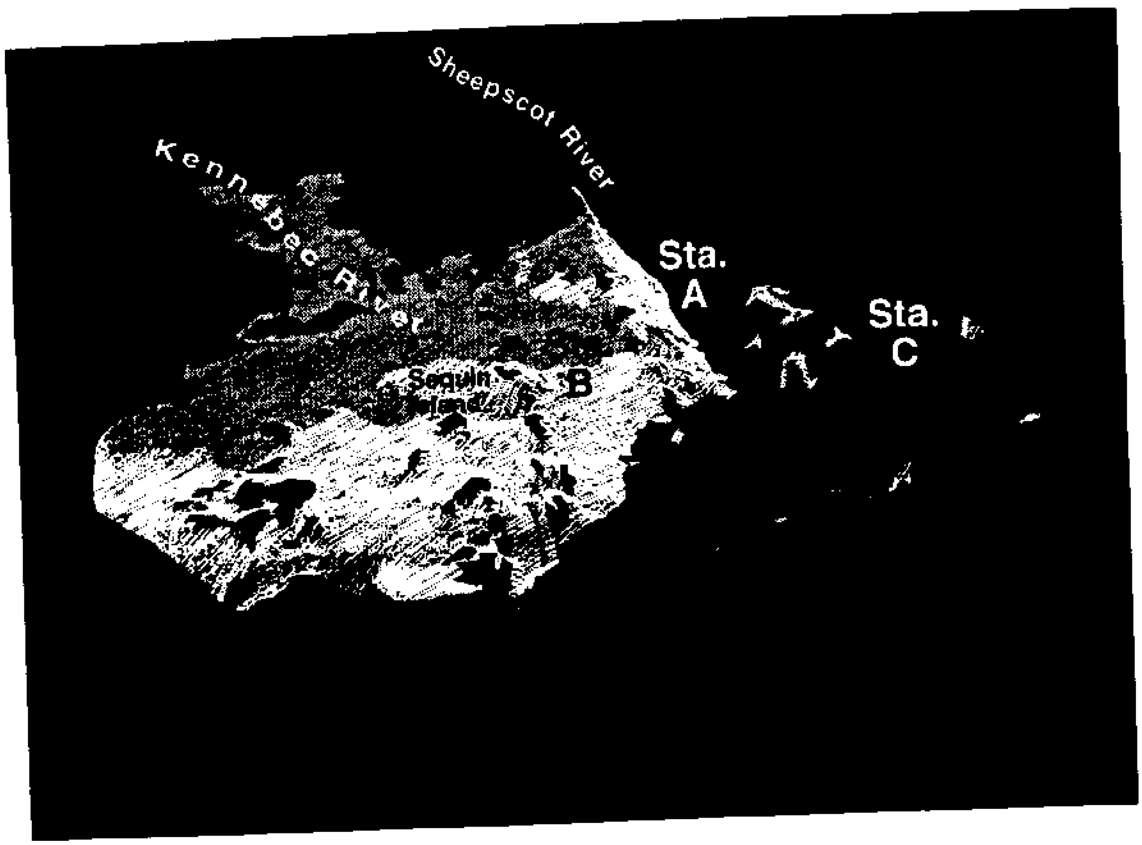

Figure 5. Bathymetric chart with surficial geology overlay of the Sheepscot Bay along the mid-coast region of Maine. Three trawl stations are indicated along A, B and C. Darkest areas = mud; next lightest shading = rock; third lightest = sand; lightest shading = gravel.

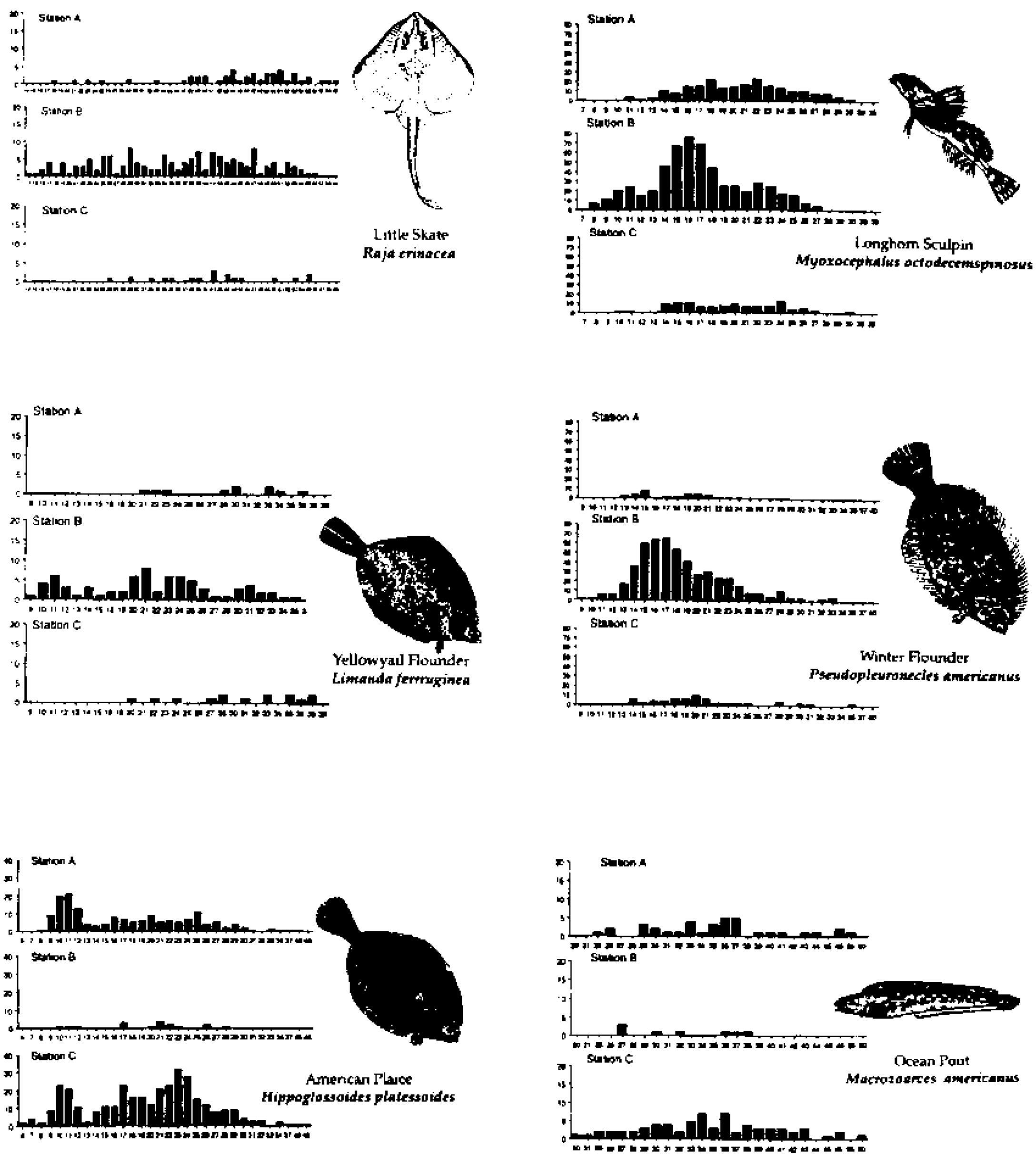

Figure 6. Length/Frequency plots of the six dominant fish occurring in the Sheepscot Bay by station. Length is in centimeters.

Spatial Coordination of Fishing Effort

The degree to which fishing effort has become increasingly focused, and hence more efficient, has not been quantified but there is considerable evidence that substantial increases in efficiency has occurred in the manner over the last several decades in the northwest Atlantic groundfishery. One important development was the distant water trawler, a bundling together of existing technologies (otter trawls, mechanical winches, freezers, filleting machines, and in some cases reduction plants). This bundling of technology greatly increased the mobility and range of these units of fishing effort. For a large freezer-trawler, the distance to port is of secondary importance to a high density of fish, which is required for a sustainable (to the vessel) daily catch rate. Another important development has been the organization of vessels into fleets whose effort is coordinated. A fleet can search a larger area than a single vessel, but once a high density aggregation is located, ships form the fleet converge on that aggregation from the larger area. Good examples of organization of effort into a fleet comes from Russian texts on fishing techniques for groundfish in the northwest Atlantic (Yudovich and Baral 1970).

The focusing of effort does not require central control, as in the organization of Russian fishing fleets. An example of convergence of effort without central control comes from the last days of the Labrador cod fishery at Black Tickle, on the Labrador coast. In September of 1989 inshore fishermen began catching far more cod than they had in previous years. This information spread rapidly by radio. Seiners and trawlers then converged on the area, removing six million tonnes from the area in two weeks (Chantraine 1993). This example shows that fishers interact with fish at several scales, ranging from the scale of local bottom features that affect catch ability, upward to the scale at which a single vessel can search for fish, and further upward to the scale at which information from other vessels can be used to locate fish.

Microhabitat Relationships

Patterns in the distribution of megafaunal organisms, especially mobile fauna such as groundfish, can be found on a multitude of scales. Assemblage level and fishing ground data have been presented to demonstrate differing perceptions of factors that control or, at least, reflect the distribution of fish. At an even finer scale, however, mobile megafaunal animals respond to environmental cues as well as physical and biological structure. The scale of these responses is on the order of centimeters to meters and may be defined as microhabitat relationships.

Wigley and Theroux (1970) recognized, based on a series of benthic photographs, that the microtopography at stations on Georges Bank was greatly influenced by the feeding and shelter seeking activities of demersal fishes. Subsequently, other studies (e.g., Wigley and Theroux 1971, Uzmann et al. 1978, Valentine et. al. 1980, Shepard et al. 1986) have noted the relationship of fish and crustaceans with specific habitat features such as depressions, burrows, and other sessile fauna. These observations were, however, generally ancillary to the primary focus of the research.

Cooper and Uzmann (1980) and Cooper et al. (1987) developed a general classification scheme of habitat types and identified associated fauna for northeast U.S. continental shelf, slope, and submarine canyons (Table 2). This scheme was based on *in situ* observation of faunal-habitat relationships and included five distinct habitat types. The different habitats were generally distinguished on the basis of increasing complexity, ranging from a featureless bottom of sand or consolidated silt (Type I) to a bottom of semiconsolidated silt (Type IV) which is heavily burrowed and utilized by animals such as tilefish *(Lopholatilus chmaeleonticeps)*, American lobster (*Homarus americanus*) and associated fauna (Cooper et al. 1987; Grimes et al. 1986). Type V habitat, however, was more typical of a higher energy environment and was therefore less complex, being described as a sand dune substrate. No attempt was made to determine if individual species exhibited statistically significant associations with particular habitat types. This work did, however, provide the basis for further studies into the role that small-scale habitat features play in affecting the distribution and abundance of mobile organisms.

Table 2. Classification scheme of habitat types for the northeast U.S. continental shelf, slope, and submarine canyons. [modified from Cooper and Uzmann, 1980].

Habitat Type	Geologic Description and Characteristic Fauna
I	Sand or semiconsolidated silt substrate (claylike consistency) with less than 5% overlay of gravel. Relatively featureless except for conical sediment mounds. Burrowing mud anemones characterize this habitat.
II	Sand or semiconsolidated silt substrate (claylike consistency) with more than 5% overlay of gravel. Relatively featureless. Burrowing mud anemones also characterize this habitat.
III	Sand or semiconsolidated silt (claylike consistency) overlain by siltstone outcrops and talus up to boulder size. Featured bottom with erosion by animals and scouring. White hake, ocean pout, rock anemones, star fish, Jonah crabs and tilefish are characteristic fauna.
IV	Consolidated silt substrate, heavily burrowed/excavated. Slope generally more that 5^{0} and less than 50^{0}. Termed "pueblo village" habitat. Jonah crabs, lobsters, and tilefish are characteristic fauna.
V	Sand dune substrate. Jonah crabs, goosefish, and white hake are characteristic of this habitat.

Many taxa, especially juvenile fish, exhibit facultative associations with more subtle but specific physical structures in low topographic environments such as occur on the southern New England continental shelf and slope. Various taxa have been shown to have statistically significant positive associations with various microhabitat features such as biogenic depressions, shells, burrows, sand wave crests, and even patches of amphipod tubes. Use of microhabitat features is a common behavioral attribute for many demersal species across the southern New England continental shelf and slope (Auster et al. 1991, 1994a and b; Malatesta et al. 1992). There are groups of species that actively produce features such as depressions (e.g. red hake, *Urophycis tenuis;* American lobster, *Homarus americanus*; and skates, *Rajidae*) and those that utilize the depressions produced by others (e.g. longfinned squid, *Loligo pealii*, and scup, *Stenotomus chrysops*) (Figure 7 label below, images on the following page 38).

Figure 7. Examples of microhabitat relationships shown by a variety of megabenthic taxa. From the top left to right of the figure: 7a) Young-of-the-year ocean pout using overturned ocean quahog valve for shelter. 7b) Thigmotactic response of red hake and Jonah crab to sponge on an open bottom 7c) Red hake exhibiting thigmotactic response to partially exposed ocean quahog valve. 7d) Silver hake following a four spot flounder in a short time period social foraging association. 7e) Red hake in a biogenic depression. 7f) An adult lobster in a dish depression excavated into the shell covered bottom. 7g) Little skate exiting a depression formed either for camouflage or foraging. (From Auster et al. 1991.)

Use of microhabitat resources can change with ontogenetic development. Late juvenile silver hake, *Merluccius bilinearis*, showed, for example, no association with any specific microhabitat features but were positively associated with the background habitat of flat sand with amphipod tubes at a depth of 55 m on the southern New England shelf (Auster et al. 1991). In a subsequent study at the same station, there was a positive correlation between postlarval silver hake density and increasing cover provided by amphipod tubes (Auster et al. 1994a and b). When undisturbed, most postlarval silver hake were partially buried in the bottom near clumps of amphipod tubes; 87% of 487 silver hake were within approximately one body length of a clump of amphipod tubes. The dorsal coloration of both postlarval and juvenile hake mimicked the pattern of amphipod tubes viewed against the bottom. Postlarval silver hake may occur in patches of dense amphipod tube cover to avoid visual predators and co-occur with preferred prey (i.e., amphipods and shrimps). Alternatively, the observed pattern in small-scale distribution could be the result of differential predation (Gotceitas and Brown, 1991; Walters and Juanes 1993). Similar patterns in distribution have been found for Atlantic cod (Lough et al. 1989) and yellowtail flounder (Walsh 1991, 1992).

Temporal variations in the use of microhabitat resources are less well understood. Seasonal variations in microhabitat utilization were examined in a shallow coastal megafaunal assemblage off Stonington, Connecticut (Malatesta et al. 1994). Replicates of "shell" microhabitat (1 shell, 0.12 m^2, 0.25 m^2) and a control (no shell) were visually censused 10 times over a 13 month period. Species richness and composition varied, with a total of 23 species observed. Microhabitat utilization was shown to vary as a function of both time as well as patch size. The larger patches were occupied by a greater number of individuals and species. However, the pattern of occupation at the small scale matched the pattern of migration and movement of species at the regional scale. That is, regional temperature patterns controlled the species assemblage that was present to utilize the shelter resources but shelter quality (=size) effected which species and individuals occupied the treatments.

Integrating Multiple Scales

Any structural component in the environment occurs within a "patch" (e.g., water mass, gravel patch), which is typically considered to be homogeneous internally and discrete from adjacent patches (Pickett and White 1985). Patches are often defined in some convenient manner in relation to the organisms studied and the questions of interest. For example, surveys conducted by the National Marine Fisheries Service to determine the abundance of fishes on the continental shelf use a stratified random survey design (Grosslein 1969) with patches based on depth and temperature. Studies which seek to understand small scale influences of habitat on fish abundance and distribution use habitat features such as cobble (Lough et al. 1989) or amphipod tubes (Auster et al. 1994) to define a patch. However, we are often restricted in our sampling of the marine environment by the technology which we choose to utilize or have available (e.g. benthic grab, trawl, camera sled, submersible).

Bias in sampling gear influences our perception of the meaning of our sample data. Figure 8 depicts a line transect through "patches" of habitat of unequal size but of identical type. Regardless of the type of sampling gear, data produced from transects which sample patches of unequal or unknown size may exhibit a very high degree of variability when compared to samples taken in discrete patches of equal or known size. This is a simple example of our inability to easily sample subtidal habitats, using traditional methods, in an ecologically meaningful way. Because of this difficulty, there have been few studies in the marine environment in which interactions of organisms with habitat have been determined in a statistically significant manner and which have transcended several orders of magnitude in space and time. Interest in heterogeneity in the environment has expanded the study of "landscape ecology" and the influence of "patchiness" at multiple scales on the distribution and abundance of species (e.g., Urban et al. 1987, Kotliar and Wiens 1990). These types of studies have traditionally been conducted in terrestrial habitats, where mapping of landscape features and subsequent sampling is more easily conducted (e.g., Baker 1989, Turner 1989).

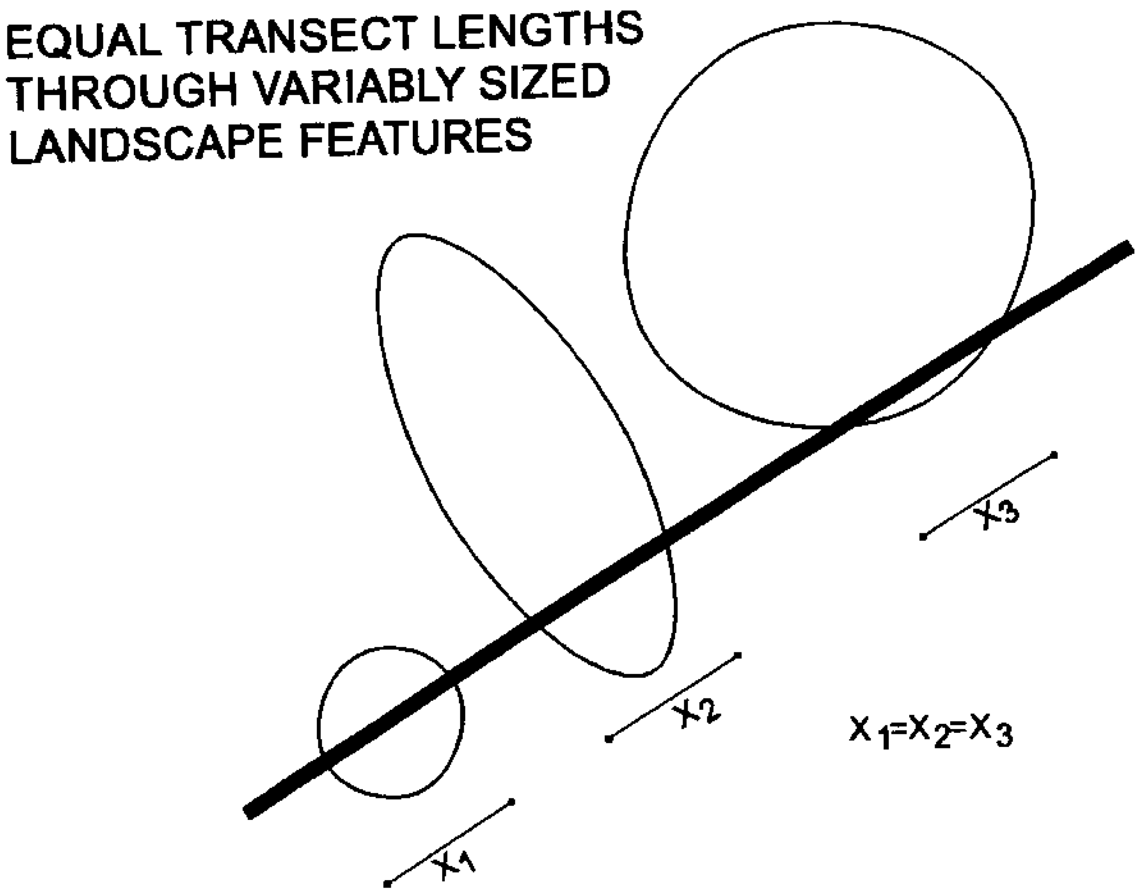

Figure 8. A transect through various sizes of landscape features. Although the transect through each "patch" is of equal length, the samples may exhibit wide variation in abundance estimates due to sampling habitats of unequal size.

Pattern, generated by processes over a continuum of scales, is the basis of a landscape (e.g., Barry and Dayton 1991). Pattern in a landscape is described as a mosaic of patches. The generation of pattern comes from disturbance, biological processes (especially population processes), and environmental limitation (Levin 1978). Figure 9 illustrates the spatial and temporal scales at which a number of factors interact on benthic habitats. For example, disturbances to the bottom can be caused by storm generated surge as well as lunar variation in tidal current patterns. Storms occur at a much lower frequencies than variation in tidal currents but with much greater intensity. Disturbances can also be very local in nature, such as the result of the feeding activities of individual infaunal predators (e.g., rock crab, *Cancer irroratus)*. Biological processes, such as settlement and growth of bivalve larvae, can change the availability of shelter and prey for a large number of mobile predators. Environmental factors, such as temperature, act on organisms at a variety of temporal scales. Water temperature limits the distribution of species, at the largest scale, and regulates predation pressure by seasonally (locally) regulating physiological processes of both predators and potential prey.

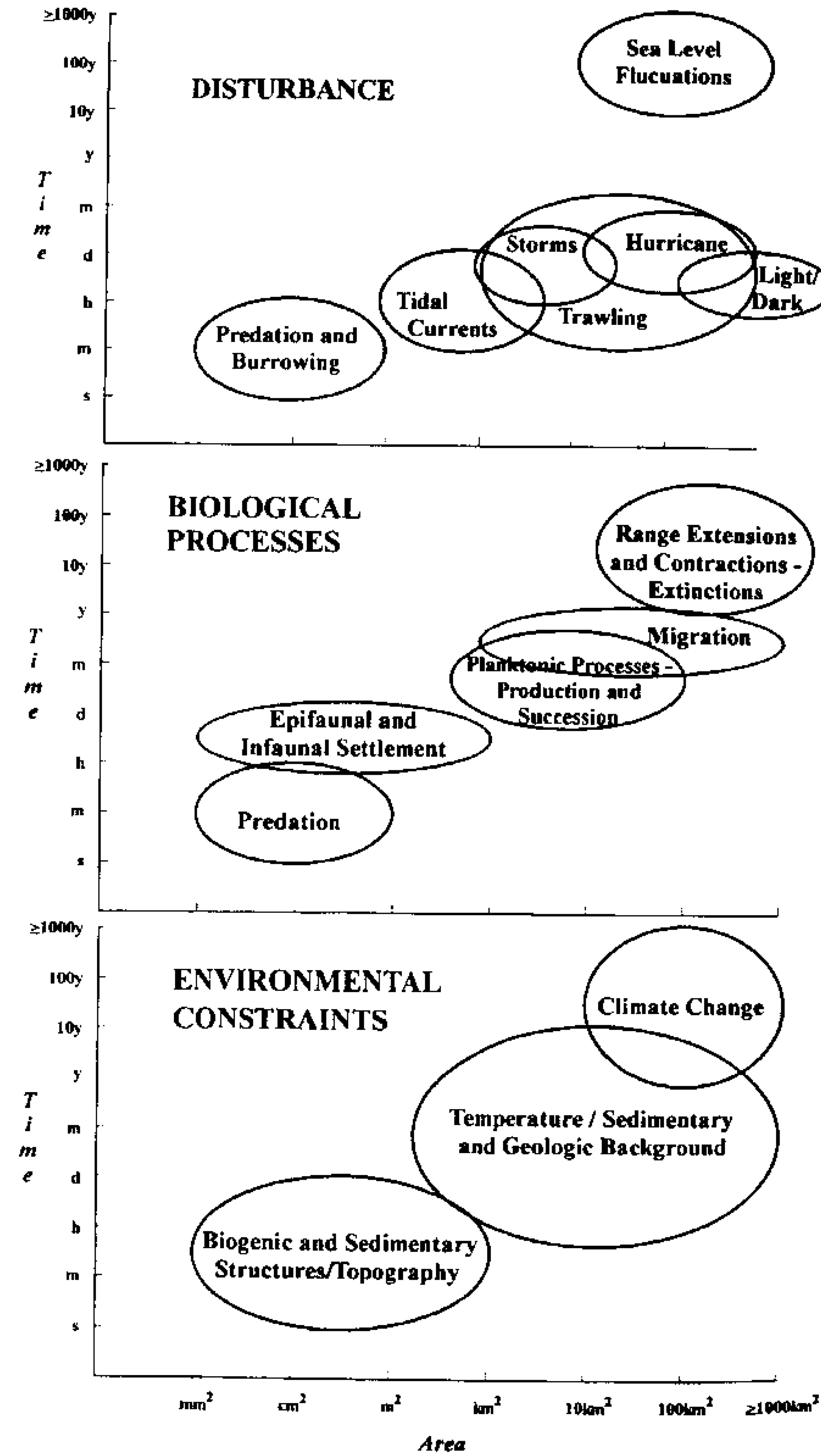

Figure 9. Spatial and temporal scales at which a number of factors interact on benthic habitats.

The proper scale to map habitat features such that the charts produced are useful for biological sampling has yet to be determined. Sampling programs in eastern Long Island Sound (Lewis and Zajac, personal communications) and Fishers Island Sound (Poppe et al. 1993) have, for example, revealed patchiness at small scales that had not been recognized in previous work. Figure 10 illustrates this point. In 1972-73 a study focused on establishing environmental baselines for Long Island Sound and Fishers Island Sound (Reid et al. 1979). The density of samples was very low, hence the resolution of detail was coarse. The chart of the area depicts a relatively simplistic view of the entire region (Figure 10a). A surficial sediment chart (Figure 10b), which was based on a compilation of studies in Fishers Island Sound area (Friedrich et al. 1986) shows a further level of environmental complexity but does not provide the resolution required to understand how variation in sedimentary habitat types effects the distribution of organisms. Figure 10c is a side-scan interpretation of an even smaller area off New London, Connecticut, which adds more detail but, even at this scale, does not provide the resolution required to understand how variation in microhabitats effects the relationships demonstrated by many organisms and sedimentary structures.

Figure 10. An example of the effect of differences of scale on the perception of benthic habitats. 10a) Long Island sediment types as identified in Reid et al.(1979). 10b) A portion of Long Island Sound, off southeast Connecticut (from Friedrich et al. 1986) showing increased complexity in surface sediment types when compared to 10a. 10c) Side-scan sonar mosaic and interpretation of a small area off New London, Connecticut showing increased complexity over 10b. (R. Lewis, Connecticut DEP, unpublished data).

Figures 10d and 10e illustrate the distribution of high density grab sampling in Fishers Island Sound and interpretation of the mosaic of sediment types. Note the level of patchiness in sediment types when compared to Figures 10 a and b, but even at high grab sample densities, side-scan sonar reveals microhabitats consisting of patches of gravel, cobble, rock, and boulders (Figure 10e).

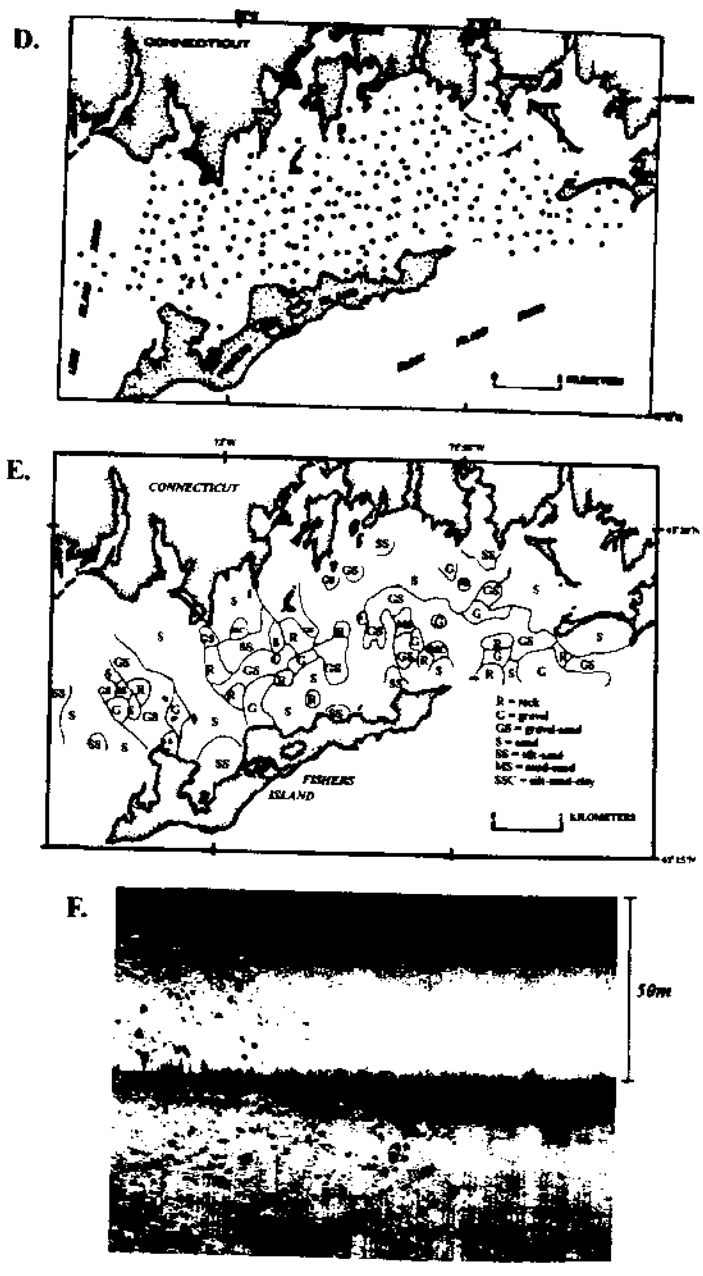

Figure 10d) and 10e) Distribution and interpretation of high density grab sampling in the Fishers Island sound area (from Poppe et al. 1993). and 10f) Within a single sediment type from Fishers Island sound, side-scan sonar reveals an increasing level of complexity with small scale patches of gravel, cobble, rock and boulder that are missed with grab sampling alone.

Field work in eastern Long Island Sound and Fishers Island Sound, conducted during the past 10 years, revealed aspects of the dynamics of landscape features. For example, the blue mussel, *Mytilus edulis*, is a common bivalve species that not only functions as an important prey item (e.g., for rock crab, lobster, tautog, *Tautoga onitis*, cunner, *Tautogolabrus adspersus*) but also produces habitat complexity in the Long Island Sound ecosystem. The life history characteristics of the blue mussel, as well as physical oceanographic factors, function to produce dynamic changes in habitat availability and quality. Larval blue mussels exhibit widespread sets across eastern Long Island Sound at 5-7 year cycles (Auster, unpublished observations). Mussels predictably attach to hard substrates such as rock but also attach to small pieces of shell hash, and each other, to produce extensive "mats" over sand and mud to depths exceeding 33 m. The mechanism behind this cyclical pattern is presently unknown. Crustaceans and fishes utilize these mats in a variety of ways, such as searching for prey and for shelter from predators, as well as for sites to reduce energy used for station keeping in strong currents. As the mussel population declines, through predation and senescence, mussel shell becomes the dominant habitat feature. Remotely operated vehicle based observations during 1992 revealed large "windrows" of shell occurring at 4-8 m intervals, at 20 m depth, at a site in eastern Long Island Sound. The orientation of windrows was north-south, indicating that east-west currents, and possibly storm generated surge, interact to create these features. Juvenile fish, squid and crustaceans were associated with these features. Side-scan sonar surveys and observations with a remotely operated vehicle during 1993 showed that the windrows were no longer present and the associated organisms were either absent or occurring at lower densities than the previous survey. Mussel beds have previously been shown to support a variety of invertebrate taxa and increase local species diversity. For example, a *Mytilus californianus* community was composed of over 303 taxa, a *Modiolus* community 90 taxa, and a *Mytilus edulis* community 69 taxa (Suchanek 1985). Species richness and diversity indices were correlated with the structural complexity of the mussel habitat.

The surface sediments of Fishers Island Sound are a mosaic of rock, cobble, gravel, and sand over a basement of mud-silts. Many areas are composed of a mixture of gravel and sand, with only one or the other predominating on the surface. Observations in this area while scuba diving (Auster, unpublished) show that edges of sand/gravel borders are dynamic. Changes in the aerial extent of exposed gravel and sand may occur due to winter storm events or tidal current energy. That is, sand or gravel may be resorted due to the energy imparted by currents or surge and change the surface distribution of sediment types. Cobble-gravel over sand-mud is a primary habitat type for juvenile lobsters. The amount of area covered by cobble-gravel may be a habitat bottleneck for the recruitment of early benthic phase lobsters (Wahle and Steneck, 1991), as well as other shelter seeking species such as Jonah (*Cancer borealis*) and rock crabs.

The preceding descriptions are two examples of the role that landscape features play on the distribution of organisms. Other types of sedimentary structures, mediated by other landscape processes, also provide habitat for mobile organisms. There have been no published studies from work in temperate or boreal subtidal areas which integrate megafaunal-habitat relationships over a continuum of scales although studies demonstrating the relationship between sedimentary types and megafaunal distributions begin the process (Scott 1982, MacDonald et al. 1984; Schneider et al 1987; Langton and Uzmann 1989). While we have identified a number of organism-habitat relationships that occur at different spatial and temporal scales, these data only suggest a variety of interactions that may have direct implications for population and community processes. A knowledge of the dynamics of landscape features and how organismal distributions and abundance are influenced by these features will have direct applications to management of living marine resources.

General Discussion

Striking a balance between exploitation and production of renewable resources has been debated since harvesting began. Incorporating the scientific information, together with an understanding of its scale dependent bias, into management schemes will remain a challenge to resource managers until all scales of importance to the ecology of the animal being harvested are properly matched with the economics of fishing. Recently, ecosystem-based management has been proposed as a scheme that should result in more stable exploited populations (Harris et al. 1987; Slocombe 1993). The essence of ecosystem-based management is the integration of environmental and developmental planning within a management unit. The critical factor is defining the management unit, which is dependent on both biophysical and socioeconomic standards determined by ecosystem research and a management vision for the resource being exploited. The challenge for marine fishery managers is to define the biophysical component of the management unit since many marine animals have ontogenetically distinct habitat requirements (Langton et al. in review) and, for many species, it is not clearly understood at what point year class strength is established. Recent work on groundfish, however, supports the hypothesis the year class strength is determined at the larval stage but density-dependent mortality of young juvenile fish may also have an important influence (see Myers and Cadigan 1993a and b) which may relate to habitat selection and predation risks (Walters and Juanes 1993).

Definition of the biophysical component of management units has to start with a consideration of climate since it is the largest scale which influences fisheries (e.g.. Serchuk et al. 1994). There is documentation of temperature cycles in the Gulf of Maine, for example, and corresponding relatively short term shifts in abundance that correlate well with the temperature (Dow 1964, 1977; Sutcliffe et al. 1977). At the extreme, it is perhaps significant that the last Ice Age (12,000 to 18,000 years before present) was responsible for the structure of the northeast North American continental shelf with major fishing grounds like Georges Bank and the Southeast Shoal of the Grand Banks of Newfoundland having been either dry land or at least intertidal (Emery 1987; Frank et al. 1989; Walsh 1992). Within the constraints of climate the geographic range of a species is a function of the physical environment. The geographic range of any fish species can usually be defined by such factors as temperature and salinity. Within the physical limits of a species range are the biological processes that determine a species distribution. The need to locate appropriate prey and migration to spawning grounds (Greer Walker et al. 1978; Harden Jones et al. 1978, 1979) are activities that represent a level of environmental awareness attributable to the fish themselves. The recent discovery of "cod highways" off Newfoundland was based on the assumption that the animals travel along a stable temperature profile (Rose 1993). The behavioral mechanism by which fish actually select and maintain position in these temperature regimes has, as Rose points out, yet to be determined. The persistence of this migratory behavior is notable but perhaps of more significance is the hypothesis that it is learned behavior (Rose 1993). As the stocks of Atlantic cod, for example, are reduced (deYoung and Rose 1993; NMFS 1993; Sinclair 1993) the younger fish may not maintain the same migratory behavior that has previously been targeted by the fishery. Finally, within the biological processes that establish a species temporal distribution are microhabitat relationships that represent the close association between the individual fish and substrate. At this scale the fish itself is modifying the physical environment, adapting to a modified environment, or selecting appropriate habitat to sustain the particular life stage. The behavioral reasons underlying these habitat relationships is unclear but it is logical to conclude that there is some advantage, either for feeding success or predator avoidance, that reinforces the maintenance of these associations for mobile fauna (Auster 1988, 1991; Gotceitas and Brown 1993; Walters and Juanes 1993).

The harvesting of living marine resources is a normal human practice that has been conducted for centuries and will no doubt continue into the future, as will the need for more detailed species specific biological information. In attempting to develop an understanding of the ecology of harvested species the scientific community has approached the problem at a number of scales, depending on the investigators interests or available technology, and it is becoming increasingly clear that major environmental problems, such as over fishing, can not be attacked at a single scale of investigation (Levin 1991; Steele 1991). What is required is multiscale analysis, in which patterns and processes are investigated through a range of scales. A vivid expression for this analytical strategy is zoom rescaling, because it is similar to the use of a zoom lens on a camera. Zooming contrasts with panning, which is the operation of scanning from one spatial unit to the next, holding the size of the unit constant. The combination of panning and zooming is far more effective than either one by itself (Schneider 1994). Multiscale analysis will provide the scientific framework for managers to concurrently consider how fishers interact with fish and fish interact with their habitat, both at a variety of scales.

Recognition and understanding of factors controlling the scale that allows the sustained harvesting of the resource should be the focus of fisheries research. The scientific community must start perceiving the environment through eyes of the fish themselves if management regimes are to be developed that sustain harvests over time. Optimum yield, as defined in the Magnuson Fishery Conservation and Management Act of 1976, allows for modification of sustainable yield by any relevant economic, social, or ecological factors. The weakness in this definition should be readily apparent, sustained exploitation of a resource over and above its potential biological production is impossible without compromising future production and yield. The question is, at what scale or scales do we manage the fisheries and what are the implications for future research which will supply required information to managers? Large scale surveys, as conducted by the National Marine Fisheries Service since 1963, have been extremely effective in documenting the persistence of patterns in the structure and geographic range of fish populations but they have not recognized the finer scale factors controlling fish behavior. Spawning grounds, or feeding migrations are not the focus of these surveys, rather they have generally been conducted in the spring and the autumn to reflect the extremes in the distributions of the populations. In contrast, fishermen have focused their efforts on fishing grounds for over 500 years, or even at smaller scale habitat associations within a generalized fishing ground, reflecting localized knowledge of a particular fishes behavior. Populations changes, brought about by fishing, are the cumulative result of individual fishermen making decisions when and where to fish. The report of Collins and Rathbun (1887), for example, makes reference to the food habits of the cod and halibut on certain grounds indicating that the fishermen were well aware of the habits of the predatory fish themselves. Anecdotal information from present day Boothbay, Maine, fishermen, and tag return data (Herb Perkins, Maine DMR, personal communications), also indicate that Atlantic cod migrate into the Sheepscot Bay region to spawn and these aggregations of fish, along with other coastal concentrations of fish, are targeted by fishermen. This is the level where human activity intersects the biological process underlying fish behavior, resulting in an efficient harvest. It is at this scale that more research effort has to be expended and it is at this scale that management efforts have to be developed.

Several authors have recently suggested that fisheries management needs to reconsider the scale of the management process (Hurley and Gray 1994; Wilson et al. 1994). The argument in both these papers is for a scheme of community based management rather that large scale, government, intervention. The appeal of such a scheme is that it vests the management process in people that are most directly effected by the success or failure of the fishery. If such a management plan is to be developed however, it must also recognize the importance of local habitats and the cumulative impact of harvesting at the population level. Although a particular group of people may be able to allocate the resource within the confines of the fishing community itself there remains a larger scale allocation problem. For migratory fauna, such as marine fish, incremental harvesting of the resource by a number of communities at locations where fish are concentrated may result in no greater success at sustained resource production than is currently being experiences in the US and Canada. Integration of our knowledge of the response of fish to the environment at all scales will be critical for this or any other fishery management effort to succeed.

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Incorporation of Habitat Information in U.S. Marine Fisheries Management Plans: An Atlantic Coast Perspective

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The development and history of marine fisheries management on the Atlantic coast of the United States has, to a large extent, proceeded along two different tracks. In coastal waters within three miles of shore where the states have jurisdiction over marine resources, individual states have acted on their own or together to manage stocks which are primarily limited to coastal habitats and harvested within state waters. Offshore, beyond three miles, the federal government has management authority. With the passage of the federal Magnuson Fishery Conservation and Management Act in 1976, federal jurisdiction over living marine resources in the Exclusive Economic Zone (EEZ) was established between three and 200 miles offshore. Prior to that time, attempts were made to control the harvest of offshore stocks through bilateral or multinational treaty agreements with other countries. It was the failure of international treaty organizations, such as the International Commission for the Northwest Atlantic Fisheries (ICNAF), to adequately protect marine fishery resources off the east coast of the United States and Canada and the consequent political pressure from frustrated United States fishermen that led Congress to enact the Magnuson Act.

The history of state management of marine fishery resources is a long one. The Atlantic States Marine Fisheries Commission (ASMFC) was formed in 1942 in order to coordinate the management activities of the different east coast states for inter jurisdictional fisheries found primarily within the states' territorial seas and internal marine and estuarine waters (Kilczewski 1992). The role of the Commission has been primarily recommendatory and advisory since it has had no authority (until recently) to require any management action by any state. In this capacity, the Commission produced fishery management plans for 17 different species or species groups between 1978 and 1994 (Table 1). Several of these management plans and/or amendments have been developed in collaboration with one or more of the three east coast federal fishery management councils for species that are distributed and harvested inside *and* outside of state waters (Table 2). In fact, there are very few species or stocks that are restricted to inshore or offshore waters, or to the waters of any particular state. Thus, coordinated interstate and state-federal management is both necessary and appropriate for the majority of the nation's marine fisheries.

Table 1. Atlantic States Marine Fisheries Commission Fisheries Management Plans & Amendments

Species	Plan Adopted	Last Major Amendment
American Lobster	1978	1990
Striped Bass	1981	1993
Atlantic Menhaden	1981	1992*
Summer Flounder	1982	1994
Red Drum	1984	1991***
Weakfish	1985	1991
Shad & River Herring	1985	1991
Spotted Sea Trout	1985	
Northern Shrimp	1986	
Hard Clam	1986	

Table 1.(continued) Atlantic States Marine Fisheries Commission Fisheries Management Plans & Amendments

Species	Plan Adopted	Last Major Amendment
Spot	1987	
Atlantic Croaker	1987	
Bluefish	1989**	
Spanish Mackerel	1990	
Atlantic Sturgeon	1990	
Winter Flounder	1992	
Atlantic Herring	1994	

* This was a revision of the 1981 Atlantic menhaden FMP

** Joint FMP with MAFMC

*** Adopted 1990 SAFMC/NEFMC/ASMFC FMP to replace original 1984 FMP

The Magnuson Act (PL 94-265) established eight regional fishery management councils which were charged with the responsibility of preparing and implementing fishery management plans "which will achieve and maintain, on a continuing basis, the optimum yield from each fishery." Three councils were established on the east coast: one in New England (Maine through Connecticut), one for the mid-Atlantic region (New York through Virginia), and the third in the South Atlantic (North Carolina through the east coast of Florida). The three Atlantic coast management councils have, on their own or in collaboration with each other and/or the Commission, prepared 16 different management plans and a large number of amendments to those plans since the late 1970s (Table 2).

Table 2. United States. Atlantic Coast Federal Fishery Management Plans

Species	Plan Adoption	Last Major Amendment
Surf Clam/Ocean Quahog	1977	1989
Sea Scallops	1982	1993
Spiny Lobster	1982	1990
American Lobster	1983	1991
Squid, Mackerel & Butterfish	1983	1991
Snapper-Grouper	1983	1991
Multispecies Groundfish	1985	1994
King & Spanish Mackerel	1985	1994
Swordfish	1985	1990
Atlantic Salmon	1987	
Summer Flounder	1987*	1994
Billfish	1988	
Bluefish	1989*	
Red Drum	1990	
Shrimp	1993	

* = Prepared in Collaboration with Atlantic States Marine Fisheries Commission

The major objective of any management plan is the maintenance of a healthy stock and the control of fishing mortality necessary to achieve sustained utilization of the stock by commercial and recreational fishermen. In the case of over-exploited stocks, the emphasis shifts to stock recovery and the limitations on fishing activity required to achieve it become more severe. Since over-exploitation is usually the primary and the most obvious source of resource depletion (and a problem that can be corrected), the emphasis on fishing mortality is quite appropriate. However, habitat loss and degradation, particularly in coastal waters, has also been known for some time to be an important factor affecting species survival, growth, and reproductive success. In fact, the new chief administrator of the National Marine Fisheries Service (NMFS), the federal agency responsible for the stewardship of the nation's living marine resources, has called the loss of near shore ocean and estuarine fishery habitat "probably the greatest long-term threat to U.S. marine fisheries productivity" (Schmitten 1994). It is clearly a problem that is not so easily corrected as excessive fishing mortality.

Loss of coastal wetlands due to residential and industrial development, particularly between the 1950s and 1970s, has been severe. It has been estimated that, by the mid 1970s, about 54% of the nation's original 915,000 km2 of wetlands (freshwater and coastal) had been lost (Tiner 1984), and over half of the nation's original salt marshes and mangrove forests had been destroyed (Johnston et al. 1992). At the same time, about 75% of the nation's commercial fishery landings of fish and shellfish are composed of species that depend on estuaries at some stage in their life history for reproduction, nursery areas, food production, or migrations (Chambers 1992). These estuarine dependent resources are therefore vulnerable to coastal habitat loss and degradation, whether as a result of lost wetlands or other, less obvious, sources of diminished environmental quality.

The National Marine Fisheries Service (NMFS) has recognized the importance of habitat protection for some time. In recognition of the "importance of habitat to the management and conservation of living marine resource," the NMFS issued a new habitat conservation policy in 1983 (FR 1983) which articulated a habitat conservation goal and a set of implementation strategies for achieving that goal. The purpose of this policy statement was to "provide a focus for NMFS' habitat conservation activities, while at the same time integrating habitat conservation considerations throughout the major programs and activities of the agency." This policy was also intended to encourage greater participation by the regional fishery management councils and the states in habitat conservation matters. In developing this new policy, it was recognized that NMFS' traditional habitat conservation policies were developed by the agency in response to federal laws (e.g., the Fisheries and Wildlife Coordination Act) which give NMFS an advisory role, primarily with respect to commenting on projects proposed by other federal agencies which would affect living marine resources, but which do not give the agency any regulatory authority to prevent alterations to fishery habitat which are determined to have a detrimental effect on those resources. This lack of regulatory authority has, by most accounts, seriously hampered the agency's ability to protect fishery habitat (more on this subject later).

With regard to fishery management plans prepared by the councils, the 1983 policy stipulates that they "should address habitat considerations, where applicable, based on the best available information." The statement reiterates the fact that "threats to habitat posed by sources other than fishermen are not subject to regulation under the [Magnuson] Act," but states that "significant discussions of important habitat and threats to it" may be required in order to adequately describe the fishery, its maximum sustainable yield, or its optimum yield. It further states that, at a minimum fishery management plans should include:

- identification and descriptions of habitat requirements and habitats of the stock(s) comprising the management unit;
- assessment of the condition of these habitats, to the extent possible, as they relate to the continued abundance and distribution of the species;
- identification, where possible, of causes of pollution and habitat degradation;
- description of programs to protect, restore, preserve, and enhance the habitat of stock(s) from destruction or degradation; and
- where appropriate, proposal of measures intended to preserve, protect, and restore habitat determined to be necessary for the life functions of the stock(s).

Prior to 1983, when the NMFS habitat conservation policy statement was issued, there were no guidelines for the regional councils to follow when considering what types of habitat information to include in their fishery management plans (FMPs). Some plans included minimal habitat-related information, others contained none at all. Following the publication of the 1983 policy statement, a number of federal FMPs (e.g., summer flounder, in 1987) were prepared which did include physical descriptions of habitat and environmental requirements, but it is only recently that evaluations of habitat condition and habitat management recommendations have been incorporated into federal management plans. Notable in this regard are the penaeid shrimp, bluefish, and red drum FMPs, all completed during the last six years. Management plans currently being prepared (e.g., scup and black sea bass) will include clearly defined habitat protection recommendations.

Although well-conceived and broad in scope, the habitat policy issued by NMFS in 1983 was an internal policy only until it was endorsed by Congress during the 1986 Magnuson Act amendment process (Rosen 1992). These amendments granted the councils discretionary authority to comment on federal actions that may affect the habitat of species and stocks that are subject to management by a federal FMP, and a requirement for the federal agency to respond in writing to council concerns, but did not give NMFS any direct regulatory authority over habitat.

The original Magnuson Act provided little opportunity for the councils to have any impact on habitat protection. Amendments to the Act in 1986 and 1990 have increased the ability of the councils to address habitat protection issues (Locandro 1992). Specifically, the Act, as amended through November 28 1990, requires that the councils "may comment on, and make recommendations concerning, any activity ... that ... may affect the habitat of a fishery resource under its jurisdiction; and shall comment on and make recommendations concerning any such activity that... is likely to affect the habitat of an anadromous fishery resource under its jurisdiction" (MFCMA, sec. 302(i)). In addition, federal agency responses regarding anadromous fish habitat (i.e., not habitat for non-anadromous species) shall include a description of measures being considered by the agency for mitigating or offsetting the impact of the activity on such habitat" (MCFMA, sec. 303(a)(7)). The amended Act further stipulates that FMPs prepared by the councils "shall include readily available information regarding the significance of habitat to the fishery and assessment as to the effects which changes to that habitat may have upon the fishery." This kind of information has proven valuable in stopping or modifying certain coastal development activities such as dredging and the filling of wetlands in instances where a FMP has identified particular habitat types or locations as crucial to the spawning or recruitment success of the managed species, or as important migratory routes (Tom Hoff, MAFMC, personal communication).

In addition to the required provisions for federal FMPs which are included in Section 302 of the amended Magnuson Act, the Act also identifies seven national standards for fishery conservation and management (Section 301) and gives the Secretary of Commerce the authority to "establish advisory guidelines (which shall not have the force of law), based on the national standards, to assist in the development of fishery management plans" (MFCMA, sec. 301 (b)). Although none of these national standards address habitat issues directly, new guidelines issued in 1989 (known as the "602 guidelines") by the National Oceanic and Atmospheric Administration (which administers the NMFS) to revise existing advisory guidelines for the first national standard (prevention of over fishing while achieving optimum yield) do mention habitat (FR 1989). Specifically, in addressing the over fishing definition now required in all federal FMPs, the 602 guidelines state "significant adverse conditions in environment/habitat conditions increase the possibility that fishing effort will contribute to a stock collapse [and] care should be taken to identify the cause of any downward trends in spawning stock sizes or average annual recruitment." The guidelines go on to state that "if man-made environmental changes are contributing to the downward trends, in addition to controlling [fishing] effort [,] Councils should recommend restoration of habitat and other ameliorative programs, to the extent possible, and consider whether to take action under section 302(i) of the Act" (sec. 602.11(c)[7](iii)). Further on, as one of the factors that are relevant to optimum yield, ecological factors "such as natural and man-made changes in wetlands or nursery grounds, and effects of pollutants on habitat and stocks" are mentioned (sec. 602.11(f)(3)(iii)).

More recent operational guidelines issued by NMFS (USDC 1992) include an outline for habitat-related information to be included in federal FMPs. That outline is as follows:

- 4.2 Description of habitat of the stock(s) comprising the management unit
  - 4.2.1 Habitat condition
  - 4.2.2 Habitat threats
  - 4.2.3 Habitat information needs
  - 4.2.4 Habitat conservation programs
  - 4.2.5 Habitat recommendations

These guidelines reiterate the fact that "threats to fishery habitat by sources other than fishing are not subject to regulation under the MFCMA," but goes on to explain that "the Council identifies habitat issues affecting the FMP species and recommends that NMFS consult with the appropriate authorities having jurisdiction to advise them of the issue."

Also included in the most recent (1990) amended version of the Magnuson Act is a charge to the Secretary of Commerce to develop and publish, within one year, and at least every three years thereafter, a strategic five year plan for fisheries research to be conducted by the NMFS. These plans will include research on the "impact of pollution on fish populations, the impact of wetland and estuarine degradation, and other matters bearing upon the abundance and availability of fish" (MFCMA, sec. 304 (e)(2)). One of the goals of the 1991 NMFS strategic plan (USDC 1991) is to protect living marine resource habitat. Objectives identified to achieve this goal and actions planned by the agency to accomplish these objectives are outlined in Table 3. As was true for the 1983 NMFS habitat conservation policy, these are ambitious actions that, if implemented, would greatly improve habitat conservation and the effectiveness of marine fishery management plans.

Table 3. 1991 NMFS Strategic Plan Habitat Protection Objectives and Actions Summary

Goal	Protect Living Marine Resource Habitat
Objective #1	Use authority of the Fish & Wildlife Coordination Act, Magnuson Act, Marine Mammal Protection Act, Endangered Species Act, Oil Pollution Act, Superfund, and other legislation to implement a cohesive strategy to protect and restore habitat of living marine resources.
Objective #2	Quantify the effects of habitat modifications and contaminants on populations of living marine resources
Objective #3	Determine if artificial or restored habitat fulfills essential habitat needs of living marine resources. artificial habitats, such as reefs, or habitat restoration may be used to mitigate development.
Objective #4	Restore depleted stocks that have been adversely impacted by habitat modifications.

Table 3. (continued) 1991 NMFS Strategic Plan Habitat Protection Objectives & Actions Summary

Goal	Protect Living Marine Resource Habitat
Action #1	Review, revise and implement arrangements (e.g., MOUs) with regulatory and development agencies, and states, to increase the effectiveness of NMFS' advice on habitat decisions.
Action #2	Fully implement habitat conservation provisions of the Magnuson act in order to elevate the stature of NMFS' habitat advice.
Action #3	Prepare scientific syntheses of information on important habitat issues.
Action #4	Expand research on the biological effects of habitat modification and contaminants.
Action #5	Conduct research to determine the critical habitat requirements that limit population sizes of living marine resources.
Action #6	Take advantage of opportunities to conduct research cooperatively with regulatory and development agencies when the research supports living marine resource habitat protection.
Action #7	Develop implementation plans to apply oil pollution act and superfund settlements to habitat restoration.

Additional, and much stronger, language is being proposed during the current (1994) Magnuson Act amendment cycle which would require the Fishery Management Councils to include additional habitat information in future (and perhaps existing) FMPs and would shift the emphasis of habitat protection to "essential" habitat. A number of amendments addressing habitat concerns have been proposed by a group representing the seafood industry (the National Fisheries Institute) and a coalition of marine conservation groups. As of this writing (September 1994), House and a Senate drafts of the amended law have been distributed for comment. Further modifications to both versions of the amended Act are expected, and it almost certain that action on Magnuson Act revisions will be delayed until the January 1995 session of Congress. There are some differences between the House (July 14) and Senate (August 4) versions of the habitat amendments. In general, the Senate version includes more references to habitat issues than the House version, but neither version significantly expands the authority of the Councils to protect fishery habitat beyond the existing "comment and recommendation" authority.

The House amendments propose no changes to Section 2 of the Act (Findings, Purposes, and Policy) that relate to habitat. The Senate version includes several new "findings" that were originally suggested by the industry-conservation group coalition. The two most significant statements are:

1. "Certain stocks of fish have declined to the point where their survival is threatened, and other stocks of fish have been so substantially reduced in number that they could become similarly threatened as a consequence of a) increased fishing pressure, b) the inadequacy of fishery resource conservation and management practices and controls, and c) *direct and indirect habitat losses which have resulted in a diminished capacity to support existing fishing levels.*" (Italics is mine).

2. "One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine and estuarine habitats on a national level. Habitat considerations must receive increased attention in the conservation and management of fishery resources of the United States."

Both drafts offer a definition of "essential" fish (or fishery) habitat. These differ somewhat, but both refer to areas which are necessary for essential biological processes (e.g., spawning and breeding). In addition, the Senate version refers to "any area essential...to the production of optimum yield throughout the range of one or more fisheries managed under this Act."

The Senate draft identifies new habitat information that must be included in future federal fishery management plans, with a new reference to the effects of fishing itself on essential habitat, i.e., in Section 303(a), paragraph (7): " identify essential habitat information including-

"(A) available information on the significance of such habitat to the fishery and the effects of changes to such habitat on the fishery, including the effects of fishing gear and practices used in the fishery on essential fish habitat for that or other fisheries; and

"(B) recommendations for regulatory and non-regulatory actions that should be considered to ensure the long-term protection of essential fish habitats, including minimizing adverse impacts caused by fishing."

The House draft, on the other hand, does not propose any change to the existing paragraph 7 in Section 303 (which reads "include readily available information regarding the significance of habitat to the fishery and assessment as to the effects which changes to that habitat may have upon the fishery"). It does, however, include a provision that each existing FMP shall be amended not later than January 1 1996 to include "a description of essential fishery habitat for that fishery."

The current (1990) Magnuson Act, as explained above, addresses fishery habitat concerns (Section 302(i)) by establishing a procedure by which a Council "may comment on and make recommendations concerning any activity undertaken, or proposed to be undertaken, by any State or Federal agency that, in the view of the Council, may affect the habitat of a fishery resource under its jurisdiction." (For anadromous species, such comments are mandatory). The proposed changes to the Act, in both the House and Senate drafts, would require that each Council notify the Secretary of Commerce regarding any such activity, in addition to giving each Council the option to also comment and make recommendations. The Act currently requires any federal agency which receives comments or recommendations from a Council to reply within 45 days; the proposed amendments would require that the response include a "description of measures being considered by the agency for avoiding, mitigating, or offsetting the impact of the activity on such [essential] habitat" (underlined word is added to the existing language). This paragraph would be further amended to include a sentence which reads "in the case of a response that is inconsistent with a Council's recommendations, the Federal agency shall explain its reasons for not following the recommendations."

Additional promising developments at the federal level are the actions taken by the three Atlantic coast regional management councils to form habitat committees and to develop habitat protection policies and procedures (Locandro 1992). This activity seems to have moved further ahead in the South Atlantic region where the South Atlantic Fishery Management Council's (SAFMC) Habitat Committee, council staff, and a habitat advisory panel has prepared a habitat and environmental protection policy and a series of policy statements regarding oil and gas exploration, development and transportation, ocean dumping and disposal of dredge materials, and the loss of aquatic habitats or wetlands. These policy statements can be (and have been) included in FMPs for species that utilize the habitat(s) in question or which could potentially be affected by a certain activity (e.g., ocean dumping) for which a policy has been developed.

These policy statements are also referenced by the SAFMC in commenting on activities that may adversely affect habitat(s) important to any species being managed under SAFMC jurisdiction. In a more recent development, the SAFMC has approved the preparation of a generic habitat management plan that would identify actions necessary for the protection and restoration of a number of habitats known to be important for south Atlantic marine fishery resources. This represents a fairly radical departure from the usual species-specific management approach.

In Canada, the situation is very different. There, habitat management policy is much more aggressive (Brouha 1993), and has been ever since the Fisheries Act of Canada became law at the time of Canada's confederation. Canada's policy is to achieve a net *gain* of fisheries habitat, as opposed to the United States policy to maintain *no net loss* of wetland habitat. This goal is to be achieved through an integration of fish habitat and fisheries management planning at all levels of government. The law is very specific in identifying and defining what constitutes the destruction or pollution of fish habitat and in granting the federal government the authority to make regulations, impose penalties, and to order modifications or additions to projects that are deemed to threaten fish habitat, or to stop them altogether. The Canadian law differs significantly from our own in that it requires anyone proposing to alter fish habitat to prove that no pollution or loss of habitat will occur. In the United States, if a case goes to court, the burden of proof falls on the government to demonstrate that a proposed activity poses a threat to habitat.

Unlike the councils, which operate under the authority of the Magnuson Act, the Atlantic States Marine Fisheries Commission has never required that its FMPs follow any particular format or that they contain any particular types of information. Groups of scientists (mostly) assembled to prepare management plans for specific species or stocks have been relatively free to define the contents of ASMFC plans, subject to the over-riding instructions of management (policy level) boards and the Commission, which in the end must approve each FMP. In this kind of environment, certain FMPs have included some relevant habitat-related information and others have included none at all.

An early ASMFC fishery management plan that included a great deal of environmental and habitat information was the 1981 striped bass FMP (as amended in 1989). Most of this information can be found in the source document to this FMP. Another species group that requires a specific and detailed treatment of habitat-related issues anywhere (like the Atlantic coast of the U.S.) where coastal development has occurred, is the anadromous fishes. The shad and river herring FMP, which was approved in 1985 and amended in 1991, included a number of habitat-related recommendations, but they were not required actions and were mostly ignored. Required habitat restoration programs will be spelled out in a future amendment to this FMP.

Perhaps the most notable example of any Atlantic coast fishery management plan, state or federal, to include relevant habitat-related information was the 1992 Winter Flounder FMP (ASMFC 1992a). This plan goes well beyond the usual physical description of habitat(s) to include a thorough summary of environmental requirements of the species, an evaluation of the status of habitat quality and alteration, an analysis of the relationship between habitat area and the size of individual stocks, a summary of the effects of power plant entrainment and impingement, and finally (and, perhaps, most significantly), an analysis of the relative effects of habitat loss or restoration versus changes in fishing mortality on young-of-the-year survival and egg production. A major conclusion of this last analysis was that coastal habitat restoration which increases juvenile production "would result in longer-term benefits {than reducing fishing mortality} and allow managers to gradually increase fishery yield from these populations." This truly exemplary plan goes on to identify seven recommended habitat management measures (Table 4) and research needs. One of the four goals of the winter flounder FMP is "to preserve, maintain, and enhance habitat and environmental quality necessary for the optimal growth and reproduction of winter flounder" (ASMFC 1992b).

Table 4. Winter Flounder Habitat Management Recommendations

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1. Assure that Clean Water Act (Section 319) Non-Point Source Plans and Coastal Non-point Pollution Control Plans are developed and implemented such that adverse impacts of non-point source pollutants on winter flounder are minimized.
   These plans should include measures such as:
   a) protective land use practices (e.g. establishment of substantial buffer zones around productive coastal nursery grounds);
   b) reduction of non-point toxic contamination of ground water and near shore coastal habitats by redirecting storm water runoff into catch basins;
   c) evaluation of the cumulative effects of in-water structures on habitat quality;

2. Strengthen enforcement of sewage discharge, or PDES (Pollution Discharge Elimination System), permit effluent limits from centralized treatment plants, and ensure proper maintenance and operation of domestic septic systems.

3. Implement effective oil and toxic chemical spill prevention and control programs to prevent accidental release, and prioritize cleanup plans to protect areas where winter flounder are known to concentrate for spawning.

4. Establish and enforce no-vessel-discharge zones, and promote education of recreational boaters to reduce their contamination of inshore waters from chronic vessel fuel spills and waste disposal.

5. Establish time frames when sediment dredge activities should be prohibited or minimized in areas where winter flounder are known to concentrate for spawning.

6. Assist industrial siting councils in siting new power plants so that areas where winter flounder are known to concentrate for spawning are avoided, and assess cooling water entertainment mortality from existing plants (Clean Water Act, Section 316) on a stage-specific basis for both local and regional flounder populations.

7. Identify sediments sufficiently contaminated to impose documentable acute or chronic impacts on winter flounder resources including the benthic communities upon which they depend, and develop remediation plans or active sediment pollution prevention programs for such areas.

Since the Commission has not had any authority to require the states to take any particular action to manage inter jurisdictional fishery resources or conserve marine fishery habitat, it has had to rely chiefly on the power of persuasion to achieve coordinated and effective management. The Commission took a significant step forward, however, in 1990, when it passed a resolution to "actively implement a 'unified habitat policy statement' that was presented at the May 1990 ASMFC meeting. This policy statement committed the member states "to use available mandates and to expand interagency efforts to minimize adverse effects of human activities on marine, estuarine, and riverine species and their habitats ... by offering "general guidance to states, federal agencies and regional bodies that share responsibility for fish habitats through their respective roles in decisions on research, management, and specific human activities." A summary of the stated objectives and the actions recommended by this statement are included in Table 5.

Table 5. Joint Statement to Conserve Marine, Estuarine and Riverine Habitat:
Abridged Summary Presented at ASMFC Meeting Washington, D.C. May 16 1990
Final Revision November 7, 1990

Statement:

The undersigned parties agree to use available mandates and to expand interagency efforts to minimize adverse effects of human activities on marine, estuarine, and riverine species and their habitats. This statement offers general guidance to states, federal agencies and regional bodies that share responsibility for fish habitats through their respective roles in decisions on research, management, and specific human activities.

Objectives:

1. To minimize avoidable adverse impacts on fish stocks and their habitat.

2. To conserve, restore, and enhance fish habitats for the long-term benefit of all users.

3. To promote innovative programs that will increase our knowledge of management strategies that may reduce habitat loss or augment fish stocks.

4. To improve our use of existing authorities and adopt new interagency procedures that will improve our habitat management efforts.

5. To foster greater interagency cooperation and collaboration.

Recommended actions:

1. Share general information, recommendations, and decisions for other important living resources that relate to habitats or related resources.

2. Collaborate with other parties on actions that relate to habitat or living resources.

3. Initiate new agreements to improve our efforts to conserve and manage living resources and their habitat.

The passage of new federal legislation has given the Commission new authority to require individual states to comply with fishery management plans approved by the Commission. The new law (PL 103-206, Title 8), entitled the "Atlantic Coastal Fisheries Cooperative Management Act," was passed in November 1993 and signed by the President on December 20 1993. This act requires that the Secretary of Commerce, in cooperation with the Secretary of the Interior, "implement a program to support the interstate fishery management efforts of the Commission," including activities to support, among other things, state cooperation in habitat conservation. As required by this new law, states participating in an ASMFC management program that includes habitat management measures (e.g., the winter flounder FMP) must comply with any habitat protection and/or restoration recommendations that are specifically identified as requiring action. As with management actions aimed at reducing fishing effort on over-exploited resources, the new law provides the Commission with the authority to implement and enforce habitat management measures. The Commission and its member states are currently engaged in identifying which management measures in the various existing management plans must be complied with and which ones do not.

As a case in point (a very relevant one), the ASMFC Winter Flounder Management Board is currently conducting a survey to determine, for each state participating in the management program, which agencies are responsible for the different types of habitat management activities required by the FMP (Table 4), and to determine how successful habitat conservation activities are in each state, particularly those that apply to winter flounder habitat management issues. At the same time, the Board has developed a set of habitat recommendations for implementation by the states participating in the management program by January 1 1995 (Table 6).

Table 6. Winter Flounder Habitat Recommendations

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1. Each state participating in the ASMFC Winter Flounder Fishery Management Program (via the ASMFC agency commissioner) shall develop a Winter Flounder Habitat Protection Strategy and initiate discussions with the applicable habitat enforcement and environmental quality programs in its state to explain the importance of the near shore aquatic environment as spawning and nursery habitat for winter flounder production. These discussions should be consistent with the Habitat Management Strategy and Measures found on pages 90-92 of the Winter Flounder Plan and in Section I.B.2 of the May 1992 Implementation Strategy. By January 1, 1995, each state shall have concluded these discussions and shall report to the Commission at the May meeting regarding any improvements to in-state procedures which have resulted from the discussions.

2. Each agency participating in the ASMFC Winter Flounder Fishery Management Program shall initiate discussions with permitting authorities regarding the effects of dredging, dredge spoil disposal, industrial facility siting, and other human uses of the coastal environment to ensure that impacts associated with such uses are clearly understood, so that avoidable impacts are eliminated, and so that unavoidable impacts are minimized or mitigated. By January 1, 1995, each state shall have concluded these discussions and shall report to the Commission at the May meeting regarding any improvements to in-state procedures which have resulted from the discussions.

3. Each state participating in the ASMFC Winter Flounder Fishery Management Program shall initiate discussions with the applicable information and education units of the Department to ensure that public communications include reference to the importance of maintaining a high quality near shore environment for the benefit of the winter flounder resource.

The new act also requires that the Commission shall establish standards and procedures governing the preparation of coastal fishery management plans. The ASMFC is currently in the midst of defining what those standards and procedures will be and expects to approve them at its October 1994 annual meeting. It is expected that they will include a minimum set of habitat-related information since the law states that the standards and procedures will ensure that "such plans promote the conservation of fish stocks" and defines "conservation" to mean "the restoring, rebuilding, and maintaining of any coastal fishery resource *and the marine environment* (italics are mine), in order to assure the availability of coastal fishery resources on a long-term basis" (ACFCMA, ß 803(4)). The ASMFC Science and Management Committee is currently developing an outline of habitat-related information to include in future ASMFC management plans and amendments. In addition, efforts may be made at some point in the future to provide habitat information "missing" from previously approved plans and amendments.

In conclusion, based on my own experience working on three different ASMFC FMPs during the last ten years and reviewing a number of other federal and state FMPs, I would like to offer the following personal observations on where we are and where we seem to be headed with regard to recognizing the importance of habitat issues in the fishery management process and in implementing effective fishery management programs.

1. There is a lot of descriptive habitat information "out there" that is only minimally utilized in the fishery management process. Too often I have heard the lament that "there isn't any

information" when just the opposite is the case. There is, in fact, so much information relating to Atlantic coastal habitats that the task of finding it and plowing through it to find the relevant bits is so daunting enough that it stops us from doing a proper job.

2. Having said this, I should qualify it by next pointing out that a lot of the information that is available is either too general and descriptive to be of much use *or* so specific to certain locations that it can not safely be applied on a regional scale. It is always tempting, but dangerous, to apply assessments of environmental quality in one or two estuaries, just to use an example, to all the estuaries in a certain stretch of coastline. However, it is also true that you can't reach the conclusion that the information is useless or limited in value until you have spent the necessary time finding and evaluating all the sources of information. This is a time consuming task. Something that would really help would be an up-to-date annotated bibliography of available Atlantic coast marine fishery habitat information (perhaps organized by species and/or habitat type) that was kept up-to-date as new publications became available.

3. There is a lot more descriptive information available than there are evaluations of environmental quality. Most fishery management plans include some kind of description of physical habitats utilized by different life history stages of the species being managed and an accounting of available information on its environmental requirements (e.g., temperature and salinity tolerances, effects of contamination, etc.), but very little information relating to the degree of habitat loss or degradation or the effects of habitat loss or degradation on species productivity or ecosystem function. These are the most important items that should be included in any FMP, but also the things that we know least about and where we need a lot more research.

4. In the end, we can have all the right standards and procedural requirements, but there is no substitute for hard work by people committed to producing the best possible product. Complete and thoroughly-researched fishery management plans require a lot of time, dedication, and teamwork. Guidelines and requirements are needed, but they won't, by themselves, produce good quality management plans.

5. Let's not forget follow-up. All the best FMPs in the world that include the latest habitat information and identify exactly what steps need to be taken to implement effective fishery management won't succeed unless there is a commitment by all the relevant management authorities to act on the recommendations in the plan. There never is 100% compliance with any management program, but since future FMPs are undoubtedly going to include more habitat management recommendations, and since the new Coastal Fisheries Management Act gives the ASMFC new powers to require compliance in habitat management efforts, some serious thought must be given to how to coordinate the management authorities and activities of different agencies in different states. This may not be an easy job (see #6).

6. As environmental management measures become more mandatory, I predict there will be resistance from some quarters to include effective habitat management requirements in future FMPs. State fishery agencies have been, properly, the lead agencies dealing with fishery management issues that affect the commercial and recreational fishing industries. Other agencies typically deal with environmental management issues and regulations. The need for more effective fishery management (i.e., management that includes habitat considerations) is going to require that state fishery agencies assume new responsibilities in coordinating fishery management activities that include environmental and habitat concerns. Some agencies and some states will probably respond better to this challenge than others, but it's not going to be easy for anyone. The current situation with regard to near shore winter flounder habitat protection and restoration is a case in point; it will be an interesting case to follow during the next year. The success in maintaining and improving winter flounder habitat during the next few months could well provide some lessons for future habitat management actions by the Atlantic coastal states.

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Impacts of Contaminants and Nearshore Pollutants on Habitats in the Gulf of Maine

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The focus of this paper is to examine the impacts of contaminants on habitats in the Gulf of Maine. The discussion is divided into four sections: sources, transport, fate (both sediment and biological), and effects and evaluated from a management perspective of the adequacy of available information. The data and information are primarily from Boston Harbor and Massachusetts coastal areas, in part, because they represent the worst case scenario for chemical contamination and data are more readily compared to nearshore areas the Gulf of Maine.

Although a detailed description of Gulf of Maine (GOM) habitats is beyond the scope of this discussion, a comprehensive overview can be found in the Proceedings of the Gulf of Maine Scientific Workshop (1992). Much of the GoM research over the past couple of decades has focused on the offshore banks and channels, particularly on the rich fishing areas in the Gulf of Maine (Figure 1). Information on inshore areas, where contaminants are introduced into the coastal ocean through rivers, direct discharges, atmospheric deposition, ocean dumping and other human activities, is more fragmented and less readily accessible. However, effects on organisms and human health from contaminants which accumulate in sediments and biota, are more likely to be observed close to sources of pollution. This discussion examines nearshore pollution and impacts.

Glacial activities have shaped much of the land form along the Gulf of Maine along with weathering and erosion resulting in deposits of silt, clay, sands, gravel, and boulders creating a highly heterogeneous substratum throughout the Gulf. Massachusetts Bay (Figure 2) is a relatively small area of the nearshore coastal environment that has been the focus of several studies examining the physical oceanography, transport, fate and effect of contaminants and living marine resources (Pederson 1992 and MWRA, 1993a, 1993b, 1994). The area is bounded by Cape Cod on the South, Cape Ann on the north and Stellwagen Bank on the seaward edge. The greatest levels of contamination co-occur with the most densely populated areas north, west and south of Boston. The impacts of contaminants on benthic communities are better understood for "soft-bottom" than "hard-bottom" communities, but in neither case are impacts of contaminants on organisms well understood. Because of the association of contaminants with particulates, sediments act as integrators of pollution, and the remainder of this discussion focuses on soft-bottom communities, habitats and pollution distribution and effects.

Sources

From colonial times when the City of Boston decided to protect public health by moving raw sewage out of the streets of the city and into the harbor, managers adopted an "out of sight, out of mind" philosophy as the solution to pollution problems. Population has increased significantly along the Massachusetts coast since the 1700s and numbers and amounts of contaminants manufactured increased significantly since the end of World War II. Approximately 1,000 new chemicals are introduced into the environment each year adding to the list of some 60,000-70,000 xenobiotics that have been manufactured since the 1940s. Chemicals which are long-lived, not readily degraded, or have toxic effects at low levels are particularly problematic. Some, such as polychlorinated biphenyls (PCBs) have not been manufactured since 1978, but are still in use in electronic equipment, and persist in the environment once they get there, nowadays primarily by atmospheric deposition.

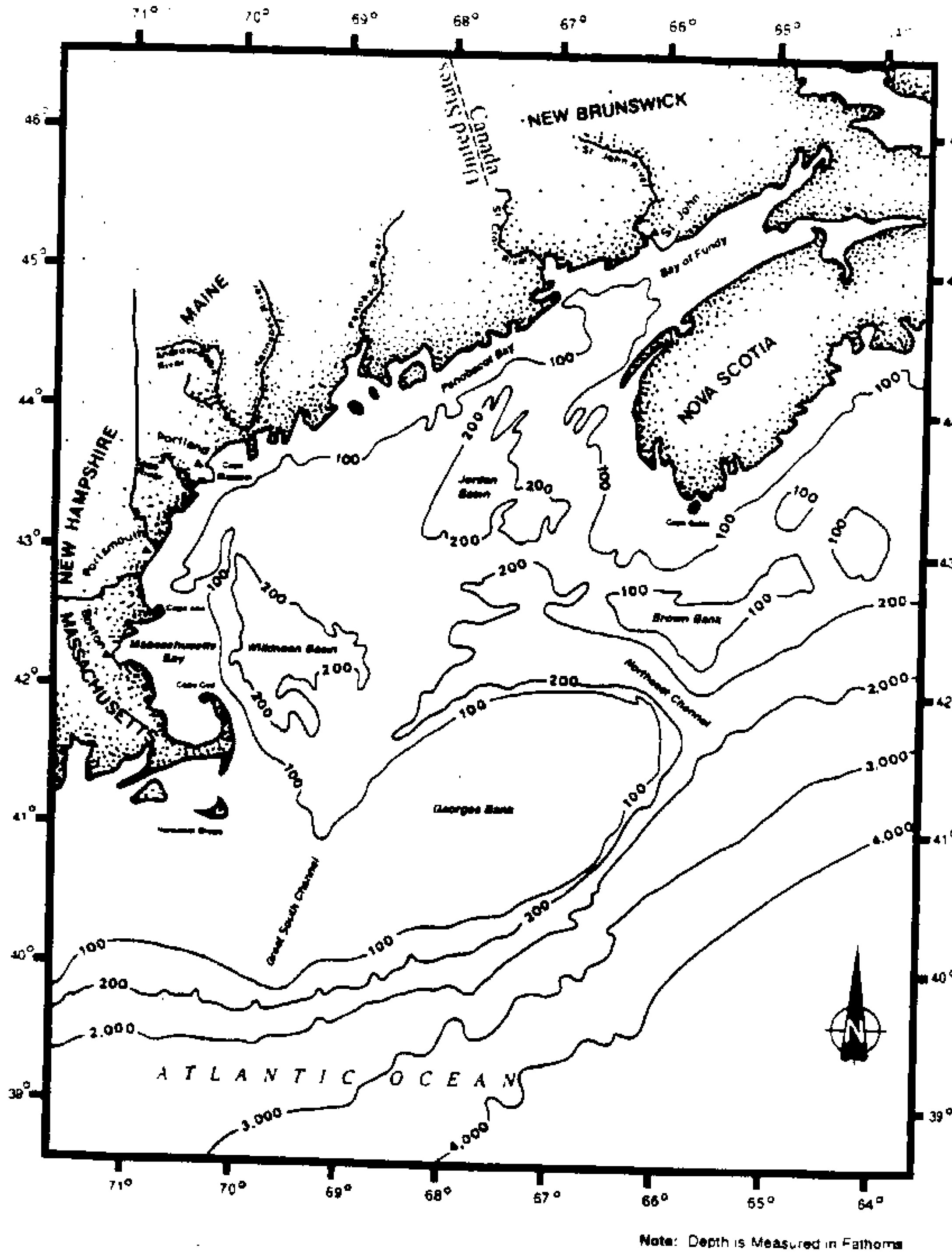
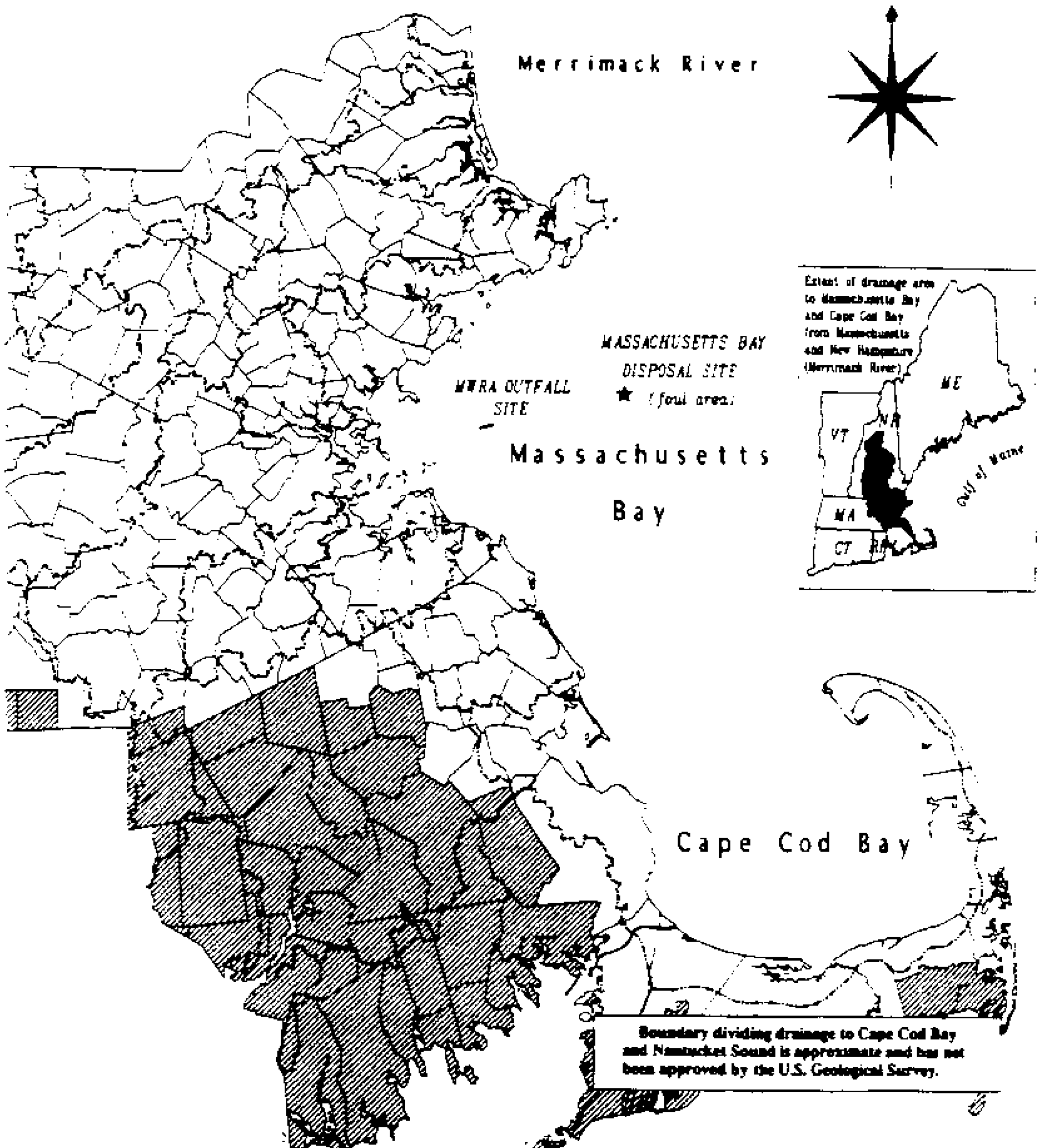


Figure 1. Map of the Gulf of Maine with insets of Boston Harbor, Massachusetts Bay and Cape Cod Bay.



	Drainage	Length		Drainage	Length		Drainage	Length
Merrimack River	5010.0	134.0	Annisquam		4.0	Cape Cod	422.0	
Charles River	307.0	80.0	Ipswich River	155.0	30.5	*Rivers*		
North Coastal	245.0		Parker River	60.0	19.1	Herring		[illegible]
Rivers			South Coastal	127.0		Pamet		[illegible]
Essex		3.1	*Rivers*					
Danvers		[illegible]	North		12.0			
Saugus		13.0	South		11.8			
[illegible]		[illegible]	Jones		[illegible]			

Total Drainage Area: [illegible]664 Square Miles

Figure 2. Map of Boston Harbor and Massachusetts and Cape Cod Bays.

Incinerators and coal burning plants are identified as the major sources of dioxin-like compounds and selected trace metals such as mercury, whereas by-products of natural and combusted fossil fuels, such as polynuclear aromatic hydrocarbons (PAHs), have many sources including automobile exhaust, power plants, home heating, oil spills, and even lawnmowers.

During the Industrial Revolution, which had its origins in New England, metal usage and release to the environment increased primarily increased through waste water discharges. Effluent and waste streams continue to be a major source of copper, trace metals and nutrients. Sediment cores provide a historical record of metal contamination with depth (Figure 3) which may be combined with radionuclide observations to determine deposition rates (USEPA 1988; Bothner 1992). Biological mixing, which usually occurs in the top 20-30 centimeters, is a confounding factor in determining deposition rates, but in Massachusetts Bay and throughout most of the GoM, deposition occurs at the rate of 1 to 2 mm per year.

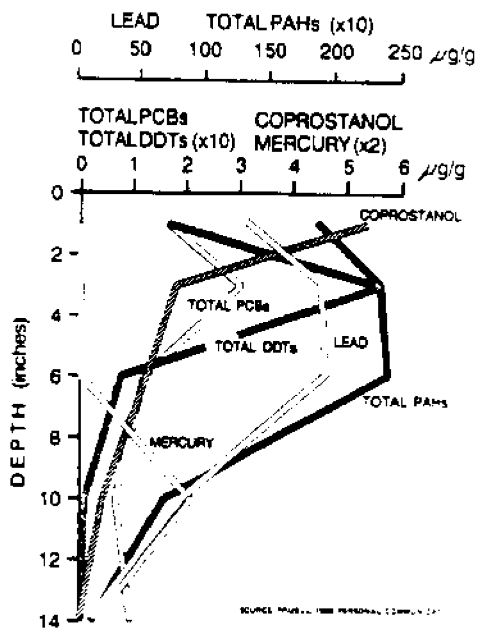


Figure 3. Sediment profiles of selected sediments in Quincy Bay, Massachusetts (U.S.EPA 1988).

For the purposes of this discussion, contaminants were selected because of their impact on humans and the ecosystem or their potential to violate water quality standards, and include: three metals: copper, lead and mercury; two classes of organic compounds: PAHs and PCBs; and nutrients, particularly nitrogen. Other metals (cadmium, chromium, nickel, zinc and silver), pesticides and several priority pollutants are frequently monitored depending on the potential for contamination. Copper is usually the metal of concern for waste water treatment facilities mandated to meet water quality standards, whereas lead and mercury are of greater concern for human health. PAH are linked to cancers, birth defects, and mutations, PCB are linked to reproductive problems and cancers (especially dioxin-like coplanars). Excessive nitrogen enrichment may cause habitat deterioration through excessive production of organic matter and decreased dissolved oxygen. Pesticides and other organic chemicals are not routinely measured in sediments, although waste water treatment facilities are required to monitor these and other priority pollutants in their waste stream. Metal and organic contamination are greatest near large population centers, whereas nutrient enrichment is most problematic in areas where flushing rates are low relative to the input. Urban harbors, such as Boston, Salem, New Bedford, Portsmouth, and Portland have sediments enriched with metals, organic chemicals, and nutrients, whereas small embayments with low flushing rates lose habitats to eutrophication.

Total pollutant loading estimates are given in Table 1 for Boston Harbor, Massachusetts Bay and Casco Bay. These estimates are based on data, some of which are of inconsistent quality, making it difficult to compare relative strengths of inputs. In general, of the available data, point source data are the most reliable and atmospheric estimates are least reliable. In some cases, major changes occurred, e.g. as of December 1991, sludge is no longer discharged from the Boston area waste water treatment plant which reduce some contaminant loadings by about 10%-30% (Leo, et al. 1993). The Massachusetts Bay and Casco Bay point source total loadings are based on National Pollution Discharge Elimination System (NPDES) permit estimates, whereas the nonpoint sources (runoff and atmospheric deposition) are based on the National Urban Runoff Program and limited atmospheric data (see MBP 1991; Hauge 1988). Errors in the estimates are likely to be in the same direction for both ecosystems. Although the total loading to Massachusetts Bay is greater than Casco Bay, on a square kilometer basis, the relative loading rates are remarkably similar. By way of illustration, the recalculation of loading estimates based on "clean lab" methodologies for metals are responsible, in part, for some of the decreased loading in the Boston Harbor 1994 effluent data (Menzie et al. 1991; Alber, et al. 1994).

Nitrogen loading is directly related to population density, with greatest loading near large population centers. Impacts are also observed in areas with smaller populations, generally in small embayments with low flushing rates. Although eutrophication can result in significant degradation of habitats, this discussion focuses on contaminant impacts to the ecosystem.

Table 1. Pollutant loadings to selected ecosystems in the Gulf of Maine.

Pollutant	Boston Harbor Sludge[a]	Boston Harbor Effluent[a]	Boston Harbor Effluent 1994[b]	1992 Mass and Cape Cod Bay[c]	Casco Bay[d]
METALS			kilograms per year		
Cadmium	370	4,580	4,580	11,360	670
Chromium	3,700	12,000	2,000	102,000	8,130
Copper	22,000	44,000	37,276	101,500	10,940
Lead	7,000	11,000	9,709	505,500	26,245
Mercury	110	110	110	559	40
Nickel	2,200	7,300	3,000		NA
Silver	180	3,600	2,000		NA
Zinc	47,000	73,000	56,147	477,500	37,197
ORGANICS					
PCB	150	<250	50	2,655	5
PAH	2,160	20,000	5,000	13,700	NA

[a]MBP 1991; [b]Alber, et al. 1994; [c]Menzie et al. 1991; [d]Hauge 1988

Transport and Fates of Contaminants

The transport of contaminants once they reach the ecosystem are controlled by physical, geological, chemical, and biological processes that determine movement of dissolved and particulate materials (Hart 1982). Most contaminants are associated with particulates and their long-term fate is controlled by transport and deposition to the sediments. Dissolved components have different fates and may be acted upon in the water column, e.g., nutrient uptake or scavenging of metals by plankton. Depending on the size of particulates, mixing rates and other factors, particles may sink rapidly to the bottom or be carried about for weeks or longer. Particles that remain in the water column may be ingested and excreted as particulate fecal material thereby reaching the sediments faster than if other factors were operating alone. If contaminants associated with food or particulates are retained in organisms, transport to sediments or biota may be slower.

The relative strength of the different pathways is not well-understood at the ecosystem level. Important processes include what occurs at the fresh water/salt water interface, exchange of materials across the pycnocline, and rates of resuspension, transport (vertical or horizontal), burial and biogeochemical transformation. On an ecosystem scale, the bottom substrate represents sites of deposition, erosion and "reworking", a term applied to areas that at times are deposition or erosional depending on the conditions (Knebel 1993 and Knebel & Circe in press). These areas have been mapped for half of Massachusetts Bay and large areas along the Maine Coast (see Knebel 1993 and Kelley 1992 and work in progress).

Trace metals are partitioned between particulate and dissolved phases, both in the water column and pore waters of sediments (Wallace et al. 1991). Where humic materials are high, there is good correlation between total organic carbon and metal concentrations, whereas in other situations, the relationships is less clear (Hart, 1992). Metal speciation affects the availability of metals to organisms as does the extent to which a metal forms organic complexes. Bacteria in sediments may form methylated complexes, e.g. methylmercury, which are a more toxic form for organisms.

Organic compounds are usually hydrophobic and are also more likely to associate with particulates. Volatile organic compounds are relatively soluble in water, are less likely to be associated with particles and are likely to be degraded. These include low molecular weight PAH (2-3 ringed) and halocarbons. Larger molecular weight PAH (4 to 5 ringed), PCBs and chlorinated pesticides are longer lived and not easily degraded. Often lower molecular weight PAH are more toxic to organisms whereas higher molecular weight and chlorinated compounds are correlated to chronic effects. Some compounds, (e.g. coprostanol or linear alkyl benzenes) serve as markers, primarily of sewage, because they are not readily broken down (Eaganhouse et al. 1989).

Biological processes can affect the fate of metals and organic compounds through bioturbation, burial, metabolic reactions, microbial mineralization and as the transport vehicle to other organisms or areas. On an ecosystem scale, our knowledge of biological transformations is poor. Data from sediment traps suggest that storms resuspend sediments to at least 5 m above the surface bottom (Bothner et al. 1992). Using *Clostridium* counts and silver as tracers of sewage, Bothner (1992) observed high levels out of Boston Harbor, lower levels at the northern end of Cape Cod Bay and higher concentrations in Cape Cod Bay itself suggesting complex circulation and deposition patterns.

Contaminant distribution in urban harbors, Massachusetts Bay and GOM reflect sources and suggest resuspension and redistribution over larger areas over time. Table 2 lists contaminant concentrations in the inner harbor, the Massachusetts Bay Disposal Site and Cape Cod Bay (see Figure 2 for locations). Concentrations at the Massachusetts Bay Disposal Site, which has been the major area of dredged material deposition from Boston Harbor and other urban ports, reflect contaminant concentrations in the inner harbor whereas concentrations in Cape Cod Bay are less.

Table 2. Mean contaminant concentrations as parts per million in Boston Harbor sediments.

Contaminant Concentration in Parts Per Million

Pollutant	Mass Category[a]	ER-L and ER-M[b]	Boston Harbor[c]	Inner Harbor[d]	Mass Bay Disposal Site[e]
CD	5-10	5-9	2.8	4	<4
CR	100-300	80-145	133	166	118
CU	200-400	85-390	105	180	70
PB	100-200	35-110	131	251	156
HG	0.5-1.5	0.15-1.3	1.3	0.81	0.14
NI	50-100	30-50	34	41	29
AG	none	12.2	3.1	none	---
ZN	200-400	120-270	219	304	220
PCB	0.5-1.5	0.05-0.4	0.6	1.6	0.8
PAH	none	4-35	84	18.3	—
DDT	none	---	0.035	---	—

[a]CMR 314.90; [b]Long and Morgan 1990; [c]MWRA 1990; [d]Massport 1994; [e]USEPA 1989.

Effects Of Contaminants

Although an understanding of the effects of contaminants at the organismal and ecosystem level is weak, nonetheless, decisions are being made about acceptable levels of contaminants in sediments based on effects to biota. Approaches to determining contaminant concentrations of concern in sediments and observed effects on organisms are reviewed in several documents (Long and Morgan, 1990; Long et al. 1993). These approaches include determining concentrations of contaminants in sediments and examining benthic community structure (biomass, numbers, species richness, and sensitive species), toxicity or mortality of selected species to a suite of contaminants, and laboratory studies cellular, tissue pathologies, and whole organism level effects to specific chemicals. There are phylogenetic and species differences in response to different chemicals, sediment texture and other subtle factors that confound easy summaries of response at either the individual or population level and even species differences within the same phyla (McElroy et al. 1994).

There are two types of tests used to determine suitability of sediments for ocean disposal of dredged materials which has been a driving force in correlating contaminant effects on biota (USEPA and USACOE 1991). The bioassay is a toxicity test that measure mortality of selected organisms, usually an amphipod, bivalve and/or polychaete to sediments with contaminant levels deemed to be of concern. How this relates to populations under field conditions is not well tested or understood.

The second biological test used for determining dredged material suitability for open ocean disposal is the bioaccumulation tests that measure contaminant levels in tissues of selected organisms, usually a bivalve and polychaete. This test examines the extent to which organisms bioaccumulate selected trace metals (usually cadmium, lead, chromium, nickel, mercury, and zinc) and selected organic chemicals (23 selected PAH, PCBs and occasionally chlorinated pesticides). There are no chronic tests used and interpretation of significant bioaccumulation or concentration levels in tissues after 28 days are not consistent, nor easily resolved based on current data and understanding. PAH metabolism is particularly complex and differs with different phyla and species within a phyla as was shown by McElroy et al. (1994) for three polychaete species.

Tissue residues for indigenous populations are also measured but impacts on organisms and populations are not easily interpreted. Concentrations of selected metals, PCB and PAH for four species of bivalves found through coastal Massachusetts are given in Table 3. There are species differences in accumulation of contaminants. *Astarte* , a deep water bivalve from the Massachusetts Bay Disposal Site (MBDS), has the highest concentrations of all chemicals. An individual species, *Mya arenaria*, has differences in tissue residue ranging from 10% to over 200%. Differences for the same chemical possibly reflect exposure, physiological and genetic variations or are due to laboratory analytical procedures. Differences of 2 to 5 fold are found in fish tissue residues defining the variability of natural populations and analyses (Capuzzo et al. 1988).

Table 3. Concentrations of contaminants in tissues of 4 species of bivalves collected throughout Massachusetts Bay.

Contaminant Concentrations in Marine Organisms

Pollutant	*Mytilus edulis*	*Arctica islandica*	*Mya arenaria*	*Astarte* (from MBDS)
CD	0.31	0.38	0.04 (0.07)*	5.4
CR	0.32	0.92	0.31 (0.8)	2.0
CU	2.5	2.6	4.1 (7.0)	11.9
HG	0.021	0.018	0.028 (0.06)	0.61
PB	0.55	1.20	0.46 (0.36)	0.58
ZN	24	12	15 (17.6)	69.7
PCB	0.06	0.02	0.08 (0.095)	NA
PAH	NA (0.515)	NA	NA (0.016)	NA

*values in parentheses are from USEPA 1989, others from Schwartz et al. 1992

Comparison of contaminant concentrations in body tissue of the blue or edible mussel, *Mytilus edulis*, between Massachusetts and Nova Scotia are as one might predict (GOMCME 1994). In heavily industrialized and populated areas, concentrations are higher (Massachusetts, New Hampshire and Boothbay Harbor, Maine) compared to New Brunswick and Nova Scotia (Figure 4). Even mussels from reference sites in Massachusetts and New Hampshire are more contaminated than further north. The difficulty is that the relationship between bioaccumulation and effects is not well-understood. Even transfer up the food web to higher trophic levels for most

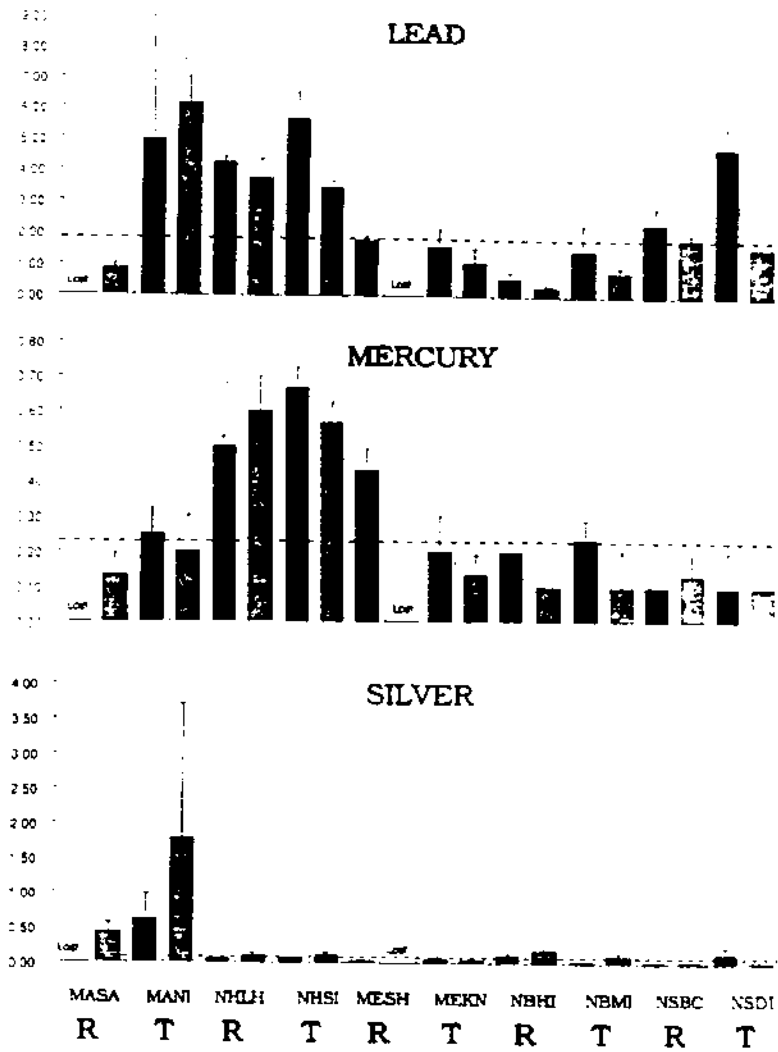


Figure 4. Distribution of lead, mercury and silver tissue concentrations (x ± SD, ug/g dry weight) in caged (T) and indigenous (R) mussels at stations in MA, NH, ME, NS and NB. Dashed line represents average concentrations in the Gulf for 1992.

metals and PAH is not obvious (Young and Mearns, 1979). PAHs are often metabolized and metals do not appear to bioaccumulate at higher trophic levels. Two exceptions which do bioaccumulate, are PCBs sometimes to incredibly high levels and methylmercury which are the primary form of total mercury in fish tissues. Lobster hepatopancreas PCB concentrations range from 5.3 to 61.8 ppm throughout Massachusetts (Schwartz et al. 1991, see table 4). The United States Food and Drug Administration (USFDA) action level is 2 ppm wet weight. An advisory against consuming lobster hepatopancreas (tomalley) from Boston Harbor, particularly for women of child bearing age and young children has been in effect since 1988. Muscle tissues of winter flounder and lobsters are below USFDA limits.

Table 4. Concentrations of PCBs in winter flounder and lobster muscle tissues and lobster hepatopancreas from four coastal Massachusetts areas; Boston Harbor (BH), Quincy Bay (QB), Massachusetts Bay (MB) and coastal (all of Massachusetts within state territorial waters.

PCBs as ppm in tissues or sediments throughout coastal Massachusetts

Organism/Sediments	Boston Harbor	Quincy Bay[a]	Mass Bay	Coastal
Winter flounder	0.09-0.7[b]	0.05-0.75	0.65[b]	0.04-0.11[b]
Lobster hepatopancreas		6.3-61.8	5.3-9.9[b]	
Lobster muscle		0.2-0.3	0.03-0.1[b]	
Sediments	0.07-50.5[c]	0.01-1.2	0.00-0.05[c]	0.03[c]

[a]USEPA 1988; [b]Schwartz, 199; [c]Boehm et al 1984

Methylmercury is another chemical that bioaccumulates up the food web and there are demonstrable effects on humans and other organisms. Mercury in fish tissue is particularly dangerous because it is found as methylmercury, which is toxic to higher predators. Many marine fish in New England have mercury levels of near 0.12 to 0.16 ppm which are considered a health concern for pregnant women, nursing mothers and young children (USEPA, in prog.). Similarly, mercury accumulates in tissues of top predators, e.g. eagles (Sowles, MEDEP pers. comm.).

The most direct application example shows how data on bioaccumulation, mortality and sediment concentrations of contaminants are applied to a management issue is determining the suitability of dredged material for open ocean disposal. Before biological testing is required, dredging project proponents perform "bulk sediment analyses" to determine whether there are concerns about contaminants in sediments. Generally there are three or four levels identified; values below which no or little impacts are observed, intermediate values which may have impacts, values above which effects are almost always observed, and levels that require clean-up.

The Massachusetts Department of Environmental Protection classifies sediments as Category I, II, or III and generally considers them as clean, moderately contaminated and contaminated sediments (Table 2). For some contaminants, a remedial level is identified in another set of regulations, e.g. superfund legislation. At the national level, Long and Morgan (1990) identified lower and mid-point sediment contaminant concentrations which had an effect on organisms based on screened available data. Using statistical evaluation of several different types of studies, Long and Morgan (1990) identified two levels of interest. ER-L represents contaminant concentrations of the lower tenth percentile at which effects were observed and ER-M the 50th percentile (Table 2). Concentrations of contamination used in designating superfund sites are based on terrestrial soils and organismic responses which may or may not be appropriate for marine sediments and organisms.

The major difficulty in setting sediment quality criteria is the lack of data on the biological effects. Long and Morgan (1990) used 150 references, some of which were based on studies conducted in the Great Lakes or other freshwater systems. Their analysis is by no means complete. Until recently, we have had few systematic, careful studies examining biological effects relative to sediment characteristics. Two studies are in the process of being analyzed, but results data were not available for this discussion. In one, NOAA (work in progress) is examining chemical concentrations in sediments in Boston Harbor and performing toxicity tests (using amphipods), sea urchin sperm tests and microtox results to determine mortality. Another study sponsored by the Massachusetts Bays Program is examining benthic community diversity, amphipod mortality tests and sediment characteristics throughout 12 sites in Massachusetts and Cape Cod Bays.

One example of good "weight of evidence" impacts include liver lesions in benthic feeding fish. Winter flounder in Boston Harbor, northwestern Massachusetts Bay and the future outfall site exhibit higher percentages of liver lesions or precancerous cells in liver compared to eastern Cape Cod Bay populations. How these lesions impact populations is not known. Higher organic chemical contamination are found in northwestern Massachusetts Bay than Cape Cod Bay (Boehm et al. 1984; MWRA 1990). These findings do not indicate significant negative correlation between contaminated sediments and organisms.

Notwithstanding uncertainties in correlating sediment contaminant concentrations to observed field biotic effects, USEPA and states are attempting to set sediment quality criteria, particularly to be used in determining suitability for dredging. The USEPA has recently issued five sediment quality criteria for nonpolar organic chemicals, fluoranthene, dieldrin, phenanthrene, endrin and anthracene (USEPA, 1993 a-f; USEPA 1994). These are based on octonal/water partitioning coefficients and estimated or measured concentrations of pore waters. These pore water concentrations are compared to water quality standards and used to determine acceptable levels.

Community Responses

If there is uncertainty about the relationship between sediment concentrations of contaminants, bioaccumulation results and tissue residue levels have on individuals, there is even less certainty about how contaminants impact benthic communities. In Massachusetts Bay and nearshore areas along the New Hampshire and Maine coast, the benthic substratum is highly heterogeneous changing from silt-, clay- and fine sand-grain sizes to gravel and boulders within a few meters. Few benthic community studies have related species composition to grain size, and less have attempted to relate faunal abundance and diversity to chemical contaminants in the Gulf of Maine. The following discussion is based on a few examples from data in the Massachusetts Bay and Boston Harbor area.

There has been no careful analysis of benthic communities comparing Boston Harbor, Massachusetts and Cape Cod Bays. Within the inner Boston Harbor numbers of individuals range from 0 to 20,000 organisms m^{-2} compared to 0 to 300,000 in the greater Boston Harbor areas and 7,000 to 15,000 for Cape Cod Bay. With depth there are fewer species and generally larger species. (Massport, 1994).

Summary

From a management perspective, a relationship between contaminants and impacts to biota or human health is difficult to demonstrate. From a habitat perspective, the greatest concentrations are associated with fine-grained compartment of sediments and are identified as areas of concern. Using total concentrations of contaminants in sediments both state and federal agencies identify sediment quality criteria that classify sediments as likely to cause no effect, likely to have impact and a gray zone where impacts are uncertain. The federal agencies have provided protocols for determining how "dirty" sediments are for dredged material disposal, namely determining mortality when exposed to sediments and determining accumulation upon exposure for 28 days. Interpretation of mortality test results are fairly straight forward, however, interpretation of bioaccumulation test results are not good indicators of overall habitat impact. Even when tissue residue concentrations of indigenous benthic species are examined, these results can not be related to specific impacts to other organisms or ecosystem wide impacts with two exceptions. Mercury is found as methylmercury in fish and can be accumulated in higher trophic levels where it affects development and reproduction at lower levels of contamination and has more pronounced effects at high concentrations. PCBs, particularly the coplanars and other dioxin-like compounds are related to serious human health effects - cancer, reproduction, and developmental problems. Scientifically valid data are clearly demonstrating ecosystem and habitat effects are lacking for the Gulf of Maine region as a whole and only partially demonstrated in areas where contaminants are most concentrated.

Changes in benthic community structure, abundance and diversity are evident through the region. Even in contaminated areas such as Boston Harbor, it is difficult to state with certainty that changes in benthic communities are related to contaminants alone. Usually total organic matter is high and in some areas such as the inner harbor channels, dissolved oxygen values are low throughout summer and fall months which significantly alter community structure. Without clear links between the various approaches to determining biological effects on communities, including single contaminant effects on individuals of a variety of species, little progress will be made understanding overall effects to habitats and the ecosystem.

Recommendations

The following recommendations are intended to help managers make better decisions. Some of the research and monitoring needed to support these recommendations are also identified.

Management needs

- Develop sediment quality criteria that are based on good science and identify areas of concern.
- Ensure that water quality standards do not result in further degradation of sediments and biota.
- Integrate eutrophication into sediment analyses.
- Develop models of loading and cumulative impact which can be used by managers.

Biological testing required of dredging project proponents is expensive and of questionable scientific validity or interpretation. Scientifically defensible sediment quality criteria can minimize the need for additional testing. Similarly, adopting water quality standards that do not further degrade sediments or biota bring two regulated components of the ecosystem into agreement. An often overlooked cause of benthic community degradation is low dissolved oxygen due to nutrient over enrichment and should be added to sediment quality criteria as they are developed. One of the most difficult tasks for managers is to integrate cumulative impacts into decision-making processes. Total loading estimates and cumulative impact models may provide information on sources and combined with guidance on levels of concern, screening levels, and multiple impacts on systems improve coastal managers ability to protect and remediate habitats.

Research needs

Four research needs identified below focus on studies that would support development of sediment quality criteria, provide insights into habitat degradation and biotic impacts, and define processes associated with transport, fate and effects of contaminants.

- Determine partitioning of contaminants between particulate and dissolve phase for developing models of transport and fate.

- Estimate residence time of contaminants in sediments and water column and how they are mediated by biological processes.

- Evaluate the effects of body burdens on organisms and populations.

- Assess the relationship between eutrophication and contaminants on benthic communities.

The physico-chemical relationship of contaminants determines how they move in the system, where they go, and eventually what effects they have on the biota. Research on these and related topics will provide the basis for setting realistic sediment and water quality criteria. A high priority of research is to develop scientifically defensible understanding of the effects of contaminants on organisms and relate these to measures that managers are likely to use, e.g. body burdens. Similarly, teasing apart impacts of organic material, low dissolved oxygen and contaminants are necessary for providing appropriate guidance and develop meaningful criteria.

Monitoring Needs

Four monitoring needs were chosen to support managers in making decisions about problem areas, to provide better overall data and information, develop models and loading estimates, and highlight the need to collect scientifically valid data today.

- Develop a data base for metals, organics and pesticides in sediments and provide maps to managers.

- Develop a data base for contaminant body burdens in a variety of organisms for identifying ambient conditions and variability and in anticipation of understanding impacts related to body burdens.

- Adopt performance-based methodologies to assist with loading estimates.

- Establish a marine monitoring program that is scientifically credible.

The data base being developed by the United States Geological Survey (Buchholz ten-Brink, et al. in progress) has already identified gaps in the data set. Establishing a monitoring program that provides additional data, using performance-based methodologies, i.e. meeting predetermined detection limits, will enhance this ongoing effort. The maps produced can be used to identify problem areas for developers and managers. Similarly, there is a need for database of body burdens for selected contaminants for a variety of species in several different habitats. As the relationship between body burdens and effects become established, these data will provide managers with tools for improved decision-making. Similarly realistic models are necessary if remediation is to move forward.

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3. Abstracts

U. S. Soil Conservation Service Activities in Coastal New Hampshire

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The Soil Conservation Service is actively engaged in the conservation of natural resources in coastal New Hampshire. Our primary goal is healthy tidal and nontidal wetlands through management and restoration. Our approach employs an interdisciplinary team of natural resource planners. In addition to our traditional role in helping farmers to reduce non point source pollution by the application of conservation practices, we have worked with the Audubon Society of New Hampshire to produce the "Method for the Comparative Evaluation of Nontidal Wetlands in New Hampshire" and the "Method for the Evaluation and Inventory of Vegetated Tidal Marshes in New Hampshire". These methods are tools for use by town officials and other lay persons to inventory and evaluate their wetlands for preservation, management, and restoration. We have also completed an inventory and evaluation of the restrictions to tidal flow in New Hampshire. The products of this study will be a report and data base which include cost estimates for replacing restrictions which prevent adequate tidal flow. This information will be useful to town and other units of government as an aid in locating potentially restorable salt marshes. We have also participated with other federal, state, and private agencies in salt marsh restoration projects in New Hampshire's coastal zone.

Small-Scale Habitat Variability and the Distribution of Post-larval Silver Hake, *Merluccius bilinearis*

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Silver hake, *Merluccius bilinearis*, are distributed on the continental shelf off eastern North America from southern Newfoundland to South Carolina and occur from just below the shoreline to over 910 m depth (Bigelow and Schroeder 1953, Scott and Scott 1988). Adults in the Gulf of Maine, Georges Bank, and Middle Atlantic Bight spawn from May to November (Bigelow and Schroeder 1953, Colton and St. Onge 1974). Eggs are pelagic and larvae remain in the water column for approximately 2 months before descending to the bottom at approximately 17-20 mm SL (Fahay 1974).

Little is known about habitat requirements for early benthic phases of most gadid species, primarily because they occur in deep water which is not easily accessible for direct observation. Lough et al. (1989) found juvenile cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) primarily in areas of pebble-gravel bottom, and not on sand substrates, on Georges Bank. They inferred that survivorship may be higher on pebble-gravel bottom as coloration of the juveniles allows crypsis and may reduce mortality caused by visual predators. Auster et al. (1991) demonstrated that a variety of fishes (e.g., ocean pout *Macrozoarces americanus*, little skate *Raja erinacea*, red hake *Urophycis chuss*) have facultative associations with specific microtopographic features (e.g., biogenic depressions, shell, sand wave crests) found in low topography habitats. These features occured within a background habitat of flat sand-silt with amphipod tubes. Use of microhabitat features is generally size or age class dependent (e.g., Caddy and Stamatopoulos 1990).

Direct underwater observations of post-larval silver hake, *Merluccius bilinearis*, were made in the northern Middle Atlantic Bight during August and September 1991. Presence-absence data, made by visual assessments during occupied submersible (*DSV Delta*) and ROV (*NURP 1*) dives along a cross shelf transect (i.e., 30-220 m), demonstrated hake were found primarily on sand-silt bottom with amphipod tubes (Table 1).

Eight quantitative video transects were obtained with the ROV at 40° 50' N, 70° 55'W along the 55 m isobath (Figure 1). The vehicle was equipped with dual remote head video cameras. One camera had a wide angle 3 mm lens and was used for video transects. The other camera had a 8 mm telephoto lens and was used for close-up observations of behavior and to record morphological details for species identification. Both cameras were calibrated in water for field-of-view, using a grid, so it was possible to obtain density estimates from individual video frames. The relationship between field-of-view and camera tilt angle was determined prior to the fieldwork so it was possible to assess horizontal visibility and select a tilt angle appropriate for quantitative transects at the dive site. Camera tilt angle was displayed in all video transect images.

Table 1. Summary of dive date (month/day), vehicle, location, depth (m), habitat description, and presence-absence of post-larval silver hake (S=sparse ~<1 m^{-2}, D=dense~>1 m^{-2}).

Date	Vehicle	Location	D	Habitat	P/A
7/29	Delta	41° 00' N 71° 32' W	47	silt-sand amphipod tubes	S
7/31	Delta	40° 00' N 71° 19' W	220	mud-silt	A
7/31	Delta	40° 19'N 71° 19'W	82	silt-sand amphipod tubes	D
8/1	Delta	40° 50' N 70° 55' W	55	silt-sand amphipod tubes	D
8/1	Delta	40° 49' N 70° 44' W	59	silt-sand amphipod tubes	D
8/2	Delta	41° 13' N 71° 32'W	30	coarse sand shell hash	A
8/31	NURP1	41° 00' N 71° 32' W	47	silt-sand amphipod tubes	D
9/1	NURP1	41° 12' N 71° 38' W	30	silt-sand amphipod tubes	A
9/2	NURP1	40° 50' N 70° 55' W	55	silt-sand amphipod tubes	D
9/2	NURP1	41° 06' N 70° 54' W	38	coarse sand	A
9/3	NURP1	41° 14' N 71° 32' W	20	coarse sand	S[1]

1 - One post-larval silver hake observed.

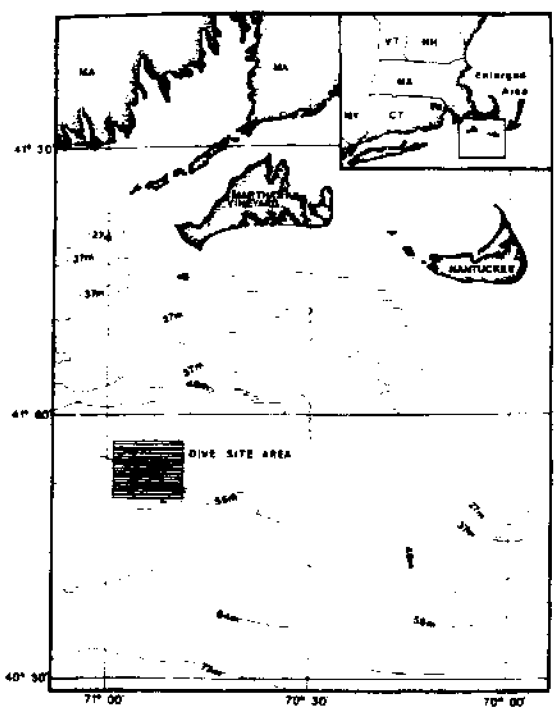
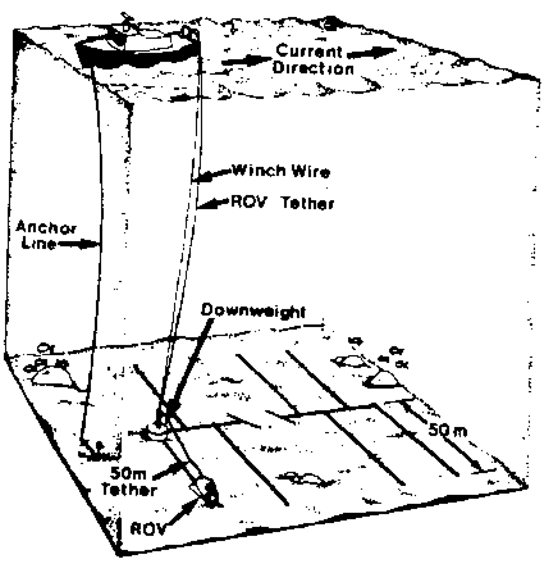


Figure 1. Chart showing location of ROV dives for quantitative transects.

Figure 2A illustrates the strategy for ROV deployment and the spatial arrangement of transects. The support ship was anchored during all ROV dives. One dive was devoted to conducting eight video transects to quantitatively assess the distribution, density and habitat associations of silver hake. The length of anchor line was adjusted to position the ROV to conduct multiple transects at the same anchorage. One transect was made at each ship position. Transects were referenced to a downweight and the ROV ran out 50 m of tether before stopping. However, variable wind and current conditions moved the ship and downweight after transects were started and most transects were greater than 50 m but of variable length. The ROV skids were kept on the bottom during all transects in order to keep the video camera referenced to the bottom and reduce variations in field-of-view caused by changes in altitude and bottom morphology. Additional dives were made to make behavioral observations and document species-habitat associations with video and 35 mm film.



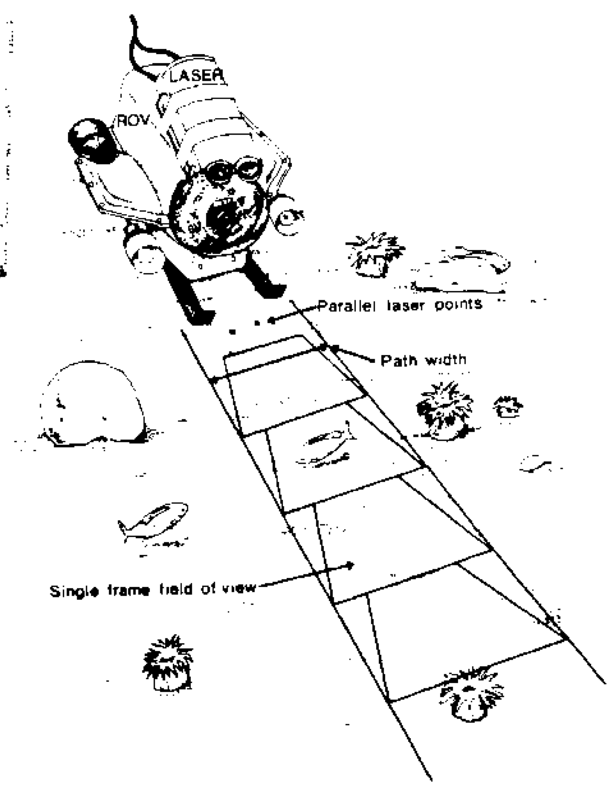


Figure 2. A. Method used to deploy the ROV for multiple transects. B. Spatial relationship of video quadrats.

Video transects were treated as a series of non-overlapping adjacent video quadrats (Figure 2B, sensu Auster et al. 1989). Video was recorded from a composite signal on Hi-8 format tape (NTSC standard, 60 fields s^{-1}). Video transects were time coded (i.e., hour, minute, second, video frame number) to identify and facilitate multiple viewing of individual video frames. Habitat types in each quadrat were classifed as either open sand-silt or amphipod tubes. A cover index (CI) of amphipod tubes in each quadrat was determined using random dot techniques. The CI was used rather than percent cover as the video images were trapezoidal (i.e., due to the oblique angle of the camera) and had foreground-backgound bias. In order to reduce foreground-background bias, each video frame was divided into two sections to assess cover. The nearfield half of each quadrat, on the video monitor, was overlaid by 20 computer generated random dots on acetate. After the forward portion of the frame was enumerated, the farfield portion of the quadrat was "rolled" forward, using the shuttle search feature of the video player, and enumerated with an additional 20 random dots. Each random dot overlay was used four times by rotating and flipping the overlay, but not within the same sequence. The CI is expressed as a percentage of the dots (n=40) covering amphipod tubes within each frame. Silver hake were counted in each full video quadrat. The shuttle search capability also allowed the frame to be rolled forward to identify and count fishes in the farfield of each quadrat. The total number of fishes was counted as well as apportioned to areas of the frame which were open bottom or within one estimated body length of a patch of amphipod tubes.

Sizes of 0-group silver hake were determined by measuring fishes on the video screen as they passed the plane between two points on opposite skids of the ROV. Distances between those points on the skid were measured to the nearest 0.1 cm. Only those fishes whose orientation was perpendicular to the axis of the ROV were measured to nearest 0.5 cm.

There was a positive correlation between hake density and increasing cover provided by amphipod tubes (Figure 3; r^2=0.62; ANOVA F=10.05, 7 d.f., significant at $p<0.05$). When undisturbed, most silver hake were partially buried in the bottom near clumps of amphipod tubes (87% of 487 post-larval silver hake were within approximately one body length of a clump of amphipod tubes). The dorsal coloration of post-larval and juvenile hake mimicked the pattern of amphipod tubes viewed against the bottom. Sizes ranged from 1.5-5 cm total length (mean = 3.3 cm, median 3.0 cm, S.D. = 0.8).

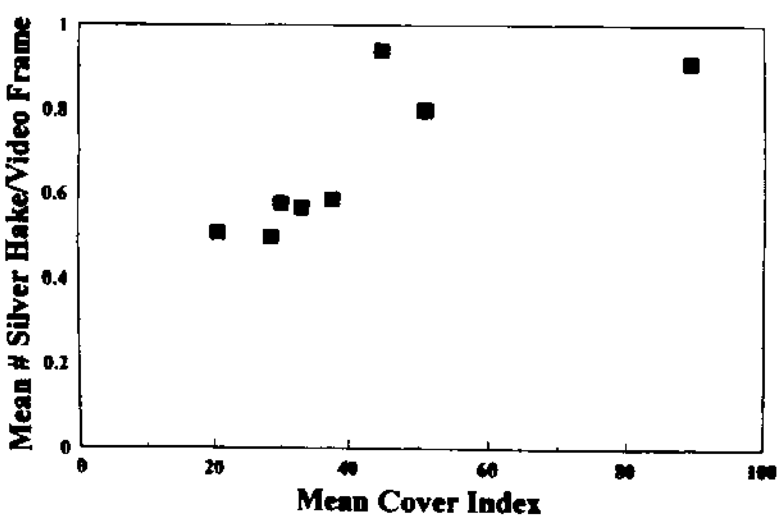


Figure 3. Plot of CI (cover index) versus mean number of post-larval silver hake per frame for each video transect.

Pattern can be found in the distribution of silver hake at multiple scales. Large scale distribution has been correlated with temperature and depth (Colvocoresses and Musick 1984, Overholtz 1982). This study demonstrated that microtopographic features effect small scale distribution. Post-larval silver hake are associated with structures during the post-larval period but as size increases, this association declines (based on Auster et al. 1991).

We posit that post-larval silver hake occur in patches of dense amphipod tube cover to avoid visual predators and co-occur with preferred prey (i.e., amphipods and shrimps). Alternatively, the observed pattern in small-scale distribution could be the result of differential predation. The role that associations with specific habitat features play in regulating the population dynamics of this species remains to be determined. Understanding the role that habitat features play in the population dynamics of other mobile taxa, commercially important species in particular, may be required for more effective fishery management given the current state of stocks on the northeast shelf of the U.S.

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New Perspectives on Seagrass Beds: A View from Lighter than Air Platforms

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Defection and quantification of spatial patterns of vegetation as well as their development and dynamics is of increasing interest to those concerned with habitat issues. Recently, remote sensing techniques have been employed to collect information on the spatial patterning of habitat structure. Information derived using these methods can be interpreted using techniques currently being developed by investigators working at the scale of "landscapes". We describe the feasibility of using lighter than air platforms (LTAPS) to detect patterns of seagrass distribution in the marine subtidal at the scale of 10m x 10m to 100m x 100m. We recovered video images of six seagrass beds taken from aboard the airship Shamu in December 1993. These images were digitized and percent cover of seagrass beds and bed shape determined. Qualitatively, images of beds from the LTAP revealed formations not obvious from high level aerial photography. Importantly, percent cover estimates from the blimp were similar to those from maps constructed for groundtruthing by walking through the seagrass beds. LTAPS can be useful for repeatedly quantifying seagrass distribution at a scale typically lower than that of aerial photography.

25 Years of Environmental Assessment of Coastal Estuarine Systems: Lessons for Environmental Quality Management

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Multidisciplinary studies of estuaries during the past 25 years have provided valuable information that may now be used in solving problems of maintaining and improving the environmental quality of valued coastal systems. Chemical contaminants are predominantly transported on suspended particulate matter, therefore an understanding of particulate dynamics is key to developing models of contaminant dispersion or accumulation. Seasonal variability of fresh water inputs into most estuaries determines that annual budget of chemical transport are dominated by short periods of time each year. Scavenging of dissolved metals and organic compounds by settling particles often results in anomalous accumulation of contaminants in depositional zones within the estuary. Deposited sediments preserve an integrated record of past environmental conditions and allow evaluations of the dominant factors contributing to contamination. Industrial development and remediation of environmental impacts can now be more accurately planned by using this knowledge. Four estuaries in eastern Canada are used to illustrate environmental problems and potential solutions.

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Restoring the Interaction of Emergent Marshes With Gulf of Maine Waters: Increasing Material and Energy Flows, Water and Habitat Quality, and Access to Specialized Habitats

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Anthropogenic impacts to salt marshes in the Gulf of Maine have reduced their interactions with marine ecosystems. For example, New Hampshire has lost approximately 50% of marsh area, and much of the remaining acreage is deteriorating, as it has been indirectly impacted by structures that reduce tidal flow (roads, etc.). Clearly, a direct loss of marsh acreage removes all functions (Figure 1) accrued from that area of marsh. What is uncertain, however, are the impacts to marsh functions due to reductions in tidal exchange, especially marine functions that relate to the Gulf of Maine. On a regional level, we need to know how these human activities have impacted salt marsh function. At the process scale, we need to improve our understanding of the relationship between salt marsh structure and function. Case studies of marshes that are being restored or created are providing information that will benefit both local and regional natural resource management.

Natural resource managers (NMFS, USF&WS, USEPA, SCS, and state agencies) have recognized the widespread loss of marsh functions is continuing at a rapid pace. To restore or replace marsh functional values, their agencies are either sponsoring marsh restoration activities, or are demanding replacement of marshes destroyed by new marine development projects (Table 1).

Table 1. Ways To Restore/Replace Functions

Restoration Of Tidal Exchange:

- Installing or Expanding Culverts Under Roadways
- Removing Dredge Spoil
- Reestablishing Marsh Creeks

Creation to Replace Destroyed Marsh:

- Design, Implementation and Monitoring for Functional Values

Clean-Up Of Contaminated Systems:

- Habitat-Based Remediation

Three types of projects are being investigated in New Hampshire: removal of dredge spoil (Awcomin Marsh, Rye), replacing a tide gate under a roadway with a large square culvert (Stuart Farm, Stratham), and creating a new marsh (Inner North Mill Pond, Portsmouth). In the case studies examined, salt marsh functions are assessed through measurements of four structural components: hydrology, soils, plants, and fish (Figure 1).

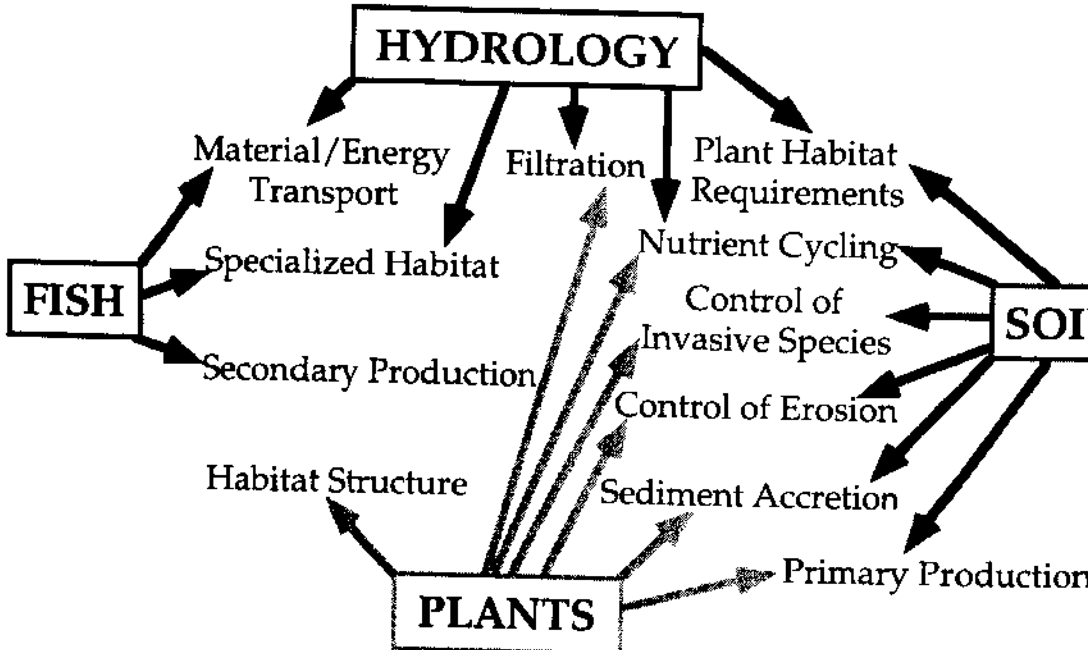

Figure 1. Structural and functional components of salt marsh ecosystems.

Dredge spoil from Rye Harbor was disposed of on the landward marsh in 1941 and 1962. The spoil restricted and excluded tidal flooding from large portions of the marsh, impounded fresh water, and caused local subsidence, thus creating brackish and fresh water pools. As a result, salt marsh vegetation (*Spartina* spp.) was replaced by *Phragmites*, *Scirpus*, and *Typha*. In 1992, construction work began to remove spoil berms and excavate tidal creeks in their historical positions, thus reestablishing tidal exchange. By fall 1993, soils were more saline and changes in vegetation were evident. Where pools had drained, *Scirpus* was replaced by *Salicornia* spp. and *Spartina* spp. In areas that were being rapidly invaded by *Phragmites*, average height fell substantially, indicating a reduction in plant vigor.

At Stuart Farm, a brackish marsh had been cut off from tidal exchange over thirty years ago. Although some relict populations of salt marsh vegetation remain, baseline sampling along permanent transects showed no *Spartina alterniflora* or *S. patens*, but large stands of the invasive weed *Lythrum* (purple loosestrife). A culvert was installed in the fall of 1993, restoring tidal flooding to over 10 acres. The subsequent changes in the system will be examined this spring.

Plans to expand the Port of Portsmouth included impacts to salt marsh, intertidal mudflats, and subtidal eelgrass beds. Mitigation plans, including salt marsh creation, were developed to restore or replace functions of these estuarine habitats. In Inner North Mill Pond, an acre of salt marsh was planted with *Spartina alterniflora* in June, 1993. When compared to a control site in October, the characteristics of the plant population (% cover, shoot density, leaf area, and aboveground biomass), as well as the fish population (#individuals, biovolume) measured 12 to 16% of control values.

Although it is now recognized that these projects need to be evaluated in terms of restoration of functional values, we know little of how these complex systems develop or how they respond to changes in hydrology. Future decisions regarding salt marsh management will depend upon the information synthesized from continued long-term research at case study sites. The information most critical to managers has yet to be procured, since marsh ecosystem changes (establishment of plant and fish communities) require rather long time periods (Figure 2).

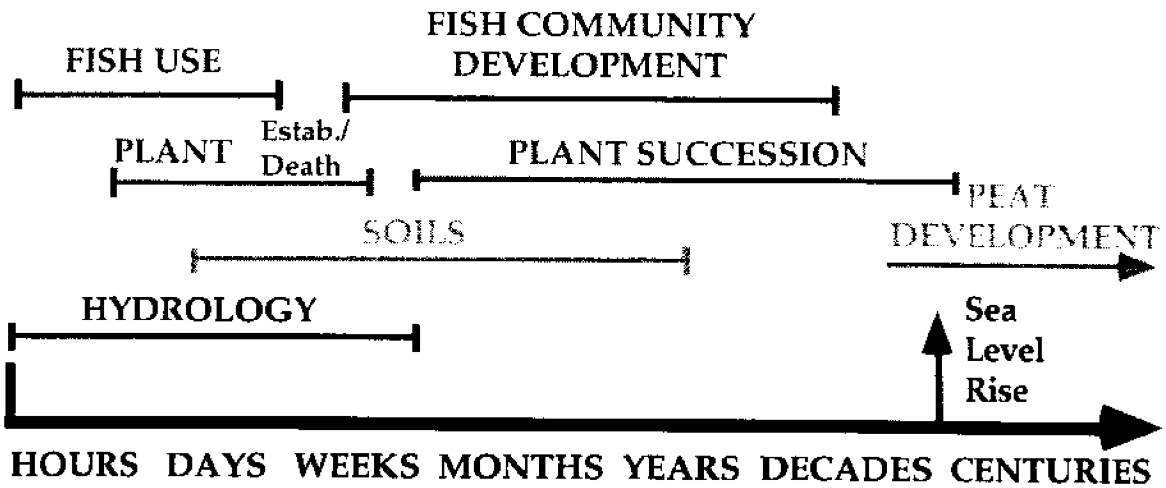

Figure 2. Chronology and ecological time scales important for assessing salt marsh restoration/creation projects.

In addition, our knowledge is absent or very limited on several other important themes addressed above. Thus, there are some urgent research needs (Table 2) that include both regional and process-scale information to understand the impacts to, and the potential role of, salt marsh interactions with Gulf of Maine waters.

Table 2. Research Needs:

- Extent of Reduction in Tidal Exchange Between Marshes and the GOM due to Human Alterations
- Potential and Costs for Restoration of Tidal Exchange
- Effects of Hydrologic Manipulations on Marsh Functions
- Filtration of Sediments and Pollutants by Marshes
- Material and Energy Fluxes Between Rivers, Marshes and Coastal Waters
- Understanding the Spread and Control of Invasive Species (*Phragmites, Lythrum*)
- Use of Marshes by Secondary Producers

Laboratory Investigations on Substrate Use by Juvenile Atlantic Cod

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While field studies can provide information about the distribution of animals, it is often difficult to examine the role of the various abiotic and biotic factors which may influence this distribution in nature. It is in these situations that laboratory experiments, examining hypotheses based on field observations, can play an important role in understanding the mechanisms involved in patterns observed in the field. For example, the results of various field studies suggest that habitat type may significantly influence the distribution of juvenile Atlantic cod, *Gadus morhua* (Keats et al. 1987, Lough et al. 1989, Clark and Green 1990). The association of juvenile cod with specific habitats has been attributed to a response by the juveniles to reduce their risk of predation. However, while several laboratory studies have shown that predation risk can influence juvenile cod activity (Gjosaeter 1987, Nordeide and Svasand 1990), no direct evidence for the interpretation that juvenile cod associate with specific habitat types in response to predation risk was provided in these earlier studies. Therefore, as part of the Early Life History Initiative of the Northern Cod Science Program (Department of Fisheries and Oceans Canada), we are conducting a laboratory based research program examining the role of substrate type, predation risk and the absence or presence of conspecifics on habitat use by juvenile Atlantic cod.

All juvenile cod (age 0+, 4 to 10 cm standard length-SL, and age 1+, 10 to 15 cm SL) used in this study were collected from the inshore environment of Trinity Bay, Newfoundland (43° 38' N, 53° 44' W) using a seine. Predators (age 2+ and 3+ cod, 25 to 45 cm SL) were also captured in this manner. When not being used in an experiment, the different age classes of fish were housed in separate holding tanks.

Experiments were conducted in tanks (2x2x0.5 m deep) divided into a central experimental area (1.84 m^2) and four predator housing compartments, one in each corner of the tank. Each predator housing compartment housed one predator and had a sliding door built into it to allow the predator access to the experimental area of the tank.

The general protocol of all experiments was to present experimentally naive groups (n=5 fish) of juvenile cod with different combinations of substrate/habitat types commonly found in the inshore environment around Newfoundland in the absence and presence of a predator and/or another age class of juvenile cod. Substrates presented included sand (< 1mm diam), gravel (4 to 16mm diam) and cobble (70 to 2500 mm diam). Habitat types presented included the above mentioned mineral substrates, artificial vegetation resembling eelgrass (30cm lengths of green polypropylene rope, 0.4mm diam) and artificial kelp (strips of brown plastic, 30cm long x 6cm wide). The artificial plant stems were attached at one end to a sinking base, and were uniformly spaced. Constructed in this way, the plants would float up in the water column. The densities of plant stems (stems/m^2) used reflected those found in the field. All combinations of substrates and habitat types were presented to at least five different groups of juvenile cod. Which predator was released in any one experimental trial was determined in a semi-random fashion, to insure that each of the four predators in the tank was exposed to that particular combination of substrates/habitat types at least once. Juvenile cod were exposed to a predator for a 1h period during any one experimental trial.

The following data were recorded during all experiments: (1) time juveniles spent in association with the different habitat types being tested, before, during and after (>2 h) exposure to a predator, (2) time the predator spent in association with the different habitat types, (3) the number of juvenile cod captured by the predator, and (4) time taken by the predator to capture its first juvenile.

SCUBA was used to survey four sites in Trinity Bay from July to mid-December 1993. The four sites differed with respect to the dominant substrate/habitat type present, and reflect the range of habitat types examined in the laboratory. Surveys were conducted by two divers swimming along a set, 100m transect at each site, once every two weeks. During each survey, the number of cod and the substrate/habitat type that they were associated with was recorded.

Experiment 1 - Substrate use in the absence and presence of a predator.

With no risk of predation, juvenile cod showed a preference for the finer grained substrate when offered a choice between sand and cobble, gravel and cobble, and sand and gravel (Fig.1) (Gotceitas and Brown 1993). In contrast, with a predator present, juvenile cod hid in among the cobble substrate when this was available. With no cobble present, juvenile cod tried to avoid the predator resulting in no apparent preference between sand and gravel (Fig.1).

The predator showed no preference among substrate types in all three combinations tested. However, the combination of substrates present did affect the time it took the predator to capture a juvenile cod as well as the number of juveniles captured (Fig. 2). The presence of cobble, and its use by juvenile cod, significantly reduce the risk to predation to the juvenile fish.

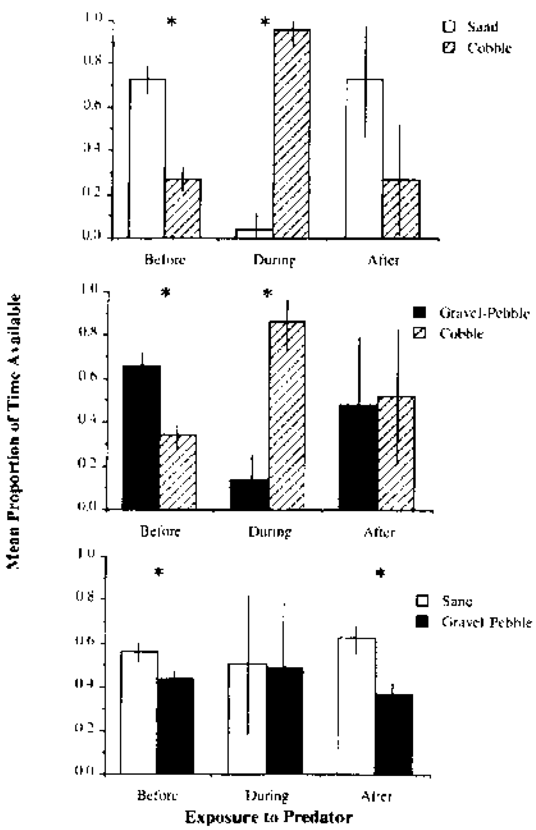

Figure 1. Mean (± 1SE) proportion of time age 0+ cod spent on different substrates before, during and 2.5 h after exposure to a predator. (* indicates a significant difference between the two substrates).

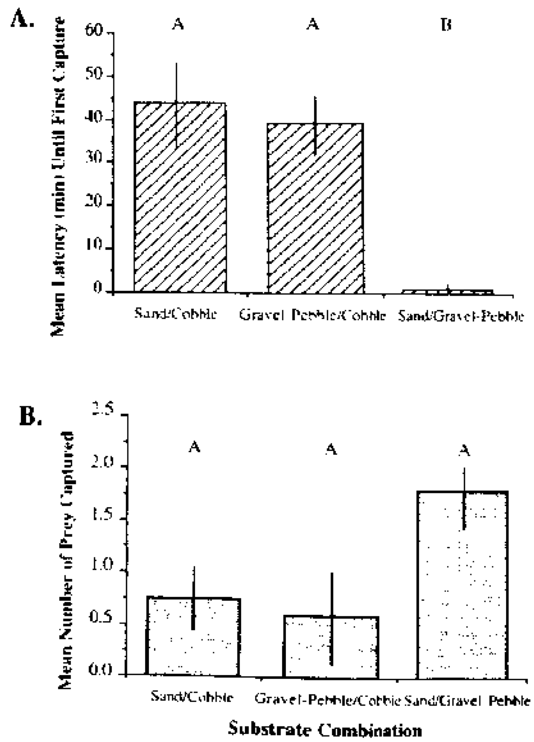

Figure 2. Mean (± 1SE) A. latency until the predator caught its first prey, and B. number of prey captured during the 1 h that the predator was present. Means with the same letter above them are not significantly different.

Experiment 2 - Use of vegetated habitats.

With no risk of predation, juvenile cod appeared to avoid patches of artificial eelgrass and kelp (Fig. 3) (Gotceitas et al. submitted). In contrast, when offered a choice between sand, gravel or a patch of vegetation, juvenile cod hid in the patch of vegetation when in the presence of a predator. When offered a choice between a fine grained mineral substrate, cobble or a patch of vegetation, juvenile cod again preferred the cobble substrate when a predator was present (Fig. 3). These results suggest that juvenile cod perceive a coarse grained mineral substrate as being safer than a vegetated one. This is most likely due to the fact that by hiding in the interstitial spaces of the coarse mineral substrate juvenile cod achieve a complete physical refuge from the predator. There was no significant difference in the number of juvenile cod captured or the time it took a predator to capture a juvenile cod when the predator was foraging in the presence of cobble or a patch of kelp, suggesting that both these habitat types offer a similar level of safety from predation to juvenile cod. The presence of artificial eelgrass also reduced the risk of predation to juvenile cod, but the level of protection offered was dependent on the density of plants present (Figure 4).

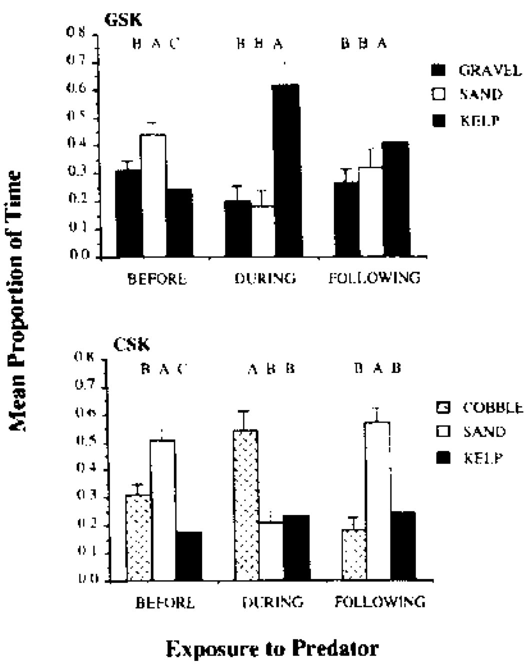

Figure 3. Mean (+1SE) proportion of time age 0+ cod spent in association with different habitats before, during and following exposure to a predator. (S=sand, G=gravel, C=cobble, K=kelp). Within each predator condition, bars with different letters above them indicate a significant difference.

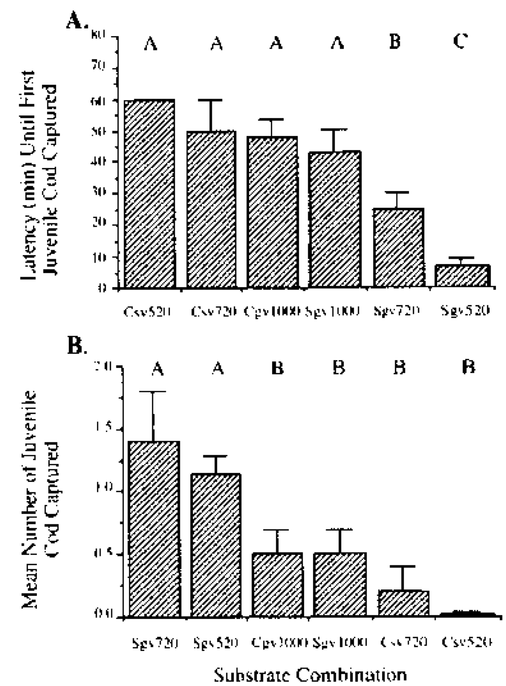

Figure 4. Mean (± 1SE) A. latency until the predator caught its first prey, and B. number of prey captured during the 1 h that the predator was present. Means with the same letter above them are not significantly different.

Experiment 3 - The influence of conspecifics.

When tested with no other age class of juvenile cod present, there was no significant difference in the pattern of substrate use between age 0+ and 1+ cod (Fig. 5) (Mercer et al., in prep.). The presence of age 0+ fish had no significant influence on substrate use by age 1+ cod. In contrast, the pattern of substrate use demonstrated by age 0+ cod when in the presence of age 1+ conspecifics was similar to that shown by the age 0+ fish when in the presence of a predator (Fig. 5). Age 0+ cod either hid from (when cobble was present), or avoided (when only fine grained substrates were available) age 1+ conspecifics.

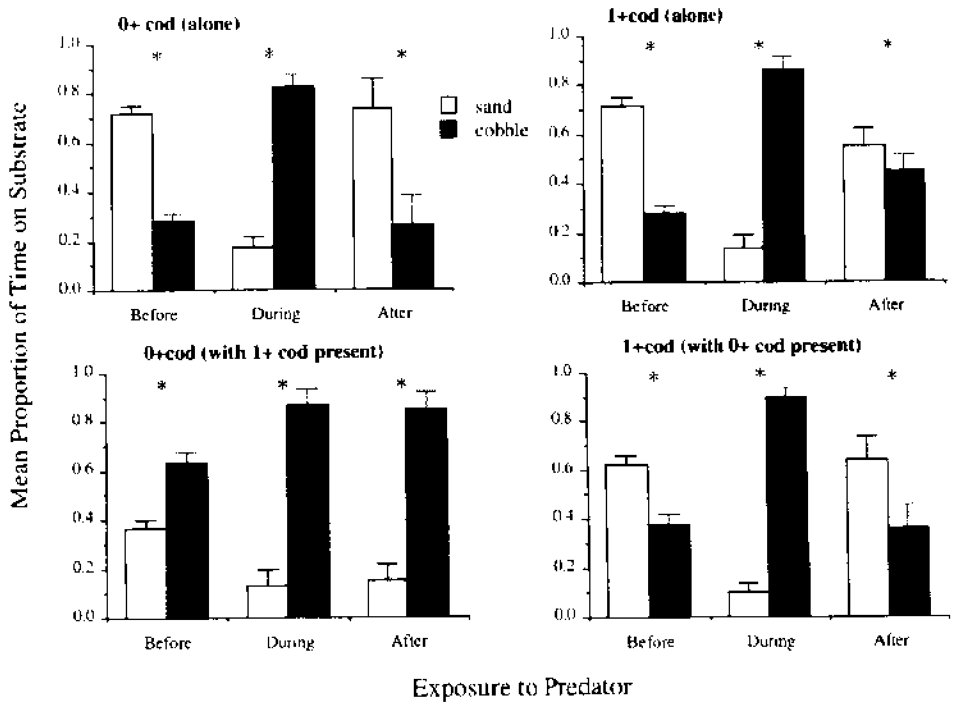

Figure 5. Mean (+ 1SE) proportion of time age 0+ and 1+ cod spent on different substrates when in the absence and presence of the other age class of juvenile, before, during and after exposure to a predator. (* indicates a significant difference between the two substrates).

Field Study

Age 0+ cod were found to primarily associate with an eelgrass habitat, while age 1+ and older individuals were primarily associated with a coarse mineral substrate and kelp (Fig. 6). The association of age 0+ cod with a fine mineral substrate (i.e. mud) was the result of age 0+ individuals being sighted at the periphery of the eelgrass bed.

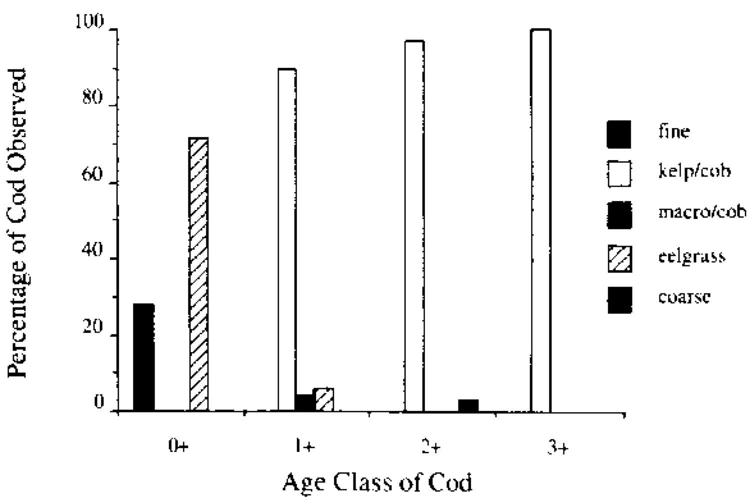

Figure 6. Percentage of juvenile cod observed by divers in association with five different habitat types during the period July to Mid-December 1993. (fine=mud, sand and/or gravel; kelp/cob=a cobble substrate with kelp associated with it; macro/cobble=a cobble substrate with associated macroalgae other than kelp; *Zostera* sp.=eelgrass bed; coarse=cobble, boulder and/or bedrock/reef).

Summary

Substrate use by juvenile cod is significantly influenced by substrate/habitat type, the absence or presence of predation risk, and the absence or presence of older age classes of conspecifics.

In the absence of predation risk, juvenile cod showed a preference for finer grained mineral substrates and avoided vegetation.

When confronted with the risk of predation, juvenile cod chose coarse mineral substrates or vegetation, and hid in among these. Selection for these habitat types resulted in a significant reduction in the risk of predation to the juvenile cod.

The response of age 0+ cod to the presence of age 1+ conspecifics was to alter their use of substrate type so as to avoid the older age class. This resulted in age 0+ fish abandoning their preferred substrate type.

Our laboratory results suggest that, in nature, juvenile cod could be expected to associate with habitat types offering safety from predation and that some level of habitat segregation between age 0+ and 1+ fish might be expected. Our field observations are consistent with this interpretation.

Our laboratory results support the interpretation of field observations made in various other studies (Keats et al. 1987, Lough et al. 1989), that juvenile cod associate with specific substrate/habitat types as a means of reducing their risk to predation.

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Nonpoint Source Pollution and Microbial Contamination in the Great Bay Estuary of New Hampshire

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Sewage and other sources of fecal microorganisms discharged into estuarine waters pose a public health hazard for all recreational users, especially for shellfish consumers. In New Hampshire, nonpoint source (NPS) pollution is the major source of present levels of fecal-borne microbial contaminants. There is some evidence that estuarine microbial communities can be affected by pollution enriched with nutrients and organic matter in such a way that indigenous bacterial pathogens may become more prevalent in polluted waters. Thus, sewage and other nonpoint sources of nutrients and organic mater can indirectly affect the sanitary quality of shellfish by serving as an enriching influence that favors indigenous pathogenic bacteria. Recent studies have shown one important indigenous bacterial pathogen, *Vibrio vulnificus*, to be present in Great Bay Estuary, although in a spatially and temporally heterogeneous manner (O'Neill et al., 1992). The presented results relate incidence and concentrations of bacterial public health significance to other water quality parameters to gain a better understanding of the fate and ecology of these organisms.

Bacteria, including fecal coliforms, *Escherichia coli*, enterococci, *Clostridium perfringens*, *V. vulnificus*, and *V. parahaemolyticus*, nutrients, including orthophosphate, ammonium, nitrate and nitrite, chlorophyll a, phaeopigments, suspended solids, temperature and salinity were measured in water samples collected from sites in Great Bay and its major tributaries for up to 5 years. Distinct spatial patterns for the incidence of the pathogenic vibrios and the fecal indicators were observed, and appeared related to nutrient concentrations and other water quality parameters. Seasonal and spatial patterns of the incidence of pathogenic vibrios and fecal indicators were related to changes in nutrient concentrations and phytoplankton dynamics to gain a better understanding of the factors associated with the onset of pathogenic vibrio incidence in late spring. Indicator bacteria, nutrients, and pathogenic vibrios generally increased in concentration along transects from Great Bay or Portsmouth Harbor up into the tributaries. The vibrios were detected from June to October at all sites, with levels varying with seasonal changes in other parameters. Natural factors associated with the benthic environment of shallow Great Bay that decrease microbial contaminant levels in water were identified and assessed. These results give basic information on the potential for NPS pollution to influence estuarine microbial communities and associated public health threats that is critical for understanding the public health implications of NPS pollution.

Gulf of Maine Seafloor Habitats: A Review of Side-Scanning Sonar Observations

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For more than eight years the Maine Geological Survey and University of Maine have collaborated to produce maps on various scales of the seafloor of the inner continental shelf (0-100 m) of the Gulf of Maine. Side-scanning sonar and seismic reflection observations, coupled with bottom grabs and submersible dives, have provided the data which have been spatially organized on a Geographic Information System (ARC/INFO GIS). At the smallest scale, five bathymetric/physiographic zones are recognized: Nearshore Ramps; Nearshore Basins; Shelf/Bedrock Valleys; Rocky Zones; Gravel Plains and Outer Basins (Kelley et al., 1989a). On a larger scale each of these regions is subdivided on the basis of sediment texture and dynamics.

Nearshore Ramps are generally sandy, seaward sloping regions offshore of large sandy beaches *(Kennebec River Mouth area shown at poster session)* (Kelley et al., 1989a, b; Belknap et al., 1989). Sand was derived from large rivers (Merrimack, Saco, Kennebec, St. John) during the lowstand of the sea (between 11,000 and 10,500 BP; Kelley et al., 1992). Rock outcrops are common and surrounded with shelly gravel; oscillation ripples formed during winter storms cover most of the paleodelta surfaces. Sand abruptly changes to mud at the level of the lowstand of the sea (-60 m).

Nearshore Basins are generally flat-bottomed, muddy regions seaward of tidal flats and protected from the sea by islands, peninsulas or chains or shoals *(Belfast Bay shown at poster session)* (Kelley et al., 1989a; Kelley and Belknap, 1991). Rock outcrops are common in these areas and are often surrounded by shelly gravel. Gas-escape pockmarks, ranging from very small features to 350 m in diameter by 35 m deep, are increasingly recognized in the Nearshore Basins (Kelley et al., 1994; Barnhardt and Kelley, 1994). Gas escape and submarine landslides (against shelf valley margins) (Kelley et al., 1989c), appear to be excavating the basins and leading to sediment export from the nearshore zone.

Shelf/Bedrock Valleys are ancient, fluvial channels carved into rock (Kelley et al., 1989a; Kelley and Kelley, 1993). Inshore they are filled with sand or mud (they are "buried valleys" on land), but are prominent bathymetric features offshore (Kelley and Belknap, 1991; Barnhardt and Kelley, 1994) *(Saco Bay shown at poster session)*. They are usually floored by rock or eroding glacial sediment with occasional drifts of modern sand or mud. They may represent sediment and water pathways connecting inshore and offshore areas.

Gravel Plains are only recognized along the eastern coast of Maine. These areas are flat, boulder-littered bottoms derived from reworking of glacial till deposits. Rocky Zones are interfluves between Shelf Valleys that, because of their high elevation, have been generally stripped of sand and mud. Sand and mud deposits, often with an abundance of shells, exist in protected depressions between the rocks. Outer Basins are deeper than 60 m, and generally muddy areas from which little data exist. Gas-escape depressions have been recognized in these areas but little is known of the sedimentology.

Reprints are available on request.

The Development of Restoration Targets and Trends in Submerged Aquatic Vegetation in Chesapeake Bay

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Quantitative levels of relevant water quality parameters necessary to support submersed aquatic vegetation (SAV) were established for Chesapeake Bay (Dennison, et al., 1993). Coupled with these habitat requirements were the establishment of a tiered set of restoration targets for areas previously vegetated between 1971 and 1990 (Tier I), one meter (Tier II), and two meter (Tier III) water depths to provide management agencies with quantitative measure of progress in SAV distribution in response to implementation of Chesapeake Bay restoration strategies. Each successive target represents expansions in SAV distribution in response to improvements in water quality over time, measured as achievement of the SAV habitat requirements for one and two meter restoration. Baywide surveys using vertical aerial photography since 1978 have documented trends in SAV population (both increasing and decreasing) and related these changes to trends in water quality parameters relevant to SAV survival. Populations of SAV appear to be most healthy and improving in the achievement in restoration targets in the mainstream lower bay where water quality has been consistently meeting SAV habitat requirements since 1984. However, many sections of the bay where water quality remains poor, still have very little or no SAV.

Research and Management Needs to Assess the Extent and Functional Values of Eelgrass Habitats in the Gulf of Maine

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Coastal and estuarine eelgrass beds have many functional values, but those paramount to Gulf of Maine waters may be grouped into two major categories: water quality and fish habitat (Table 1). Not only do eelgrass beds reduce erosion and re suspension of sediments because they reduce current velocities near the bottom, but their buoyant leaves reduce currents throughout the water column, in addition to filtering and trapping suspended sediments. The leaves also filter pollutants, absorbing metal contaminants (Johnston et al. 1993). Excess nutrients entering the coastal zone may be removed by eelgrass from the water as well as the sediments, thus reducing the amount of nutrients reaching deeper Gulf of Maine waters.

Table 1. Functional Values of Eelgrass in Gulf of Maine Waters

Water Quality	Fisheries Habitat
Nutrient Reduction	Nursery
Metal Bioaccumulation	Specialized Refuge
Suspended Sediment Removal	Rich Food Source
Resuspension and Erosion Reduction	Life Cycle Transition Zone

Eelgrass beds provide certain species with specialized habitat, being able to afford protection (nursery function) to some species (lobster, scallops), a rich source of food to others (wading birds, lobster, game fish), a place to metamorphose during transitional phases of life history (e.g., blue mussels as they develop from larval to benthic stage).

Habitat mapping via remote sensing is needed to identify the magnitude and distribution of eelgrass resources in the Gulf of Maine. Such habitat mapping will create a baseline of information that is critical to determine losses of marine resources and to undertake change analysis of eelgrass habitats in coastal Gulf of Maine waters. We have begun this process for part of the Great Bay Estuary, New Hampshire, and in Penobscot Bay, Maine, but complete GOM baseline information is needed. In our work in New Hampshire, we are currently undertaking a change analysis to evaluate habitat losses and gains since the mid 1980s.

The major threat to eelgrass habitat throughout the Gulf of Maine is reduction of water quality, followed by direct physical disturbance; both result from human activity and development in the coastal area. These impacts have resulted in the loss of extensive eelgrass areas which have gone largely unassessed. Currently, there is no way to determine the ongoing rate of eelgrass habitat loss.

Habitat change analysis is critical for identifying changes in resource distribution. Large scale changes in eelgrass habitat need to be documented and their causes understood. If management is to function effectively to protect our natural resources and sustain fisheries productivity, areas of habitat loss must be identified so that corrective measures can be instituted for recovery of these resources.

Our current research is modeling eelgrass habitat change using a process-oriented model coupled with a spatial landscape model. Spatial modeling is a technology that provides managers with on-line methods of describing habitat change and identifying sources of habitat degradation. Our eelgrass process models have been developed from mesocosm experiments that have identified the etiology and effects of disease, the effects of excess nutrients, and shade effects on eelgrass beds. Specifically, in Great Bay, New Hampshire, a spatial model is being developed that will simulate long-term changes in eelgrass habitats in response to these causal factors. This modeling effort will be used to relate the causes of eelgrass loss to changes in distribution as well as to predict gains in eelgrass area resulting from restoration or mitigation efforts in the estuary.

We are also conducting eelgrass habitat mitigation and restoration in the Piscataqua River on the border of Maine and New Hampshire in order to reestablish habitat loss to development; similar efforts are planned for Penobscot Bay, Maine. Critically needed research to advance eelgrass mitigation and restoration includes further development of methods to recreate lost eelgrass habitat. Also needed is a critical assessment of functional values (biomass, canopy structure, invertebrate populations, and fisheries) to determine what aspects of eelgrass habitats require management emphasis. Overall, the contribution of eelgrass habitats to the Gulf of Maine must be thoroughly investigated.

Habitat and Other Limitations to the Carrying Capacity for Lobsters in the Gulf of Maine

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Ecological research suggests the carrying capacity of the Gulf of Maine ecosystem for the lobster, *Homarus americanus*, is recruitment limited and that population densities of preharvestable lobsters are set in their first year on the benthos. The carrying capacity model is based on three sequential conditions. The first two are "supply side" components which determine if pelagic post-larval lobsters are available in the water column and reach the benthos (i.e., exhibit settling behavior). The third is the "habitat limitation" component which, provided the first two conditions are met, determines the number of young lobsters surviving their first year, and thus may be a "demographic bottleneck" for lobsters. In U. S. regions of the Gulf of Maine, supply side-control of post larvae may limit coastal lobster stocks northeast of Penobscot Bay whereas nursery ground substrata (i.e., available cobble habitat) may limit stocks to the southwest. Enhancement and stocking efforts could be aided by supplying early benthic lobsters to supply side limited regions, and recruitment substratum in habitat limited regions. A team of U. S. and Canadian researchers have proposed to test these hypotheses with experiments in both coastal regions of the Gulf of Maine and offshore regions of Georges and Browns Banks.

Sediment-Water Exchange

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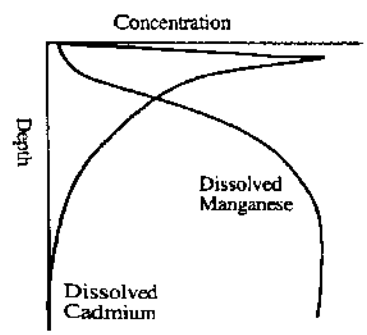
Introduction

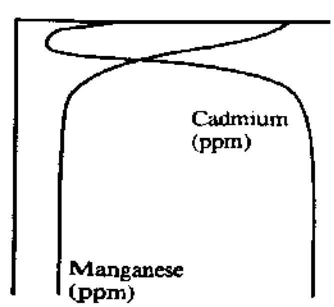
The water column and the underlying sediment are coupled through the exchange of particulate and dissolved material across the sediment-water interface. Sedimentation of particulate organic and inorganic matter supplies the building blocks for constructing the sediment pile and provides the raw material for the microbiological and chemical reactions that take place within it. The bacterial degradation of organic matter, which consumes oxygen and other electron acceptors dissolved in the pore water, changes the composition of the pore water from that of the overlying water. This creates concentration gradients across the sediment-water interface along which pore water constituents migrate into or out of the sediment, depending on the direction of the gradient. There are two principal approaches to estimating the extent of sediment-water exchange of pore water constituents, neither one without problems: one can measure concentration gradients in carefully collected sediment cores and calculate fluxes via an appropriate transport model, or one can try to measure fluxes directly. The latter is usually done with a benthic flux chamber, which encloses a small area of bottom sediment and a volume of the overlying water. Benthic chambers measure fluxes by monitoring the time rate of change of the composition of the enclosed water.

Redox zonation and fluxes in sediments

Micro-organisms remineralize organic matter, consume oxygen, nitrate, and sulfate, change the redox potential, and change the solubility of many trace constitutents of sediments. The transport of solutes along the concentration gradients creates a dynamic environment where many sediment constitutents constantly migrate from regions where they dissolve to regions where they precipitatethus cycling continously between their dissolved and precipitated forms.

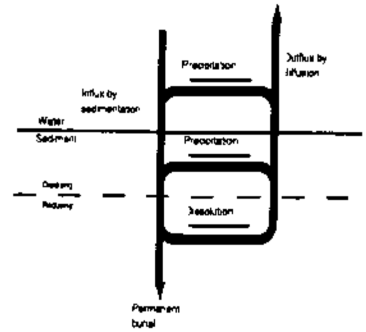
To the right are examples of how differently metals can be influenced by the absence or presence of oxygen (adapted from Gobeil et al. 1987). The upper panel shows that, in the oxygen-containing sediment surface layer, we find at the same time the lowest concentrations of dissolved manganese and the highest concentrations of dissolved cadmium. Deeper in the sediment column, where there is no oxygen, dissolved manganese is high whereas dissolved cadmium can barely be detected. The distributions of manganese and cadmium in the solid phase of the sediment are equally contrasting. In the surface layer, manganese is enriched and cadmium is depleted; in the deeper layer, manganese is depleted and cadmium is enriched (lower panel).





The case of manganese

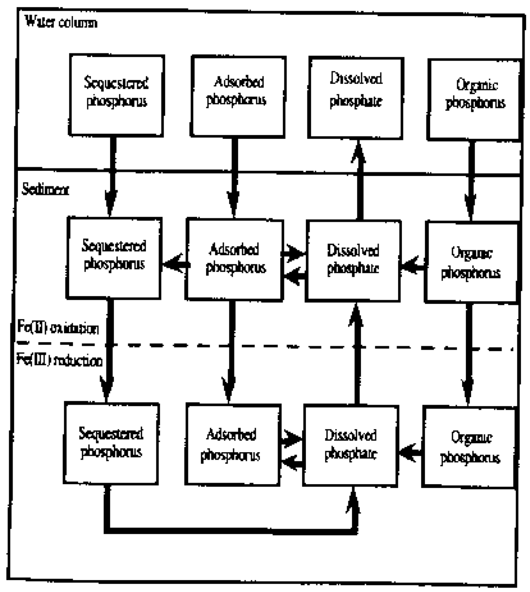
Characteristic of manganese is that it dissolves in the anoxic reducing subsurface zone of a sediment and precipitates in the oxic surface layer, creating a strong vertical concentration gradient in the solid phase.When benthic organisms mix particles from the manganese-enriched surface layer with manganese-poor particles from the deeper layers, the result is a net downward flux of particulate manganese.When this manganese dissolves, the pore water concentration of dissolved manganese increases, and dissolved manganese migrates back to the surface layer. The flux of dissolved manganese may be confined to the interior of the sediment or it may escape into the bottom water, depending on the completeness of the precipitation.The cycling of manganese between its dissolved and precipitated forms can be quite rapid. In some coastal marine sediments the manganese rich layer goes through a complete cycle of downward mixing, dissolution, upward diffusion, and precipitation several times per year.



The case of phosphorus

The approach to trace metals in sediments has been greatly influenced by work done on the phosphorus cycle, and it may be useful to consider some aspects of phosphate exchange at the sediment-water interface. Briefly, the idea is that iron oxides in the sediment surface layer adsorb the phosphate diffusing up from the deeper sediment layers and immobilize it until the bottom water becomes anoxic. At that time the iron oxides in the sediment are reduced and the adsorbed phosphate is released. This basic idea has been refined by introducing the notion that sorption equilibria between dissolved and adsorbed phosphate can buffer the phosphate concentration in the sediment pore water. This buffering places upper limits on the concentration gradient across the sediment-water interface and thus controls the instantaneous flux of phosphate into or out of the sediment.

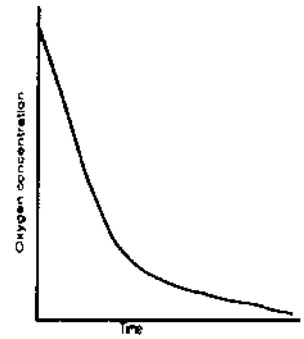
The principal processes involved in the phosphorus cycle are indicated in the figure to the right. A major portion of the sedimentation flux of organic phosphorus is mineralized in the oxidizing surface sediment and the released phosphate is partitioned between the pore water and adsorption sites on solid sediment phases. Adsorbed phosphate is released to the pore water as needed to maintain the equilibrium concentration and replace the dissolved phosphate that escapes to the overlying water. More phosphate is released deeper in the sediment column from iron oxides undergoing reduction. The released phosphate is free to participate in exchange reactions with remaining adsorption sites and to migrate upward and out of the sediment, which it could not do as long as it was sequestered. Sedimentation and biological mixing transport adsorbed, sequestered, and organic phosphorus downward into the reducing region of the sediment, and diffusion transports dissolved



phosphate upward towards the sediment surface. Mobilized phosphate, by being readsorbed in the oxidizing layer, can be recycled several times across the redox boundary for iron, before escaping the sediment.

Benthic flux chambers

If one wishes to make flux measurements with benthic chambers, one should be aware of their limitations. Benthic flux chambers interfere with the transfer of mass and momentum at the sediment-water interface, and the composition of the water at the sediment-water boundary inside a chamber changes continually during an incubation. The results of experiments with benthic chambers can therefore be difficult to interpret in terms of what actually takes place at the sediment-water interface. Employed with caution, however, benthic chambers can nevertheless provide useful information.



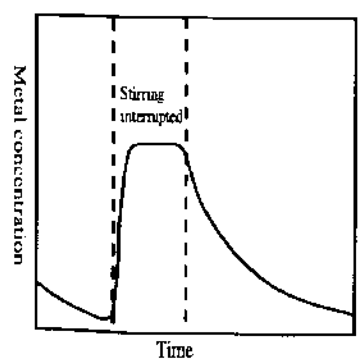
To understand the major problem involved in the use of flux chambers, it is useful to examine the way the oxygen concentration evolves during an incubation and then relate this to the fluxes of other pore water constituents. In the beginning of an incubation, the oxygen concentration decreases at an approximately constant rate, but once the oxygen concentration reaches about 100μM, the rate of decrease slows down. The pattern to the right is typical.

This means that the oxygen flux into the sediment is not constant, except in the beginning of the incubation. The reason for this is that the concentration gradient across the diffusive boundary layer at the sediment-water interface keeps decreasing and the resulting thinning of the oxygen-containing sediment layer reduces the number of microorganisms that respire with oxygen.

The dependence of trace metal fluxes on the oxygen regime in a flux chamber

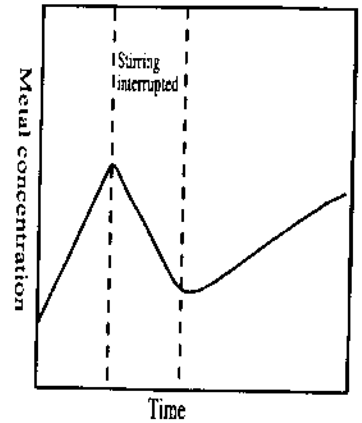
The sensitivity of the trace metals fluxes to the oxygen concentration at the sediment-water interface can be illustrated with a benthic chamber experiment. In this experiment, the oxygen concentration in the enclosed water was maintained approximately constant by adding oxygen through a diffuser to replace the oxygen consumed by respiration. Then, after 10 days, the stirring was interrupted, allowing the water column to stratify and become anoxic near the sediment surface. After another 10 days, the stirring was resumed and oxygenated water was brought down again to the sediment-water interface. The way the trace metal concentrations evolved allows us to us group them into two distinctly different classes: manganese, iron, and cobalt in one and cadmium, zinc, copper, and nickel in the other.

Class 1: **Manganese, iron and cobalt**



As long as the oxygen concentration in the water was kept near the ambient level and the water column was kept well mixed, none of these metals were released from the sediment. Instead, there was a small flux from the water column into the sediment. The interruption of the stirring on day 10 resulted in a sudden release of dissolved iron, manganese and cobalt. When the stirring resumed and oxygenated water again was brought down to the sediment-water interface, all three metals gradually disappeared from the water column and were taken up by the sediment. The removal of these metals took place at the bottom of the diffusive sublayer where the concentration of the dissolved ions was kept low by the continuous precipitation of insoluble metal oxides.

Class 2: **Cadmium, zinc, copper and nickel**



During the initial 10-day period, cadmium, zinc, copper, and nickel were released to the water column at nearly constant rates. When the stirring was interrupted, the fluxes were reversed and all four metals were taken up by the sediment. When the stirring resumed, cadmium, zinc and copper were once again released from the sediment to the water column. Nickel was not released during this phase, and the release rates of the three other trace metals were significantly lower than during the first phase of the experiment.

The relationship between the oxygen regime and trace metal fluxes is consistent with what we know about the chemistry of these trace metals. Manganese, iron, and cobalt, which are known to form insoluble precipitates in the presence of oxygen, were not released from the sediment when the water column was kept oxygenated and well stirred; they were only released when the sediment-water interface went anoxic. Cadmium, zinc, copper, and nickel, which are soluble in the presence of oxygen but forms insoluble precipitates with sulfide, were removed from the water column when the sediment-water interface went anoxic but were released from the sediment when the water column was kept oxygenated. The rapidity with which the fluxes respond to changes in the oxygen regime is remarkable.

Summary

It is not a simple matter to measure the fluxes of solutes at the interface between the water column and the bottom sediment since benthic chambers may, by their very nature, interfere with the measurements. In spite of their attractive simplicity, benthic chambers should be used with caution because the conditions at the sediment-water interface changes during an incubation. Special precautions should be taken to avoid such changes. The pore water composition of sediments and the fluxes of trace metals and nutrient salts are particularly sensitive to changes in the concentration of oxygenat the sediment-water interface.

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Recruitment and Attachment Mechanisms of Intertidal Rockweeds

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Rockweeds provide a major habitat and nursery resource along much of the Gulf of Maine. Previous and ongoing research on *Ascophyllum nodosum* reveals a natural bottleneck in successful attachment of zygotes and recruitment of germlings on rocky intertidal shores. Zygotes settled for three hours were readily dislodged by low energy waves and current speeds of 10 cm sec^{-1} or greater. Comparative studies of *Fucus evanescens* showed that this species withstood approximately twice the flow forces of *A. nodosum* but were nonetheless vulnerable to dislodgment. We postulate that the removal of the canopy cover of *A. nodosum* by intensive harvesting will increase the flow forces within a stand and further reduce the ability of this alga to recruit new individuals into the population. Preliminary tests of this hypothesis, however, have been inconclusive. The continued existence of this long-lived resource appears to be dependent on both vegetative proliferation and intermittent recruitment. The widespread harvesting of *A. nodosum* coupled with reductions in recruitment potential may lead to a substantial decline of this ecologically important alga.

4. Working Group Reports

Biodiversity

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I. Preface

"The one process ongoing in the 1990s that will take millions of years to correct is the loss of genetic and species diversity by the destruction of natural habitats. This is the folly that our descendants are least likely to forgive us." E.O. Wilson made this statement which is quoted in the Global Biodiversity Strategy (WRI 1992). Biodiversity is generally considered only at the species level. However, biodiversity refers not only to numbers of species, but at a lower level to genetic diversity and at a higher level to ecosystem (community) diversity. Each level has inextricable links to habitat diversity. A species may exhibit high genetic diversity based on selection of variable traits which enhance survival in specific habitat types. Species diversity is linked to habitat diversity since more species may be able to coexist in an area because of variable habitats in which only a smaller number of species can live. A similar sized area with homogeneous habitat features may support a smaller number of species. Ecosystem diversity is linked to habitat diversity as energy flows through more component parts of a community (i.e., a more complex trophic web) with high species diversity.

The science community has recently organized to emphasize the need for greater understanding of processes controlling, maintaining, and monitoring marine biodiversity on a global scale (Butman and Carlton 1993, Grassle et al. 1991, Ray and Grassle 1991). Non-governmental organizations have also joined in the call to governments to increase funding for research linked to biodiversity issues (e.g., Norse 1993). Our state of knowledge regarding the role that biodiversity plays in maintaining important ecosystem functions is totally inadequate considering the present and potential impacts humans are having on marine resources at local, regional, and global scales.

II. What Are Mangers Trying To Accomplish?

Federal, state, and local laws give agencies specific trustee responsibilities regarding preservation and management of particular species or biotic assemblages within constrained geographic boundaries. For example, the U.S. Fish and Wildlife Service has particular programs for management of endangered species such as piping plovers, NOAA's National Marine Fisheries Service deals directly with harvested species, and NOAA's Sanctuaries and Reserves Division has responsibilities for maintaining biotic integrity within National Marine Sanctuaries.

There is no paradigm within government agencies to manage for preservation of biodiversity at any level (i.e., genetic, species, ecosystem). In fact, there can be conflicts. For example, some agencies and non governmental organizations are involved in maintaining freshwater marshes created from previously diked and drained salt marshes to attract migratory waterfowl. The priority has been maintenance of freshwater marshes rather than restoration of salt marshes. The Clean Water Act has a provision for maintaining the biological integrity of the waters of the U.S. The Act gives agencies more latitude when evaluating permits, other than trustee species, to include effects on biodiversity, if so inclined. The Gulf of Maine Council on the Marine Environment is currently implementing a project which takes a systematic approach to the identification, classification, and protection of regionally significant habitats.

Biodiversity can be viewed as the canary in the mine shaft, an indicator of ecosystem health. Managers are generally charged with maintaining ecological integrity and productivity. However, management has traditionally taken place at the single species level. While it is recognized that managing at an ecosystem level is the best functional approach, the information needed to accomplish this goal does not presently exist.

III. Actual Or Potential Threats To Biodiversity

The following list of threats were identified by the working group as most likely causes of loss of biodiversity:

Fishing activities

All habitats are affected as fishing activities are widespread. Refuges are increasingly limited due to the maturation of fishing gear technology which allows use in many, previously restricted habitats. Specific fishing methods (e.g., mobile fishing gear, clam rakes, rockweed and bloodworm harvest) disrupt sediment and rock surfaces, potentially causing major shifts in community composition, organic matter burial and isolation from microbial food webs, and sediment surface erosion which can cause escape of interstitial fluids and gases. In shallow waters, power boats can directly remove submerged vegetation with associated attached organisms. Fixed gear entanglement and ingestion of marine debris directly impact marine mammals, reptiles, birds, many of which are presently endangered.

Diversity may change with continued fishing pressure. Mortality caused by harvesting selects for slow growth and fast reproduction and incidental mortality of long lived species causes faster growing species to dominate. It is difficult to differentiate anthropogenic change due to gear impacts in dynamic habitats such as sand. Studies of the impacts of fishing may be more tractable in rock, gravel and mud areas. However, it is difficult to measure long-term change due to the long history of fishing.

Dam construction

Dam construction on tidal rivers results in degradation of habitats due to siltation up and downstream including the estuarine flats, resulting changes in community structure. Concomitant changes in flow result in loss of freshwater and estuarine habitats. For example, there are losses of relict populations at heads of specific estuaries and changes in migratory path of shorebirds due to changes in the distribution, or local extinction, of prey species. Tidal power dams will produce both near and far field effects. It is difficult to track changes in historically modified systems as only dominant species were recorded in older studies.

Sea walls and other coastal construction

The use of sea walls and bulkheading results in a loss of inter tidal habitat and associated communities. There are also cascading effects on marsh and tidal flat expansion due to changes in sediment transport processes. Construction of hard surfaces produces shifts from soft to hard bottom communities. Shorebird habitat is reduced or eliminated.

Docks which are constructed from chemically treated wood affect genetic diversity of epibenthos by selecting for tolerant individuals. Shading effects from docks on submerged aquatic vegetation produce bluegreen algal dominated communities.

The cumulative impacts at regional scale may be significant.

Land use practices and wetlands alterations

Wetlands - current degradation is constrained by current legal restrictions. Maintain loss of functional role.

Land use - road and railroad crossings and culverts reduce flow to tidal creeks.

Perhaps there is a need to address reversing historic impacts by opening tidal flow constrictions, evaluating buffer strips as a way to restore functional wetlands and attendant assemblages. This is an important area for expanded research.

Contaminants

Selection for resistant individuals. Impacts on reproductive capacity (fecundity, egg and larvae viability). Reduction of assemblage diversity. Changes in biomass.

Use of antibiotics from aquaculture promotes resistant species.

Sentinel species used to evaluate impacts of contaminants (Velpar=Mya)

Dredging and mining

Sand mining - removal of top 15 cm of seafloor over large areas. The Minerals Management Service leases offshore areas for sand and mixed aggregate mining.

Dredging - in small harbors changes flow and salinity structure and alters the estuarine habitats. Impacts to Virginian relict communities.

Aquaculture

Siting of leases for salmon pens near island seabird rookeries which can result in disturbance of mating and rearing behaviors having population level consequences for a variety of species, especially those with reduced population sizes

Use of antibiotics which can result in antibiotic resistant diseases

Genetic influence of introduced, released species,

Localized eutrophication , algal blooms

Transplantation of mussels/oysters reduces diversity of associated communities.

IV. Common Threads From A Management Perspective

The working group members asked the question "who is a manager of an ecosystem?" Management responsibilities are generally taxa specific. Many managers and decision makers need to be educated regarding the value of biodiversity. It must be recognized that single species management approaches are inadequate to deal with the multiple and complex problems facing those required to manage communities or ecosystems for the benefit of single or multiple taxa. New approaches to management should be ecosystem or habitat based.

V. Current Information Needs

In order to track change in any system, it is necessary to know the distribution and abundance of components of that system. Maps of habitat features which address the features of the environment that maintain the integrity of assemblages of organisms are the primary information needed to track changes in communities based on habitat alteration. Understanding the dynamics of habitat features (e.g., turbidity effects on seagrass distribution, storm induced changes in sediment distribution) is critical to developing a predictive capability for determining assemblage distributions and impacts that change may have on assemblage structure. Baseline surveys of associated fauna, including components of spatial and temporal variability, are a first-order information need. Concomitantly, it will be necessary to identify life histories of key taxa and functional linkages through assemblages.

VI. Research

Research required to provide knowledge for a habitat based approach to managing for biodiversity includes:

(1) Determining the appropriate scale for resolving features of habitat and communities suitable for management for each habitat type. (Selection of representative habitats is required for this research component.) This work requires determining the appropriate physical parameters needed for characterization of each habitat type.

(2) Determining the role that biodiversity plays in maintaining ecosystem health vis a vis the functional role of biodiversity in carbon flow, contaminant cycling and sequestering of carbon/contaminants.

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Coastal Habitat Alteration

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I. Coastal Habitats in the Gulf of Maine

The coastline of the Gulf of Maine is comprised of a wide array of habitats (Fefer and Schettig 1980). They range from habitats in soft substrates such as sand and mud flats, eel grass beds and salt marshes (Niering and Warren 1980; Larsen et al. 1983; Thayer et al. 1984; Commito 1982; Jacobson et al. 1987; Bertness 1991; Larsen and Doggett 1991; Short et al. 1992) to those on hard substrates such as ledge, gravel, cobble, algal beds, and mollusk reefs (Witman 1985; Witman 1987; Ojeda and Dearborn 1991; Sebens 1991; Vadas 1992). The variety of these habitats is greatest along the shorelines and inlets of estuaries. Their interactive effects have a large influence on resources throughout the Gulf of Maine. Given that human activity along the densely populated Gulf of Maine coastline is focused within estuarine watersheds, coastal habitats have experienced widespread alteration.

The Gulf of Maine coastline is subject to several common forms of human activity. The inlets of tidal rivers are frequently stabilized with jetties or breakwaters and the inlet channels are regularly dredged. Until recently, dredge material was regularly used to fill salt marsh. The barrier beaches that protect salt marsh habitats are heavily developed and stabilized with seawalls. The marshes themselves are highly fragmented both physically and hydrologically by extensive networks of roads, causeways, railroad beds and dikes (Roman et al. 1984; Rozsa 1988; Sinicrope et al. 1990). Commercial and residential development within the tidal and freshwater portions of estuarine watersheds can be extensive, and commonly occurs within feet of the shoreline, or on filled areas of wetland.

These various human activities have altered coastal habitats directly through actual habitat loss (especially for coastal wetland habitats), and indirectly through hydromodification, sedimentation, and erosion. Given the great extent and intensity of these alterations, it is important to understand their influence on both coastal and offshore ecosystems, to guide the management of Gulf of Maine marine resources. In this working group report, we discuss the most pressing coastal habitat management needs, and suggest areas of research that should be undertaken to meet these needs.

II. What are Managers Trying to Accomplish?

Management of coastal habitats in the Gulf of Maine is dictated in large part by a substantial list of federal, state and local regulations. For any given coastal area or habitat, agencies from each of the three tiers of government may have regulatory responsibilities. The purpose of these regulations fall generally into three broad categories: 1) protection, 2) restoration, and 3) reduction of human impact to water quality, wetlands, and deepwater habitats. In large measure, management activities involve the permitting of human activities, compliance monitoring, and enforcement of permits and regulations. The success of these management efforts is in part a function of the quality of information available to managers. Currently, decisions about methods of protection, enhancement, and permissible levels of impact often must be made in the absence of adequate, accessible, environmental and ecological information.

The working group identified a comprehensive list of habitat-related management needs for the Gulf of Maine ecosystem. These needs can be grouped into four categories: 1) basic ecological parameters and processes, 2) human impacts, 3) ecological effects of impacts, and 4) impact management or remediation. These categories are related in a simple hierarchy. The end goal - impact management or remediation - requires an understanding of the ecological effects of the impact. The ecological effects of an impact depends on the nature and extent of the impact. And, in order to detect an impact, some change in pre-impact ecological parameters or processes must be observed. In this hierarchy (below), it is clear that we need to know more about habitat parameters and processes if we are to move forward in our efforts to manage and remediate coastal habitat alteration.

Coastal Habitat Management Needs

1. Ecological parameters and processes:
   - Inventory existing, historical, and potential habitat resources; identify vulnerable sites.
   - Define and measure functions and values of existing habitats.
   - Identify and quantify commercial and noncommercial living resource habitat requirements.
   - Identify critical habitats for target species.
   - Determine processes necessary for long-term habitat stability.
   - Determine habitat susceptibility to invasion by introduced species.
   - Determine linkages between coastal zone and offshore processes.

2. Human impacts:
   - Identify extent of dredging, dragging, resource harvesting, fish waste disposal, dumping, aquaculture and habitat mitigation.
   - Identify land-use patterns in coastal watersheds.
   - Identify point and non-point source pollution of coastal habitats.
   - Assess cumulative extent of chronic, multiple impacts to coastal habitats.

3. Ecological effects of impacts:
   - Identify habitats at risk of degradation or loss through human impact.
   - Assess effects of land use on coastal habitat systems.
   - Assess degradation rates of critical habitats for target species.
   - Assess relationship between habitat degradation and loss, and species recruitment.

4. Impact management and remediation:
   - Develop and use indicators to detect change in habitat function and value due to human action.
   - Monitor functions and values of restored and created habitats to improve current and future projects.
   - Design buffers sufficient to protect habitat functions and values from human land use practices.

III. A Habitat-Specific Approach

The many coastal habitats that have been identified for the Gulf of Maine (Brown 1993) are not all equal in terms of management concerns. The working group selected habitat categories for discussion based on their importance to managers and/or their need for management. Vegetation is an important feature of coastal habitat ecology, therefore coastal habitats were first divided into "vegetated" and "unvegetated" coastal habitats. Within the category of vegetated coastal habitats we selected salt marsh habitat (intertidal), eel grass habitat (intertidal to subtidal), and kelp/macroalgal habitat (intertidal to subtidal) for discussion. Mud flat was the sole unvegetated coastal habitat the group discussed. Beach and dune habitat was also selected for consideration. After some discussion, the group agreed that this habitat has been well studied, relative to other coastal habitats. We concluded that the existing research base is sufficient for current management needs, so beaches and dunes were not discussed further. However, geologists consulted later state that management of specific systems may well require detailed information about sediment supply and transport.

IV. Research Priorities over the Next Five Years

For each coastal habitat of concern, management needs were defined and the most pressing (i.e. priority) needs identified. The primary factors considered in determining priority management needs were:

1. Degree of ongoing habitat alteration under existing management regime and
2. Level of understanding of ecological changes resulting from alteration.

Human impacts posing the greatest potential threat to habitat function, and for which the ecological effects were least understood, were selected as priority subjects for research. Each item under "Management Needs and Goals" is paired with a corresponding item under "Research Priorities".

Management priorities and research needs common to all habitats are presented separately under "All Habitats".

Salt Marsh Habitat

The priority salt marsh management issues concern changes in estuarine functions and values, due either to loss of salt marsh habitat, changes in tidal flow, or changes in land use that influence freshwater inputs. To improve management of salt marsh habitats, research priorities were identified that would contribute to answering the question:

"What is the impact of anthropogenic habitat lass and hydrologic modification on salt marsh functions and values in the Gulf of Maine ecosystem, and how can these functions and values be restored?"

Salt Marsh Habitat (continued)

Management Needs and Goals:	Research Priorities:
Regulate coastal dredge and fill activities on marshes.	Determine the extent of degradation from tidal restriction, and the rate of habitat loss from dredge and fill activities.
	Determine the influence of habitat loss on marsh dependent resources (e.g. birds, fish, shellfish).
Reduce impacts of tidal restriction and other hydrologic modifications (e.g. tide gates, causeways, culverts, water diversion).	Develop hydrologic models to guide restoration of tidal flow.
	Develop ecological models to predict the rate and extent of changes in functions and values with loss/restoration of tidal flow.
Implement adequate buffer zones.	Determine the influence of existing buffer zones influence habitat functions and values.
	Determine changes in buffer requirements needed to improve buffer effectiveness.

Eel Grass Habitat

The primary eel grass management issues concern the need for defining habitat functions and values (they have already been defined for salt marshes), and managing human activities that influence these functions. Human influences may be indirect, through water quality (see section V.), or direct, through physical destruction or the presence of physical structures. To improve management of eelgrass habitats, research priorities were identified that would contribute to the larger question:

"What functions and values are being lost through the effects of human activity on eelgrass habitats in the Gulf of Maine ecosystem, and how can they be restored?"

Management Needs and Goals:	Research Priorities:
Identify existing habitat, and habitat functions and values.	Conduct baseline inventory and create habitat maps.
Regulate impact of water quality on habitat function and value.	Determine habitat water quality requirements.
Assess impact of mechanical destruction from dragging.	Determine the effects of harvesting on habitat stability.
Assess impact of marine structures & activities (docks, coated structures, boats, aquaculture).	Determine the effects of marine structures/activities on habitat stability.
Select sites suitable for restoration.	Determine conditions needed for habitat restoration &the best assessment methodology.

Kelp / Macroalgae Habitat

Management issues concerning macroalgal habitats are very similar to those for eelgrass habitats. Again, there is a need to define habitat functions and values, and to manage human activities that influence these functions. These influences may be direct or indirect. To improve management of macroalgal habitats, research priorities were identified that would provide information needed to answer the question:

"What functions and values are being lost through the effects of human activity on macroalgal habitats in the Gulf of Maine ecosystem?"

Management Needs and Goals:	**Research Priorities:**
Identify existing habitat, and habitat functions and values.	Conduct baseline inventory and create habitat maps.
Regulate impact of water quality on habitat function and value.	Determine habitat water quality requirements.
Regulate impact of mechanical destruction from dragging.	Determine the effects of harvesting activities on habitat stability.
Regulate impact of urchin and lobster harvesting.	Develop model describing relationship between macroalgal habitat, urchin population structure and lobster population structure.

Mud Flat Habitat

For mud flat habitat, management issues concern changes in functions and values due either to discharge and dumping of anthropogenic materials, or through the physical effects of resource harvesting. To improve management of mud flat habitats, research priorities were identified that would contribute to the question:

"What is the impact of anthropogenic materials and physical disturbance on the functions and values of mud flat habitat in the Gulf of Maine ecosystem?"

Management Needs and Goals:	**Research Priorities:**
Identify existing habitat, and habitat functions and values.	Conduct baseline inventory and create habitat maps.
Select location of discharge and dump sites, using resource information from above coupled with hydrodynamic data.	Determine habitat response to discharge / dumping.
	Develop site selection protocols based on habitat response to impact.
Assess impact of resource harvesting (e.g. clamming, worming, dragging, fish wastes).	Modify harvesting methods to reduce loss of habitat functions and values.

All Habitats

A number of management needs and goals were identified that encompass all habitats. They can be viewed as a refined subset of the overall needs and goals from section II, representing those areas most in need of further research. In combination, these management issues point to the need to 1) develop adequate baseline data on the distribution and health of all coastal habitats, and 2) determine effective methods of measuring and mitigating cumulative direct and indirect human impacts that influence valued Gulf of Maine natural resources. Research priorities are directed at the overall question:

> *"What is the role of coastal habitat in the functioning of the Gulf of Maine ecosystem, and how does alteration of these habitats (direct and indirect) influence Gulf of Maine resource dynamics?"*

Management Needs and Goals:	**Research Priorities:**
Conduct Gulf-wide assessment of individual impacts, especially habitat loss.	Develop Gulf-wide, high resolution, habitat maps and inventories.
Conduct Gulf-wide assessment of effects of combined impacts on habitat health (cumulative impacts).	Determine the synergistic effects of multiple impacts on habitat health.
Use indicators to monitor habitat health.	Identify and test the utility of potential indicator species, species groups, or multi-parameter indices of habitat health.
Assess the trade-offs between different approaches to impact remediation.	Determine the relative benefits to habitat functions and values of protection vs. restoration vs. creation.
Achieve comprehensive coastal watershed management and planning.	Determine the relative impacts of different land use practices on coastal habitat functions and values.
Determine impact of coastal zone habitat alteration on Gulf of Maine living resources (coastal and offshore).	Develop models to predict response of target Gulf of Maine resources (coastal and offshore) to coastal habitat alteration.

V. Research Based Habitat Management: An Example from the Chesapeake Bay

During the past two decades, the Chesapeake Bay has experienced dramatic declines in the distribution of submerged vegetated habitats (Orth and Moore 1983; Orth and Moore 1984). At one time, most shallow areas of the Bay (< 2m depth) were covered with submerged aquatic vegetation (SAV), comprised of more than twenty species of flowering plants. An important member of this group is eelgrass (*Zostera marina*), the same species of eelgrass present in the Gulf of Maine. Prior to and during the decline, a considerable body of research established that aquatic vegetation was an extremely important habitat for the fish and other animals of the Bay. A concerted research effort in the late seventies and early eighties was undertaken to determine the causes of SAV decline. Insufficient light penetration of the water column, due to suspended sediment and phytoplankton, were identified as the cause. High sediment levels were the result of agricultural runoff, and phytoplankton blooms were fueled by high levels of nitrogen and phosphorous (Galloway 1993; Chesapeake Bay Program 1993).

In 1983, recognition of the importance of different living resources - including eelgrass - by the public and policy makers alike, led to creation of a regional political agreement to restore the Bay's living resources. Subsequent research in the late eighties and early nineties identified the minimum water quality parameters required to allow plant establishment and survival at different depths (Batiuk et al. 1992). This body of work led to a second, unprecedented regional political agreement to improve the water quality of the Chesapeake sufficiently for vegetation to recolonize the Bay to the 1m depth contour. Ultimately, it is hoped the 1 m restoration goal will be extended to the 2m depth contour.

This decade-long effort to restore an important element of the Chesapeake Bay ecosystem is an encouraging example of collaboration between researchers and coastal managers. It demonstrates the utility of a concerted ecological research effort in addressing a coastal habitat management problem. The Chesapeake Bay Program also demonstrates that coastal habitat management need not be guided solely by existing regulations. In this instance, new legislation was created specifically to mandate the support for habitat restoration goals based upon the results of an ambitious ecological research program. It would serve well as a model for collaboration between researchers and coastal managers in the Gulf of Maine.

VI. Communicating Research Results

The working group recognized that achievement of the research goals identified will not contribute to management needs and goals unless results are made available in a usable form. To support attainment of management goals, research results *must* be incorporated into clear, simple, management protocols, manuals, and reviews. These documents should then be modified as appropriate for the following audiences and user groups:

- Decision Makers and Politicians
- Agency Managers
- Agency Staff
- Resource Users
- General Public
- Primary and Secondary Educators
- Citizen Volunteers

The publications of the Chesapeake Bay program provide good models for translating research results into publications tailored for use by different audiences.

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Fisheries Resources

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The Fisheries Resources Working group focused on marine commercial and recreational fisheries, both vertebrate and invertebrate. The group considered first the goals of resource management, then developed a flow diagram that organizes research priorities toward management goals. It finally considered the research-management interface and the development of a means to set management priorities in an ecological context.

I. What Are Managers Trying To Accomplish?

The goal of management is to conserve, protect, restore and enhance the natural resources. It must also sustain resource stability and maintain quality of production through the control of human activity and the environment. This latter point, regarding quality, reflects concern about contaminant loading and pollution.

The Fisheries Resources Working Group considered these goals in the context that habitat *per se* is an essential resource for sustaining the production of commercially and recreationally important species. In many cases, however, our knowledge of whether a particular habitat component of the marine ecosystem is essential for any given species, at any point in its life, is poorly known. Obviously this must be determined before we can define the geographic limits of the habitat type or evaluate the vulnerability of the habitat to anthropogenic impacts. Resource management suffers from this lack of species specific knowledge and is often perceived of as reactive rather than proactive, focusing on resource crises rather than protection, restoration or enhancement. For resource management to succeed it is imperative that managers develop an ecological approach rather than an economically driven approach to resolving management problems. The Fisheries Resources Working Group addressed this issue.

II. What Researchers Should Try To Accomplish

Identifying essential habitats

The highest priority research is to determine if there is an "essential habitat" for any fisheries species. Essential habitats are defined as geographically and/or physically discrete areas that a species must utilize at some phase in its life history.

To identify essential habitats, sufficient knowledge must exist to evaluate all major phases in the life history, representing both ontogenetic and functional shifts, for each species of interest. Rather than trying to address this topic in a species-specific way, the working group proposed a generalized scheme for determining the importance of essential habitat by developing a habitat-life history matrix.

In principle, the habitat-life history matrix integrates large scale distribution (e.g. distance from shore) with local habitat characteristics (e.g. substrate characteristics and/or complexity; see Brown 1994 for a habitat characterization scheme). Distinct ontogenetic or functional phases in a species life history (X1 through Xn) can then be arrayed in the matrix. As part of this exercise it is important to recognize if there exists a "critical phase" in the species life history. The critical phase is the time in the life history when cohort size is determined. The critical phase may or may not be related to an essential habitat, however, when the two intersect the importance of habitat is overriding.

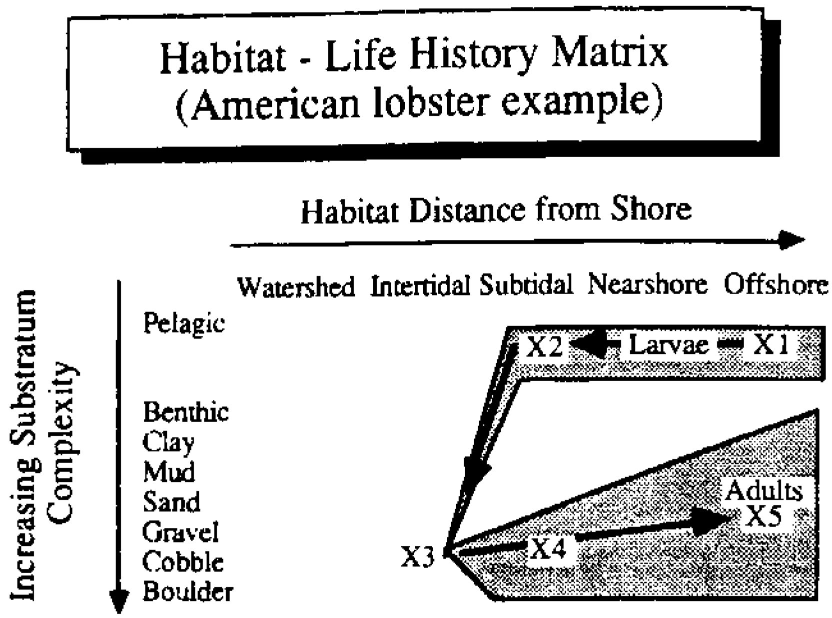

Figure 1. The American lobster is a graphic example of the identification of essential habitat. Its larvae may be offshore or nearshore but at the time of settlement there is a very strong habitat selection for shallow subtidal or low intertidal cobble substratum. As lobsters grow, their selection of benthic habitats is much less discriminating. The pinching in of the shaded portion of the plot in the figure, at X3, identifies a critical phase in the lobster's life history (ie. at the time of recruitment of postlarval lobsters to the benthos) and the essential habitat (ie. shallow cobble substrata).

Other examples of potential essential habitats for commercially important species include:

1) Post larval Atlantic cod-gravel bottom associations where the occurrence of young cod is restricted to the gravel pavement on Georges Bank (Lough et al. 1989; Gotceitas and Brown 1993).
2) The dependence of Atlantic herring on gravel bottom in the Gulf of Maine for successful spawning (Stevenson and Knowles, 1988).
3) The restriction of sea scallops to high energy sand bottoms and the lack of tolerance of these animals to fine sediments (Langton and Uzmann, 1989; Cranford and Gordon, 1992).

Focusing habitat-related research

The working group developed a logic flow diagram (Figure 2) that facilitates the making of decisions regarding the protection, conservation, restoration, and enhancement of fisheries habitats. In the flow diagram a series of questions are posed and the research actions to be taken are indicated in the boxes. For a given species what is known about its biology and ecology are initially summarized in a species profile and arrayed in a habitat matrix. If an essential habitat is identified then research is required to develop a detailed habitat characterization, based on both experimental and field observations. Assuming that an essential habitat has been identified, the areal extent of the habitat has to be considered and the question posed as to whether the habitat is at risk. Species interactions are indicated if other non-targeted species are identified as being at risk but for the single species the flow continues through the development of a management regime that will balance the need for harvesting the resource against the managers charge for conserving, protecting, restoring, and enhancing the resource and its essential habitat(s).

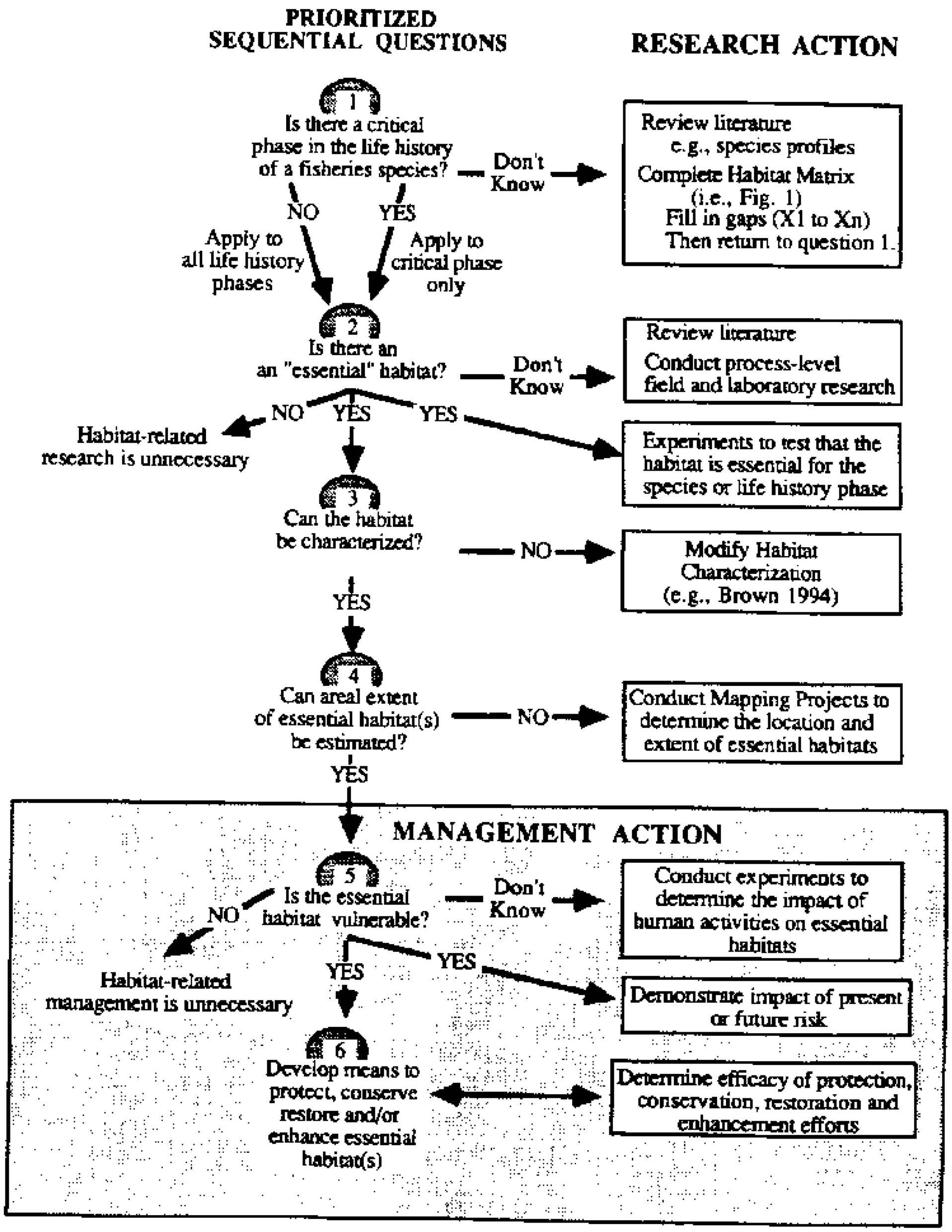

Figure 2. Flow diagram showing a series of prioritized sequential questions and their required research actions. Beginning at step 5, management actions lead to the conservation, protection, restoration and/or enhancement of the particular habitats of concern. As indicated by inclusion in the shaded box, management actions stimulate research actions aimed at evaluating the degree of habitat risk.

Information for habitat managers and a list of research topics

The habitat management community requires the development of profile reports from existing data that detail the extent of known species specific life history information. Examples of profiles can be found in a variety of fisheries management plans prepared by the U.S. federal Fishery Management Councils and the Atlantic States Marine Fisheries Commission as well as NOAA's National Marine Fisheries Service Technical Memoranda Series and the equivalent Canadian Technical Report series on Fisheries and Aquatic Science, as well as the peer reviewed scientific literature.

A series of eight research topics were identified that address many of the questions brought up in the conceptual discussion of habitat and management interactions (see Figure 2). These topics are not intended to exclude other avenues of research but rather serve as specific examples considered germane to the habitat approach developed by the working group.

The topics include:

1) Process level studies on why habitats are important and at risk. Included are laboratory studies to demonstrate the importance of three dimensional space to juvenile fish and invertebrate survival, and ultimate recruitment, and field work to demonstrate the effects of habitat structure modification for habitat restoration and enhancement.

2) Field and laboratory experiments on the effects and scale of physical disturbances (e.g. trawling, dumping and algal harvesting).

3) Mapping to identify habitats at the level of resolution required for research.

4) Linking process studies, that are necessarily conducted on a small scale, to habitat mapping to address larger scale effects.

5) Identification and filling in gaps in life history information and physical habitat/life history interactions.

6) Development of numerical models that quantitatively describe known habitat/species interactions and explore potential areas of habitat research.

7) Develop geographic information systems for the display of human populations, habitat, wildlife etc.

8) Evaluate the function and value of refugia relative to stock enhancement efforts, and other management techniques for habitat conservation and protection.

The Research-Management Interface

Natural resource management plans require the development of a balance between the social and economic demands placed on the resource and the absolute biological limit to resource harvesting. This balance, relative to habitat protection and the resultant biological production, is depicted in Figure 2. A series of research actions feed into a management process resulting in a strategy to conserve, protect, restore and/or enhance the living resource of concern. The fishing closure in Sheepscot Bay, Maine, (Maine Department of Marine Resources Regulation # 34.05) or the haddock area I and II closure in the Gulf of Maine (Amendment # 5 to the Northeast Multispecies Fishery Management Plan; New England Fishery Management Council) that were promulgated to protect known groundfish spawning and nursery areas are examples of this management process. These actions might also define essential habitats, however these closures inevitably protect larger geographic areas than the essential habitat *per se*, and defining a closure on this basis is a managers prerogative. Without understanding the specific reason why fish congregate in the area (see Rose 1993), other than simply to spawn or grow, confounds the definition of essential habitat and the leaves the question as to habitat vulnerability in the realm of research.

The matrix and flow diagram help delimit a species essential habitat, and an overlay of matrices will demonstrate the potential importance of a particular habitat type for a multitude of species, but it does not rank the importance of these habitats for management purposes. One suggestion to assist management is to consider economically important fisheries species, that have relatively small essential habitats, as the highest ranking while species of low economic importance, with a widespread essential habitat, rank lowest. In other words, this scheme offers an objective way for management to weight social/political demands against the biological constraints within which a fishery must operate. The essential habitats would be identified by scientific researchers but managers now have a framework for debating the protection of a particular area.

If no essential habitat is identified for the species of interest management is not restricted by habitat considerations, unless the overlay of other species' habitat-life history matrices indicate a reliance on the habitat of concern by other commercially, or ecologically, significant animals. It is anticipated that as biological databases expand, and are incorporated into interactive geographic information systems, it will be possible to interface our biological understanding of a species requirements for sustained production with the social and political demands that now often override the biological constraints to unrestricted resource harvesting.

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Sediment and Water Quality

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Preface

The discussion in the working group on sediment and water quality was structured to first define the problem, then define the current knowledge and needs, and finally to identify research priorities.

I. DEFINE THE PROBLEM →

II. DEFINE THE CURRENT KNOWLEDGE AND NEEDS →

III. IDENTIFY RESEARCH PRIORITIES

I. DEFINE THE PROBLEM

Assumptions

The group first examined whether the summary statements in the existing *Gulf of Maine (GOM) Research Plan* [1] were acceptable as initial assumptions pertaining to water and sediment quality in the Gulf. The following statements A through D are quoted from the GOM Research Plan, and items in brackets are from discussion in the plan that follows the italicized statements. The working group suggested modifications which follow each statement.

has the potential to

"A. *Contamination of GOM ~~either~~ degrades living marine resources or alters-ecosystem structure.*" (page 2, section III)

- Statement A as it stands is too sweeping. We cannot always document that degradation of ecosystems, and alteration of resources, occurs as a consequence of contamination; nor can we show clearly how it occurs. We recommend that the word "either" be replaced with "has the potential to".

human and ecosystem

"B. *Reasons for concern about environmental quality in GOM are to 1) protect ~~human~~ health and 2) ensure human use of GOM's resources are not inadvertently precluded or modified.* " (page 6, paragraph 4)

- Statement B as it stands is too restrictive in that it does not recognize the value of healthy, integrated ecosystems. We recognize that human health is of paramount importance, however, we feel that since humans are part of the system, protecting ecological health will increase protection of human health. We recommend that the words "human health" should be appended with addition of "ecosystem health".

C. Trace metal concentrations are elevated in sediment and/or water for [nearly every large] estuary and measured levels are high in organisms from these sites. (page 11, paragraphs 3-4). "Effects of contaminant loadings in GOM are poorly understood at present." (page 2, paragraph 1)
Current research priorities for the GOM are (page 25, questions #1-4):

- *sources, pathways, fatess, and effects of contaminants*
- *factors contributing to noxious/excessive phytoplankton concentration*
- *natural vs. human induced changes*
- *susceptibility to anoxia/hypoxia*

- These statements and general research priorities remain valid, although they should not be construed as restrictive to either the importance or study of all chemical contaminants, not just metals.

D. Specific information is needed with respect to water [and sediment] quality and ecosystem health [in order to manage and/or restore our degraded systems.](page 2, section III) This information pertaining to contaminants is (page 25, question #1):

- *patterns of contaminants*
- *identification of sources*
- *transport and cycling*
  - *physicochemical form*
  - *sedimentary processes*
  - *water column transport*
  - *biogeochemical transformations*
- *biological effects*

[• natural variability]"

- Statement D continues to identify areas that need additional information and research. We recommend only slight modification here. The words in brackets should be included with the statements rather than in peripheral text in order to clarify and broaden this statement of information need. Points raised in discussion included the need: to identify natural variability prior to setting management policies; consider sublethal effects and other less frequently studied indicators of deleterious effects; use both targeted studies and analogy studies; assess temporal and spatial variability in both contaminants and induced effects; consider scale, magnitude, and relative risk within GOM and relative to other areas; and place particular focus on relationships between contaminant amounts, forms, the system behavior, and synergistic effects.

What are Managers Trying to Accomplish?

The group asked the question:

What is the purpose or goal of habitat management or restoration as it relates to sediment and water quality?

The following goals were identified without prioritization:

- **Protection of human health**
- **Quality of (human) life**: aesthetics, disease, reproduction, perception of risk
- **Multiple use**: recreation, commerce, waste disposal, resource utilization
- **Protect living resources**: recreation, diversity, health, commerce
- **Optimize habitat health for its own sake**: losses, restoration, biodiversity, ecosystem health

Areas with differing degrees of environmental quality (contamination or degradation) may have to coexist. Efforts should be made to rank various habitats and locations in order to 1) identify some pristine areas and justify their preservation, and 2) identify affected areas and determine the degree of degradation that is acceptable for specific areas, e.g. urban harbors. These aims require establishment of baseline conditions and an inventory of current conditions against which success or failure can be measured.

It is necessary to continue improving communication between the scientists, managers and general public. An optimal scenario is one in which managers define the endpoint(s) desired for habitats using information and the democratic process and in which scientists 1) advise managers and the public as to which questions they need to ask, 2) provide guidance on how to reach the desired endpoints, and 3) provide information on the implications of various practices. In hand with this, good information transfer to the public and to managers helps create an informed democratic process.

II. CURRENT KNOWLEDGE AND NEEDS

Information Categories and Criteria

The group then asked:

What information is needed to manage or restore degraded systems?

Factors were grouped into **information categories** where interactions between factors and categories are the processes that create ecosystem functioning.

[Human Activity]	**[Contaminant Type]**	**[Habitat Type]**	**[Habitat or contaminant location]**	**[Resource or Activity]**	**[Toxicity or Effect]**

The following **criteria** for setting research priorities were established prior to discussing the current state of knowledge and levels of research priority. This list is not ranked or exclusionary:

The study should:

- be feasible or practical
- have positive cost-benefit
- be of a basic nature
- provide needed information
- address a management question
- address a management priority at the resolution that management needs.
  (note that management priorities include dredge disposal, human health, recreation, and fisheries)
- have a clear, well focused research objective
  (often in response to clearly stated management objectives)
- consider issues of spatial and temporal scale
- have broad application and implication (i.e., high extrapolation value),
  either throughout the GOM, its ecosystems, or scientific disciplines; but not to the exclusion of more specific, perhaps localized problems.
- utilize community research resources effectively

The charge to the group was to focus on a 5-year time frame for a discussion of research priorities. Although a 5-year research plan with hard deliverables and goals may be laudable, the group felt that this was too short for attaining long-term goals and constituted crisis management. We felt that we should be identifying what the situation would be in 20-25 years and identifying decisions that would help managers create better solutions over the longer time frame. This would better encompass the time scales of natural variability, land development, remediation, engineering projects, regulatory enforcement, and biological life cycles. A goal should be to be able to predict the impacts of a projected activity and recommend action. For example, what types of development or activity can be anticipated in a specific location, what contaminants are associated with that activity, what are the projected ecological impacts, and how much would source reduction or regulation lessen the impact?

The group recognized that some of the criteria may be perceived as mutually exclusive, and that qualities such as "feasible", "positive cost-benefit," and "of a basic nature" are subject to interpretation. Nevertheless, these criteria offer a framework for evaluating research at many scales. The group discussed the current knowledge state, the research needs, and the research priorities for each listed category. The goals of the discussions were to identify important information needs and gaps, prioritize research needs and goals, identify appropriate geographical and topical areas of study, and outline approaches for achieving the research goals:

What do we know and what don't we know?
What do we need to know and why?
What are research priorities?

We also felt that one must keep in mind the endpoint that we wish to maintain for each affected habitat. Research needs will differ somewhat for different situations where the desired endpoint may be a pristine system, a managed "garden", or a targeted-use area. Clearly, some multiple uses will be incompatible.

Information Components

Discussion and priorities for each of the information categories follows. The lists primarily target major issues within each category and should not be considered comprehensive. The group's assessment of the information categories outlined above was focused by specific questions for each category; these are listed under each topic in the following discussion. In addition, the group kept the following questions before them throughout their discussion.

*In order to see deleterious effects or identify affected **systems**, one must be able to separate a signal from the noise of natural variability.*
For all aspects, what do we need to know about temporal scales-- residence times? response times? accessibility times?
What about issues of spatial scale?
What is the value and the cost of protection or remediation for habitats or populations that are at risk or degraded?
How do we define value?

Human Activities

Which human activities have the greatest effect on sediment and water quality?
Which activities can we remediate quickly or easily?
Are larger projects easier to study, monitor or control?
Do diffuse activities (i.e., many but local) result in greater impact or risk of habitat degradation than focused activities (i.e., few but influencing a large area)?
How can cumulative effects be assessed?

First, those human activities which have significant detrimental effects on the marine ecosystem were identified:

Human Activities

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

Different human activities will always create some inevitable conflict. A combination of education and regulation is needed to reduce those human activities which result in reduced sediment and water quality. A 1989 workshop[2] on a similar topic recommended that immediate action be taken to enforce existing regulations and educate the public; these recommendations still stand. Some activities can be stopped at once and immediate improvements will be seen in the ecosystem; others may have a long response time. Technological development and alternative strategies have great potential to reduce the impact of human activities on the environment.

Research on temporal changes is needed concerning these activities and ecosystem responses. It was noted that many contaminant sources have been reduced by changes in human activity while some historical activity has created continuing contaminant loadings. The effects of chronic contamination or poor water/sediment quality may differ substantially from the effects of catastrophic events. Human activities should also be characterized as having a local effect or a widespread effect. Many of the activities and their impacts are site-specific and local differences in contaminant sources and activities are often large. The Gulf-wide scale is inappropriate for many issues relating to factors causing poor water or sediment quality. For example, marina operations may cause only local effects but the generic activity is common and the combined local effects may be widespread. Commercial fishing, on the other hand, may have a widespread effect because it is practiced over a large area.

We do not know enough to set research priorities for all of the human activities listed, but we do make some suggestions about many of them. Many new organic compounds are introduced through agricultural and industrial practice; screening should be required for toxicity in the marine ecosystem before approval is given for use (current regulations are based on impact to land-based organisms). It was noted that "clean" sewage technology will probably be in place in 20 years and fisheries processing will decrease as a consequence of reduced stocks. Dredging of shipping channels must occur so an effort should be made to control the release of contaminants; technology is probably in place to do so. Attempts at general source reduction for atmospheric and land-based non-point sources have been successful and, given aggressive enforcement, will continue to be. Currently, economic pressures are counterproductive to ecosystem health, primarily because only short-term costs are used in the economic equation. It was felt that best management practices for balanced or multiple use might include establishment of zones for allowed contaminant use, with surrounding buffering regions. The group felt that the role of the research community should be to help in predicting land/sea use, human activity and its marine impact.

Contaminants

A contaminant is defined[3] as any physical or chemical condition caused by human activity that is significantly at variance with natural background conditions, and that the condition may pose a threat to living resources or human health. Since the terms "contaminated" and "polluted" are often confused, it is worth elaborating that pollution has occurred when physical or chemical conditions have been altered (contaminated) to such an extent that significant damage to living resources or human health has been demonstrated.

Which contaminants cause the most deleterious effects?
Which are most feasible to study?
Which ones are so poorly known that the magnitude of a potential problem cannot yet be established?
What contaminants might create a problem in the future?
Which ones will soon become an issue of the past?

Listed here are contaminants that the group felt affected sediment or water quality in the Gulf of Maine ecosystems:

Contaminants

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

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

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

Research should focus on synergistic interactions, contaminant forms and ratios in the habitat, and the quality of induced effects rather than limiting consideration to environmental concentrations or body burdens. It was noted that human health (in the context of degraded marine habitats and ensuing consequences) may be as positively impacted by education as by new research.

Chemical contaminants are of major concern because of their persistence, longevity, and the poorly understood response in biota. As regulations become more restrictive or are enforced more vigorously, the data which supports the regulations will undergo increasing pressure and inspection. Consequently, further research is indeed needed on sources and transport paths for this class of contaminants to the marine system.

Metals- These are primarily from automotive, industrial, and historical sources in the Gulf of Maine. Motor vehicles and road runoff are significant and unpredictable sources of both atmospheric, diffuse, and point-source pollution. Existing engineering and management can reduce the amopunt of contaminants introduced by street runoff.

Fertilizers - These have primarily local sources and local to widespread effects, but the number of areas affected may be large and widely dispersed. It was felt that additional research was needed for local sources and transport paths in the affected embayments for development of management practices. Synergistic effects such as the relationship between contaminants and eutrophication in benthic communities was also noted as an area needing further study. Research could be transferable between geographic areas for work focused on similar types of sources.

Toxic organics- Information is needed about transport paths in the environment, in the organisms, and toxic or sublethal effects on the organisms. Currently, more is known about PAH's and PCB's and less about herbicides and insecticides in marine environments. Detailed information is needed on biodegradation, bioaccumulation, and transport processes for these substances in the marine environment to support management and regulatory decisions pertaining to these compounds. Atmospheric inputs from New England and the midwest haveresulted in low-level input of organic contaminants throughout the Gulf of Maine.

Environmentals- Information about the natural levels and fluctuations of temperature and salinity would be helpful in understanding both the transport paths for contaminants and the biological effects. These measurements are integral to nearly all studies currently undertaken by any regulatory or research agency in the Gulf, although this information is widely scattered and of unknown data quality. In addition, a current RMRP focus is to better determine the general circulation in the Gulf.

Pathogens - Pathogen loading can be both a consequence of a disturbed system and a contaminant in its own right. These contaminants tend to be a local issue; but is a critical Gulfwide problem. Common point sources are raw sewage discharges , land runoff, marinas, and aquaculture operations, whereas indigenous pathogens are more ubiquitous. As indicators of disruption, we need to know how perturbations in ecosystems are inducive to pathogen growth and what conditions in the Gulf allow the persistence of different types of pathogens. Antibiotics are primarily introduced in relatively small quantities at aquaculture sites to control pathogens. They are unlikely to significantly impact either large areas or large numbers of habitats or organisms in the Gulf of Maine. However, as fisheries depends more and more on aquaculture, the use of antibiotics may become a health issue analogous to that in livestock farming.

Physical structure - Issues of alterations in the physical structure of the sediment (sometimes the result of contaminant loading) were not discussed since they fell under the auspices of the group discussing "habitat alteration". One issue that was raised was that of water column turbidity. It was felt that general effects of human induced turbidity were understood and regulations in place (not always enforced) to address them; however, further thought and study should go into potential future human activities and their impact. In addition, the spatial and temporal scale of natural variations in turbidity are not well understood. Generation of turbidity by tidal energy may be significant in the Gulf of Maine.

Radionuclides - It was felt that knowledge on the distribution and toxic effects of artificial radionuclides in the Gulf of Maine was probably adequate for determining risk levels and making informed management decisions. This contaminant type was given lower priority for research than many others since monitoring plans and disposal regulations are currently in place.

Habitat types and locations

Which habitats and locations are affected or at risk?
What is required to characterize locations or habitats with unknown quality?
Which locations are most difficult to study?
How do we define a degraded habitat?
What do we know about the natural assimilation capacity?
What actions will protect or remediate identified habitats?

The habitat types and locations presented in the plenary sessions were discussed by listing important habitats, identifying the quality of existing information and later prioritizing habitats as they relate to water and sediment quality issues. Within each geographical region or habitat type, a sub priority should be given to those areas containing biological resources.

Habitat Types and Locations

* asterisk indicates priority needs for research/ and information

- * **Areas of fine-grained sediment or deposition** (because they tend to have higher contaminant concentrations or accumulation rates). This habitat type includes intertidal mudflats, since little is known about them yet they are dominant areas of contamination.
- * **Nearshore sites of all habitat types that are in close proximity to where contaminants are discharged into marine environments.** Included was recognition that loading occurs from point and non point sources, from watersheds, and includes "natural" contaminants such as nutrients.
- * **Fronts in the water column**, particularly aspects relating to nutrient excesses, particle dynamics and the ephemeral state of the fronts. This includes pyncnocline, tidal, plume edge, halocline, and neuston fronts.
- * **Other areas where fluxes of contaminants in the water column or sediments are large.**
- * **Offshore basins, banks, and ledges.**

Research in offshore regions should focus on atmospheric inputs, effects of lower levels of contaminants, and related phenomena such as fluctuations in oxygen levels. It was recognized that basins were the most difficult location/habitat to study because of the high cost of ship time.

A difficulty in setting priorities occurs because a balance is needed between 1) expense, 2) uncertainty of impact and 3) the differing scales of study required for different problems. The most important factors to understand are the linkages between information categories. For example: What human activity introduces which contaminant in which location? In a specific location or habitat, what are the toxic effects caused by which contaminant or habitat loss factors and how are they produced?

Resources

Which living resources or populations are affected or at risk?
Are those at most risk the same ones as those which we have a good knowledge base for?
Are they the ones with the greatest perceived value?

Resource Use or Activity of Value

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

***Living resources**--primarily concern is about stock replenishment

*fish: *bottom feeders & *juvenile stages	*birds- shore and sea	*mollusks
*crustaceans	*invertebrates	
phytoplanktons	zooplankton	echinoderms
eelgrass	marine mammals	rockweed

***Biodiversity**

Recreation

-Mineral: sand and gravel	hydrocarbons	

***Waste disposal**--need to determine assimilation capacity of the system

*intentional (e.g., sewage and dumping)	inadvertent	
water column	sediment	location
Commercial: * aquaculture	land creation	transportation

The question of target species was discussed--what is a reasonable and/or feasible level to manage the contaminant or habitat if you use indicator species? Sea and shore birds and mammals have high recreation value and may also be valuable as indicators of ecosystem health or as a point of ecosystem management. The establishment of clear links between water or sediment quality and the health or reproduction success of specific populations in the Gulf would be invaluable.

Recreation was considered a lower research priority but a high education priority with the potential for high benefit at a low cost. It was noted that aquaculture would have increasing economic importance as the importance of harvesting wild populations declines.

Toxicity and Effects

Toxicity is a broad term used to encompass detrimental effects of contaminants on living organisms. Currently, there are no agreed-upon criteria for defining chronic or acute toxicity for sediments or most marine organisms.

How do we define toxicity or deleterious effects?
What factors about habitat or ecosystem response are most uncertain?
What is the risk associated with poor sediment or water quality relative to the risk associated with other processes or factors that contribute to habitat alteration or degradation?
What must be done before risks can be assigned?

Listed here are indicators that can be used to evaluate and assess the degree of toxic effects in organisms and populations.

Toxicity and Effects

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

***Disease and/or individual health**: sublethal effects and indicators of stress

***Reproduction**

Population distribution and population range

***Market quality**

Endocrine alteration

Population size

***Mortality**

***Community structure**

Biodiversity

***Nutrient enrichment / fertilization**

Stability (dynamic response)

It was recognized that establishing the link between sediment or water quality and degraded ecosystems is the highest information need from the viewpoint of resource management. There are many effective ways to establish links between poor sediment/water quality and biotic effects; e.g., physiological studies, community studies, bioavailability studies which look at organisms (not mud). It is important that multiple approaches be utilized.

Effects studies can be ordered by system complexity; for example,

↓ biochemical
↓ cellular
↓ organism
↓ population
↓ community
↓ ecosystem

A need to establish cause and effect at *all* scales was recognized. It was felt that too little was known about synergistic effects and more direct causal relationships to recommend any particular type of effects studies. It was suggested that multiple approaches be used to address issues and establish impact and risk; i.e., both 1) understanding systems from basic components or targeted studies and 2) using inferences, analogy, and probability studies. Synergistic effects and sublethal effects should also be studied. In addition, it was noted that biological functions, such as reproduction, are a complex indicator of toxicity and we need to know more about the mechanisms that cause observable toxic effects.

III. RESEARCH PRIORITIES

In setting priorities, the endpoint must be identified and the goals continuously kept in mind. The endpoint discussed was zero toxic effects. The first goal was for most, if not all, waters to be fishable and swimable. A second goal was to maintain ecological diversity and multiple human use in the Gulf of Maine. A third goal was to maintain healthy ecosystems. A fourth goal was to manage the Gulf of Maine in such a way that we progress towards pristine ecosystems.

Research topics were listed and prioritized using criteria and goals discussed above.

1) The link between potentially toxic contaminant concentrations and biotic effects must be better established. A number of related issues should be recognized:

- bioavailability, efficiency of contaminant transfer and organism responses to contaminants
- ways in which linkages can be made through physiological or community studies
- need to understand how ecosystem and organisms' systems function
- studies should include consideration of how to eventually establish sediment criteria for toxic contaminants
- definition and study at various spatial and temporal scales and response times is needed (paleoecological techniques may be useful)
- links must be established between ecosystem effects and contaminants that may not be inherently toxic, such as excessive nutrient and organic carbon loadings.,

2) Transport paths must be studied to determine how contaminants move and become mobilized in the environment and subsequently become accessible to organisms.

- routes and rates of anthropogenic and natural loading
- contaminant distributions and concentrations
- spatial and temporal variability and response times
- sediment, geochemical, and biological transport and transformation processes
- water circulation and dynamics of associated contaminants on macro and micro scales
- biological uptake efficiency and bioaccumulation
- human physical perturbation

3) The effectiveness and net costs of remediation practices in meeting goals needs to be more clearly established.

- Does restoration or remediation work and should we do it?
- Can remediation strategies be developed based on manipulation to enhance transformation of toxic to nontoxic contaminants and mitigate ecological effects?
- Can alternatives to existing activities or regulations that result in contamination (e.g. dumping) be developed?

References

[1]RARGOM 1992. *Gulf of Maine Research Plan.* Report prepared for Regional Marine Research Board, Orono, ME.

[2]Belknap, D., T. Bigford, D. Gordon, G. Jacobson, and B. Nicholls. 1989. *Summary report for Dec. 1989 GOM Conference on Habitat/Habitat Loss.*. Portland, ME.

[3]Buckley, D.E., 1994. *25 Years of Environmental Assessment of Coastal and Estuarine Systems: Lessons for Environmental Quality Management.* Proceedings of Coastal Zone Canada '94. Halifax, Nova Scotia, September, 1994.

Appendix A: Defining Habitat

Some Thoughts about Defining Habitat

David Stevenson, Maine Dept. of Marine Resources

(Written for the Winter 1994 **Gulf of Maine News**, a quarterly newsletter of the Regional Association for Research on the Gulf of Maine)

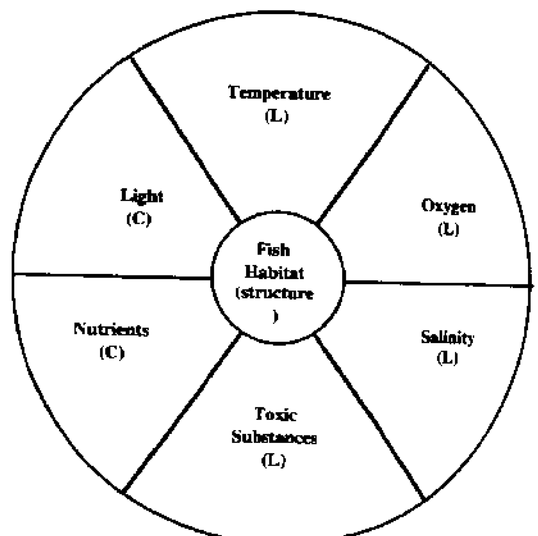
Everyone these days seems to be talking about habitat. In the marine arena, an amendment to the Magnuson Fishery Conservation and Management Act (the federal law that established U.S. jurisdiction and management authority for fishery resources within the 200 mile limit) is being drafted that would protect certain important fishery habitats, and the regional Fishery Management Councils and the Atlantic States Marine Fisheries Commission are, or soon will be, required to include descriptions of habitat, habitat quality, and environmental requirements in fishery management plans for exploited species.

Closer to home, the Gulf of Maine Council on the Marine Environment has drawn up an Action Plan that calls for the protection, restoration, and enhancement of fish and wildlife habitats, the Regional Marine Research Program has developed a ten year research plan that encourages, among other things, research proposals that address the effects of "natural and human-induced changes to the physical environment on ecosystem structure and function" and RARGOM is planning a workshop in April to define and prioritize habitat-related research needs in the Gulf of Maine. Despite all the attention on habitat, however, a lot of marine scientists, environmental managers, and fisheries managers have a pretty vague idea of what is meant by the term. It turns out that there are some good reasons for this confusion.

Habitat means different things to different people because definitions vary according to the use that is made of the concept. However the term is defined, it refers to the ecological relationship that exists between a species, or a community of species, and its environment. It is helpful to consider habitat as "the local structural component of the environment which attracts organisms and serves as a center of biological activity." The separation of structure from other environmental factors that limit or control biological activity (see figure), focuses attention on physical features of the environment which display a definite organizational pattern. In the more conventional view, these may be kelp beds, marshes, inter tidal mud flats, or offshore ledges; less obvious examples are fronts separating different water masses or plumes of turbid, low salinity water produced by large rivers. Environmental properties such as temperature, salinity, and nutrient (food) availability may greatly influence the use or value that a species makes of its habitat. In this context, therefore, knowledge of a species' environmental requirements (or tolerances) is critical to understanding the nature of its interaction (or dependence) on certain habitats.

Trying to define and describe marine habitats is further complicated by the fact that different life history stages occupy different habitats, many organisms move around, and habitat definitions change as more is learned about the environment and the interactions between a species, or a community of species, and its environment. Also, habitat boundaries may change as populations grow or diminish in size and as environmental conditions which define a habitat change. In the case of an open water, pelagic, habitat like a convergence zone between two water masses, the habitat itself may not remain stationary or even persist for very long.

Research is needed to further define the ecological relationships that exist between individual species, or groups of species, and their environment, and to evaluate habitat quality and the interactions between habitats. Until more is known about the role of habitat and the biological responses of organisms to controlling or limiting environmental factors, fishery managers will not be able to predict whether actions taken to protect or improve habitat will have any beneficial effect on species survival, reproductive success, or productivity.



Major environmental properties which limit (L) or control (C) utilization of coastal fish habitat (modified from Ryder & Kerr 1989).

[1] This definition of habitat, as well as most of the other thoughts summarized here, have been borrowed from a chapter entitled "What is coastal fish habitat?" by David Peters and Ford Cross in a 1992 publication of the National Coalition for Marine Conservation "Stemming the Tide of Coastal Fish Habitat Loss," edited by R.H. Stroud. These authors, in turn, utilized concepts presented originally by Ryder, R.A. and S.R. Kerr (1989). Environmental priorities: placing habitat in hierarchic perspective, in C.D. Levings, L.B. Holt and M.A. Henderson (eds.), Proceedings of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks. Can. Spec. Publ. Fish. Aquat. Sci. 105:2-12.

Appendix B: Workshop Agenda

Habitat Workshop Agenda

Maine Department of Marine Resources Laboratory
West Boothbay Harbor, Maine
April 12-13, 1994

April 12	
8:00 - 8:30	Continental breakfast at DMR Laboratory
8:30 - 8:40	Welcome and introduction E. Penn Estabrook, Deputy Commissioner of Marine Resources Maine Department of Marine Resources
8:40 - 10:00	Plenary talks and discussion 1. *Location, extent and importance of marine habitats in the Gulf of Maine* Donald Gordon, Department of Fisheries and Oceans, Bedford Institute of Oceanography 2. *A spatial and temporal perspective on fish distributions: improving our definition of fish habitat in the Gulf of Maine* Richard Langton, Maine Department of Marine Resources Peter Auster, National Undersea Research Center, Univ. Connecticut at Avery Point David Schneider, Memorial University
10:00-10:20	Coffee Break
10:20 - 11:40	3. *The incorporation of habitat information in U.S. marine fisheries plans: an Atlantic coast perspective* David Stevenson, Maine Department of Marine Resources 4. *Impacts of contaminants and nearshore pollution on habitats in the Gulf of Maine* Judith Pederson, Massachusetts Coastal Zone Management
11:40-12:00	Charge to the working groups
12:00-1:30	Poster session and lunch
1:30-5:00	Working group meetings: discuss information needs, research priorities, draft recommendations
6:00 - 7:00	Social Hour
7:00 - 9:00	Dinner
April 13	
8:00 - 8:30	Continental breakfast at DMR Laboratory
8:30 - 10:00	Working groups: review and revise reports
10:00 - 10:30	Coffee Break, copy working group reports
10:30 - 12:00	Plenary session: presentation of group reports, discussion of reports and themes
12:00 -1:00	Lunch
1:00 - 3:00	Steering Committee and working group leaders meet to plan workshop report

Appendix C: Participants

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