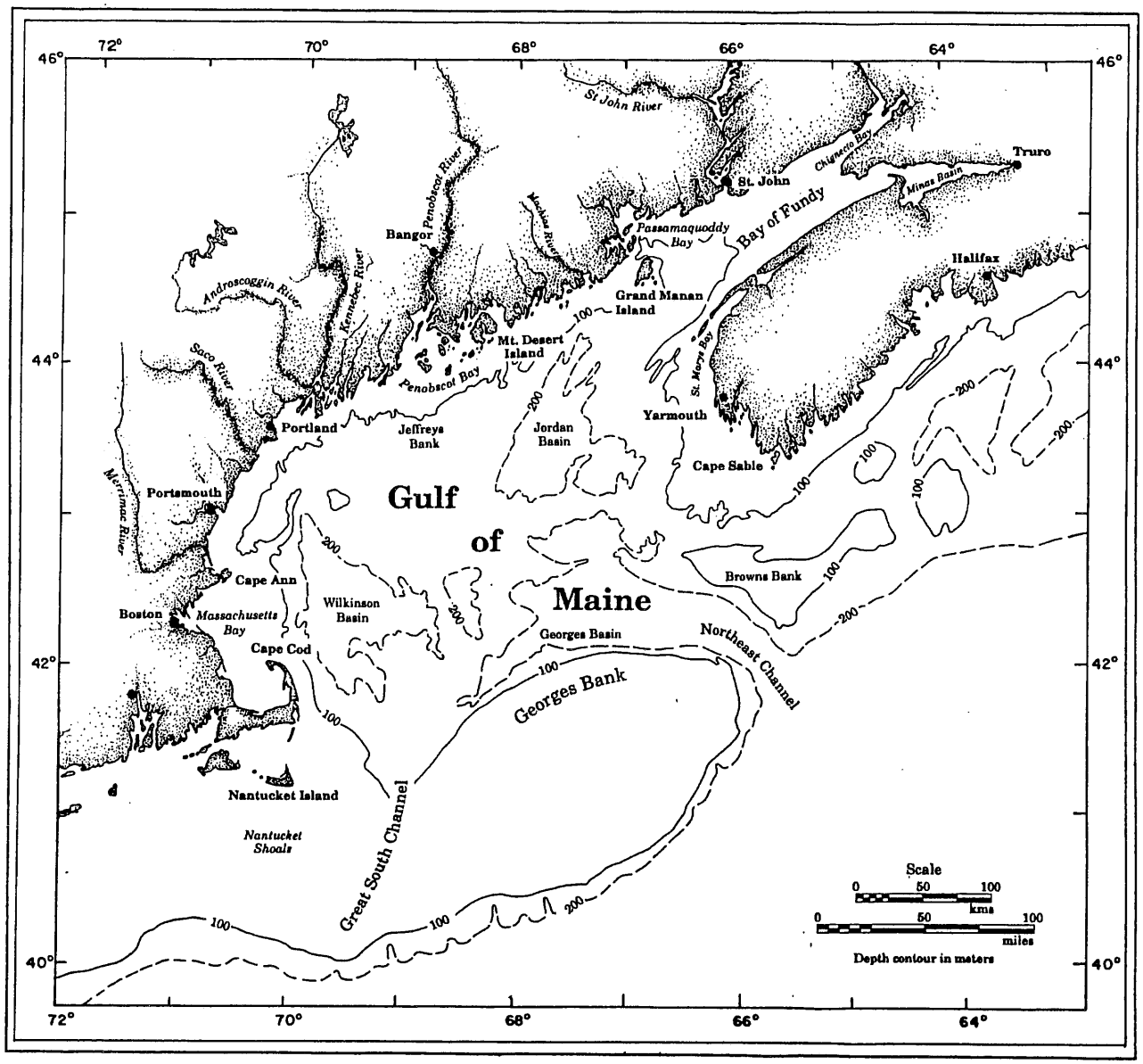
# The Gulf of Maine Regional Marine Research Program




# Gulf of Maine Research Plan

## June 1992

REGIONAL MARINE RESEARCH PROGRAM
for the
GULF OF MAINE
14 Coburn Hall
Orono, Maine 04469
207/581-1435
FAX 207/581-1426



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## June 1992

**Prepared by: The Gulf of Maine Regional Marine Research Program**

THE LAND GRANT UNIVERSITY *and* SEA GRANT COLLEGE OF MAINE
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# EXECUTIVE SUMMARY

## A. THE SIGNIFICANCE OF OUR COASTAL OCEANS AND THE GULF OF MAINE.

The coastal oceans, between land and the edge of the continental shelf, represent 10% of the world ocean yet yield 95% of the world's fisheries. More than 50% of the world's peoples live in coastal regions; and both they and this percentage are increasing. The accompanying anthropogenic stresses on coastal oceans are growing as well. Some of the stresses and their effects on coastal marine ecosystems are direct and demonstrable. Others are indirect and their impacts are uncertain or unknown.t

In addition to human-induced changes in our coastal oceans, there are those likely to be associated with global climate changes-either naturally or anthropogenically caused. It is in coastal regions that sea level changes are most dramatically felt. In addition, because of the shorter time scales on which they function, the coastal oceans are likely to respond more quickly and significantly to climatic variations.

This is especially so for the Gulf of Maine. Its size and basin shape puts it in near tidal resonance so that sea level changes may have large effects on the interrelated tidal amplitudes and mixing, coastal erosion, nutrient fluxes and biological productivity. In addition, because of its latitude, physiography, and hydrography, the Gulf of Maine contains a rich mix of fauna and flora from differing biogeographic provinces. Many of these species are at the limits of their latitudinal range and might be seriously impacted by changing climate in the Gulf.

Each of the possible alterations to the coastal zone of the world ocean, both natural and anthropogenic, carry great uncertainties with regard to the size and sign of the possible change. What is certain is that coastal ecosystems will be among the first marine environments to exhibit measurable changes. Also true is that the effects of these changes remain largely speculative in the absence of an adequate understanding of how these coastal ecosystems, with all their components, fundamentally operate. The Gulf of Maine is one such ecosystems.

## B. THE REGIONAL MARINE RESEARCH PROGRAM.

The Regional Marine Research Act was enacted in recognition of the value of the Nation's coastal marine waters, the mounting pressures that threaten their ecological integrity, and the need for regional research to safeguard their quality and health. The purpose of the Act was to establish regional marine research programs around the country, and to provide sustained Federal funding for planned research within each region.

The present Marine Research Plan for the Gulf of Maine Regional Marine Research Program (RMRP) consists of five major sections as required by law. They are: an overview of marine environmental quality in the region; an inventory of current research activities; a statement of the research needs and priorities within the context of a 10-year goal; an assessment of how the plan will incorporate existing research and management in the region; and, a description and schedule of the research objectives for the region during the 4-year period covered by the plan.

## SECTION I: THE ENVIRONMENTAL HEALTH OF THE GULF OF MAINE.

The Gulf of Maine has thus far escaped many of the problems now facing other coastal areas around the world. There are, however, clear signs of altered environmental health of the

Gulf of Maine. Habitats are being altered. Many of its living resources appear to be overstressed and on a long-term decline. And, certain areas of the Gulf, such as Boston and Salem Harbors exhibit pollution levels among the highest in the U.S. Of the pollution problems facing the marine waters of the Gulf of Maine, sediment contamination is perhaps the best studied, though confined largely to specific sites such as Boston and Portland Harbors. It is safe to say the effects of contaminant loadings in the Gulf of Maine are poorly understood at present. Indeed, much of what we know about the effects of anthropogenic changes to the coastal marine environment is based on case studies from other parts of the world.

## SECTION II: CURRENT RESEARCH ACTIVITIES IN THE GULF OF MAINE REGION.

The nature of current research activities in the Gulf of Maine region covers a broad spectrum from applied to basic, from field-observational to theoretical/modelling, from site specific to global ocean-scale, and from laboratory/experimental to remote sensing. An inventory of the research programs in the region reveals that many have individual mission-oriented goals. They understandably tend to focus on their own limited set of issues in politically defined geographic areas. And, they must be primarily responsive to needs for specific and short-term information. Others, such as those sponsored by the National Science Foundation, tend to be primarily process-oriented and driven by the long-term needs for globally significant, basic research. Clearly missing is a research program that is focussed on the Gulf of Maine ecosystem as a whole and which can serve as a nexus for the existing activities.

## SECTION III: NEEDS AND PRIORITIES FOR RESEARCH ON THE GULF OF MAINE.

Our needs for scientific information with respect to the water quality and ecosystem health of the Gulf of Maine are great. These needs have been presented at several recent regional meetings involving marine scientists, resource managers, environmentalists, policy makers, and commercial representatives. The reports from these activities provide a comprehensive picture of marine issues and related research needs, as well as a firm basis for long-term regional research planning.

Guiding principles in the planning and conduct of the RMRP are that it:

- be regional in scope and impact, and long-term in perspective;
- recognize the integrated nature of the Gulf of Maine ecosystem;
- foster cooperation and coordination in the research community;
- enhance understanding between the research and user communities; and
- develop its own programmatic identity while complementing existing programs.

The 10-year Program Goal is to work toward development of a suite of models that collectively simulate how the Gulf of Maine ecosystem and its interacting components function naturally, and under stress. Such an integrative goal would be challenging and exciting, and its benefits manifold.

The two overarching societal concerns to be addressed by the Program can be stated as follows:

1. Contamination of the Gulf of Maine either degrades living marine resources or alters ecosystem structure.
2. Physical changes to habitats in the Gulf of Maine alters ecosystem structure and functioning.

Addressing these issues requires scientific information on:

- The patterns of contaminants; their sources, transport, and cycling; and their biological effects.
- The physical, chemical, and biological factors causing noxious and/or excessive phytoplankton concentrations; and the effects of these concentrations on the ecosystem.
- The natural variability of the Gulf of Maine ecosystem in order to distinguish natural from human-induced changes.
- The susceptibility of the Gulf to dissolved oxygen depletion.

Of these scientific informational needs, the highest priority for initial support are those concerning transport and cycling of contaminants and the causes of noxious or excessive phytoplankton concentrations. Also, of continuing importance in all RMR projects will be the need to develop information on the system's natural variability. It is only against such information that one can measure anthropogenic changes.

## SECTION IV: INCORPORATION OF EXISTING ACTIVITIES.

The planned regional research will support and complement existing marine research, monitoring and management, and link them together into a more comprehensive and interrelated framework. The long-term goal of simulative/predictive ecosystem models will help focus and integrate the different disciplines and ways of doing marine research. The information developed on the Gulf of Maine ecosystem will provide outer boundary conditions for, and help interconnect, the numerous site-specific, smaller-scale efforts. The same information will provide a broader scientific context for regional scale but single-issue programs. And, it will help link all of these ongoing programs with larger scale research such as that directed at global climate change.

At the regional and international level, ties have already been made between the RMR Program and the Regional Association (of marine research institutions) for Research on the Gulf of Maine. These two entities are mutually supportive of one another. In addition, the RMR Program will benefit from and support the 10-year Action Plan recently developed by the three-state, two-province Gulf of Maine Council on the Marine Environment. Data information and management are important aspects of the Council's activities which will be carefully coordinated with that of the RMR Program.

## SECTION V: PROGRAM OBJECTIVES AND SCHEDULE.

The primary objectives during the developmental stage of the RMR Program will be to support research projects designed to meet initial, high priority needs. These needs focus on the:

- patterns and mechanisms of transport of contaminants and their effects on living marine resources,
- physical, chemical, and biological controls on noxious/excessive phytoplankton phenomena.

Of great importance is the development of a working model of the circulation of the Gulf of Maine. Such a model would greatly facilitate research activities in other disciplines, such as studies of pollutant transport, nutrient budgets, and plankton spatial patterns. In addition, well justified analyses and interpretations of existing data sets will be encouraged.

During years two through four, the RMR Program will continue to work toward the 10-year goal, with a focus on the higher priority research needs identified in the plan. An important element of this will be continued, coordinated planning to identify the most

appropriate approaches to follow in pursuing the 10-year goal. Planning workshops are envisioned in the following areas:

- Data management
- Circulation modelling
- Ecosystem modelling
- Chemical contaminant cycling and effects
- Data syntheses
- Risk assessment
- Relationships with other programs
- Coastal/ocean boundaries
- Extension/education/advisory activities

The detailed evolution of the RMR Program will develop from these planning workshops as they are held.

# ii. INTRODUCTION

## A. The Coastal Zone, Environmental Change, and Environmental Quality in the Gulf of Maine

The world's land-sea margins, those coastal zones between land and the edge of the continental shelf, act as a buffer between human activities and the open oceans. The coastal zone is already heavily exploited as a direct result of population pressures, with more than 50% of the world's population residing on coastal plains (Ray, 1988). Industrial, agricultural and domestic pollution problems in the coastal zone are increasing world-wide, bringing with them uncertain ecological pressures to these, the most biologically productive zones in the ocean.

Though the coastal zone accounts for only 10% by area of the world ocean, it represents 25% of the primary productivity, and contributes 95% of the fisheries yield (Walsh, 1988a). This is without consideration of the changes imparted by human activities, though there are indications that the magnitude and style of biological production of the world's coastal zone is in a state of change. For example, it is estimated that anthropogenic loadings of nitrogen into the coastal zone have increased approximately 10-fold during the last century (Walsh, 1988b). Because shelf seas have a wider range in statistical variability in space and time than the open ocean, they have not been sampled sufficiently in the past in order to assess adequately the effects of these anthropogenic changes. In fact, it has been speculated that shelf seas may be 2 or 3 times more biologically productive than presently estimated (Walsh, 1988b). We do know, however, that the nature of biological production on continental shelf seas can change quickly and dramatically. For example, Postma (1978) observed that primary production in the Southern Bight of the North Sea increased from 80 $gC \cdot m^{-2} \cdot yr^{-1}$ to 240 $gC \cdot m^{-2} \cdot yr^{-1}$ in the twenty year period from 1950 to 1970.

The coastal zone is not only vulnerable to direct human-induced changes to the environment, but it will be among the first ecosystems to exhibit the effects of predicted global climate change. One reason is that the coastal zone operates on much shorter time scales (decade) than the open ocean (millennium). It is already an area of high energy and biological production, and it may reflect more readily human alterations to the environment in a more direct fashion. There is an increasing awareness of the potentially dramatic effects that global greenhouse warming could have on the world's coastal zone, and this topic is being proposed as the newest core project of the International Geosphere-Biosphere Program (Holligan, 1990), along with existing IGBP core projects such as the Joint Global Ocean Flux Study (JGOFS). Oceanographic changes predicted as a result of global warming will be most important to continental shelf regions in our latitude. Model predictions indicate that the greatest changes in water temperatures in the upper mixed layer of the ocean, which might result from a doubling of atmospheric $CO_2$ and attendant global warming, would occur between 40 and 70°N latitude (Manabe and Stouffer, 1980). The result would be an increase of 1 to 3°C in surface water temperatures, an increase in precipitation-minus-evaporation, a decrease in wind stress and Ekman transport, and a decrease in transport of the Gulf Stream (Wright et al., 1986). These changes would intensify vertical water column stratification and increase the duration of the stratified season, reduce cross-shelf exchanges and reduce coastal upwelling in the coastal zone at these latitudes. Superimposed upon these processes would be the uncertain effects of elevated sea-level.

The effects of such alterations to the oceanography of the Gulf of Maine will likely be very significant. For example, changes in sea-level in the Gulf of Maine, which is in near-resonance with the semi-diurnal lunar tide, could well reduce (or enhance) the significance of tidal mixing, thus altering the nature of nutrient fluxes and biological production. Increased

stratification of the water column (Wright et al., 1986) could alter the species composition of phytoplankton.

Because of its physiography and hydrography, the Gulf of Maine is home to fauna and flora from several biogeographic affinities that presently are at the limits of their latitudinal ranges, making the Gulf extremely rich in species. It has been documented that during periods of anomalously higher or lower water temperatures in the Gulf of Maine, there were shifts in the abundances of species already at the limits of their ranges (Taylor et al., 1957; Colton, 1972; Frank et al., 1990). One could argue, then, that the Gulf of Maine might be among the first marine ecosystems to exhibit species shifts in response to changing climate.

Each of the presumed alterations to the coastal zone of the world ocean, both natural and anthropogenic, carry great uncertainties with regard to magnitude, as well as the sign of the expected change, and are the subject of great debate. However, it is evident that the physics of the coastal zone will likely change in response to global climate change, and that these coastal systems will be the first marine environments to exhibit measurable changes. Of more immediate concern, however, are direct anthropogenic contamination and alteration of the coastal zone, the effects of which remain largely speculative in the absence of an adequate understanding of how the Gulf of Maine, with all its components, fundamentally operates.

The Gulf of Maine has thus far escaped much of the problems now facing other coastal areas around the world, such as the example cited for the North Sea. There are, however, clear signs of altered environmental quality of the Gulf of Maine as a whole, with certain areas of the Gulf exhibiting pollution levels among the highest in the U.S. Of the pollution problems facing the marine waters of the Gulf of Maine, sediment contamination is the perhaps the best studied, and is generally confined to specific sites such as Boston and Portland Harbors. We present an overview of these documented cases in the first section of this Plan. Though better studied than other pollution problems, it is safe to say the effects of contaminant loadings in the Gulf of Maine remain only poorly understood, and that much of what we know about the effects of anthropogenic changes to the coastal marine environment is based on case studies from other parts of the world.

There are two principal reasons for being concerned about environmental quality in the Gulf of Maine, or any other body of water: 1) protecting human health and 2) ensuring human uses of the Gulf of Maine's resources are not inadvertently precluded or reduced. In the first case, we are concerned about natural and human produced or mobilized chemicals or biological agents which are a threat to human health: e.g. toxins from red tides; contamination of seafood by industrial chemicals; contamination of shellfish with human pathogens. In the second case we are concerned with several issues such as losses of habitat for recreational and commercial fisheries, losses of habitats for birds and marine mammals, adverse impacts of toxic chemicals on various species and communities of species, physical alteration of coastal resources in a manner that significantly alters human uses e.g. losses of beaches and marshes with their recreational and aesthetic values.

Knowledge of coastal and continental margin ecosystems has progressed to the point where we know that we must investigate many of the above issues on a regional Gulf of Maine scale as well as past, present, and future efforts focused locally on smaller scales of embayments, local estuaries, and individual town or cities', or focused more broadly on the collective of states' or provinces' coastal ecosystems. An analogy illustrates the overarching concern: it is important to study, understand, and monitor a local economy but such studies are most effective if they are embedded in an appropriate framework of knowledge of state/province, regional, national, and international economies. From the perspective of environmental concerns, there has been an apparent lack of appropriate study and monitoring on the regional, i.e., the Gulf of Maine scale, commensurate with the real and perceived

problems in the Gulf in the environmental arena.

The Regional Marine Research Act was enacted in recognition of the value of our nation's coastal marine waters, the mounting pressures that threaten their ecological integrity, and the need to provide federal support for regional approaches to marine research, so that we may improve our understanding of the present conditions and future trends in our coastal marine waters. The purpose of the Act was to establish regional marine research programs around the country, and to provide sustained funding for marine research and related activities within each regional program.

### B. The Gulf of Maine Regional Marine Research Program:

The Regional Marine Research Act of 1991 (Public Law 101-593) establishes 9 Regional Marine Research Programs, each with a Regional Marine Research Board responsible for carrying out the provisions of the act. One of these Programs is for the Gulf of Maine region. The legislation requires each Board to develop and submit to the Administrators of the National Oceanic and Atmospheric Administration and the Environmental Protection Agency a comprehensive 4-year Marine Research Plan for the region, and to amend the Plan at such times as the Board considers necessary to reflect changing conditions, but no less frequently than once every 4 years. The contents of the Plan are to include:

1. An overview of the environmental quality conditions in the coastal and marine waters of the region and expected trends in these conditions;

2. A comprehensive inventory and description of all marine research related to water quality and ecosystem health expected to be conducted in the region during the 4-year term of the plan;

3. A statement and explanation of the marine research needs and priorities applicable to the marine and coastal waters of the region over the upcoming 10-year period with emphasis on the upcoming 3-to-5 year period;

4. An assessment of how the plan will incorporate existing marine, coastal, and estuarine research and management in the region, including activities pursuant to section 320 of the Federal Water Pollution Control Act (33 U.S.C. 1330) and section 315 of the Coastal Zone Management Act of 1972 (16 U.S.C. 1461); and

5. A general description of marine research and monitoring objectives and timetables for achievement through the funding of projects under this title during the 4-year period covered by the plan so as to meet the priorities specified in the plan in accordance with paragraph (3).

### C. Development of the Gulf of Maine Marine Research Plan:

A Tri-State Task Group was formed in the spring of 1991 to provide assistance to the Governors of Maine, New Hampshire and Massachusetts on the formation and operations of the Regional Marine Research Board for the Gulf of Maine. The Task Group's recommendations included the recognized need to involve the scientific community in the development of the Plan. Thus, this Marine Research Plan has been prepared in consultation with the marine research institutions in the Gulf of Maine region. In the absence of a formally-appointed Regional Marine Research Board, the designated Chairman of that Board requested the assistance of the Regional Association for Research on the Gulf of Maine in preparing a draft Plan. That draft Plan was

subsequently used by the full Board in preparing this final version. The Regional Association is a federation of the Marine research institutions in the Gulf of Maine region and was formed in 1991; its mission is to coordinate, facilitate, and stimulate marine scientific research on the Gulf of Maine, through better communications among the institutions in the region. Its membership includes 10 full member institutions and 6 associate member institutions.

The Regional Association convened several meetings over the past year which were concerned with developing an effective and representative approach to developing this Research Plan. A steering committee, with members from Maine, New Hampshire and Massachusetts, was formed and charged with developing the various sections.

Much of the planning process that has lead to the development of this Plan, however, was begun well in advance of the authorization of the Regional Marine Research Act. Researchers interested in the Gulf of Maine, both in the U.S. and Canada, historically have maintained informal contacts among themselves. Those contacts, along with common scientific interest in the Gulf of Maine, has resulted in many general and thematic symposia and workshops over the past decade which were initiated by the research community. These *ad hoc* efforts among the marine scientists, as well as the concerns of local governmental agencies, lead to a more formal conference, entitled "The Gulf of Maine, Sustaining Our Common Heritage", held in Portland, Maine, on 10-12 December 1989, which was convened by the governors of Maine, New Hampshire and Massachusetts, and the premiers of New Brunswick and Nova Scotia. The goal of the conference was to determine what cooperative state/provincial work was needed to sustain, in the broadest sense, the productivity of the Gulf of Maine. The conference focussed on issues primarily of interest to resource managers and environmental policy makers, with some input from the scientific research community, and concluded with an agreement signed by the governors and premiers forming the Gulf of Maine Council on the Marine Environment. The Council has recently finished an initial plan for an environmental quality monitoring program for the Gulf of Maine, which was based on an inventory of ongoing programs, surveys of interested scientists and managers in the region, and a workshop held in Halifax, N.S. in June, 1990. The Council on the Marine Environment has also issued a Gulf of Maine Action Plan for 1991-2000, the mission of which is "To maintain and enhance marine environmental quality in the Gulf of Maine and to allow for sustainable resource use by existing and future generations".

A subsequent scientific workshop on the Gulf of Maine was held in January of 1991 at Woods Hole, Massachusetts, and dealt primarily with issues more directly related to scientific research. The conference was thus driven by the scientific research community, but with input from the environmental managers and policy makers. The program included invited scientific reviews, contributed poster presentations, working group deliberations and reports, and panel discussions. The 1991 conference was very successful in summarizing the current status of our understanding of the Gulf of Maine, identifying outstanding gaps in our knowledge, and developing recommendations for future research. The proceedings are *in press* and are expected to be published in spring, 1992.

Last year the State of Maine Marine Research Board developed a Marine Research Priority and Action Plan, which began with a roundtable discussion of research needs among 31 members of the marine and coastal user community. A total of 43 research themes were identified, which were grouped into five priority issues from which research foci could be developed. The five issues were: 1) balancing growth and development with environmental quality, 2) the wise granting of permits, 3) managing a dynamic marine ecosystem, 4) Maine's fishing industry, and 5) capturing new opportunities. These five main issues were divided further into sub-issue questions, upon which a number of research themes were focussed.

Collectively, these efforts represent a significant intellectual contribution toward organizing a coordinated research approach to the many issues facing the Gulf of Maine, for which the Regional Marine Research Program was created. Moreover, the efforts served as starting points for the development of this Plan, and they will be referred to throughout the document. Thus, although this plan as submitted is appropriately as a product and responsibility of the Regional Marine Research Board for the Gulf of Maine Region, it is based on extensive preceding work by others.

### D. Organization of the Plan:

This Marine Research Plan for the Gulf of Maine Region has been organized according to the 5 main sections required by the authorizing legislation (listed above). Each of the authorizing legislation's sections is dealt with separately in the body of the Plan, with additional materials appended, particularly, the relevant excerpts from the three conferences and workshops cited above, and details of the research inventory for Section II.

In addition, certain cross-cutting issues, such as the philosophy of an approach to research on the Gulf of Maine, matters concerned with data management, shared equipment and facilities, and other aspects of coordinating research activities in the region, are incorporated into Sections III and IV.

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## I. Overview of the environmental quality conditions in the coastal and marine waters of the Gulf of Maine region and expected trends in these conditions:

Existing information on the environmental quality of the Gulf of Maine comes from a variety of past and ongoing surveys, monitoring programs and research activities. These include programs sponsored by local, state and federal governments, as well as private institutions and interest groups. An inventory of the marine environmental quality monitoring programs in the Gulf of Maine was prepared by the Maine State Planning Office (MSPO) in 1989 as an initial step in organizing a comprehensive Gulf of Maine monitoring program by the newly formed Council on the Marine Environment (CME; formed by the governors and premiers of Massachusetts, New Hampshire, Maine, New Brunswick and Nova Scotia to discuss and act upon environmental issues of common concern). The MSPO inventory concentrated on, but did not limit itself to, the monitoring of contaminants, and presented overview descriptions of 3 proposed, 23 ongoing, and 35 historical programs. Collectively, these programs suffered from the lack of standardization with respect to sites and methodologies. The CME has recently finished an initial plan for an environmental quality monitoring program for the Gulf of Maine, which was based on the Maine State Planning Office's inventory of ongoing programs, surveys of interested scientists and managers in the region, and a workshop held in Halifax, N.S. in June, 1990. Part of that plan calls for bringing together the results of past and present monitoring activities.

Two reviews of the health and environmental quality of the Northwest Atlantic region, which included the Canadian half of the Gulf of Maine, were published by the Canadian Government (Wilson and Addison, 1984; Eaton et al., 1986). A brief report prepared by NOAA, based on monitoring activities at about 300 sites in the coastal United States, summarized the status in 1990 of chemical contamination in sediments and tissues of selected finfish and shellfish (O'Connor, 1990).

Larsen (1992) recently published an overview of the environmental quality of the Gulf of Maine which synthesizes data from NOAA's Status and Trends Program, EPA's Mussel Watch Program, and results of his own research. Although, as Larsen points out, the Gulf of Maine is widely believed to have the highest environmental quality of the coastal waters of the eastern United States, there are a number of sites that are exceptions. Trace metal concentrations in sediments and/or the water column of a number of estuaries (Saco River, Great Bay, Penobscot Bay and Casco Bay, Merrimack River, Boston Harbor, Massachusetts Bay) are elevated (Armstrong et al., 1976; Mayer and Fink, 1980; Larsen et al., 1983; 1984; Gardner et al., 1986; MacDonald, 1991; Manheim and Hathaway, 1991) due in part to old industries and sewage discharge practices in New England, and are comparable to other east coast sites traditionally thought to be more heavily polluted. Sediment trace metal concentrations generally decrease with distance offshore, although activities associated with offshore oil exploration may contribute significant quantities (Bothner et al., 1987).

Large concentrations of trace metals have also been found in marine animal tissues (reviewed by Uthe, 1990), particularly organisms from urban, coastal waters. Liver tissues from winter flounder collected from the area of the Kennebec River coastal plume had among the highest trace metal concentrations in the U.S. (NOAA, 1987). Concentrations of Ag, Hg, Cu and Pb in mussels from Boston Harbor place them in the top 20% of the 78 sites surveyed nationwide, while concentrations of Hg in the livers of winter flounder from Boston Harbor were the highest observed in NOAA's National Status and Trends Benthic Surveillance Program (MacDonald, 1991). In addition, EPA's Mussel Watch Program showed that three relatively

undeveloped sites along the Maine coast (Bailey Island, Cape Newagen and Blue Hill Falls) had among the nation's highest levels of lead in mussel tissue (Goldberg et al., 1983) as did tissues of crabs collected from Boothbay Harbor (Maine Department of Marine Resources, unpublished). Some trace metals (mercury and cadmium) may reach relatively high levels in higher trophic level consumers, even at offshore sites in the Gulf of Maine (Wagemann and Muir, 1984; Uthe and Chou, 1987; Uthe, 1990).

Though fewer data are available , pesticide contamination in the Gulf of Maine has also been documented (Larsen, 1992). Concentrations of DDT and PCBs in liver tissues of winter flounder from Boston are the highest in the nation (NOAA, 1987; MacDonald, 1991).

Sample sites in the southern Gulf of Maine coastal areas exhibit among the highest concentrations of polychlorinated biphenyls (PCBs), and PCB levels in sediments from sites to the north may be increasing (Larsen, 1992). Sediments from Portland Harbor and Casco Bay showed an increase from levels below detection in 1980 to as much as 0.32 ppm in 1983 (Larsen et al., 1983b; 1984b), while PCB concentrations of at least 0.13 ppm were sampled at deep water stations (>200m) in the offshore basins of the Gulf of Maine in 1983 (Larsen et al., 1985). It is generally believed that PCB contaminations are confined mostly to harbors, and that concentrations decrease with distance offshore (Farrington and Boehm, 1987). PCB contamination in marine animals is also well documented in the Gulf of Maine, and may be greater for higher trophic level species (Uthe, 1990).

Polycyclic aromatic hydrocarbons (PAHs) are also commonly found in sediments throughout the Gulf of Maine (Windsor and Hites, 1979; Boehm et al., 1984; Larsen et al., 1986; Shiaris and Jambard-Sweet, 1986). Their accumulation in animal tissues, though also documented, may be reduced in higher trophic level species relative to that of PCBs (Uthe, 1990). However, the potential effects of metabolic breakdown products of PAHs are of increasing concern (McElroy et al., 1989).

NOAA's recently published National Status and Trends Program report on toxic contamination in the Gulf of Maine (Gottholm and Turgeon, 1992) complements the conclusions of Larsen (1992) and others. On a national basis, sites in Boston Harbor, Salem Harbor and Casco Bay consistently exhibited high levels of contamination in sediments, mussels and fish collected between 1984 and 1989. For example, a Salem Harbor sediment site exhibited the highest mean concentration of chromium and the second highest for cadmium among all sites in the nation. Casco Bay ranked among the highest in the nation for various metal concentrations in winter flounder livers. For certain organic compounds (PAHs, DDTs, and PCBs), sediments and mussels in Boston Harbor sites were also among the highest in the nation.

The Gulf of Maine has a number of embayments with relatively low freshwater flow and low flushing rates. Thus, certain areas are susceptible to accumulation of pollutants (Gottholm and Turgeon, 1992). Although most of the highly contaminated sites in the National Status and Trends Program were associated with urban areas, occasional sites distant from large urban areas also exhibited high levels of contamination. These included sites in Machias and Penobscot Bays, which exhibited high levels of cadmium in fish (longhorn sculpin) livers, and Pickering Island, in Penobscot Bay, which exhibited high levels of total PAHs in sediments and mercury in mussels.

As noted above, distributions and concentrations of chemical contaminants in the sediments and tissues of animals from the Gulf of Maine show a number of hot spots, most being confined to the coastal zone, such as in the immediate vicinity of Boston Harbor. Other sites are not so easily explained on the basis of simple proximity to a likely source, and lead to questions regarding the possible transport processes that create such spotty distributions, as well as questions about their possible fate in both the near and long term future.

The adverse effects of such chemical pollutants on marine animals is presently being documented. In his review, Larsen (1992) presented evidence of the increased incidence of diseased marine animals in recent years which may result from chemical contamination. Examples included observations by fishermen of fin rot in flounders and tumors on cod, observations by National Marine Fishery Service scientists of viral diseases in winter flounder, and observations by Maine Department of Marine Resources scientists of cancer in soft shell clams and large kidney concretions in mussels. Although some information exists, less is known about the impacts of pollutants on reproduction, growth or survival of various life stages.

Relatively little information exists with regard to enhancement of natural biological cycles such as stimulation of primary production or increasing biological oxygen demand by nutrient enrichment in Gulf of Maine waters. Loder and Becker (1990) concluded in their review that the dangers of eutrophication in the Gulf of Maine are presently minimal. In part, this is because the Gulf in general lacks those characteristics that contribute to eutrophication in other, more notable, locations such as the Gulf of Mexico, Long Island Sound and Chesapeake Bay. The rivers entering the Gulf of Maine do not appear to carry high nutrient loads. Furthermore, the Gulf of Maine is generally deeper and has greater vertical mixing, thus diluting and removing nutrients from the photic zone. Some nearshore areas of the highly indented Gulf of Maine, however, are more susceptible, with shallower depths, less energetic vertical mixing, and greater nutrient injections. Perhaps more significantly, Smayda (1991) has pointed out that altered ratios of dissolved inorganic nutrients, from that of normal ratios, particularly N:Si and N:P, which often result from coastal eutrophication, may be the cause of increased incidences of harmful algal blooms. There is public concern that the planned relocation of the sewage outfall from Boston Harbor to Massachusetts Bay may disrupt normal phytoplankton succession patterns, enhance noxious algae blooms, depress ambient oxygen levels, affect benthic-pelagic coupling and alter both soft and hard bottom community structure. These concerns are not necessarily unique to Boston Harbor and Massachusetts and Cape Cod Bays but are representative of those areas where population pressure and coastal development along the coast of the Gulf of Maine continues to increase.

Nearshore areas are also more susceptible to hypoxic or anoxic conditions. Such examples point out the proximity of coastal embayments to the threshold of oxygen depletion. An unusual, and especially intense dinoflagellate bloom in Maquoit Bay, a shallow enbayment at the head of Casco Bay, Maine, during the summer of 1989 resulted in oxygen depletion and large mortalities of benthic invertebrates. The causes of that event remain uncertain, but are believed to have been related to local eutrophication in combination with warm summer water temperatures. The waters of Boston Harbor and inner Massachusetts Bay exhibit some hypoxic conditions, though no anoxic conditions have been documented (Townsend et al., 1991). Diversion of sewage effluent to offshore sites will presumably reduce this problem. A more recent problem producing hypoxic conditions episodically over the past 20 years results from dense schools of menhaden moving (or being driven by predatory schools of bluefish) into restricted coves and embayments where they deplete the oxygen and produce massive fish kills.

The aquaculture industry in the Gulf of Maine is increasing rapidly and there is a growing concern for its adverse environmental effects, particularly with respect to finfish culture (Hayden and Choate, 1990). Concerns focus on the deposition of fecal material and excess feed beneath the fish pens as related to nutrient enrichment and possible localized oxygen depletion. Presently, finfish culture is concentrated in coastal embayments of the eastern Gulf of Maine where tidal flushing mitigates adverse impacts. Shallower areas, with less tidal flushing, in the western Gulf of Maine might be more sensitive to these impacts should the salmon pen industry, or other aquacultural industries, continue to grow and move west.

The Gulf of Maine is home to many coastal habitats, including salt marshes, tidal flats, eel grass beds, rocky subtidal, barrier beaches, anadromous fish runs, and offshore banks. Over the last century, these habitats have either disappeared or been seriously degraded as a result of filling, ditching, diking, or siltation, or their use impaired by sewage or industrial discharges, acid precipitation, stormwater runoff, or fecal contamination. The result is loss of valuable wetlands, fishery resources or closure of harvestable shellfish beds. For example, Massachusetts is estimated to have lost more than 20% of its salt marshes since the seventeenth century . Although documentation of the effects of lose of habitat is hard to come by, it is likely that the loss of anadromous fisheries, for example, is directly tied to coastal development.

The future trends in the environmental quality of the Gulf of Maine are not certain, but as populations increase, greater pressure on resources are a likely outcome. More intensive use of the nearshore zone will certainly develop. Large population centers presently are confined to the southwestern Gulf of Maine, but demographic trends in the coming decades may alter this pattern. In 1970, 50% of the population of the United States was confined to within 150 miles of the coast, but by the year 2000, it is expected that this will have grown to 75%. The Gulf of Maine region encompasses some of the most pristine and also some of the most contaminated coastal environments in the country. Future trends in enhancement or continued degradation of its quality will be predicated on decisions that encompass both socioeconomic and scientific understanding of the consequences of those decisions.

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## II. A comprehensive inventory and description of all marine research related to water quality and ecosystem health expected to be conducted in the region during the 4-year term of the plan;

One of the first accomplishments of the Gulf of Maine Council on the Marine Environment was the production and publication of Gulf-links in 1991. Gulf-links is a comprehensive guide to the marine related organizations in the Gulf of Maine region of Canada and the United States. It includes listings of aquariums and maritime museums; educational and research organizations; environmental and conservation organizations; fishing, aquaculture and marine trade organizations; national parks and wildlife refuges, and regional, state, provincial and federal agencies in the Gulf of Maine region. Along with the addresses and names of contact persons for each organization, there are brief descriptions of the goals, current marine programs, and resources for each.

Gulf-links provided the first step in our inventory of the present and ongoing marine research activities. Based on this information, we sent a simple form to the various organizations in the region that fund research, requesting additional information on:

- The general purposes of research sponsored by the program;
- The administrative character of the research program;
- The technical character/funding levels of the CURRENT research program; and
- The technical character/funding levels of the PROJECTED research program through 1995.

Responses were returned by the following:

University of Maine/University of New Hampshire Sea Grant College Program
Environmental Protection Agency (Narragansett Lab)
U.S. Geological Survey Woods Hole
National Science Foundation, Division of Ocean Sciences
Maine State Planning Office; Maine Coastal Management Program
Maine Department of Marine Resources
EPA; Casco Bay Estuary Project
EPA; Massachusetts Bays Program
NOAA; Wells National Estuarine Research Reserve Research Program
National Aeronautics and Space Administration
NOAA; National Marine Fisheries Service, Northeast Fisheries Center
NOAA; National Marine Fisheries Service, Northeast Regional Operations Office
NOAA; National Undersea Research Program, University of Connecticut
New Hampshire State Planning Office; New Hampshire Coastal Program
New Hampshire Fish and Game Department
Massachusetts Institute of Technology Sea Grant College Program
Massachusetts Coastal Zone Management Office; Executive Office of Environmental Affairs
NOAA; Great Bay National Estuary Research Reserve
Woods Hole Oceanographic Institution Sea Grant Program
NOAA; Coastal Ocean Program
Canada Marine Laboratories

These responses are presented in Appendix A. In addition, we received information on Gulf of Maine research supported by the U.S. Fish and Wildlife Service, in the form of reports from the University of Maine Cooperative Fish and Wildlife Research Unit and the Massachusetts Cooperative Fish and Wildlife Research Unit.

The nature of current research activities in the Gulf of Maine region covers a broad spectrum from applied to basic, from field-observational to theoretical/modelling, from site specific to global ocean-scale, and from laboratory/experimental to remote sensing. These are briefly summarized in the following paragraphs:

Research activities under EPA's Coastal and Marine Issue Strategy is concerned with the identification of sources of coastal pollution and to assess the efficacy of control measures to reduce ecosystem effects of these pollutants. Strictly speaking, EPA has no mandate to guide research in coastal ecosystems. The EPA Coastal Strategy covers a broad geographical area, of which the Gulf of Maine is a focal point for a number of monitoring activities. Their present research and monitoring approach is to identify, analyze and rank environmental problems, while this approach will evolve in the upcoming 3-5 year period to an integrated ecosystem-wide protection program. Current research activities deal with modelling the fate and effects of point-source wastes discharged into coastal waters, as well as basic research on a number of diverse topics, including: subcellular toxic effects on marine organisms, toxic body burdens of marine mammals, ecosystem recovery, applied modelling studies of wasteload allocation. Future efforts will focus on developing theory, methods and data needed to assess risk associated with nutrient and toxic contamination.

The U.S. Fish and Wildlife Service supports several individual research projects related to fish migrations in the Gulf of Maine and its estuaries (salmon, shad and bluback herring), as well as studies of winter flounder, sea lampreys, ecology of intertidal fishes, macroalgae as it relates to fish production, methods of whale identification, effects of oil on clams, and studies of sea birds.

Gulf of Maine programs funded by EPA's National Estuary Program, including the Casco Bay Program and the Massachusetts Bays Program, as well as the Massachusetts Coastal Zone Management program, are driven by the overall goal of providing the scientific basis for developing and implementing a management plan to protect each system. Projects presently funded include studies of sediment contamination and analyses of circulation patterns in these systems, and other projects related to transport, fate and effects of pollutants on the ecosystem.

Very limited marine research activities are associated with NOAA's National Estuarine Research Reserve Programs in the Gulf of Maine region, which include the Wells Estuary in Maine and Great Bay Estuary in New Hampshire. Individual research projects are funded through the Sanctuaries and Reserves Division of NOAA, and focus primarily on site-specific studies. These presently include water column monitoring in Great Bay, and three projects in Wells: a study of suspended sediments and nutrients, a paleontological study of the stratigraphy and geological history, and a study of the meiobenthos, zooplankton and fish.

Gulf of Maine research funded by the U.S.Geological Survey is focused on marine sediments. These efforts include studies on: contaminant transport and accumulation in Massachusetts Bay and Boston Harbor; the effects of fish trawls on Georges bank; compiling a data bank of sediment properties; producing a data bank for contaminated sediments of Boston Harbor and Massachusetts Bay; and a multidisciplinary study of the geological characteristics of Gulf of Maine submarine banks and ledges.

Research in the Gulf sponsored by NSF's Ocean Sciences program includes several disparate basic research activities, ranging from a study of the effects of freezing on intertidal seaweeds, to modelling the circulation, to a study of the glacial history of the Gulf.

NASA is presently funding only one project in the Gulf of Maine: a study of the bio-optical properties of phytoplankton.

Though not strictly a research funding program, the Offices of State Planning in Maine and New Hampshire, through the Coastal Zone Management Program, are concerned with coastal and ocean policy development, socio-economic analysis and natural resource management, and provide limited funds for research in a few selected priority areas (in NH and ME) and oversees the Massachusetts Bays Program in Massachusetts (see Appendices).

State agencies in the region, including the Maine Department of Marine Resources, the Massachusetts Division of Marine Fisheries, and the New Hampshire Fish and Game Department, fund more applied research directly related to marine resource assessment, protection and restoration, generally in their geographical jurisdictions.

The National Oceanic and Atmospheric Administration funds significant research activities in the Gulf of Maine through the National Marine Fisheries Service, the National Undersea Research Program, and Sea Grant. There currently is much less research activity funded under the Coastal Ocean Program (and the Sanctuaries and Reserves Division, as mentioned above).

The National Marine Fisheries Service conducts resource surveys and research in relation to the region's living marine resources for the primary purpose of providing sound management advice to the New England Fisheries Management Service.

The Undersea Research Program provides funds for both in situ dive system support, including submarines and submersibles, in support of scientific research projects, as well as funding for direct science support, in a ratio of approximately 4 to 1. Four projects are currently supported in the Gulf of Maine: three deal with the Biosphere and Living Resources, and the fourth is concerned with a longterm benthic ecology study along the coast.

NOAA's Coastal Ocean Program funds research in the coastal waters of the United States around 5 main themes: Nutrient Enhanced Productivity, Toxic Chemical Contamination, Coastal Fisheries Ecosystems, Estuarine Habitats, and Coastal Hazards. One currently funded research project is relevant to the Gulf of Maine: a national assessment of coastal and estuarine areas threatened by nutrient enrichment. A second project targeted for future funding is also relevant, which pertains to fisheries problems on Georges Bank.

The NOAA Sea Grant programs supports the greatest number of individual research activities in the region. The three programs: University of Maine / University of New Hampshire, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution, fund mission-oriented regionally-relevant research as given in Appendix A. In general, the topics can be related to issues that bear on either: managing/developing/sustaining living marine resources, coastal development/management, or engineering/technology.

A wealth of marine research activities is presently being conducted by our Canadian colleagues in the Gulf of Maine region. Activities range from basic to strictly applied research. The activities by scientists at the Bedford Institute of Oceanography, the Halifax Fisheries Research Laboratory and the St. Andrews Biological Station are summarized in Appendix A.

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## III. A statement and explanation of the marine research needs and priorities applicable to the marine and coastal waters of the Gulf of Maine region over the upcoming 10-year period with emphasis on the upcoming 3-to-5 year period:

### 3.1 Identification of Research Needs:

Marine research needs in the Gulf of Maine have been brought into sharper focus in recent years, primarily due to a heightened awareness of the potential for increasing environmental stresses that lie ahead. These needs have been identified in a series of workshops and conferences involving environmental managers, users, and research scientists during the past few years. The three principal group efforts that bear on the issue of identification of research needs are discussed below, followed by sets of research priorities that have been developed based on the research needs that are most appropriate for funding by the Regional Marine Research Act. Lists of the research needs identified in each of the three efforts are given in Appendix B.

#### 3.1.1. December 1990 Conference: The Gulf of Maine, Sustaining Our Common Heritage.

A conference was held in Portland, Maine, on 10-12 December 1990, convened by the governors of Maine, New Hampshire and Massachusetts, and the premiers of New Brunswick and Nova Scotia. The goal of the conference was to determine what cooperative state/provincial work was needed to sustain, in the broadest sense, the productivity of the Gulf of Maine. The conference focussed on issues primarily of interest to resource managers and environmental policy makers, with some input from the scientific research community. The program included invited presentations and working group sessions on the topics of toxic contamination, eutrophication, public health hazards, habitat loss, and the ecosystem effects of harvesting living resources. Each of the working group reports included: a goal statement, key themes and priorities, and work session recommendations. Within the sections on recommendations were subsections dealing with management, monitoring, research, public education, and long- and short-term implementation. The subsections on research gave detailed lists and, in some cases, explanations of research needs with reference to specific research projects that might be developed. In order to preserve the integrity of those working session reports we have not attempted to reduce the research subsections of the working group reports to a consensus statement, and instead present in Appendix B the unabridged research recommendation lists from each of the five working group reports.

### 3.1.2. Scientific Workshop on the Gulf of Maine, January 1991:

A subsequent conference was held in January of 1991 at Woods Hole, Massachusetts, and dealt primarily with issues more directly related to scientific research. The conference was thus driven by the scientific research community, but with input from the environmental managers and policy makers. The program included invited scientific reviews, contributed poster presentations, working group deliberations and reports, and panel discussions. The 1991 conference was very successful in summarizing the current status of our understanding of the Gulf of Maine, identifying outstanding gaps in our knowledge, and developing recommendations for future research.

The Workshop had ten working groups, namely: Circulation and Hydrography; Nearshore and Benthic Processes; Toxic Contaminants; the Georges Bank Ecosystem; Plankton Dynamics; Nutrients, Algal Blooms, and Hypoxia; Fishery Resources, Marine Mammals and Seabirds; Interactions of the Gulf's Rivers, Estuaries and Bays; Gulf and Global Climate Change; and Biodiverstiy. The working group reports included sections on priority research needs. Those unabridged reports on priority research are presented in Appendix B.

### 3.1.3. Maine Marine Research Board Report

Last year the State of Maine Marine Research Board developed a Marine Research Priority and Action Plan. The process that led to the report began with a roundtable discussion of research needs among 31 members of the marine and coastal user community. A total of 43 research themes were identified. These themes were grouped into five priority issues from which research foci could be developed. The five issues were: 1) balancing growth and development with environmental quality, 2) the wise granting of permits, 3) managing a dynamic marine ecosystem, 4) Maine's fishing industry, and 5) capturing new opportunities. These five main issues were divided further into sub-issue questions, upon which a number of research themes could be focussed. The unabridged report on the later activity is given in Appendix B.

## 3.2 Identification of Research Priorities:

The results of the three efforts summarized in the previous section represent valuable lists of the research needs for the Gulf of Maine according to groups of (a) resource managers, (b) environmental policy makers, and (c) research scientists. The next step is to develop a set of research priorities based on those research needs, in terms of a Regional Gulf of Maine Research Program with access to modest resources.

### 3.2.1 10-Year Goal

Very extensive needs for scientific information in the face of limited resources dictate that priorities in research direction must be made. Although it is desirable to achieve a thorough understanding of the Gulf of Maine ecosystem, this goal is unachievable in a program of this size.

Identifying research areas of high priority should be done with attention paid to several key guidelines emphasized in the authorizing legislation: water quality; ecosystem health; regional research; and regional cooperation/coordination. The time frame for planning and implementation of these priority research programs is 3-to-5 years within the context of a

10-year vision. The nature of these research programs should fit the guidelines, the time frame, and the long-term goal or mission. The research should recognize the complex interactive character of the Gulf of Maine ecosystem, the understanding of which we both seek, and want to use. Further, it should provide a Gulf-wide, research-driven focus for, and integration of, the multitude of marine scientists, programs, and interest groups active in the Gulf of Maine region.

From both a scientific and practical perspective, a long-term goal with great appeal is the development of a set of models that collectively simulate what we know, and what we can learn, about the Gulf of Maine ecosystem and its interacting components -- how they function in their natural state, and how they would function under stress and/or when perturbed. The details of such a set of models, as well as the specifics of how to go about developing them, are not at all clear, nor are they as important at this time as using that goal as a guide or a way of thinking. The potential benefits of working toward, and perhaps realizing, such a goal are many and great. These benefits include:

- a wide variety of conceptually integrated research needs ranging from laboratory studies, through basic process-oriented field work and synthesis, to analytical and numerical modelling activities;
- a broad spectrum of disciplinary efforts to understand better the interacting physics, chemistry, geology and biology of the Gulf of Maine ecosystem;
- a means of bringing individual research projects into a bigger picture;
- a framework to which researchers, however supported, can relate their own efforts;
- a product goal that is scientifically and intellectually challenging, and which as it is pursued, expands these challenges and opens up new, unforeseen opportunities;
- an approach and focus that productively forces (1) big-picture and little-picture researchers to acknowledge one another's value, and (2) the lab experimental, field/observational, and modelling communities to work together;
- a scientific undertaking that will foster within the research community the development and application of more effective research opportunities and research tools, such as ships of opportunity, aircraft remote sensing, time series data sites, autonomous underwater vehicles, acoustic tomography, etc.
- products that will have broad usefulness in management of marine resources (water quality, habitat, living resources) by virtue of their potential ability to describe credibly for the Gulf of Maine, or any part thereof:
    - the transport and transformation of pollutants from source to sink;
    - the time-varying, spatial distribution of sediments, nutrients, benthonic and planktonic life, larval, juvenile and adult fishes;
    - the impact of pollutants, predators, prey and environmental conditions on any ecologically or commercially important species or habitat;
- products with a predictive capability for both researchers and for marine

resource managers;

- products that will allow a quantitative, statistical description of the natural ecosystem in terms of spatial and temporal variabilities (of all kinds) and from which long term changes can be assessed.

### 3.2.2. A Strategy for Setting Priorities

Within the framework of this guiding philosophy must be a strategy that identifies the major societal issues, translates them into scientific terms, and then applies criteria for setting priorities which should maximize the socially useful and scientifically sound environmental information. Our scheme for setting priorities is therefore driven by the problems in the Gulf that impinge on the human use of it. This problem-driven science was identified in the three conferences and reports discussed in the previous parts of this section. Here we provide a synthesis of the findings from these reports and apply our strategy for setting priorities.

Our logic scheme is to respond to the following questions:

1) What are the priority marine issues at the scale of the Gulf of Maine, from a societal perspective, that science can address with a predictive capability?

2) What are the scientific questions that are posed by these issues, and what specific information needs are thus implied?

3) How much of this information is either already available, presently being generated in other programs, and/or fits the purview of this specific legislation?

4) What are the most important of these information needs, in order to bring about usable predictive capability over a decadal time span?

5) Which of these issues need to be addressed earlier versus later in this decadal span?

### 3.2.3 Findings

In addressing Nos. 1 and 3 of our logic scheme, we can incorporate the many relevant marine issues identified by the workshop reports into two primary categories of societal problem:

- Contamination of the Gulf of Maine (for example: by toxins, nutrients, or pathogens) either degrades living marine resources or alters ecosystem structure.

- Physical changes to habitats in the Gulf (for example: water temperature change, wetland loss, sediment disturbance) alters ecosystem structure and functioning.

In addressing No. 2 of the logic scheme we arrive at four general classes of scientific questions that are posed by these issues, each with a series of sub-areas where information is needed to improve our predictive capability:

**Scientific Question #1:** What are the sources, pathways, fates, and effects on living marine resources, of contaminants in the Gulf of Maine?

**Information Needed:**

1. Patterns of contaminants in space and time
2. Identification of sources (for example: point vs. non-point)
3. Transport and cycling
    a. Physicochemical form (for example: particle/dissolved, bioavailable)
    b. Patterns and mechanisms of water column transport (for example: currents, particle mediated processes)
    c. Sedimentary processes (for example: resuspension, burial, transformation)
    d. Biogeochemical transformation (for example: food chain, dissolution)
4. Biological effects (for example: genetic, physiological, organismal, population, community)

**Scientific Question #2:** What are the causes and effects of noxious and/or excessive phytoplankton concentrations?

**Information Needed:**

1. Causes (external forcing functions and internal processes)
    a. Nutrients (for example: fluxes, ratios)
    b. Physics (for example: vertical and horizontal processes, optics)
    c. Biological dynamics/modulation
2. Effects (higher level)
    a. Noxious blooms (for example: transport, bioaccumulation)
    b. Eutrophication (for example: food chain alteration)

**Scientific Question #3:** What is the relative importance of natural and human-induced changes to the physical environment on ecosystem structure and function?

**Information Needed:**

1. Effects of climate change (intra- and interannual variations)
2. Effects of sediment disturbance (for example: dredging, dragging)
3. Effects of intertidal wetland alterations
4. Effects of damming of rivers
5. Effects of changes in biological composition

**Scientific Question #4:** How susceptible are various parts of the Gulf to dissolved oxygen depletion?

**Information Needed:**

1. Water (and hence oxygen) flushing of embayments
2. Oxygen metabolism of embayments

Numbers 3, 4 and 5 of our logic scheme provide the means for bringing this list of information needs a step further in terms of priorities; these are presented in Table 1. Three

columns provide, respectively, (1) the appropriateness of this research area for study in a regional program such as this (Low, Medium, High); (2) the importance of study in this area to the achievement of predictive capability in a decadal time span (Low, Medium, High), and (3) the time frame in which first funding should be granted (1 = first year, 5 = first five years, 10 = anytime during the decade).

The assignment of ratings was by its very nature subjective. Each issue was given equal attention by the Research Plan Steering Committee, and the attributes for a higher or lower ranking were discussed fully, until a consensus among the group members was reached. Specific criteria used by the Steering Committee in assigning ratings included consideration with respect to: (a) regional scope, (e.g. the research should be truly regional so that the results will have a regional impact as opposed to one that is primarily local); (b) the interdisciplinary nature of the approach, (e.g. research that applies to more than one of the scientific question areas was judged higher. This criterion would discriminate against narrow, site specific research, against monitoring, unless it is research-driven and regionally significant, and against the 'one-more-species, one-more-site' kind of theme); (c) the relationship to the two issues, or categories of problem; and (d) the state of the existing knowledge (i.e., do we presently have sufficient information or is that information totally lacking? Also, is that information presently being collected by another program?). The ratings given in Table 1 were defended at a subsequent full meeting of the Regional Association for Research on the Gulf of Maine on January 27, 1992, where only slight modifications were made. The RMRP Board believes that another group would most likely arrive at a very similar set of research priorities.

In addition to the rating scheme in Table 1, other features of proposed research will be important in the judging of fundable science, including the normal criteria of scientific and personnel quality, adequacy of facilities, etc. Furthermore, projects will be more favorably regarded if they can demonstrate linkages to other ongoing work, with a clearly converging path to predictive capability for the scientific questions. Linkages to existing and projected data bases, interdisciplinary research approaches, and multi-disciplinary modelling efforts will be encouraged.

The research areas identified here are not presumed to be exhaustive or complete. It is fully acknowledged that new and innovative ideas, which have not been anticipated here, will invariable evolve, and research proposals in new and exciting areas are thus encouraged.

Finally, it was recognized that technological research, in the area of instrument development as related to the pursuit of answers to the four main scientific questions, should be encouraged.

Table 1. Research priorities that come under each of the four general classes of scientific questions posed by the two driving issues in Sec. 3.2.1. Column 1 indicates the appropriateness of this research area for study in this program (Low, Medium, High); column 2 indicates the importance of study in this area to the achievement of predictive capability in a decadal time span (Low, Medium, High); column 3 indicates the time frame in which first funding should be granted (1 = first year, 5 = first five years, 10 = anytime during the decade).

| Appropr. | Importance | Time Frame | |
|---|---|---|---|
| | | | **Question 1.** What are the sources, pathways, fates, and effects on living marine resources, of contaminants in the Gulf of Maine? |
| | | | **Information Needed:** |
| M | M | 1 | 1. Patterns of contaminants in space and time |
| M | M | 1 | 2. Identification of sources (for example: point vs. non-point, atmosphere) |
| | | | 3. Transport and cycling |
| H | H | 5 | a. Physicochemical form (for example: particle/dissolved, bioavailable) |
| H | H | 1 | b. Patterns and mechanisms of water column transport (for example: currents, particle settling) |
| H | H | 5 | c. Sedimentary processes (for example: resuspension, burial) |
| H | H | 5 | d. Biogeochemical transformation (for example: food chain, dissolution) |
| H | H | 5 | 4. Biological effects (for example: genetic, physiological, organismal, population, community) |
| | | | **Question 2.** What are the causes and effects of noxious and/or excessive phytoplankton concentrations? |
| | | | **Information Needed:** |
| | | | 1. Causes (external forcing functions and internal processes) |
| H | H | 1 | a. Nutrients (for example: fluxes, ratios) |
| H | H | 1 | b. Physics (for example: vertical and horizontal processes, optics) |
| H | M | 1 | c. Biological dynamics/modulation |
| | | | 2. Effects (higher level) |
| H | H | 5 | a. Noxious blooms (for example: transport, bioaccumulation) |
| H | L | 5 | b. Eutrophication (for example: food chain alteration) |
| | | | **Question 3.** What is the relative importance of natural and human-induced changes to the physical environment on ecosystem structure and function? |
| | | | **Information Needed:** |
| H | H | 5 | 1. Effects of climate change (intra- and interannual variations) |
| M | M | 5 | 2. Effects of sediment disturbance (for example: dredging, dragging) |
| M | M | 5 | 3. Effects of intertidal wetland alterations |
| M | M | 10 | 4. Effects of damming of rivers |
| H | M | 5 | 5. Effects of changes in biological composition |
| | | | **Question 4.** How susceptible are various parts of the Gulf to dissolved oxygen depletion? |
| | | | **Information Needed:** |
| H | L | 10 | 1. Water, and hence oxygen, flushing of embayments |
| H | L | 10 | 2. Oxygen metabolism of embayments |

## 3.3 Summary

The highest priority areas for initial research funding concern the transport and cycling of contaminants, and the causes and effects of noxious or excessive phytoplankton populations. The need for information that would allow discrimination between natural environmental variability and anthropogenic change, such as might occur with global warming, also was determined to be important. But, the complexity of assessing such changes and the long-term perspective required suggest it not be a specific focus but rather a principle underlying all of the RMRP-supported research.

Significant points that fall out of this exercise are that our information needs are great, and many are interrelated; to deal with any one of the informational needs requires information from other areas. For example, questions relating to nutrient availability for phytoplankton growth necessitates some knowledge of physical transport processes. As this section and the appended reports testify, the overall functioning of the Gulf of Maine is extremely complex and not well understood. The Regional Marine Research Program will begin to fund research that addresses some of the more pressing informational needs identified here, which, in subsequent revisions of this statement of research needs and priorities, will be revised to incorporate and build upon the results of those researches.

## 3.4 References

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Maine Marine Research Board. 1991. Marine Research Priority and Action Plan. State of Maine Marine Research Board, State House Station #147, Augusta, ME 04333. 44 p.

Mooers, C., and J. Wiggin. 1991. Scientific Workshop on the Gulf of Maine. Proceedings of Workshop held January 1991, Woods Hole, MA. (In Press)

## IV. Assessment of how the plan will incorporate existing marine, coastal, and estuarine research and management in the region.

### 4.1. Introduction

Section 404 (b) (4) of the authorizing legislation for the Regional Marine Research Program calls for an assessment of how the Gulf of Maine Regional Marine Research Plan will incorporate existing marine, coastal and estuarine research and management in the region, including activities pursuant to section 320 of the Federal Water Pollution Control Act (33 U.S.C. 1330; The National Estuary Program), and section 315 of the Coastal Zone Management Act of 1972 (16 U.S.C. 1461). We present here an assessment of how the research prioritiies in the preceding section of this Plan (Section III), which are intended to be funded by the Gulf of Maine Regional Marine Research Program, will be coordinated, with and supportive of, other regional activities. It is fully recognized that such coordination with other activities in the region will minimize duplication of research effort and will make maximum use of limited resources. Further, it is anticipated that the Regional Marine Research Program, through its relation to, and coordination with, other activities in the region, will lead to more fruitful and meaningful research results and their effective use.

### 4.2. The Nature of Existing Activities

An inventory of the present and projected research activities in the region, grouped by the various funding agencies, is presented in Section II (and Appendix A) of this document. Activities funded under the National Estuary Program are included in that section, as are activities funded under the Coastal Zone Management Act. The inventory reveals that most of the activities funded by these two programs, as well as many of those funded in the Gulf of Maine region by other local, state and federal agencies, are generally site-specific, rather than regional in scope, and to a large degree are driven by individual mission-oriented goals (see Section II). Thus, the various programs inventoried are by necessity of their legislative mandates restrictive in scope, and are born of the need for information to support particular management and policy goals. Other research activities in the Gulf of Maine region, such as those sponsored by the National Science Foundation, are less site-specific, and are driven by more globally significant basic research needs. By their nature, these two general classes of research agendas often preclude the funding of (a) activities that do not deal directly with local, site-specific problems, and hence are not of immediate value to agencies with local or state purview; and (b) activities that are not truly globally significant, which normally are funded by agencies like NSF. Prior to the enactment of the Regional Marine Research Program, there was little opportunity to conduct important regional, ecosystem-level research that fell between the jurisdictions and mandates of various government agencies.

Certain research programs sponsored by other federal agencies, such as EPA, NOAA's National Marine Fisheries Service, the U.S. Geological Survey, and the Canadians do fund regional research, but again with a view toward meeting their agency's particular mission-oriented goals, such as addressing the information needs for reliable fisheries assessment, as one example. The National Sea Grant College Program also sponsors research that in some instances is more regional in nature than many of the others inventoried in Section II, but the nature of the research funded is largely on a project by project basis and by necessity is limited by the small size of research grants awarded. In addition, the Sea Grant programs in this region are, generally speaking, directed at understanding and managing marine resources, which further limits the scope research funded in relation to the research priorities given in Section

III of this Plan.

### 4.3. The Integrative Role of the RMR Program

The highest priorities research areas identified in Table 1 of Section III represent areas that are not now receiving adequate funding in the Gulf of Maine region, but which are areas of growing scientific concern. A regional approach to marine, coastal and estuarine research provides a unique opportunity to link the various ongoing efforts described in Section II into a more comprehensive and better interrelated framework, which will in turn provide much needed new information about processes important in the basic functioning of the Gulf of Maine ecosystems, and about how those processes might be perturbed. Research activities funded under the Regional Marine Research Program will couple many of the present research and monitoring activities in the region (see Section I) by providing outer boundary conditions for site-specific, small-scale studies. These same RMRP activities will serve to connect ongoing programs to the larger scale research such as those funded under the broad heading of global climate change.

The strategy adopted in Section III to facilitate setting of priorities of research projects emphasizes the integration of theoretical and observational science with the future development of a suite of models. It is strongly believed that the process of pursuing the development of models will by its very nature provide insight into a complex environment, help to integrate the efforts of a diverse group of scientists, and ultimately lead to the development of predictive tools for managing marine resources. If this goal were met, these sets of models would be able to (1) simulate what we know about how the Gulf of Maine ecosystem (composed of interacting components) functions in its natural state, and (2) provide guidance as to how it would function under increased stress and/or perturbation. The details and configuration of such sets of models, as well as the specifics of how to go about developing them, are at present unknown. Nevertheless, a framework that emphasizes their development is of great value in guiding research and formulating of new ideas.

Such a modelling approach encompasses many scales, in both time and space, and thus requires a coordinated effort to acquire the information necessary to develop a predictive capability. The need to incorporate existing research activities in the Gulf of Maine region is thus inherent in the research philosophy and strategy adopted here. There are many examples that clearly demonstrate the need to link, integrate and coordinate research across various scales and disciplines. For example, research activities concerned with pollution problems in coastal embayments, as might be funded under the auspices of the National Estuary Program, require outer boundary conditions for adequate understanding of exchanges of energy and materials between coastal and near-shore waters. Another example, and one often avoided for political reasons, concerns the myriad of scientific problems related to fisheries. Imbedded in those problems are research questions that relate to the basic functioning of the ecosystem at all levels, from the dynamics of the circulation in the Gulf and coastal waters, to the base of the planktonic food web, to the functioning of animal communities.

### 4.4. The Roles of Related Regional Efforts

The Regional Association for Research on the Gulf of Maine was formed in 1991 in recognition of the need to coordinate marine research activities in the Gulf of Maine region. This association provides the mechanism for regular communications among researchers and research institutions, and it forms the network necessary to adequately support large and expensive facilities, such as ship time. Future large, common-use equipment acquisitions will be coordinated most effectively through the Regional Association.

Scientific meetings and smaller thematic workshops on special topics will be an important aspect in cooperation and collaboration within the region. The Regional Association will be instrumental in fostering future workshops, while the more general and larger scientific meeting needs will be met by the New England Estuarine Research Society (NEERS), which meets twice yearly, and bring(s) together many of the active coastal researchers in New England and Canada.

The Gulf of Maine Council on the Marine Environment represents the political cooperation among the states and provinces in the region to maintain the resources and environmental health of the Gulf. Its 1991, 10-year Action Plan explicitly recognizes the need for augmented research on the Gulf, and the other elements of the Action Plan containing underlying needs for scientific information and will help guide and make use of RMRP research results.

### 4.5. Data Management

The incorporation of existing marine research in the region raises a number of sub-issues that will need to be addressed as the RMR Program develops. Chief among them is the issue of data management. Research funded by the Gulf of Maine Regional Marine Research Program, with its regional emphasis, will play a unique role in the overall research effort in the Gulf of Maine. Not only will this new research effort generate a considerable body of new observational data and model results, but it will energize a synthesis of old and new results from other research efforts, as alluded to above. Clearly, the overall effort will benefit most if the research data and results are made available to the community in a timely way. Thus, it is proposed that, within the framework of the Regional Marine Research Program, an efficient research data and information management system (DIMS) be established for the Gulf of Maine region. Given the long-term advantage in making data and information accessible to a diverse user community, it is fully intended that the DIMS, adopted under the Regional Marine Research Program, will interface effectively with the system presently being developed under the auspices of the Gulf of Maine Council on the Marine Environment.

The Gulf of Maine Council on the Marine Environment Working Group has established a committee charged with implementing a prototype DIMS for the region by October 1992. NOAA is funding the effort, which in early January, is beginning to make progress toward that end. As presently envisioned, the GOM/CME DIMS will be flexible enough to evolve in ways necessary to support anticipated changes in the future needs of a diverse user group -- a group that will likely include marine environment and resource managers, planners, fishermen, aquaculturists, engineers and scientists. The GOM/CME DIMS will incorporate a large and diverse blend of archived and real-time data from operational and research sources. We expect that as users become more familiar with the advantages of being connected to some of these heretofore inaccessible data sets, their needs will be articulated more clearly. Thus the attributes and services of future generation DIMS will evolve and expand.

In addition to the need for a data management system for the Regional Marine Research Program, truly cooperative research efforts will need a Regional Marine Research Program data exchange policy. The timeliness with which data become available to the Regional Maine Research Program participants and collaborators in the region is critical to the success of such a program. While much of that data exchange will occur in an informal way, the adoption of a research data (and information) and exchange policy will facilitate that exchange. The policy, however, must balance the need of researchers to first publish research results, with the need of Program participants for timely access to the research data and results. The development of such a policy is presently being dealt with as an agenda item for the Regional Association for Research on the Gulf of Maine, in consultation with the Council on the Marine Environment.

## V. A general description of marine research and monitoring objectives and timetables for achievement through the funding of projects under this title during the 4-year period covered by the plan so as to meet the priorities specified in the plan in accordance with paragraph (3).

### 5.1. General

Table 1 in Section III identifies two main research themes that need to be addressed early in the development of the Regional Marine Research Program:

- *Patterns and mechanisms of transport of contaminants and their effects on living marine resources; and*

- *Physical, chemical and biological controls on occurrences of noxious/excessive phytoplankton phenomena.*

Individual research projects that address these problems directly should commence soon, but the Regional Marine Research Board will continue to give consideration to the ramifications of developing simultaneously a sound understanding of the ecological and oceanographic processes operating under only against which one can measure change. Thus, in concert with efforts to address these two high priority research areas, we must also direct attention to the basic workings of the Gulf of Maine.

Proposals that address the highest priority research areas identified in Table 1 will need to be funded within the first 3 years of the Program. However, of particular concern is the need to develop as soon as possible a working circulation model of the Gulf of Maine. This technology is presently available for application to the Gulf (see NSF and Canadian research activities in Appendix A). Depending on the grid scale, there are models that can be run on the newer and faster personal desk top computers. An availability of such working models would greatly facilitate research activities in other disciplines, such as studies of pollutant transport, nutrient budgets, and plankton spatial patterns. That is, the development of a basic understanding of the circulation in the Gulf of Maine, as might be obtained from crude models, could be instructive in research efforts directed at determining the nutrient budget for the Gulf of Maine, several of the Gulf's subsystems, such as Massachusetts Bay and Casco Bay, and the fluxes between them and the open Gulf. This approach should be the first step in any attempts to understand the dynamics of plankton production, fisheries production, and in beginning to address the issue of nuisance algal blooms.

There is a wealth of information presently available from the growth in oceanographic research activities in the Gulf of Maine that began in 1981. Most of these data sit in the form of scattered data reports and disk files. Coupled with the existing archives of satellite remote sensing images of the Gulf of Maine (both CZCS and AVHRR), and with the availability of desk top computer circulation models, we can begin to distill some of these data into a more fundamental understanding of the natural variability of oceanographic processes in the Gulf of Maine. Thus, the funding of well thought-out and carefully conceived research proposals in this area of analysis and interpretation of existing data should be encouraged.

The development of a data management system should be pursued in concert with the efforts of the Council on the Marine Environment. It is not clear if these activities, however, should receive funding from the research budget of the RMRP.

By developing an integrated approach to addressing present uncertainties concerning the basic processes operating in the Gulf of Maine, we can then build on new projects in the out years of this program which encompass new hypotheses that direct research at the specific questions we have laid out in Table 1.

### 5.2. Programmatic Plan

The following tentative program plan will guide the Regional Marine Research Program in the Gulf of Maine for the first four years. It assumes research funding levels of about $1.5 million per year in accord with the authorizing legislation. It also recognizes the necessity of continued planning and coordinating activities within the research community, and between it and other marine programs in the region.

There are two major action items for the first four years. The first is to conduct the research necessary to address the needs presented in Section III. The second is to work toward instilling in the research community a sense of the value of the 10-year goal of this program (p. 17), and the value of coordinated, collaborative research in working toward that goal. Three other actions for the Board during the first four years of the program include: Educating the non-scientific, user community of the value of scientific research, to gain their support and advice; Reporting the Board's activities to the region and federal government; and, Determining the Board's administrative operating structure. The two major action items are discussed in the next two subsections.

#### 5.2.1. Year 1 Research:

First year research funding will be directed at meritorious research projects that address information needs for the Gulf of Maine ecosystem with regard to:

- The physical oceanographic patterns and processes that control the physical transport of contaminants and other properties and constituents, including nutrients, that play a significant role in noxious/excessive phytoplankton phenomena (e.g., Question 1 of Table 1);

- The factors controlling the distribution, fluxes and cycling of nutrients with regard to the role of nutrients in noxious/excessive phytoplankton phenomena (e.g., Question 2 of Table 1).

In addition to these two research areas, high priority for funding will be given to research projects that address the analysis, interpretation, and informational dissemination of *existing data* pertinent to the following areas:

- Patterns and physiochemical form of significant contaminants in space and time (e.g., Question 1 of Table 1);

- Identification of contaminant sources (e.g., Question 1 of Table 1);

- Sedimentary processes and biogeochemical transformations that bear on the transport and cycling of contaminants (e.g., Question 1 of table 1);

- Biotic transfer and accumulation of phytoplankton toxins that affect higher trophic levels (e.g., Question 2 of Table 1).

In all research conducted, investigators will be encouraged to pay critical attention to the long-term need to be able to distinguish between environmental changes resulting from natural variability and those changes influenced by human activities.

### 5.2.2. Planning, Years 1-4:

Effective planning and coordination of ongoing and future research activities is essential for a regional research program that has a 10-year goal of acquiring a better understanding, in a predictive sense, of the basic workings of the Gulf of Maine. The 10-year goal, the approach to meeting it, and its attendant problems were discussed in detail in Section III. Working toward that goal will require that the research community recognize the value of coordinating research, and of identifying the gaps and shortcomings that impede progress toward the envisioned set of simulation models. Thus, it will be necessary to organize and support a number of workshops in the initial stages of the program. These would commence the first year of the program and continue over the next three years. The Board recognizes the value of workshops on the following subjects:

- *Data Management.* This should involve managers and scientists, and have as one goal, to arrive at a mechanism to insure the prompt access by other researchers and modellers to newly acquired data, and to insure the quality of those data.

- *Circulation Modelling.* This should involve primarily physical oceanographers and numerical modellers to develop an action plan/implementation plan for construct a "community" circulation model of the Gulf of Maine.

- *Ecosystem Modelling.* The key ingredients or critical components required for an ecosystem simulation model of the Gulf of Maine, or parts of the Gulf, should be discussed by researchers and modellers. This workshop should be structured so as to educate modellers with respect to what is known and what is not known about the Gulf of Maine and its parts, and to identify new avenues of research that are needed for the development of such models.

- *Chemical Contaminants.* There is an obvious need to bring scientists active in chemical and biogeochemical studies of contaminants together to discuss the problems facing the Gulf of Maine, problems that were made clear in the discussion in Section I. To date, these researchers have most often presented their findings at general meetings, where only a handful of listeners have an active interest. Much remains to be studied on chemical contaminants in the Gulf of Maine; the approach to future research should be mapped out and key issues identified by those most active in this field.

- *Data Synthesis.* The Board recognizes the wealth of information extant on the Gulf of Maine and the value of assuring its analysis before and while other activitues commence. But the exact nature of those existing data -- type, quality, temporal and spatial extent -- have not yet been summarized or catalogued sufficiently to determine their true value.

- *Risk Assessment.* This issue was prominent in the deliberations of the Maine Marine Research Board with regard to all the problems associated with the wise granting of permits. When is there significant threat of damage to the ecosystem to warrant legal restraints? This issue plagues managers continually and might be made clearer if it were the subject of a focused workshop.

- *Boundaries with Other Programs.* The Regional Marine Research Program provides the opportunity to support regional-scale research on the Gulf of Maine. This research is

argued to be needed to fill a void in our present funding structure -- between local and state agency research and monitoring activities, and larger scale federal programs. To be most effective, research sponsored by the RMRP should complement research funded by these other programs, but it stands to reason that the reverse is also true. A workshop that brings out the various agency research agendas could map out a more productive set of research programs.

• *Coastal/Ocean Boundaries.* A more scientifically focused workshop might examine comparatively the exchanges of materials at the land-sea interface and at the shelf-slope edge. This is a topic of international concern, and in the case of the Gulf of Maine, it is not well known, for example, how comparable the flux of nutrients from rivers is to the nutrient loads coming into the Gulf with deep slope water.

• *Extension/Education/Advisory Roles.* The roles of the RMRP, Sea Grant, and state and university extension services may be made more effective and efficient through combining their efforts and talents. A workshop to explore these possibilities might bring out unforeseen ways to meet the collective needs and goals of the various outreach programs in the region.

This list of potential workshops is not intended to be complete; it will evolve as the RMR Program develops. Nor is it indented that all these workshops be convened in the first year. The order of listing is intended to relate to scheduling, with the Data Management Workshop being held first.