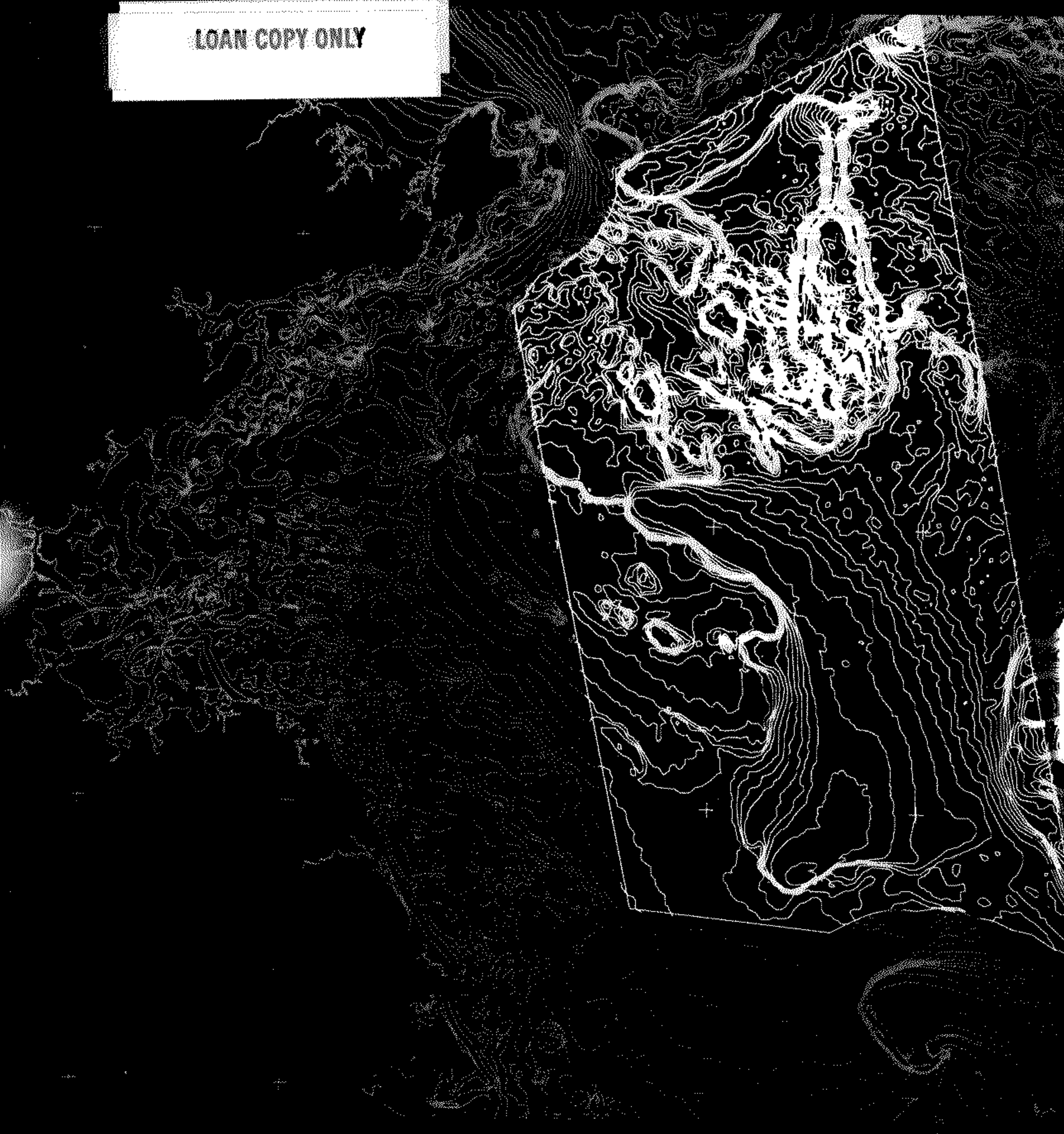
STELLWAGEN BANK NATIONAL MARINE SANCTUARY MONITORING PLAN



Editors R. Michael Lohse and Judith T. Kildow, Ph.D

Image Reference

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STELLWAGEN BANK NATIONAL MARINE SANCTUARY MONITORING PLAN

Editors R. Michael Lohse and Judith T. Kildow, Ph.D

MITSG 96-16

MIT Sea Grant College Program

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To the Reader:

In 1994, the MIT Department of Ocean Engineering introduced a new graduate degree to meet the needs of a changing society. The Masters of Engineering, Program in Marine Environmental Systems, is a one year graduate program, intended to serve the needs of professionals, who desire to change or enhance their careers, and graduate students, who wish to apply their skills to marine environmental fields. The program is both practical and interdisciplinary, meshing marine science, ocean engineering and marine management to provide students with a balance of breadth and depth that allows them to function effectively in this growing field. Students can customize their core program to fit a range of interests, including marine safety, resource management, and instrumentation and marine monitoring. Students must take a design course, Ocean Systems Management, that integrates these three disciplines required in the program. Students work in groups on a project for a client, closely simulating a work experience they might encounter outside of the classroom.

The first year of the program, the students prepared a marine monitoring plan for Sanctuary Manager, Mr. Brad Barr of the newly designated Stellwagen Bank National Marine Sanctuary. Working under the supervision and guidance of the faculty member in charge of the course, Professor Judith Kildow, and consulting with numerous professionals throughout New England, the students produced the report that follows. One member of the class, Mr. Michael Lohse, edited the class report and oversaw the peer review of the work the following summer. During the editing process, Dr. Judith Pederson (formerly a coastal ecologist with the Massachusetts Office of Coastal Zone Management, and currently manager of the coastal advisory program for the MIT Sea Grant Program), in addition to providing valuable assistance and technical advice to the students, played a vital role in the final draft of this report. The MIT Sea Grant Program, under the Directorship of Professor Chryssostomos Chryssostomidis (also Ocean Engineering Department Head), generously offered to publish this work as a Sea Grant Publication.

The report that follows is the product of this student effort. Because of its multidisciplinary approach, the report reflects the students' sensitivities to the political and economic limitations of the Sanctuary Manager whose budgets are both limited and unpredictable, as well as reflecting their scientific expertise and knowledge of technological options that could serve his monitoring needs.

This document has been peer reviewed by staff members at the Massachusetts Department of Environmental Protection, the Massachusetts Coastal Zone Management Program, the Massachusetts Water Resources Authority, the U.S. Geological Survey, the U.S. Army Corps of Engineers, the Woods Hole Oceanographic Institution, the Cetacean Research Unit, the Massachusetts Audubon Society and others involved with the Massachusetts Bays Program and the Stellwagen Bank National Marine Sanctuary.

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List of Abbreviations

CFR	Code of Federal Regulations
COE	United States Army Corps of Engineers (also USACE)
CRU	Cetacean Research Unit
CTD	conductivity, temperature, and depth
CWA	Clean Water Act
DAMOS	Disposal Area Monitoring System
DIN	dissolved inorganic nitrogen
DMF	Division of Marine Fisheries
DO	dissolved oxygen
DON	dissolved organic nitrogen
EPA	United States Environmental Protection Agency (also USEPA)
ESA	Endangered Species Act
FMP	Fisheries Management Plan
IWS	Industrial Waste Site
MBDS	Massachusetts Bay Disposal Site
MBTA	Migratory Bird Treaty Act
MCZM	Massachusetts Coastal Zone Management
MGD	millions of gallons per day
MGLA	Massachusetts General Laws Annotated
MIT	Massachusetts Institute of Technology
MMPA	Marine Mammal Protection Act
MMS	Mineral Management Service
MPRSA	Marine Protection Research and Sanctuaries Act
MWRA	Massachusetts Water Resources Authority
NERRS	National Estuarine Research Reserve System
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
OCS	Outer Continental Shelf
OSCLA	Outer Continental Shelf Lands Act
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyls
PON	particulate organic nitrogen
SAC	Sanctuary Advisory Council
SAIC	Science Applications International Corporation
SBNMS	Stellwagen Bank National Marine Sanctuary
SBNMS FEIS/MP	*SBNMS Final Environmental Impact Statement/Management Plan*
SRD	Sanctuaries and Reserves Division
TOC	total organic carbon
TIC	total inorganic carbon
USACE	United States Army Corps of Engineers (also COE)
USCG	United States Coast Guard
USGS	United States Geological Survey
WHOI	Woods Hole Oceanographic Institution

Executive Summary

This document is a proposed plan for a monitoring system, and a plan for its use, for the Stellwagen Bank National Marine Sanctuary, henceforth referred to as the Sanctuary. The monitoring *system* includes the tools, instruments, and indicators necessary to assess the condition of the ecosystem, while the monitoring *plan* is the coordinated implementation and use of this monitoring system as it pertains to the Sanctuary, taking into account internal and external influences. Located twenty-five nautical miles east of Boston, Massachusetts, the Sanctuary lies at the eastern edge of Massachusetts Bay and measures approximately sixteen by five nautical miles (Figure 1). Congressionally designated in 1992 to facilitate long-term protection and management of the resources and quality of the area, the Sanctuary provides a habitat for numerous commercial species as well as endangered migratory mammals, while supporting several commercial activities at the same time.

The Sanctuary Monitoring Plan is the product of a group of fifteen graduate students (see contributors names in acknowledgments) from the Department of Ocean Engineering at the Massachusetts Institute of Technology (MIT) participating under the direction of Professor Judith Kildow in an ocean systems design course during the 1995 spring semester. This report is the first effort to design a monitoring plan at the request of the Sanctuary Manager, and it borrows and incorporates concepts and methods from many different monitoring programs to form a single and robust system.

The first section of this document describes the methodology of the course, providing insight into the design process as well as highlighting the relevant speakers and texts. This section also identifies some of the external constraints that members of the course encountered such as limited time and funding.

The second section outlines the initial design parameters of the monitoring system, including physical description, problem definition, legal framework, and identification of available information and interested constituencies.

The third section outlines the goals and objectives of the proposed Sanctuary Monitoring Plan, which include 1) establishing baselines from which potentially threatening changes can be detected, 2) designing a flexible and adaptive system, 3) complying with all legal requirements, and 4) boosting public perception.

The fourth section presents a generic three tiered monitoring system design strategy and model that together provide cost-efficient flexibility and modularity in response to uncertainty of financial and other resources. Characterizing the Sanctuary in three groups, sediment/benthos, living resources, and water column, provides a framework for the tiered model; the model serves as a graphical interpretation of the monitoring plan. Within each group are three tiers comprised of indicators, perturbations, and sources of perturbation. Links between tiers show, in some cases, potential causal relationships, and these links are justified by specification sheets in the Appendix.

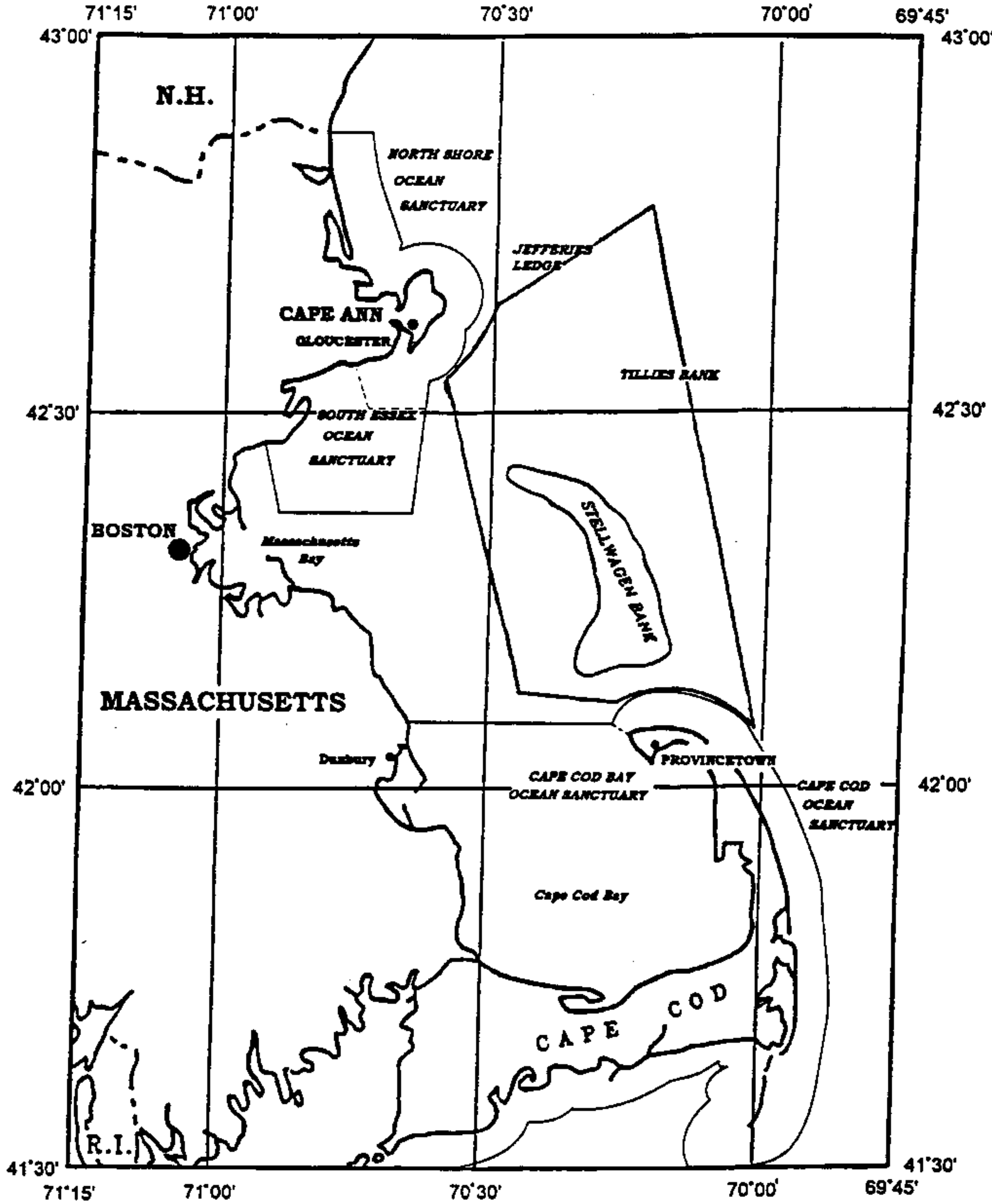

Figure 1. Stellwagen Bank National Marine Sanctuary

The fifth section explicitly defines each of the components in the Monitoring Plan. It describes the Sanctuary-specific three-tiered structure created to meet the goals and objectives described in the third section, while remaining within the confines of the initial design constraints presented in the second section. The fifth section also provides a summary of the Sanctuary Monitoring Plan's initial sampling design.

Included at the end of the fifth section is a cause and effect matrix linking some of the most probable sources of perturbation for Massachusetts Bay with the Monitoring Plan indicators. Among these probable sources are the Massachusetts Water Resources Authority (MWRA) outfall, the disposal of dredged material, overfishing, changes in freshwater inputs, commercial shipping, recreational activities, and natural fluctuations.

The sixth section describes a computer version of the monitoring strategy and model. The computer model is a graphical interpretation of the monitoring plan, and it incorporates the information that is contained within the fifth section and the Appendix, which contains the specification sheets, in a simple, user-friendly database package. The user's guide for the computer model appears in the seventh section.

The last section presents the recommendations and conclusions derived from the development of this monitoring system. This Sanctuary Monitoring Plan represents a practical management tool, providing early warnings to larger events in a cost-effective and flexible manner to the Manager of the Sanctuary, who is congressionally mandated to monitor the Sanctuary and ensure its integrity. While calling for direct data gathering, the Sanctuary Monitoring Plan also uses existing data from other agencies to build baseline measures quickly and inexpensively. There are also some difficulties that are inherent to the monitoring system approach. Of these difficulties, the lack of baseline data for the second tier items is the most limiting; however, some of these data are available from other agencies. Use of the borrowed data also adds some difficulties in standardizing a format and may lead to poor quality control. Another drawback to a tiered monitoring system is that it may lack focus if hypotheses and questions are not stated clearly by the Sanctuary Management (e.g., the Monitoring Plan may be too broad to address cause and effect or specific issues).

The Appendix contains specification sheets which include background and operational information on indicators and other variables that the Monitoring Plan uses to assess the condition of the Sanctuary.

Final Recommendations

Model Development and Implementation

1. Identify critical areas of concern in the Sanctuary on which to focus monitoring efforts and formulate hypotheses. When identified, ensure that the sampling design of the monitoring system takes into account the known threats to the health of the Sanctuary.
2. Further develop and refine the Monitoring Plan to meet the goals and objectives of the Sanctuary Management.

Data Collection

3. Gather available data, integrate data into a computer database, and establish a standard format for data. The analysis of the data will also include verification for relevance to the Sanctuary Monitoring Plan (*in progress: The Sanctuary Manager is currently in the process of collecting relevant available data from state and federal agencies and incorporating these data into a single database*).
4. Establish a professional relationship with NMFS and one or more local organizations that are concerned with the protection and conservation of marine mammals. NMFS conducts semi-annual trawls of the bank, and has records of these trawls for the past twenty years. The population data from these trawls may provide the necessary baseline to recognize changes outside of natural variations. The population data from local conservation organizations may help to identify whale behavior patterns within the Sanctuary (*in progress*).
5. Purchase the necessary software to perform data analysis such as MATLAB, or equivalent.
6. Use existing data and identify additional data needs.

Acquisition of Equipment

7. Utilize the Sanctuary management's existing instrumentation as outlined in subsequent sections to perform water column analysis (*in progress*).
8. Acquire bottom observation equipment to conduct benthic studies. Based upon financial capabilities, this can be as inexpensive as a camera, or as costly as a high-resolution sonar suite.
9. Invest in an instrument to measure turbidity. If a transmissometer is cost prohibitive then a Secchi disk is sufficient to ascertain surface water turbidity levels and trends.

Program Integration and Precedents

10. Establish a no-drag control area. As dragging activity increases on Stellwagen Bank, it is necessary to determine if there are detrimental effects. By establishing a no-drag zone, the management can undertake a comparison study to demonstrate the effects of dragging (*in progress*).
11. Integrate a bivalve study in conjunction with an existing program such as the National Oceanic and Atmospheric Administration's (NOAA) Mussel Watch. This type of program provides an excellent indicator of benthic health.

In completing all of the above, it is fundamental that the management places primary focus on the production and development of a database to establish baseline monitoring levels. Baseline data are essential to the development of (marine) monitoring programs because they serve as historical references of environmental conditions. New data are compared with these baseline values to assess the state of the ecosystem. In addition, baseline values are used to test theories and hypotheses. The baseline is also essential to determining trigger levels which lead to a more detailed and focused monitoring efforts. From these baselines, the Manager can choose more focused hypotheses and test them with an iterative (revised based on baseline monitoring) sampling design. The time constraint of the semester precluded the creation of effective hypotheses and an advanced sampling design. Furthermore, indicators may change over time because of variations in the marine environment. Thus, the Monitoring Plan should change accordingly to adjust to these natural changes.

While this proposed plan is specific to the Stellwagen Bank National Marine Sanctuary, the methodology, strategy, and framework have universal application to other marine monitoring systems. Portions of this Monitoring Plan, such as the water column and sediment/benthos variables, can be applied to other marine monitoring programs. This plan is only the first step in the design process of a monitoring system, but it may provide many users with a starting point and some insight from which to create and implement marine monitoring programs. Figure 2 is a simplified version of the Sanctuary Monitoring Plan.

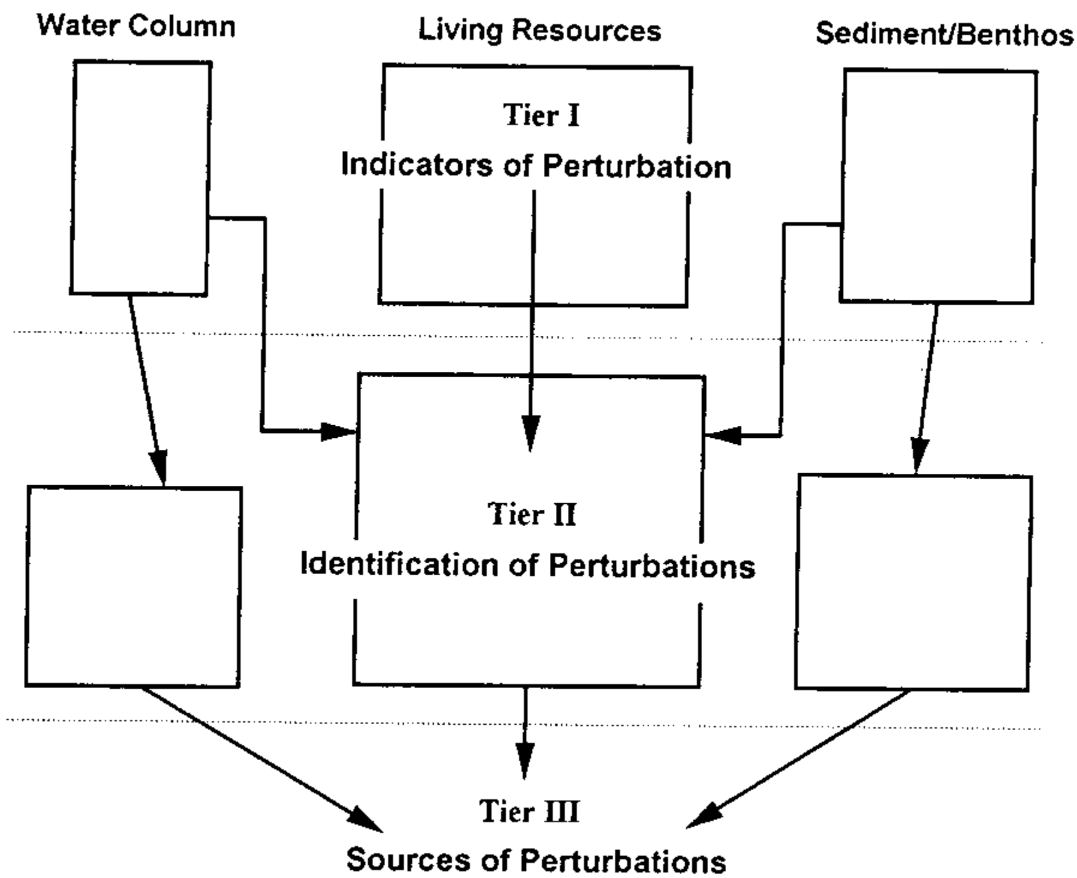

Figure 2. Simplified Sanctuary Monitoring Plan Model

Methodology of the Sanctuary Monitoring Plan

Introduction

A Course in Ocean Systems Management

The Stellwagen Bank National Marine Sanctuary (SBNMS) Monitoring Plan, hereafter called the Plan, is the product of a semester long, fourteen week, course* in the Department of Ocean Engineering at the Massachusetts Institute of Technology (MIT) to design and develop a flexible marine monitoring program to identify significant adverse changes in the marine environment, understand the effects of these changes on the ecosystem, and provide the Sanctuary Manager with a strategic tool for policy development and enforcement. The course brought together a multidisciplinary group of fifteen graduate students serving as consultants to the Sanctuary Manager to design and develop a monitoring system for the Sanctuary that is flexible, inexpensive, and robust.

Background Information and Marine Monitoring Systems

The 1993 *Stellwagen Bank National Marine Sanctuary Final Environmental Impact Statement/Management Plan* (SBNMS, 1993) provided useful background information on the Sanctuary. Additionally, the National Research Council's (NRC) *Managing Troubled Waters* (NRC, 1990a) and *Monitoring Southern California's Coastal Waters* (NRC, 1990b) provide a comprehensive introduction and systematic approach to the design of marine monitoring systems. All three of these texts proved to be helpful references for the students involved with the design of the Plan.

Approach

The approach taken in designing and developing the monitoring system and plan is based on the conceptual framework, below, from NRC (1990a,b) with some minor clarifications:

- Develop Problem Statement
- Define Expectations and Goals
- Conduct Exploratory Studies
- Design Framework for Monitoring System
- Define Study Strategy
- Develop Sampling Design
- Implement Study

These tasks expedited the underlying organization and procedures necessary to design and develop the Plan by creating sequential steps through the design process. The conceptual framework from

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* 13.64 Projects in Ocean Systems Management, taught by Professor Judith T. Kildow, Department of Ocean Engineering, Massachusetts Institute of Technology, Spring 1995.

NRC (1990a,b) that organizes these tasks into a sequential feedback loop has been reprinted in Figure 1.1.

Development of Problem Statement

The problem statement defined the issues of the monitoring system, lead to the eventual development of the goals of the Plan, and attempted to answer the following three questions:

What makes the Sanctuary a valuable resource, and what brought about the area's designation as a national marine sanctuary?

The Sanctuary supports a variety of plankton, invertebrates, and fish species, which serve as food for endangered marine mammals, such as the humpback, northern right whale, and fin whale, that visit the area annually, as well as important commercial fisheries. Stellwagen Bank, however, is in Federal waters, which does not fully protect it from potentially harmful activities, such as commercial shipping traffic, effluent discharges, and disposal sites, and no comprehensive or coordinated management of the Bank's resources existed prior to its designation as a national marine sanctuary (SBNMS, 1993). A more comprehensive review of the designation of the Sanctuary can be found in the *Stellwagen Bank National Marine Sanctuary Federal Environmental Impact Statement and Management Plan* (SBNMS, 1993).

What are the critical issues for the Sanctuary that require a monitoring program?

SBNMS (1993) indicated that a monitoring system was a necessary tool to help the Sanctuary management maintain and protect the living and non-living resources of the Sanctuary by identifying adverse changes in the environment.

What problems or obstacles exist that may impede the design and development of a monitoring program for the Sanctuary?

The problems and obstacles were divided into internal and external problems (see sections 2.2.2 and 2.2.3). Internal problems included those items that were directly related to the monitoring plan, or over which the Sanctuary management had some direct or indirect influence or political leverage including the new Massachusetts Water Resources Authority (MWRA) outfall site, the Massachusetts Bay Disposal Site (MBDS) and human activities such as fishing and shipping. External obstacles included those items over which the Sanctuary management had no control, or those which were indirectly related to the monitoring plan including availability of resources, funding, and constituencies.

Defining Expectations and Goals

After adopting a problem statement (section 2.25), expectations and goals (section 3) of the Sanctuary monitoring program were defined (Step 1, Figure 1.1). These studies that were used to define the problem statement proved helpful in setting priorities for the goals and objectives. Additionally, NRC (1990a,b) provided useful information in the form of examples and suggestions.

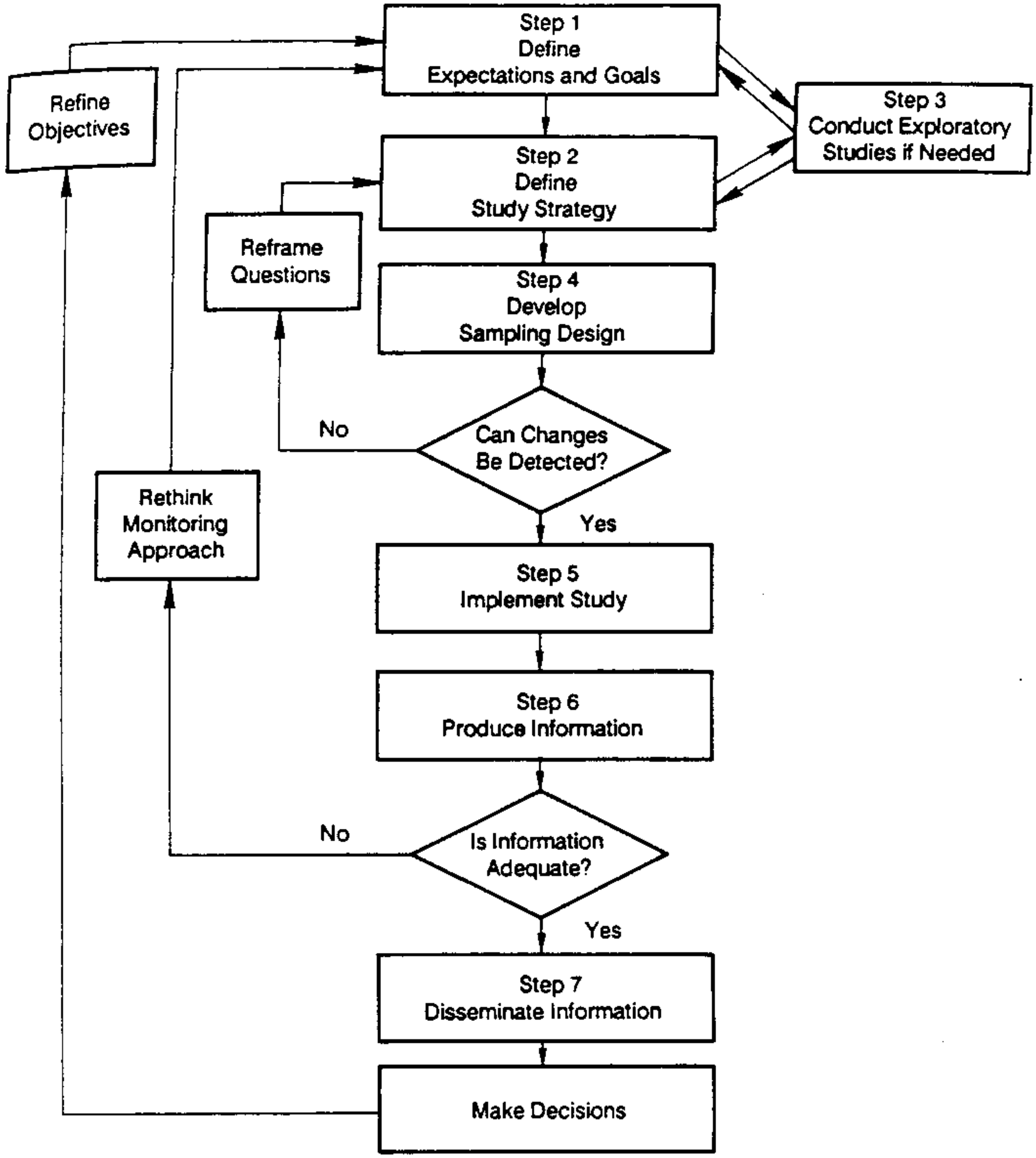


Figure 1.1. Conceptual Framework for the Design and Implementation of a Monitoring Program (NRC, 1990a,b)

Reprinted with permission from *Managing Troubled Waters: The Role of Marine Environmental Monitoring*. Copyright 1991 by the National Academy of Sciences. Courtesy of the National Academy Press, Washington, D.C.

The most important goals and objectives were the following:

- Flexibility
- Cost-efficiency
- Public accountability
- Baseline establishment

Other goals and objectives included meeting all legal requirements, providing an early warning system, and formatting data effectively.

Conducting Exploratory Studies

The initial studies from SBNMS (1993) that were used to define the problem statement and goals and objectives of the monitoring plan were not comprehensive enough to fulfill the goals and objectives, however, SBNMS (1993) was used to indicate areas that needed further research. It was necessary to identify the available information (section 2.4) pertaining to the Stellwagen Bank area including past and current studies, databases, and monitoring programs, and provide an overview of the agencies that operate monitoring programs and the data that has been collected. These initial studies later helped to define and refine the study strategy (Steps 2 and 3, Figure 1.1). The information search was divided into three groups: fisheries, oceanographic and physical data, and legislative mandates. Members of each group contacted the major organizations and monitoring agencies within the Greater Boston area including, but not limited to, the following:

- Massachusetts Water Resources Authority (MWRA)
- U.S. Geological Survey (USGS) - Woods Hole
- U.S. Environmental Protection Agency (EPA) Region I
- U.S. Army Corps of Engineers (USACE or USCOE) - New England Division
- Massachusetts Bays Program
- Woods Hole Oceanographic Institution (WHOI)
- Cetacean Research Unit (CRU)
- New England Aquarium (NEAq)
- National Marine Fisheries Service (NMFS)

Each group subdivided further for greater depth of research: the living resources/fisheries group divided the data gathering task into different classifications of fish species: endangered, migratory, and non-migratory; the oceanographic section categorized the available information into sediment transport and contamination, nutrients and toxic contamination, and physical oceanographic studies; and the legislative group compiled a listing of the past and current legislative mandates that might affect the monitoring plan or Sanctuary area. Each group reported its findings to the other groups. The fisheries group concluded that the monitoring plan should focus on the non-migratory and endangered species because the non-migratory species are less temporally variable than migratory species, and the protection of endangered species is a high priority issue for the Sanctuary. The oceanographic group found that several studies and monitoring programs were currently in operation in Massachusetts Bay, and the legislative group found that the Sanctuary management was required to monitor the Sanctuary under the Marine Protection, Research and Sanctuaries Act, Article §1442.

Design of Framework for Monitoring System

Using available information, the group proceeded to design a monitoring system. First attempts were unsuccessful because of the diversity and complexity of the Sanctuary ecosystem. While it was obvious that the monitoring system could characterize the marine ecosystem into the general categories of water, sediment, and living resources, it was unclear how to best apply a substructure to these. At first none of the ideas that were presented possessed the right level of flexibility and cost-effectiveness. There was a need to define an initial structure or framework from which to build and modify.

During the fourteen week term, the members of the course participated in a team building exercise to assure group dynamics and to facilitate communication within the group. A number of speakers also provided valuable insight into aspects of monitoring Massachusetts Bay and/or Stellwagen Bank. The speakers included the following (in order of appearance):

- Mr. Bradley W. Barr
  Manager, Stellwagen Bank National Marine Sanctuary
- Dr. Judith Pederson
  Coastal Ecologist, Massachusetts Coastal Zone Management
- Dr. Richard Signell
  Oceanographer, U.S. Geological Survey, Woods Hole, MA
- Dr. Tom Fredette
  Disposal Area Monitoring System (DAMOS) Program Manager, U.S. Army Corps of Engineers-New England Division
- Dr. Michael S. Connor
  Director, MWRA Environmental Quality Department

The speakers provided members of the class with five different perceptions of what the Sanctuary monitoring system should focus on (and what to monitor) and how the system should be designed. After reviewing the different approaches, the members of the course adopted a tiered system based on the Army Corps of Engineer's (USACE) tiered DAMOS program (Germano *et al.*, 1994) that provided a cost-effective and flexible structure from which to build.

Defining the Study Strategy

Modification of the USACE DAMOS framework helped to define the study strategy (Step 2, Figure 1.1) and led to a three tiered model focusing on three areas: water column, living resources, and the sediment and benthos, with indicators at the first tier, identification of perturbations at the second tier, and probable sources of perturbation at the third tier (section 4). Figure 1.2 shows a simplified version, or schematic, of the Sanctuary Monitoring Plan Model (a more detailed version of the model appears in section 5). Members of the class divided data collection into each of the three areas (water column, living resources, and sediment/benthos), and each subgroup was responsible for identifying and prioritizing the indicator variables for their areas. Additionally, each subgroup was responsible for defining the connections, or links, and cross-connections within and among the three subgroups of water, living resources and sediment/benthos. Defining the links involved understanding the connections from the sources of perturbations to the indicator variables. As an example, early studies suggested that for reasons of public perception the system should monitor the health of whales, particularly right whales, and their activity in the Sanctuary.

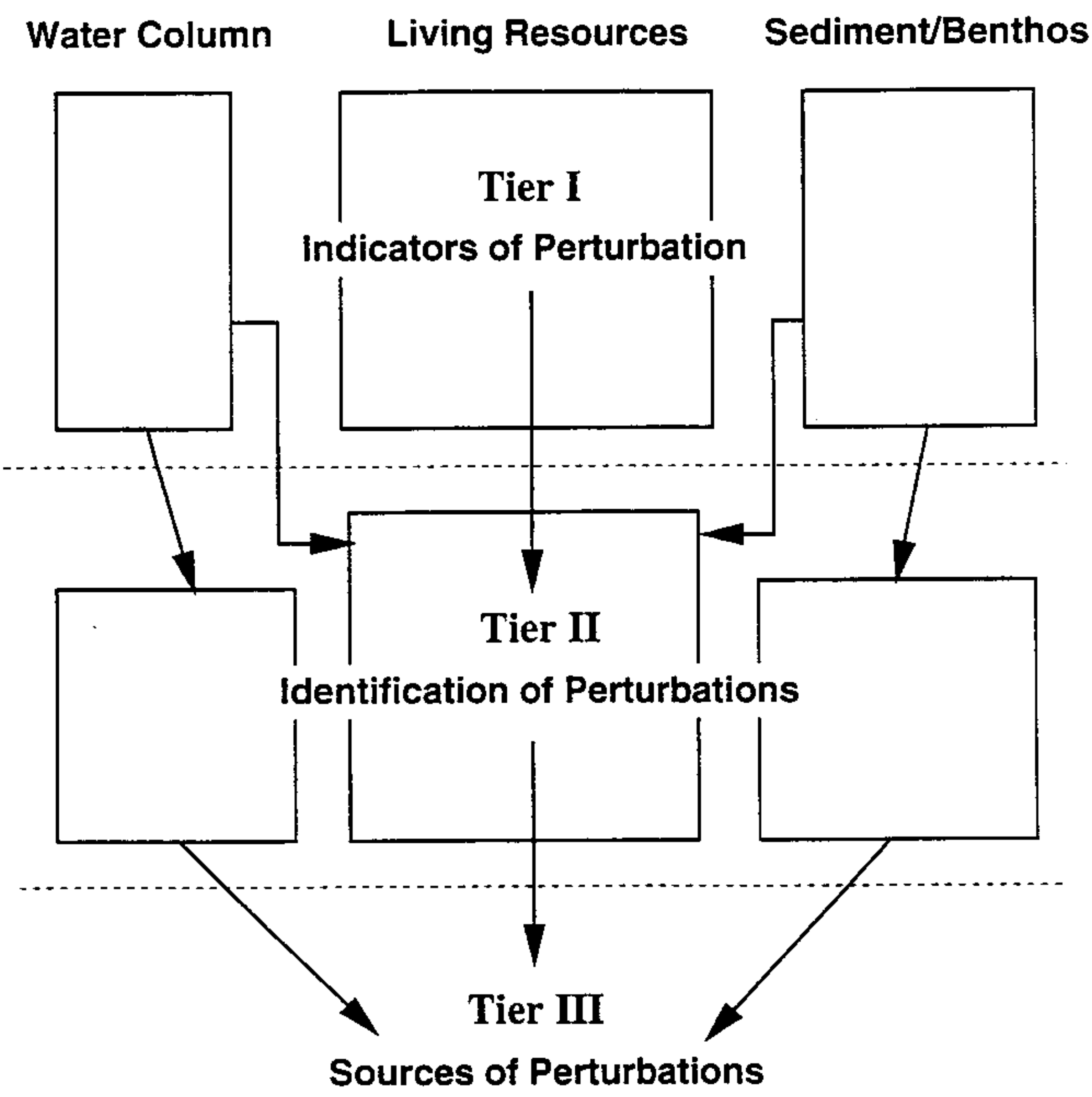


Figure 1.2. Simplified Sanctuary Monitoring Plan Model

However, whale migration patterns and the length of stays within the Sanctuary are highly variable depending on the availability of food in and beyond the boundaries of the Sanctuary. In addition, external factors such as commercial fishing appear to modify whale visits to the area. These and other problems associated with migratory species and marine mammals lead to the exclusion of whales as indicator species.

Defining Sampling Strategy and Sampling Design

To streamline the monitoring system's database and to simplify the cross-connections, the group developed specification sheets (see Appendix). Within the specification sheets are topics such as methods, equipment, analysis, costs, available information, and sampling frequency. So, in addition to defining the indicators and other items in the monitoring plan, each subgroup designed an initial sampling strategy for each item (Step 4, Figure 1.1). Limited class time and resources precluded an advanced sampling design and developed hypotheses. The group used data from existing monitoring programs in the area, such as those of the MWRA, for the Monitoring Plan's exploratory studies.

Future Work

Upon completion of a robust and statistically valid sampling design as well as the development of specific and focused hypotheses, the Sanctuary management should acquire the necessary equipment and implement the Monitoring Plan (Step 5, Figure 1.1). After initial monitoring begins, the management should refine the sampling design and hypotheses to better address the needs of the Sanctuary.

Background and Context for the Study

Physical Description

The Stellwagen Bank National Marine Sanctuary is approximately twenty-five nautical miles east of Boston, Massachusetts, enclosing Stellwagen Bank, Tillies Bank, and the southern portion of Jefferies Ledge within its boundaries and encompassing approximately 638 square nautical miles (842 square miles), as shown in Figure 2.1. The Cape Cod Bay Ocean Sanctuary to the south and North Shore Ocean Sanctuary to the north border the Sanctuary; they are part of the Massachusetts Ocean Sanctuary Program, which are state regulated in accordance with Massachusetts General Laws Annotated (M.G.L.A.) c.132A, §12-13, as opposed to the Stellwagen Bank National Marine Sanctuary which is federally regulated. The Sanctuary's close proximity to Boston and Woods Hole also allows for many educational, scientific, and research opportunities within the Sanctuary.

Stellwagen Bank is a glacially deposited, mostly sandy, submarine feature, varying in depth from sixty-five to three-hundred feet, that extends over sixteen nautical miles (eighteen miles) in a southeast to northwest direction from Provincetown on the tip of Cape Cod to Cape Ann, Massachusetts. The glacial formation of the bank over 13,000 years ago led to massive deposits of sand, gravel, and silt, making it a prime location for proposed underwater mining operations. The abundance of sandy bottom type provides a suitable habitat for bottom-dwelling species such as *Ammodytes americanus*, sand lance, (Sherman *et al.*, 1981 and Covill, 1959) which attracts humpback whales and several commercial finfish species (Payne *et al.*, 1986 and Clapham *et al.*, 1993). The area supports one of the oldest fishing industries in the United States, and within the past twenty years, whale watching activities have increased dramatically. The muddy, or silty, areas are also the home to scallops, drawing bottom draggers to the area (Goudey, 1994).

Nutrient-rich waters from the Gulf of Maine, and rivers such as the Merrimack that feed into it, are carried in a counterclockwise pattern around Massachusetts Bay and over Stellwagen Bank (Geyer *et al.*, 1992). These nutrients support large blooms of phytoplankton, and subsequently zooplankton, the latter of which is the preferred food of the sand lance and northern right whales. Maximum current velocities of forty-five centimeters per second exist near the seafloor over Stellwagen Bank as well as in-between the bank and the northern tip of Cape Cod, and they suggest a mechanism for sediment, water, and nutrient (or pollutant) transport over and around the bank (SBNMS, 1993).

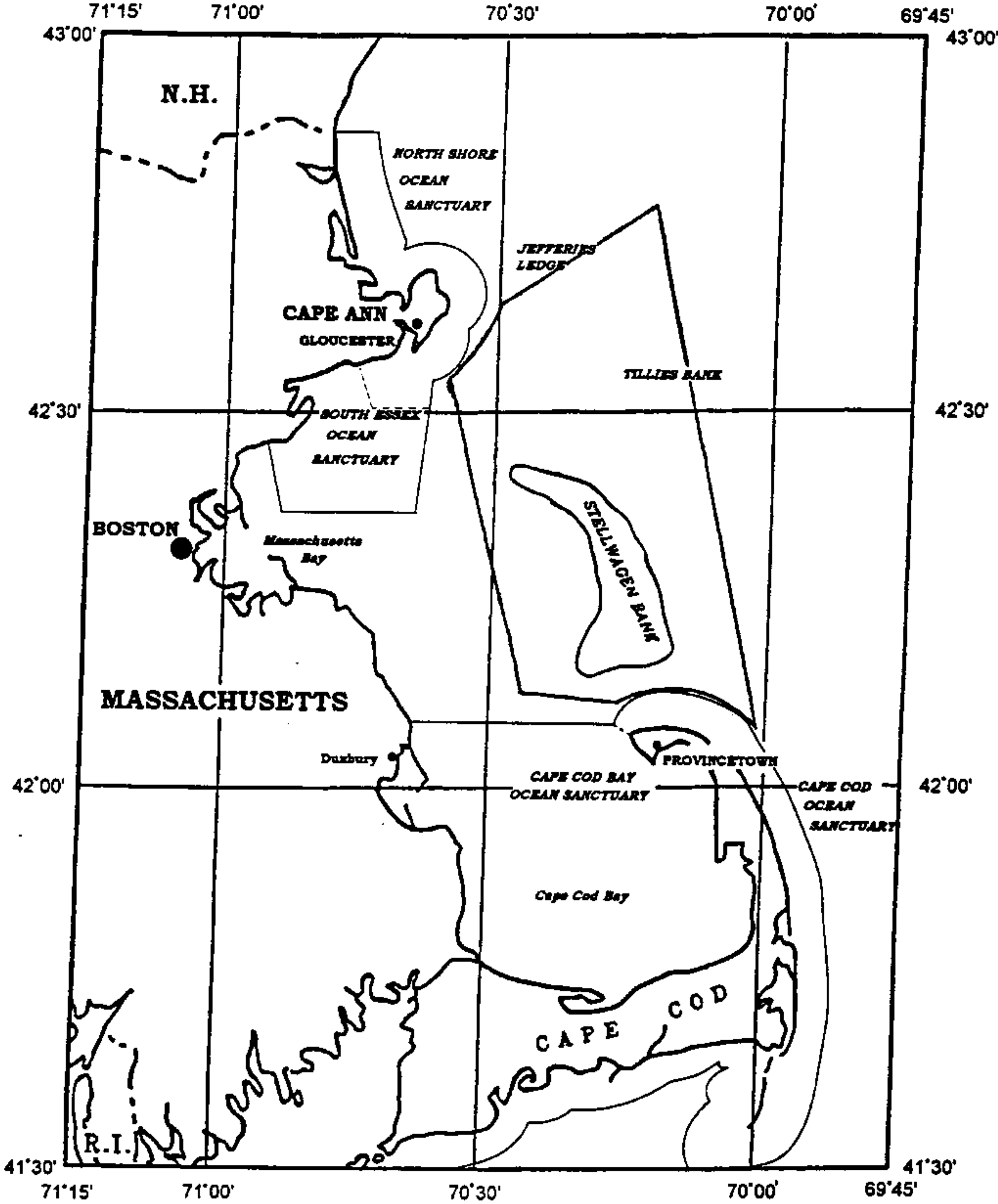


Figure 2.1. Stellwagen Bank National Marine Sanctuary Boundaries

Problem Definition for the Establishment of a Monitoring System

Effective management techniques depend on sufficient data upon which to base decisions and to determine the accuracy and effectiveness of those decisions. Early warning of future problems and some knowledge of how to act/react can prevent or reduce the damage to the marine environment due to human actions. To design a monitoring system for a marine environment, it is necessary to understand the environment, what is valuable about it, and the many factors that affect it, either directly or indirectly. Additionally, it is necessary to understand the variables that affect the monitoring system.

Generic Considerations

In the early stages of development, monitoring agencies must understand 1) the marine environment that they will be monitoring, 2) the impacts and effects on human health, 3) environmental modeling issues, and 4) legal regulations and compliance standards.

Not well understood or quantified, the marine environment is a highly complex system that brings together many species and systems into a single ecosystem. Every system or species is interdependent, relying on the functions and roles of the others as well as on the physical environment. Since living systems are not fully elastic, it may not be possible to restore such a system once damaged or endangered. This inelasticity necessitates a monitoring system that can provide early warning or detection of potentially catastrophic events.

Human health is, of course, another important consideration, and contaminants in fish and shellfish can cause serious health hazards to the public. Industrial pollution, sewage outfalls, and ocean disposal of toxic materials may lead to contamination and degradation of the marine ecosystem. Besides ingestion of contaminated seafood, humans may also be at risk during water-based recreational activities. This need for human safety necessitates a monitoring system that can provide information about the contamination of the living resources, water column, and sediments of the target ecosystem.

Many monitoring programs, such as those of the MWRA and USGS, use environmental modeling to simulate or forecast various conditions (MWRA, 1991, 1992, 1995a,b,c, Bothner *et al.*, 1994, and Butman *et al.*, 1992). Modeling trends require long term and accurate calibration data. Long term data can help differentiate between natural cycles and human induced reactions. Models are most useful only if the initial modeling efforts prove to be valid and correct; however, continual updates of the model through feedback is necessary to account for system changes as inputs and parameters change. Verification of model results and validation of predictions are necessary for assurance and accuracy.

The most important legal mandates and compliance standards that a marine monitoring system faces are from the Clean Water Act and the Marine Protection, Research and Sanctuaries Act of 1972 (see section 2.3), also known as the Ocean Dumping Act. Other constraints may come from state Coastal Zone Management offices, other state agencies, or public opinion. Enforcement agencies include the Environmental Protection Agency and the United States Coast Guard, among others.

Possible Internal Problems or Obstacles in the Design and Implementation

There are several issues internal to the monitoring system that relate to its design and implementation. Among them are 1) understanding the cyclical and natural variation of the ecosystem, 2) designing a system with flexibility to adjust to changing conditions, and 3) formatting and interpreting data for managerial decisions.

To understand the undisturbed ecosystem dynamics, a program should include, but not be limited to, studies to determine large-scale nutrient and contaminant cycle behavior, population dynamics and productivity of living resources, bioaccumulation of contaminants, sediment transport and water circulation within and around the area of interest, and chemical by-product concentrations in the water column. Once a monitoring agency completes these basic studies, and more fully understands the target ecosystem, it can initiate a monitoring plan following NRC (1990a,b) guidelines. In designing a monitoring system, a monitoring agency must identify the parameters to monitor, the time scales of the desired parameters, and the sampling frequency and size necessary to maintain statistical significance. The monitoring agency should build into the system a review process including re-examination of the technological, managerial, and strategic program objectives and structure. This review process allows for flexibility to adapt to changing conditions. Finally, the format of the data is almost as crucial as the interpretation of the data for managerial decision making. Within an organization's monitoring program there must be standardized data formats to simplify analysis and transfer of the data.

Possible External Problems or Obstacles in the Design and Implementation

Several external problems that are indirectly related to the monitoring program, or over which the Sanctuary management has no control, are apparent when designing a marine monitoring system. These external problems include 1) limited Sanctuary management-owned equipment resources, 2) uncertain funding, 3) conflicting public and private interests, and 4) new legislation. Limited equipment resources may lead to cooperation with other agencies, sharing of equipment or data, or dovetailing of operations. Funding may be highly variable in amount and consistency, and consistency may vary in distribution, such as large start-up funding with little follow-up support, or reallocation possibilities. The constituencies involved in the Sanctuary program range from public to private and from local to national. Finally, a monitoring system may need to meet future legislative mandates and must be readily able to comply without jeopardizing monitoring operations.

Specific Threats to the Sanctuary and Other Considerations

There are a few agencies operating in the Massachusetts Bay area whose activities may have potentially adverse effects on the health of the Sanctuary ecosystem. One of these operations is the 1997 startup of the Massachusetts Water Resource Authority (MWRA) sewage outfall diffuser, which is located 10.2 nautical miles west of the Sanctuary at its closest point (Mickelson, 1995). There are concerns that contaminants, nutrients, or increased turbidity from the outfall will degrade the quality of the Sanctuary. The MWRA is conducting a baseline monitoring study to characterize and forecast the effects of the outfall when it becomes operational in 1998. Among these studies, the MWRA has conducted extensive water (Hunt *et al.*, 1995) and sediment (Blake *et al.*, 1993) quality monitoring in addition to fish and shellfish (Hillman *et al.*, 1994) studies. The MWRA is also developing numerical models in cooperation with USGS to forecast the transport of nutrients from the new outfall location (Bothner *et al.*, 1994 and Butman, *et al.*, 1992).

Another potential threat to the Sanctuary ecosystem is the Massachusetts Bay Disposal Site (MBDS), located just west of the northwest corner of Stellwagen Bank, which serves as the primary disposal site for dredged material. The MBDS has been the site of low level radioactive wastes, hazardous materials, and sediments from urban harbors, often contaminated with organic chemicals and metals. Currently, the MBDS is designated to accept only dredged material deemed suitable for open ocean disposal, e.g., "clean" sediments. Impacts to the Sanctuary may arise, even if the material is not contaminated, e.g., the dredged material may increase turbidity and/or smother benthic organisms. The USACE and the EPA oversee and monitor the disposal site to ensure the impacts on the ecosystem are minimal (Liebman, 1995).

Human activity within the Sanctuary varies from commercial shipping to recreational and commercial fishing. With the closing of Georges Bank to fishing, heavier activity may increase within Sanctuary boundaries, thereby increasing the likelihood of overfishing and traffic within the Sanctuary.

While the MWRA outfall and the MBDS are the most publicly visible potential threats to the Sanctuary, they are also the most carefully monitored. There are other possible threats that are less obvious including a number of non-point sources from agricultural runoff and Gulf of Maine inflow. A map summarizing some of the point sources and threats to the Sanctuary appears in Figure 2.2. Further discussion of the threats to the Sanctuary appear in section 2.5.

Problem Statement

The Sanctuary supports a variety of plankton, invertebrates, and fish species, which serve as food for endangered marine mammals, such as the humpback, northern right whale, and fin whale, that visit the area annually, as well as important commercial fisheries. Stellwagen Bank, however, is in Federal waters, which does not fully protect it from potentially harmful activities, such as commercial shipping traffic, effluent discharges, and disposal sites, and no comprehensive or coordinated management of the Bank's resources existed prior to its designation as a national marine sanctuary (SBNMS, 1993).

The monitoring system must enable the Sanctuary management to regulate and maintain the current health of the Sanctuary and its resources, while providing the manager with an effective tool on which to base decisions. A monitoring system can be used to minimize environmentally damaging events by providing early warning signals. To provide an early warning, a monitoring system must incorporate indicator species that react to small perturbations in the ecosystem, allowing the monitoring system operator to understand the direct and indirect ecosystem interactions. The monitoring system also provides the tools such that the operator can recognize seasonal variations and distinguish between significant and insignificant changes in the environment. Sections 2.3 through 2.5 present some of the legal regulations concerning marine monitoring and sanctuaries, the available information and data on the Stellwagen Bank area, and the interested public and private organizations that may influence the design and functionality of the Sanctuary Monitoring Plan.

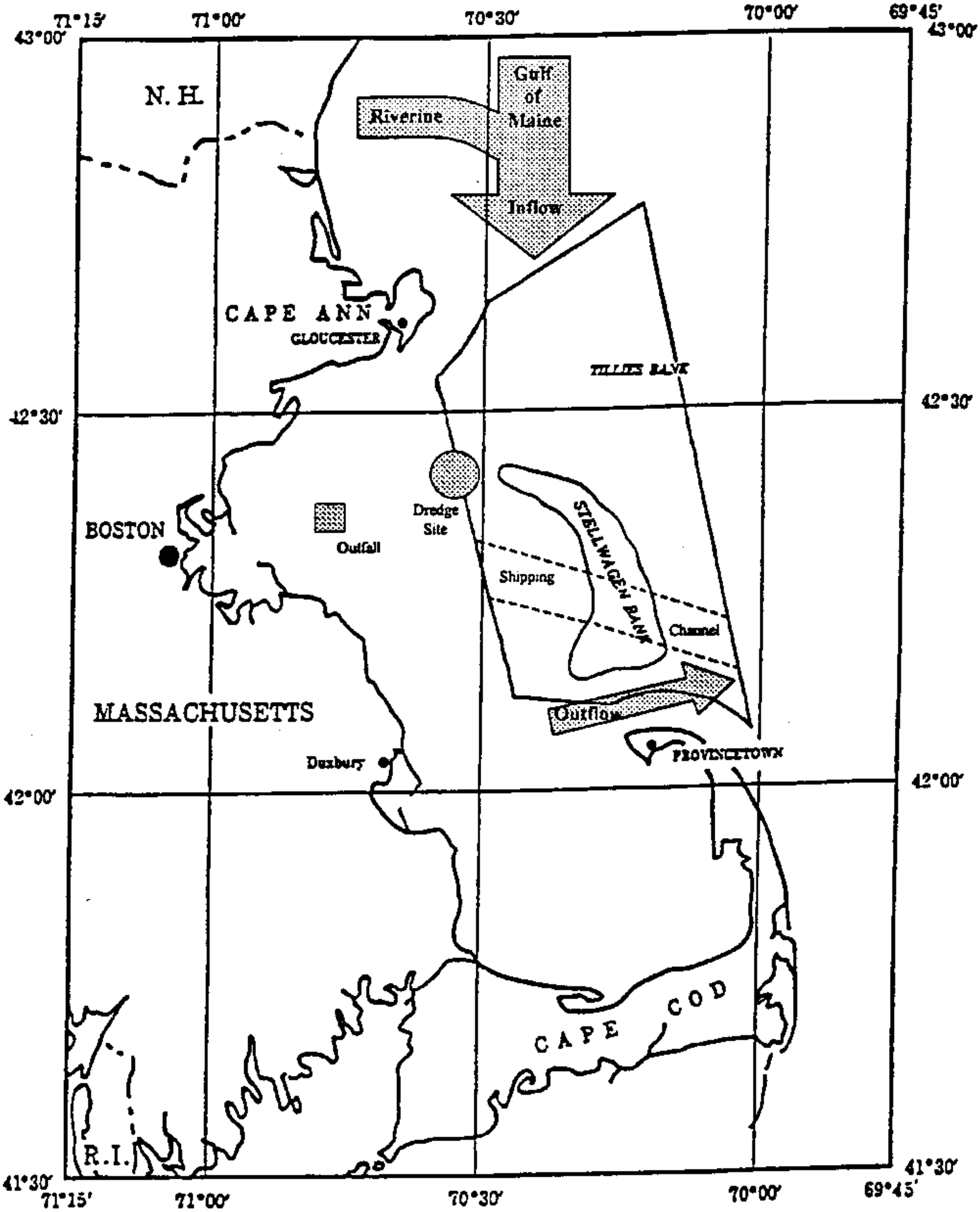


Figure 2.2. Potential Sanctuary Threats

Legal Framework

As stated in the description of the problem, the purpose of this monitoring system is to protect the integrity and sustainability of the Sanctuary. This subsection presents the findings of a comprehensive study of the existing legal framework identifying possible constraints, obligations or limitations specific to the design and implementation of this monitoring program:

According to the 15 CFR Ch.IX §922.1 (a) and (b) 1994 ed. of the National Marine Sanctuary Program, the mission of the program is to identify, designate and manage areas of the marine environment of special national, and in some cases international, significance due to their conservation, recreational, ecological, historical, research, educational, or esthetics qualities. The goals of the program are to:

- Provide authority for comprehensive and coordinated conservation and management of these marine areas, and activities affecting them, in a manner which complements existing regulatory authorities.
- Support, promote, and coordinate scientific research on, and monitoring of, the resources of these marine areas, especially long-term monitoring and research of this areas.
- Create models of, and incentive for, ways to conserve and manage these areas.
- Cooperate with global programs encouraging conservation of marine resources.
- Maintain, restore, and enhance living resources by providing places for species that depend upon this marine areas to survive and propagate.

According to the 15 CFR Ch.IX §922.1, *sanctuary resource* refers to any living or non-living resource of a national marine sanctuary that contributes to the conservation, recreational, ecological, historical, research, educational, or aesthetic value of the sanctuary.

The sanctuary designation standards established in 1994 CFR Ch.XXXII §1433 state:

> The Secretary may designate any discrete area of the marine environment as a national marine sanctuary and promulgate regulations implementing the designation of the sanctuary.

CFR Ch.XXXII §1433 also states that existing state and federal authorities are inadequate to ensure coordinated and comprehensive conservation and management of the area, including resource protection, scientific research, and public education.

CFR Ch.XVI §1440 defines aspects regarding research, monitoring and education and states:

> The Secretary of the U.S. Department of Commerce shall conduct research, monitoring, evaluation, and educational programs as are necessary and reasonable to carry out the purposes and policies of the goals defined under the National Marine Sanctuary Program. [The Secretary] shall take such actions as is necessary and reasonable to promote and coordinate the use of National Marine Sanctuaries for research, monitoring, and education purposes. Such actions may include consulting with federal agencies, state, local governments, regional agencies, or other persons to promote use of one or more sanctuaries for research, monitoring, education, including coordination with the National Estuarine Research Reserve System (NERRS).

Moreover, it is important to highlight four articles of the Marine Protection, Research and Sanctuaries Act (MPRSA):

Article §1441 requires special use permits from the Department of Commerce to authorize specific activities that are compatible with the purpose of the sanctuary. It also requires the Secretary of Commerce and the Coast Guard to initiate comprehensive and continuing programs for monitoring and research regarding the effects of dumping.

Article §1436 states that it is "unlawful to destroy, cause the loss of, or injure a sanctuary resource managed under law or regulations of that sanctuary. It is also unlawful to possess, sell, deliver, carry, transport, or ship by any means any sanctuary resource taken in violation of §1436."

Article §1442 requires a monitoring program to "assess the health of the marine environment, including but not limited to the monitoring of the bottom oxygen concentrations, contaminant levels in biota, sediments, and the water column, diseases in fish and shellfish, and changes in types and abundance of indicator species."

Article §1412 requires the EPA to establish a program for monitoring dredged material disposal sites. Furthermore, it requires the Army Corps of Engineers to make an independent determination as to the need for the dumping.

Article §1401 "prohibits any person from transporting, without a permit, from the U.S. any material for the purpose of dumping it into ocean waters."

Other existing legislation includes the High Seas Driftnet Fisheries Enforcement Act of 1992, which prohibits high seas drift net fishing, and the Magnuson Fishery and Conservation Management Act of 1976, which limits foreign vessel fishing in U.S. waters and mandates the Department of Commerce to provide a Fisheries Management Plan (FMP) for each species.

The Endangered Species Act (ESA), 16 U.S.C. §1531-1543, provides for the protection of endangered and threatened species of animals, plants, and their habitats in both state and federal waters. The ESA accomplishes this by establishing a consultation process designed to ensure that federal projects do not jeopardize the continued existence of endangered or threatened species or "result in the destruction or modification of habitat of such species which is determined adverse...to be critical" (16 U.S.C. §1536).

Somewhat similar are the Marine Mammal Protection Act (MMPA), 16 U.S.C. §1361 *et seq.*, which provides protection to marine mammals and their habitats in both state and federal waters, and the international Migratory Bird Treaty Act (MBTA), 16 U.S.C. §703 *et seq.*, which protects migratory birds.

Finally, the Clean Water Act (CWA) "prohibits the discharge of oil and hazardous substances in quantities that may be harmful to the public health or the environment, such as fish, shellfish, wildlife, public and private property, shorelines and beaches into or upon the navigable waters of the U.S., adjoining shorelines, or into waters of the contiguous zone, or in connection with the activities under the Outer Continental Shelf Lands Act or the Deepwater Port Act of 1974." Included in the CWA is anything which may "affect natural resources belonging to, appertaining to, or under the exclusive management authority of the U.S., except in the case of such discharges into or upon the waters of the contiguous zone or which may affect the above mentioned natural resources, where permitted under the Protocol of 1978 Relating to the International Convention for the Prevention of Pollution from Ships."

The CWA also requires that publicly owned sewage treatment works meet effluent limitations based on effluent reductions attainable through the application of secondary treatment by July 1, 1977 [33 U.S.C. §1311(b)(1)]. The EPA has the authority, however, to waive the July 1, 1977 deadline for secondary treatment for discharges into marine waters under certain circumstances [33 U.S.C. §1311(h)].

Additionally, the CWA requires permits, based on EPA guidelines, from the United States Army Corps of Engineers (USACE) prior to the discharge of dredged or fill material into navigable waters, which lie within three miles of the coast, or territorial seas, outside the three mile range [33 U.S.C §1344].

This overview of the existing legal framework indicates that the MPRSA, the ESA, and the CWA are the primary pieces of legislation with which a National Marine Sanctuary monitoring system must comply. Other legislation has been included in this section to show the complexity and multi-jurisdictional nature of a national marine sanctuary. As stated previously, a program should also account for the possibility of new legislation, especially with respect to state coastal zone management legislation. For these reasons, the monitoring system presented in this document utilizes standards and guidelines from coastal monitoring applications, such as the MWRA, to provide a more than adequate information system and database in the event that regulations change.

Available Information

There are many agencies that are involved in the management and operation of the Sanctuary, either directly or indirectly. These agencies may propose strategies to coordinate their activities with the Sanctuary and/or may provide for periodic evaluation of the overall effectiveness of the management plan. Additionally, these agencies may provide valuable information necessary for establishing baselines. This subsection provides an overview of the general administrative roles of each agency as well as a listing of monitoring programs in the Massachusetts Bay area.

Sanctuaries and Reserves Division

The Sanctuaries and Reserves Division (SRD), an office under the National Oceanic and Atmospheric Administration (NOAA) within the Department of Commerce administers the National Marine Sanctuary Program. SRD prepares a site-specific management plan for each individual sanctuary to ensure the coordination of on-site activities involving resource protection, research, and education/interpretation as well as to ensure consistency with the goals and objectives of the sanctuary.

SRD develops a general budget, setting out expenditures for program development, operation costs, and staffing. It also reviews, adjusts, and annually sets priorities for funding to reflect evolving conditions within the individual sanctuary and within the National Marine Sanctuary Program Priorities and Requirements. Finally, SRD establishes policies and procedures in response to specific issues in each sanctuary.

National Marine Fisheries Service, Northeast Region

The National Marine Fisheries Service (NMFS), within NOAA, implements and enforces a variety of Fishery Management Plans as well as the Marine Mammal Protection Act of 1972 and Endangered Species Act of 1973. NMFS carries out semi-annual trawls, or surveys, of the Massachusetts Bays to assess the finfish populations and analyzing the population data for trends or significant changes. All species caught during the trawls are recorded, but only a few key species data are analyzed; however, the unanalyzed portions of the data are available for analysis by others.

United States Coast Guard

The U.S. Coast Guard (USCG) is responsible for the enforcement of federal laws in waters under U.S. jurisdiction, including those related to vessel traffic and search and rescue activities. The First Coast Guard District office is in Boston, while other Coast Guard stations serving the Massachusetts Bay area are in Gloucester, Scituate, Sandwich, Merrimack River, Provincetown, Cape Cod Air Station, and Woods Hole.

Sanctuary Advisory Committee

The National Marine Sanctuary Program differs from many other special area management programs, in that the sanctuary management serves to enhance research and education/interpretation, as well as to ensure the primary goal of overall resource protection. Several agencies, organizations, and interest groups are already involved with protecting resources and monitoring water and sediment quality within the area of the Sanctuary. The Sanctuary Advisory Committee (SAC) establishes a mechanism to facilitate the participation of interested and appropriate individuals and groups in providing the Sanctuary Manager with recommendations on sanctuary management policy.

The SAC consults with groups, individuals and other agencies to ensure representation of all interested parties and constituencies. For example, interests represented by the SAC should include commercial and recreational fishing, commercial whale watching, commercial and recreational boating, environmental, research, and education groups, and regional ocean/coastal management initiatives. Final selection of SAC members is the responsibility of the Secretary of Commerce, as parent agency to NOAA.

Other Federal Agencies

The United States Environmental Protection Agency (USEPA or EPA), Region I, office in Boston, has regulatory responsibilities over sewage outfalls and ocean disposal activities. The United States Army Corps of Engineers (USACE or COE), New England Division, located in Waltham, MA, provides permits and monitors certain ocean disposal activities. USACE is also responsible for monitoring the dredging and disposal activities in navigable waters.

The Mineral Management Service (MMS), within the U.S. Department of the Interior, is responsible for activities conducted pursuant to the Outer Continental Shelf Lands Act (OSCLA) such as offshore oil drilling.

Coordination with State, Regional, and Local Agencies

In addition to the agencies presented above, NOAA acts as an overview agency to facilitate and coordinate efforts between local and federal agencies. NOAA works closely within the existing administrative framework of the Commonwealth of Massachusetts agencies, such as the Massachusetts Coastal Zone Management Office (MCZM) and the Division of Marine Fisheries (DMF), to ensure a coordinated approach to the ocean and ocean resource management responsibilities of all agencies. It is NOAA's intention to ensure full cooperation and coordination with other state and state/federal programs, such as the Massachusetts Bays Program. This cooperation may involve formalization of *Cooperative Agreements* and/or *Memoranda of Understanding*. NOAA also facilitates the administrative procedures regarding certification and notification of leases, licenses, permits, approvals, rights or other authorizations.

Given the proximity of the Sanctuary to the Commonwealth of Massachusetts, and the close ties between resources of the Commonwealth and those of the Stellwagen Bank area, proposed Sanctuary activities may potentially affect land and water uses as well as natural resources of the Massachusetts coastal zone. These activities will, therefore, be subject to the jurisdiction of the MCZM Program. In addition, these activities, whether they are direct federal activities, which require federal permits, or have federal funding, are subject to review by MCZM to determine whether they are consistent with applicable enforceable MCZM Program policies. The MCZM Program Office determines the consistency of programs with the Commonwealth's enforceable policies, known as the Federal Consistency Review, pursuant to section 307 of the Federal Coastal Zone Management Act and its implementing regulations.

NOAA seeks the active participation of the MCZM Program Office in Sanctuary management issues to draw upon the Commonwealth's experience and expertise in coastal ocean resource management and to provide direct links with relevant Commonwealth environmental management and regulatory agencies. When feasible, both the Sanctuary and MCZM concurrently review proposed activities which are subject to both jurisdictions.

Overview of Existing Monitoring Programs in Massachusetts Bay Area*

*From Ayuso and Pederson. 1992. *Directory of Marine Monitoring Programs in Massachusetts*

Federal

- National Status and Trends (NOAA)
  - Benthic surveillance
  - Mussel watch
  - Special projects
- National Marine Fisheries Service (NOAA)
  - Marine assessment program
  - Habitat assessment program
- U.S. Army Corps of Engineers
  - Disposal area monitoring system
- U.S. Environmental Protection Agency
  - Special projects
- U.S. Geological Survey
  - 3-D model of Massachusetts Bay
  - Sediment mapping of Mass Bay
  - Stream gauge monitoring (2 in MA)
- U.S. Fish and Wildlife
  - Bird monitoring
  - Habitat mapping

Massachusetts

- Department of Fish and Wildlife and Environmental Law Enforcement
- Division of Fish and Wildlife
  Fish and waterfowl special projects
- Division of Marine Fisheries
  - Resource assessment of fish, lobsters and shellfish
  - Paralytic shellfish poisoning surveys
- Department of Environmental Protection
- Division of Water Pollution Control: Technical Services Branch
  - Water quality sampling of estuaries
- Department of Environmental Management
  - Watershed/stream monitoring
- Department of Public Health
  - Seafood market survey
- Metropolitan District Commission
  - Bacterial pathogen surveys for beach safety

Other Programs

- Massachusetts Water Resources Authority
  - Outfall monitoring: baseline assessment
  - Special projects
- Buzzards Bay project
  - Citizen monitoring program
- Massachusetts Bays program
  - Special projects
  - Will prepare a monitoring plan
- New England Aquarium
  Water quality and whale monitoring
- Gulf of Maine: Council for Marine Environment
  - Gulfwatch: mussel bioaccumulation survey
- Local governments
  - Largely shellfish bed surveys and swimming beach safety
- Citizen monitoring programs
  - Largely water quality issues
- Power plants
  - Fish, benthic, water quality surveys

Interested Constituencies

The wealth of the Stellwagen Bank area constitutes an attraction for a variety of interest groups, and it supports a number of activities. Its location in the middle of Massachusetts Bay, between Boston Harbor and the Atlantic Ocean, supports commercial shipping traffic via a shipping lane directly over the bank (see Figures 2.4 and 2.5 at the end of section 2). Furthermore, the

Sanctuary supports a vast array of wildlife including many commercial and recreational fishing species in addition to migratory mammals, offshore birds, and reptiles. An increase in the number of whales in the area over the past two decades has resulted in additional whale watching vessel activity in the Sanctuary. Other relevant activities, e.g., those which may degrade the quality of the Sanctuary, include military activities, offshore oil and gas exploration activities, sand and gravel exploration and/or mining, disposal activities, and ocean discharges.

For convenience, the following sections highlight, summarize, and in some cases reprint, some of the key information presented in the 1993 *Stellwagen Bank National Marine Sanctuary Final Environmental Impact Statement / Management Plan* (SBNMS, 1993). Additional figures and maps from the July 1990 *Supplemental Draft Environmental Impact Statement for the Designation of Dredged Material Disposal Site in Massachusetts Bay: Alternative Site Screening* (Keckler, 1990), have been reproduced in this document with permission from the U.S. EPA, Region I, Boston, Massachusetts.

Commercial Fishing

Commercial fishing is one of the most important economic activities in the New England area, and the New England region is one of the pioneer fishing communities in the United States, dating back to colonial times. Drawn by the great availability of demersal species such as cod, the early immigrants settled in Plymouth on the northern edge of Massachusetts Bay. This immigration led to explosive growth and new fishing industries in the towns of Salem, Gloucester, and Marblehead. By the 1770's, nearly 1500 fishermen operated over 600 cod fishing vessels in the area, leading to strong family fishing traditions (McFarland, 1911 as referenced in SBNMS, 1993). Over the years the fishing industry continued to grow, incorporating new vessels, technology, materials, and nets. Fish landings increased, making Boston the primary fishing port of the area.

In the 1960's and 1970's, not only national but also international trawlers targeted New England, the Gulf of Maine and Georges Bank areas. In 1976, the Magnuson Fishery Conservation and Management Act limited foreign fishing activities in U.S. waters, within 200 miles of the coast, revitalizing the area (MacIssac and Hotz, 1982 as referenced in SBNMS, 1993).

Nonetheless, the U.S. fleet overfished the area, severely depleting fish populations. This overfishing condition finally surfaced in the Georges Bank area in the early 1990's. To rejuvenate fish stocks NMFS officials closed this area to all fishing. In 1990, over 280 commercial vessels fished the Stellwagen Bank area (SBNMS, 1993). NMFS data indicates that fishing revenues for 1990 topped fifteen million dollars from all species sold (NMFS, 1991 as referenced in SBNMS, 1993). According to NOAA's information, the most significant species are:

- Demersals: cod, haddock, hake, pollack, whiting, and cusk
- Pelagics: mackerel, herring, bluefin tuna, swordfish, and capelin.
- Invertebrates: squids, lobsters, shrimps, clams, quahog, and scallops.

Scallop dragging is another area of concern to the Sanctuary. Fishermen drag the silty and muddy areas of Stellwagen Bank for scallops, gouging the bottom and suspending particles into the water column. It is not clear whether this activity degrades the environment from possible resuspension of contaminants and solids and increased turbidity, or improves the benthos by, in essence, tilling the sediment, and thereby aerating it much like a farmer's crop. Figure 2.3, is a USGS side-scan sonar digital mosaic image of the drag marks (indicated by the light-colored tracks) left by bottom trawlers in a section of Stellwagen Bank.

Sport and Recreational Fishing

Sport fishing is a major commercial activity in the area of Stellwagen Bank. There are three types, or sizes, of vessels: party boats which carry between twenty and eighty passengers, charter boats with an average of six passengers, and private rental boats for families or personal recreation. Prior to the mid-1970's recreational fishermen mostly stayed within coastal waters (five miles from shore), but with improvements in marine vessels, the development of the sport, and the opening of different fish markets, the fishermen have since expanded to deeper waters (SBNMS, 1993). Records from 1987 show that statewide, over 195,000 boat trips with a chartering revenue of $9.5 million and private rental revenues of $167 million from 1.6 million trips (Massachusetts Bays Program, 1989 as referenced in SBNMS, 1993). Statewide expenditures for 1987 of nearly 800,000 saltwater angler fishermen, shore and open water fishermen together, total approximately $803 million in related sales (Hart, 1989; NMFS, 1988 as referenced in SBNMS, 1993).

Whale Watching Charters

Since its inception in the area in 1976, whale watching has realized explosive growth. Whale watching trips have become a tourist attraction as well as a recreational and educational activity. The most targeted species are right, humpbacks, fin, and minke whales. Whale watching vessels range from 50 to 140 feet, and they may make one to three trips per day to the Sanctuary area. Statistics of 1985 show that over 9,200 vessel

Figure 2.3. Digital Side-Scan Sonar Mosaic of Bottom Trawl Marks on Stellwagen Bank
(image courtesy of U.S. Geological Survey, Woods Hole, MA)
http://vineyard.er.usgs.gov/images/trawlblowup.gif

trips occurred over Stellwagen Bank carrying over one million passengers. Revenues for 1990 were in excess of $17 million (Rummage, 1990 as referenced in SBNMS, 1993). While whale watching significantly increases the level of human activity in the Sanctuary, it also provides a large quantity of whale watch data that one can use to estimate whale populations in the Sanctuary.

Commercial Shipping

Commercial shipping traffic crossing the Sanctuary has two major sources: vessels traveling in an east-west direction to and from Boston Harbor and those traveling in a north-south direction through the Cape Cod Canal. Those ships traveling in the east-west direction must travel in designated shipping lanes (see Figures 2.4 and 2.5 at the end of this section), which pass north of Provincetown, Massachusetts, at the tip of Cape Cod, directly over Stellwagen Bank, and into Boston Harbor. The principle threat from commercial shipping is oil spills, however even this risk is small (SBNMS, 1993). Statistics from 1990 show an average of 225 vessels per month crossing the area totaling approximately 2,700 vessels for the year. Half of the cargo is oil products, while the other half is bulk cargo, cars, and other products. Fluctuations in maritime traffic in and out of Boston depend on world trade and local markets; however, it is dominated by the movement of petroleum (SBNMS, 1993).

While petroleum shipments into Boston may remain steady in the future, the future shipment of other goods into Boston is not as certain. Recently, there has been a trend towards larger vessels and efficient intermodal systems. Even with the deepening of Boston Harbor, larger vessel traffic will probably not increase (SBNMS, 1993); local needs, therefore, may drive future trends in cargo movements through Boston Harbor. An increase in cruise ships, however, is likely with improvements to Black Falcon Cruise Terminal in Boston Harbor (SBNMS, 1993).

The activities that represent potential sources of contamination from shipping traffic are discharges of oil from tank washing and ballast discharge, lightering from transferring of oil products, and routine discharge of garbage and other materials. Another concern is the risk of collision in the area; in the past decade, there have been 105 vessel casualties in the Massachusetts Bay area, of which ninety-eight involved fishing vessels, and only two were actual collisions (SBNMS, 1993). Vessel collision with whales is another issue to consider in the Sanctuary. In the last two decades, there have been twenty-five right whale mortalities in the study area of the Massachusetts coastline, of which five were attributed to ships. Only one occurred over Stellwagen Bank (NMFS, 1990 as referenced in SBNMS, 1993), however the New England Aquarium has identified several whales with markings indicative of vessel collision (SBNMS, 1993).

Military Activities

The military carries out a number of activities in and adjacent to the Sanctuary. The water exercises include gunnery practice, submarine operations, warship maneuverings, and general operations. Air exercises occur outside of the Sanctuary boundaries, in U.S. Air Force Warning Areas W-103 and W-104A, and include high-speed aircraft operations (SBNMS, 1993).

Offshore Oil and Gas Activities

The planning for and offering leases of Outer Continental Shelf (OCS) acreage for offshore oil and gas activities are the responsibility of the Secretary of the Interior as directed by the Outer Continental Shelf Lands Act as amended (43 U.S.C. §1331 *et seq.*). The Sanctuary lies within the northwest portion of the North Atlantic Planning Area of the Atlantic OCS Region, encompassing waters from New York to Maine. Geological surveys have identified the areas of Georges Bank and the Gulf of Maine as potential hydrocarbon, e.g., petroleum, areas. In 1982, MMS drilled eight wells in the area of Georges Bank; the results were negative. The Coastal States Protection Act of 1995 amends 43 U.S.C. §1337, restricting OCS leases and places coastal state moratoria on "oil, gas or other mineral exploration, or development activities" (104th Congress). This Act was the product of an earlier Presidential moratorium statement of June 26, 1990 concerning offshore oil leases that also added a cessation date for the moratorium of January 1, 2001. With any drilling operation, the Sanctuary must also consider marine transportation of oil and gas products as well as pipe line corridors and possible transportation scenarios based on the potential hydrocarbon discoveries.

Sand and Gravel Mining

Increases in housing and transportation industries in the Boston area have resulted in an increased demand for sand and gravel. The construction of the Central Artery Tunnel, the Third Harbor Tunnel and new Wastewater Treatment Facility create additional demands for building materials. Besides waters just off of Boston Harbor, Stellwagen Bank is one of the principle sources of sand and gravel (Stubblefield and Duane, 1988 as referenced in SBNMS, 1993). The Bank's relatively shallow waters and proximity to Boston make it a prime target for mining operations. Two methods exist for mining sand and gravel deposits: scraping the surface of the bottom by using trailing suction dredges, or excavating pits and tunnels into the surface by using anchored suction dredges; the latter is the more likely method for Stellwagen Bank. Elevated levels of suspended sediment and disruption of habitats are two of the possible threats to the Sanctuary. Additionally, excavation of material from the bank, thereby altering the bathymetry of the bank, may alter circulation patterns (SBNMS, 1993). Inherent to the mining operations is increased traffic over the Sanctuary, subsequently increasing the likelihood of collision and spillage.

Disposal Activities

In the past, various agencies and individuals have used Massachusetts Bay as a disposal site for a variety of industrial waste products and waste materials including industrial wastes, toxic or hazardous chemicals, low-level radioactive materials and dredged materials. Low level radioactive wastes were disposed from 1946 to 1959, and in 1963 the U.S. Coast Guard designated the Massachusetts Bay Disposal Site (MBDS), formerly called the Foul Area Disposal Site (FADS), as an Industrial Waste Site (IWS) for the disposal of toxic and hazardous wastes, which lasted until 1975. In 1977, the EPA promulgated the Ocean Dumping Regulations to control dumping at sea. In order to formally designate the MBDS, the EPA prepared a Draft Environmental Impact Statement (EIS) in 1989 as well as a Supplemental EIS in July 1990. The EPA identified reasonable alternative site locations to the MBDS based on some of the following criteria: costs of dredging, transport, and disposal; navigation restrictions, distance to the edge of the continental shelf, and locations of environmentally sensitive areas (SBNMS, 1993). In 1993, the MBDS was officially designated by the EPA as a permanent site for clean materials only, with the result that the state, EPA and project proponents must find alternative sites for sediments that are not suitable for open ocean disposal.

The EPA has been monitoring the MBDS for chemical concentrations in sediments and biota, and for toxicity, on an intermittent basis, most recently sampling in September 1994 (Liebman, 1995). The EPA is in the process of developing a monitoring plan, based on the DAMOS program, in coordination with USACE (Tomey, 1995). The actual disposal activities at the MBDS are monitored by the Corps so that no disposed material lies within the Sanctuary boundary; however, new findings from USGS indicate that some MBDS disposal operations have been careless, and in some places disposed material violates the Sanctuary boundary (Barr, 1995).

Ocean Discharges

The Massachusetts Ocean Sanctuaries Act (M.G.L.A. c.132A, §12-13) prohibits wastewater discharges into areas designated as sanctuaries. Massachusetts Bay and Cape Cod Bay currently receive wastes from effluent or sludge of approximately 566 million gallons per day (MGD). Of that amount, the MWRA treatment plants at Deer and Nut Islands discharged approximately 500 MGD in 1992 (SBNMS, 1993), but less in more recent years. The new facilities under construction by the MWRA at Deer Island have eliminated the discharge of sludge, and the MWRA is upgrading its facilities to full primary and expects full secondary by 1997. The outfall diffuser pipe, approximately ten nautical miles west of the Sanctuary at its closest point, will not become operational until 1998 (Mickelson, 1995).

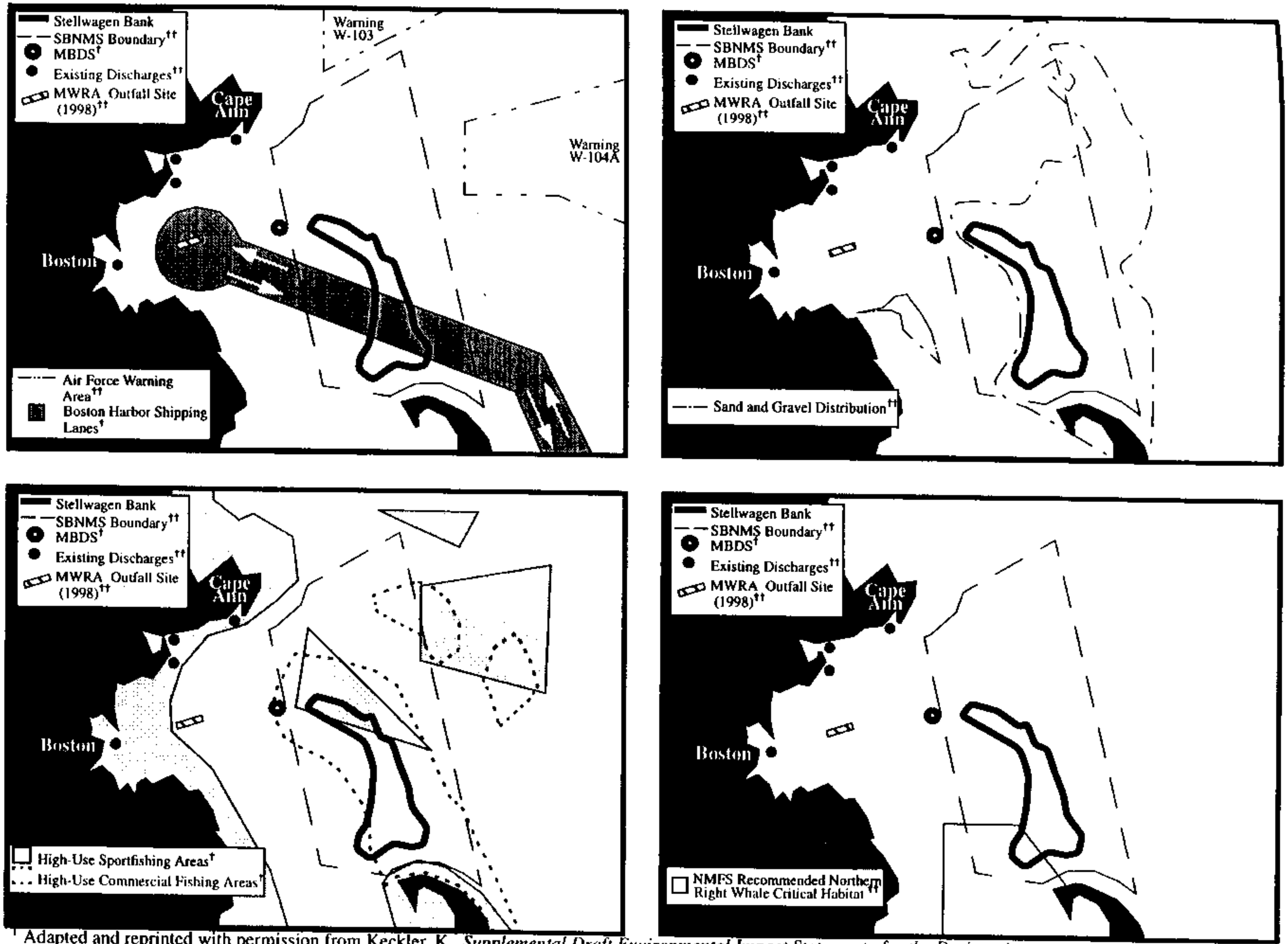
Research and Education

Because of the proximity of the Sanctuary to Boston and Woods Hole, opportunities within the Sanctuary exist for research institutions and educational facilities in exchange for providing the Sanctuary management with valuable data. Some of the participating educational and research institutions include the following:

- Harvard University
- Marine Biological Laboratory
- Massachusetts Institute of Technology
- National Underwater Research Center
- New England Aquarium
- University of Massachusetts
- University of Rhode Island
- Woods Hole Oceanographic Institution

Summary

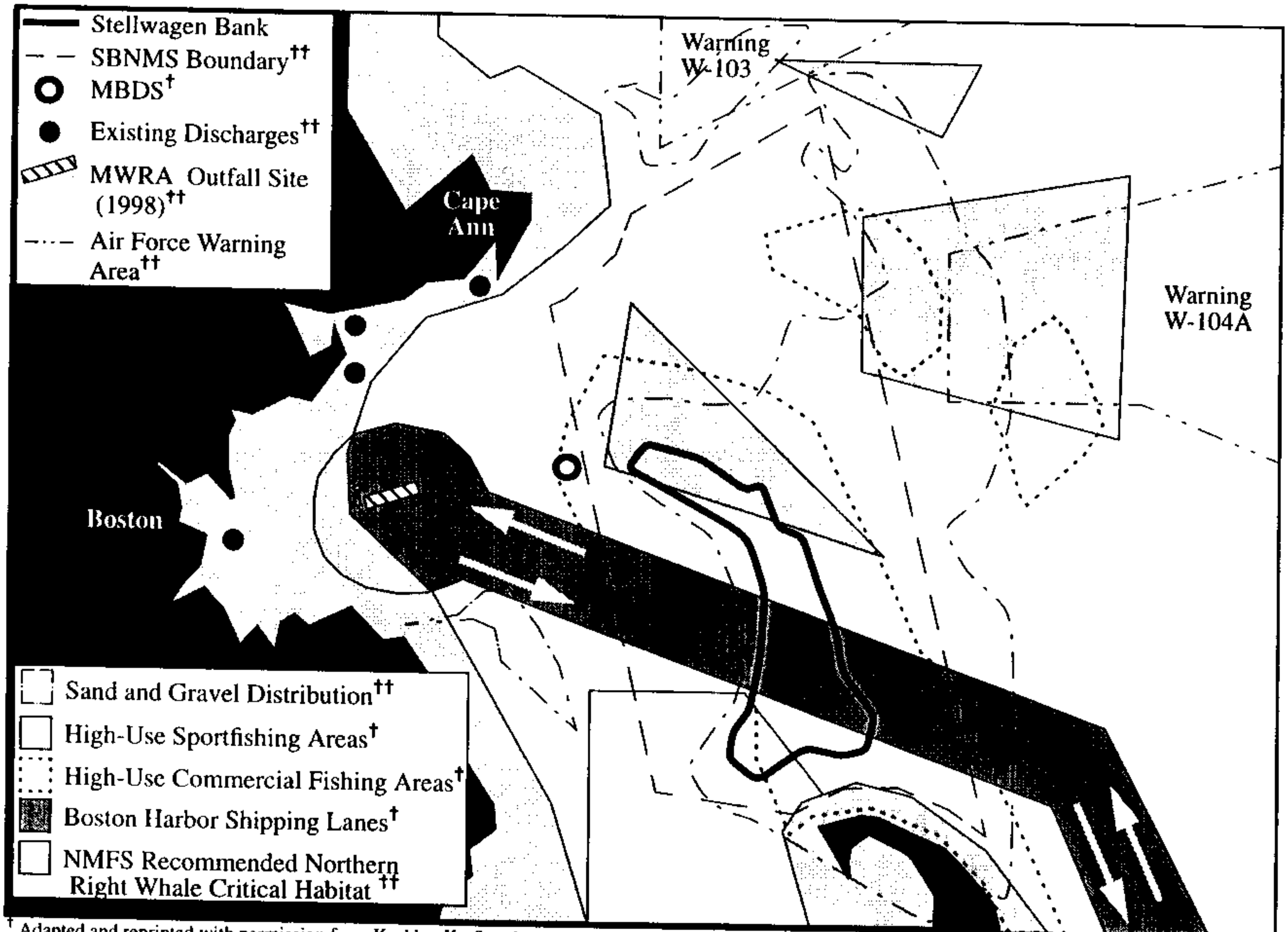
The number and diversity of activities taking place within or around the perimeter of the Sanctuary makes the development of a monitoring system necessary to protect the integrity and sustainability of the area and to provide an early warning to the living and non-living resources of the Sanctuary. Figures 2.4 and 2.5 show this diversity in the Sanctuary area. While Figure 2.5 overlays many different regions, it nevertheless illustrates the high level of activity within and around the Sanctuary. The previous sections help to shape the design and implementation of the monitoring program by identifying the interested constituencies. With this information, the Sanctuary monitoring program (e.g., current management activities) can formulate goals and objectives with which to further focus the monitoring plan (e.g., planned monitoring activities) design efforts.



† Adapted and reprinted with permission from Keckler, K. *Supplemental Draft Environmental Impact Statement for the Designation of Dredged Material Disposal Site in Massachusetts Bay: Alternative Site Screening*, U.S. EPA, Region I, July 1990.

†† Adapted and reprinted with permission from U.S. Dept. of Commerce, NOAA, SRD, *Stellwagen Bank National Marine Sanctuary Final Environmental Impact Statement / Management Plan*, Volume I, July 1993.

Figure 2.4. Sanctuary Diversity and Multiplicity



† Adapted and reprinted with permission from Keckler, K. *Supplemental Draft Environmental Impact Statement for the Designation of Dredged Material Disposal Site in Massachusetts Bay: Alternative Site Screening*, U.S. EPA, Region I, July 1990.
†† Adapted and reprinted with permission from U.S. Dept. of Commerce, NOAA, SRD, *Stellwagen Bank National Marine Sanctuary Final Environmental Impact Statement / Management Plan*, Volume I, July 1993.

Figure 2.5. Sanctuary Diversity and Multiplicity: Overlay

Goals and Objectives

With the formation of a comprehensive problem statement from the identification of the constituencies, threats, and characteristics of the Sanctuary and monitoring system, the next step is to define goals and objectives for the monitoring plan.

Establishing Goals and Objectives

Establishing clear goals and objectives is an important step prior to designing and developing a monitoring plan. The goals and objectives define the priorities of the plan and provide structure to the design process. There are three components that structure the goals and objectives: public accountability, legal requirements, and the monitoring plan design.

Public Accountability

The need for public accountability is an important consideration to assure continued public support. Therefore, public perception and response make up the first component of goals and objectives. If the public is not an advocate of systems that monitor the environment, it becomes harder to justify the existence of the National Marine Sanctuaries Program. It makes little sense to devise a monitoring plan that does not in some way enhance the public's perception of issues that affect their environment.

Apart from the public at large and those constituencies summarized in the previous section, the scientific community and decision makers involved in environmental or social policy are another important constituent. The scientific community is of great significance because the Sanctuary can serve as a scientific laboratory for academic researchers, scientists, and managers in various government agencies and environmental organizations. Apart from the value in the discovery of new environmental problems or complications, a monitoring plan can also provide society with information feedback that demonstrates the significance of environmental issues. Additionally, a monitoring system may help generate positive publicity, and eventually may increase voter support for Sanctuary related issues.

To increase public awareness, an agency must produce and transmit information. The format and presentation of this information is important and varies depending on the target audience. Hence, the format for the scientific data from the monitoring program is also important, not only to drive public opinion, but also to simplify the Sanctuary Manager's decision-making process by providing unambiguous information on the state of the environment. Furthermore, the data transmitted to the public must be meaningful *to the public* such as the status of the whale populations in the southern Gulf of Maine.

Evidently, this first component of goals and objectives is rather broad; however, it becomes increasingly important as the monitoring plan becomes more effective. Since the designers of the monitoring plan are inherently part of the public, and the ultimate beneficiaries of environmental monitoring and improvement, public perception plays a significant role in the design of the plan.

Legal Requirements

The legal requirements that guide the Sanctuary's activities create the second component of goals and objectives. The monitoring plan has to fulfill the requirements for environmental management as stipulated in the bylaws of the National Marine Sanctuaries Program. Accordingly, the goals of the National Marine Sanctuary Program, outlined in Section 2.3 of this document, help to define the framework for the Sanctuary Monitoring Plan.

Monitoring Plan Design

The third component of goals and objectives focuses on the design of a monitoring plan specifically for the Stellwagen Bank National Marine Sanctuary. At this level, goals and objectives must be specific and applicable to the particular characteristics of the Sanctuary. Driving the design and study of the Sanctuary plan are two overall goals: the need for flexibility and reliable baselines.

Flexibility

The monitoring plan has to be flexible and must be easy to understand and use. The third section will present the monitoring strategy, but for the purposes of this discussion, it is important to highlight the objectives that form the guidelines of the monitoring plan.

In developing a monitoring plan, it is important for the monitoring system to have the ability to adapt to additional information or technological innovation, while retaining continuity in the plan. There are several reasons for developing a flexible system, including uncertainty regarding financial resources, inadequate information about the workings of the ecosystem, and technological innovation in the environmental management field.

Reliable Baselines

Uncertainties about the ecosystem and the need for iterative feedback lead to the necessity for reliable baseline data. A baseline is a dataset that serves as a reference and a description of the ambient conditions which may fluctuate daily, seasonally, or yearly. Baseline data, therefore, provides upper and lower bounds of natural fluctuations for environmental parameters such as dissolved oxygen. From baseline data, one can compare new data to determine the present state or condition of the environment. Deviation beyond the natural variability, defined by the baseline data, may indicate a change of inputs into the system, natural environmental changes, or other alterations. The lack of baseline information from which to frame the monitoring plan inhibits the initial design of a monitoring plan because there are no pre-set levels with which to compare later results. The definition and establishment of baseline data are, therefore, two of the most significant objectives. Without baseline data it is difficult to recognize trends or make use of an early warning system that may trigger a more detailed response, lead to modified policies and management decisions, or support enforcement activities. Furthermore, long term monitoring is not possible without having developed standards for environmental quality, and baseline data help set those standards.

Monitoring Plan Goals and Objectives

The needs and constraints discussed above helped to clarify and resolve the goals and objectives of the Sanctuary Monitoring Plan. In summary, the following goals and objectives guide the final design of the monitoring plan for the Stellwagen Bank National Marine Sanctuary:

- Increase overall, general knowledge base of the public, scientific community, policy makers.
- Meet the legal requirements of the Stellwagen Bank National Marine Sanctuary as part of the National Marine Sanctuaries Program.
- Devise a flexible monitoring scheme, available to modification as made possible and/or necessary by technological, budgetary, or other changes.
- Establish baselines to recognize trends, develop standards for environmental quality, and mandate enforcement.

Strategy

Strategy Goals

Once the goals and objectives establish the scope of the project, it is necessary to determine the design constraints that are unique to the Sanctuary, which either hinder or assist in the development of the system. The development of a cost effective monitoring plan hinges on two items: available data and available resources. In this context, *resource* refers to financial, instrumental, and all other kinds of managerial tools necessary to implement a monitoring program; it does not refer to the living and non-living resources within the Sanctuary which are specified as such.

The available data from other organizations that have surveyed the Massachusetts Bay or Boston Harbor are extensive. Due to limited internal Sanctuary resources, including funding, equipment, and personnel, the Sanctuary Monitoring Plan must make use of these available external resources and data.

The fragmentation of the data among the many different organizations, in the form of different formats and processing, poses possible problems in the implementation of the plan. Besides the fragmented nature of the data, the framework for the monitoring plan must also take into account an unknown budget. This framework must maximize the use of available data, and it must utilize the resources that are available to the management of the Sanctuary. Additionally, the framework must adapt to changes in the understanding of the ecosystem and the availability of information. Finally, and perhaps most importantly, it must not compromise the effectiveness or efficiency of the monitoring plan due to the aforementioned system constraints, which eliminates many possible system configurations.

The framework for the Stellwagen Bank National Marine Sanctuary Monitoring Plan is an adaptation of the Disposal Area Monitoring System (DAMOS) tiered approach used by the U.S. Army Corps of Engineers for the monitoring of dredged material disposal sites (Fredette *et al.*, 1986 and Germano *et al.*, 1994). The goal of DAMOS is to assess and determine the level of benthic recolonization in dredged material disposal site sediments, which is a more limited and focused goal than the Sanctuary Monitoring Plan has adopted. The cost effectiveness and flexibility of DAMOS offers a convenient platform for the Sanctuary Monitoring Plan. Figures 4.1 and 4.2 are reprints of the DAMOS tiered model from Germano *et al.* (1994). The figures propose different hypotheses: the first concerning benthic recolonization and the second concerning the effectiveness of dredged material capping procedures. The Sanctuary Monitoring Plan provides a tool for monitoring, but it leaves the development of the hypotheses to the Sanctuary management for the following reasons: 1) the hypotheses may involve tactical, or policy-based, decisions which the Sanctuary Monitoring Plan does not address; and 2) some initial monitoring (implementation) is necessary to create focused and concise hypotheses.

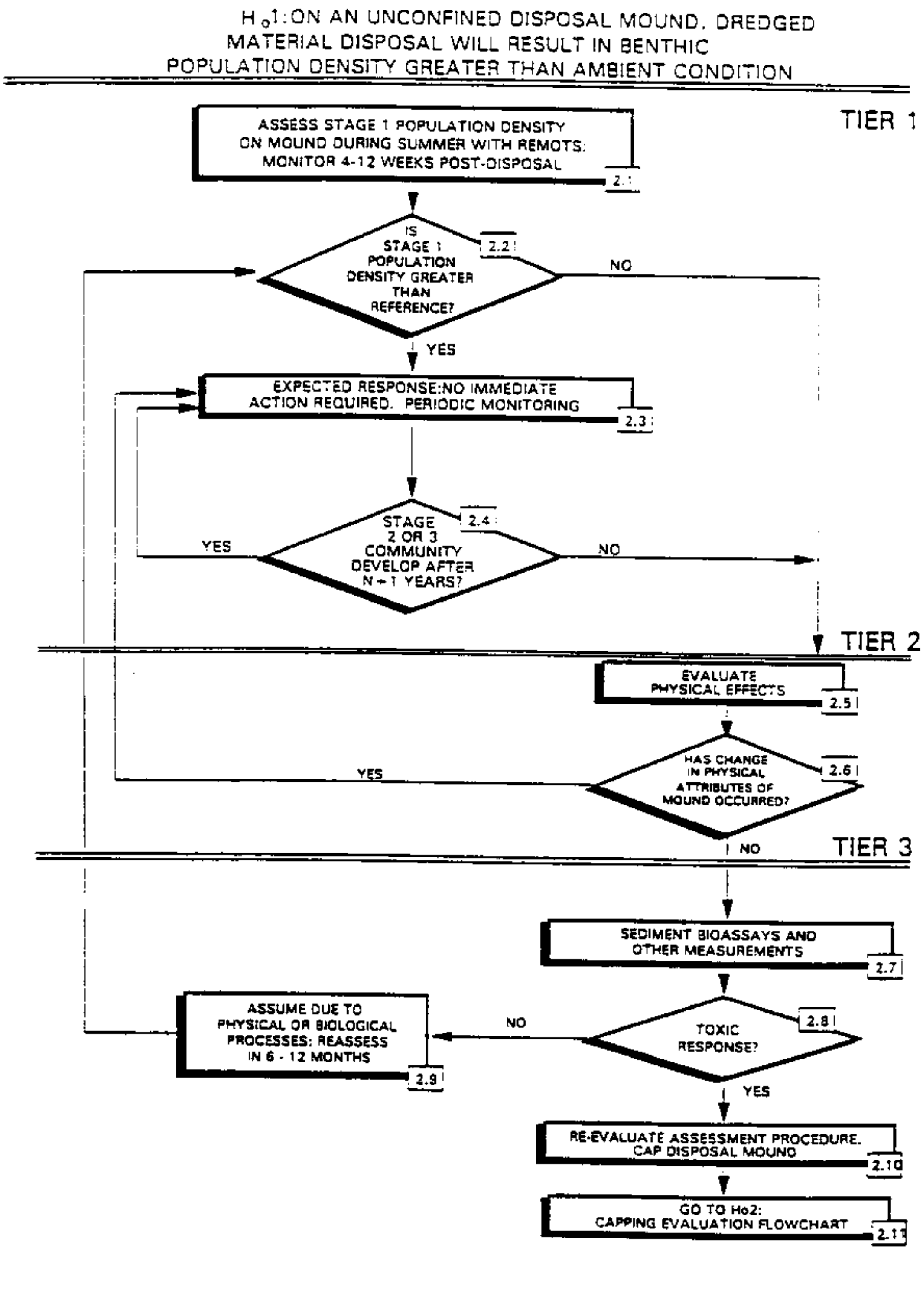


Figure 4.1. DAMOS Tiered Model: Benthic Recolonization
(Germano *et al.*, 1994)

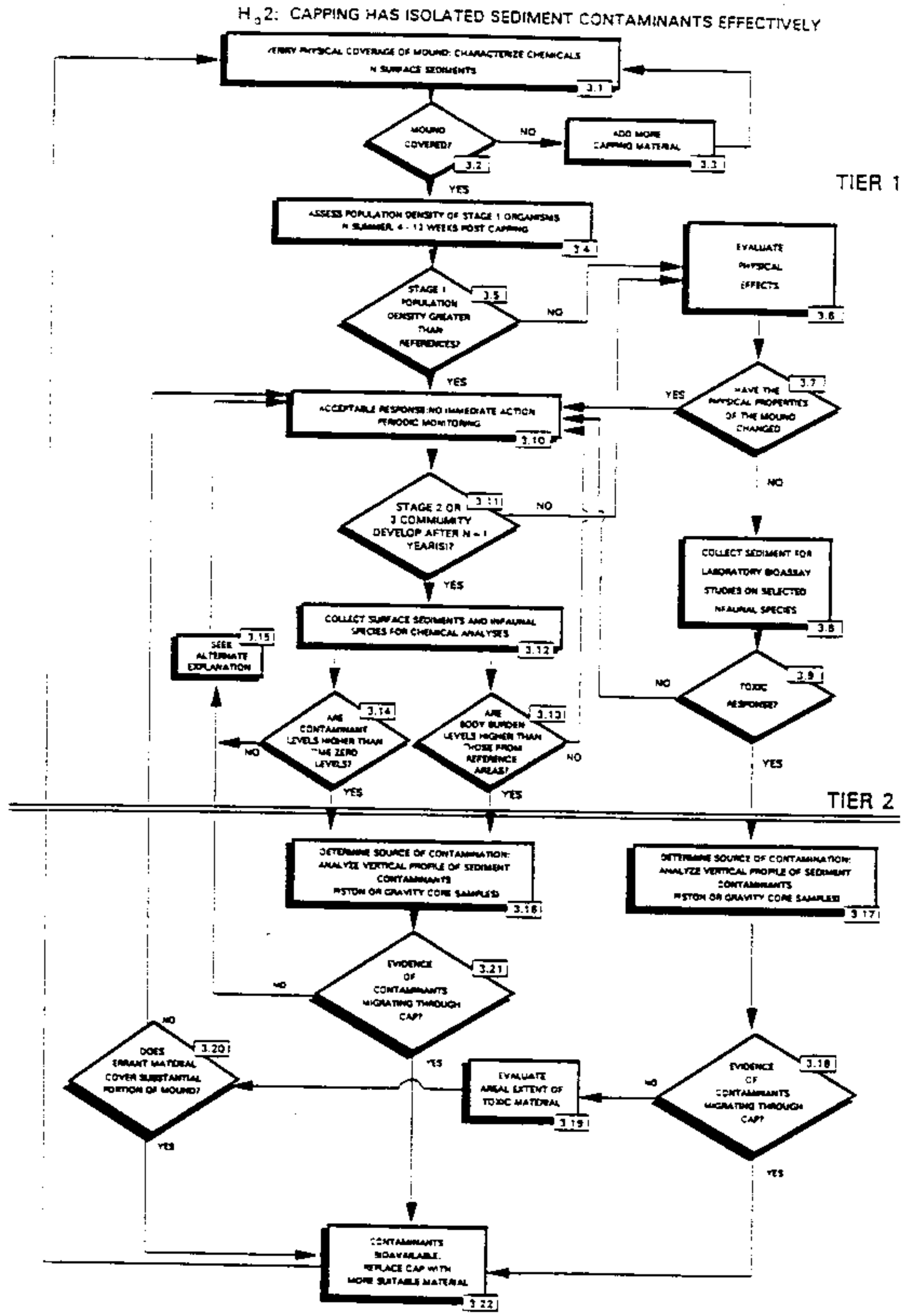


Figure 4.2. DAMOS Tiered Model: Capping Effectiveness
(Germano *et al.*, 1994)

Tiered System Structure

The tiered approach for the Sanctuary Monitoring Plan is structured according to three generic classifications that characterize all areas of potential impact within the Sanctuary: 1) Water Column, 2) Living Resources, and 3) Sediment/Benthos.

Under each of the three classification categories of water column, living resources, and sediment/benthos, there are three tiers, or levels of increasing complexity and cost, with the simpler and lower cost operations performed first (at the top of Figure 4.3) and the more complex and expensive operations performed last (at the bottom of Figure 4.3). Figure 4.3 is a graphical model of the generic structure of the Monitoring Plan, showing the three tiers within the three categories; arrows indicate links. The three tiers of the Monitoring Plan model, in order of increasing complexity and cost, consist of 1) indicators of change, 2) identification of perturbation, and 3) sources of perturbation. Each tier contains indicator variables of the three inter-related (e.g., water column, living resources, and sediment/benthos) environments and the tools, instruments, and equipment necessary to measure or monitor each variable. Links, connecting the three tiers in the model, direct the user to the next, more complex level or tier, indicating a need to obtain additional information about a variable in order to more fully understand trends in the data obtained at the current level of complexity. With this tiered approach, all variables may be inexpensively measured at the first tier using standardized equipment and methods, allowing the Sanctuary management to broadly monitor the Sanctuary to obtain baseline data and characterize the environment.

The tiered system is a modular approach, allowing for changes in the program description and design as baseline data grow and system parameters change. The plan allows the Sanctuary Manager to be selective about which parameters to pursue once the system raises a warning flag. A warning flag, threshold, or trigger, is an undesirable level in one or more measurements, as demonstrated in MWRA's Phase II Monitoring Plan (MWRA, 1995a). A Sanctuary monitoring program may adopt various levels of warning flags from undesirable levels to danger, or unacceptable, levels based on federal, state, or local standards. The modularity in the tiered approach allows a program to select or ignore a link, or branch, according to scientific importance, available resources, or new information about activities within or impacting the system. Furthermore, the tiered system in Figure 4.3 provides for both top-down and bottom-up approaches. In its most efficient form, the operator follows the tiers top-down, keying off of indicators in the first tier to identify the most probable sources in the third tier; however, if a known source is introduced into the system, then the operator can follow the links up the model to find the most greatly affected indicators. By using this approach, the operator can focus resources on those indicators.

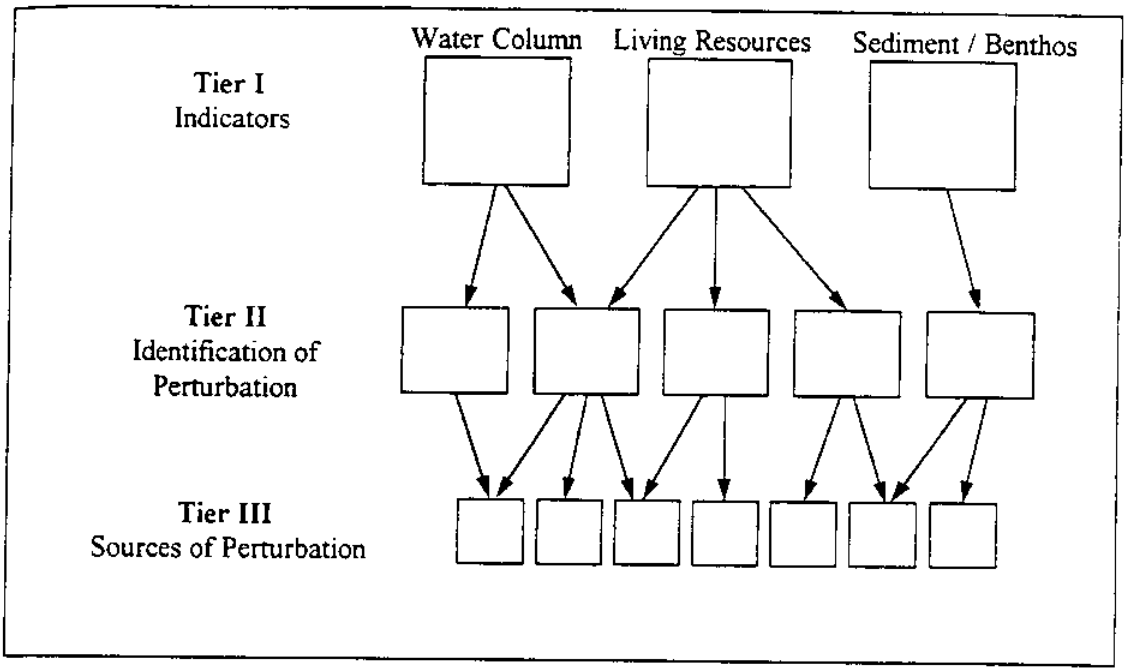


Figure 4.3. Three-Tiered Strategy

Tier I: Indicators

The tiered approach maximizes the price performance of the plan to its operators, yet maintains the flexibility to respond to a wide range of problems in the system. By focusing on parameters that are easy to monitor, or are currently available through the programs of other agencies, the plan can examine a wide range of indicators at minimum expenditure to the monitoring program. Although the performance of any one of these indicators may be the result of several causes, the tiered arrangement and links help to focus the monitoring efforts before the program undertakes the more costly and time consuming surveys of the more complex Tier II and Tier III.

Tier I variables, or indicators, in the Sanctuary Monitoring Plan react quickly to changes in the system and may give advanced notice of upcoming events such as algal blooms. Tier I parameters are primarily indicators of change, but they do not necessarily indicate changes due to human-induced perturbation in the ecosystem. These changes are based on a comparison of the newest data with prior baseline monitoring survey data from which ambient and trigger (e.g., significantly above or below ambient) levels (MWRA, 1995a) are determined. Tier I indicator variables may also act as early indicators of larger and more serious problems in a broad range of areas. The Sanctuary management may measure all of the Tier I indicator variables, either using *in situ* measurement methods or through cooperative efforts and legal means at the disposal of the management of Sanctuary. The Sanctuary management may already own the necessary equipment to measure the Tier I variables, or it may use equipment and resources from other agencies such as National Marine Fisheries Service (NMFS). By using data collected by others when available, the Sanctuary Monitoring Plan avoids unnecessary, costly, and redundant sampling and monitoring efforts. Hence, the Sanctuary management can measure most of the Tier I variables with minimal effort or direct cost to the monitoring program. This statement does not take into account other inherent costs of ship time, equipment maintenance and calibration, and data analysis and processing, but the Monitoring Plan recommends dovetailing (e.g., using ships of opportunity) operations whenever possible.

Tier I model items include water quality variables, such as temperature and dissolved oxygen, living resources, such as the population of a marine species, and sediment/benthos variables such as bivalve studies (additional details of these variables and their use in the Sanctuary Monitoring Plan are given in section 5). Again, these may be variables that other agencies monitor within the Sanctuary boundary, providing a viable and inexpensive route to collect data; however, the Sanctuary management should verify data that has been collected from other agencies for reliability, accuracy, and quality assurance.

Tier II: Identification of Perturbation

If an indicator level at Tier I in the model is not within the bounds of a prescribed threshold or trigger level, a monitoring program may initiate activities at Tier II to try to identify the perturbation and the extent of the problem. Operations at Tier II may be considerably more expensive than those at Tier I because of increased precision and the need for extensive laboratory analysis. In some cases, especially for living resources (as section 5 will describe), a variable that acts as an indicator at the Tier I level may also be a Tier II variable, with the difference being the intensity and complexity of the analysis of the variable (e.g., population studies at Tier I versus tissue analyses at Tier II). The links from Tier I to Tier II focus monitoring efforts on those indicators that may lead to the identification of the most probable perturbation (e.g., nutrient loading, contaminants, etc.) responsible for the undesirable level detected at Tier I.

For instance, a decrease in dissolved oxygen (Tier I) in the water column may be the result of increased phytoplankton activity or input of organic matter into the system. To determine the cause of the undesirable decreased levels of dissolved oxygen, the Sanctuary management may undertake Tier II studies of phytoplankton and nutrients to determine which, if either, of the suspected causes has occurred. Thus, Tier II studies can be thought of as additional information that helps to identify the perturbations, such as nutrients or toxins.

The gathering of Tier II data is quite tedious, involving labor intensive collection methods and costly laboratory analyses. *In situ* data collection methods are not usually possible at the Tier II level because a higher level of information than that provided by *in situ* instruments is required. In Tier II, the Sanctuary management must perform these costly analyses, such as water column chemical analyses, tissue analyses, and sediment grab sample analyses, in a laboratory, but these techniques result in higher costs and increased time lag between the event and the usable data. These costs may be outweighed by the increased level of information; however, as with any environmental variable, data may be highly variant, and a small increase in the level of information about a variable may not be worth the added cost.

Tier III: Sources of Perturbation

As in Tier I, changes in Tier II variables beyond trigger levels indicate that further study is needed to identify the cause or source of the perturbation, which is referred to as Tier III. Tier III is intended to provide the most probable sources of the change, or perturbation, in system inputs, and it links these probable sources, or causes, to the situation described by earlier investigations. A change in a single indicator variable may be due to a combination of multiple sources or causes. For example, an increase in turbidity may be the result of increase freshwater flow from the Gulf of Maine, the sewage outfall, the disposal site, a recent storm, or it may be a combination of these. Alternatively, a single source may cause changes, or have effects, on several indicator variables. Increased turbidity from dredged material disposal, for example, may lead to decreased levels of dissolved oxygen, increased turbidity readings, and/or benthic organism mortalities. In essence, Tier III actions involve the tracing of the offending inputs back to their source(s). Studies undertaken in Tier III are potentially the most expensive and may require increased monitoring and analysis in time and/or space.

As a practicable approach, one can display causes and effects in a matrix format independent of the rest of the model. The matrix, shown in the fifth section of this document, provides a simple means for cross-evaluation of multiple potential sources of perturbation to the system. The matrix can identify natural fluctuations and human induced sources as well as combinations of input factors, in some cases. The matrix, however, is somewhat idealistic because it does not take into account problems associated with dilution and dispersion of a source's "signal", but the matrix does provide a starting point from which to initiate Tier III monitoring efforts. For the Sanctuary, there are several distinct point sources of pollution, as identified in section two, that may contaminate the water, benthos, or living resources. The matrix identifies these point sources and characterizes their impacts. Prior extensive studies in the Massachusetts Bay area have documented and characterized many of the obvious sources, reducing the amount of research that would have to be done to trace an input back to its source. The burden of responsibility belongs to the Sanctuary management to evaluate all potential sources of perturbation and to weigh each threat appropriately.

As new information becomes available, some sources may assume greater importance. The management must not ignore sources, such as agricultural runoff or atmospheric deposition, for which the model, matrix, and studies may not account. In this case, if all other possible sources have been eliminated, and impacts from the unknown source(s) are substantial, then the management, as an example, may add agricultural runoff and/or atmospheric monitoring to the Sanctuary Monitoring Plan model. Under these circumstances, **Atmospheric** and **Land-based** may be additional classifications within the structure of the Monitoring Plan, along with water column, living resources, and sediment/benthos, under which would be three tiers of increasing cost and complexity. The impacts from non-point sources have not yet been shown to be substantial enought to justify direct monitoring by the Sanctuary management, and therefore these classifications do not appear in the Sanctuary Monitoring Plan.

Specification Sheets

Specification sheets were developed to standardize the record keeping format and facilitate easy access to the multiple components of the model structure. Specification sheets for each item in the Monitoring Plan appear in the Appendix of this document, and they summarize existing studies, trigger levels, necessary equipment for continued monitoring, and information concerning the item being monitored. Not every item in the Monitoring Plan fits readily into a single format, but most items can be grouped with a fair amount of uniformity. All specification sheets provide justifications for using each variable in the Monitoring Plan, however, some of them provide up-to-date monitoring information, while others provide only historical monitoring information from which to base and develop further monitoring. Specification sheet entry fields include the following fields:

- Monitoring Status
- Can the Sanctuary Manager Do It?
- Purpose for Study
- Alternative Methods
- Estimated Cost
- Trigger Level*
- Existing information, studies, and data
- Method of Other Survey
- Sampling Required
- Accuracy of Measurement
- Source of Trigger Level
- Typical Range of Measurement
- Baseline Available
- Equipment Required
- Links (to other items)

*Many of the trigger levels in the Sanctuary Monitoring Plan are adapted from unpublished or DRAFT MWRA reports. The editors gratefully acknowledge the work done by the MWRA as well as any agencies which may have provided information to the MWRA.

The use of specification sheets facilitates the conversion of the model into a computer database format. The computer version allows for relatively simple and quick movement through the model while retaining all of the necessary information. The information contained in the specification sheets provides quick reference to the available data at each node, or link, of the structure, and they provide a starting point for more in-depth analyses.

Links Between Tiers

The links between tiers of the model embody and characterize the three components of baseline data, trigger levels, and hypotheses.

Baseline data determine the natural ranges and variability of the monitored parameters within the system. These data provide a range of expected values for the parameters, and thus define levels of meaningful change. An adequate baseline allows a program to distinguish expected events, such as seasonal fluctuations, from other anomalies that represent a change in the inputs to the system. This clarification and negation of anomalous flags further strengthens the power of the system.

The meaningful change levels establish trigger, or threshold, levels.* Since the deviation, or meaningful change, occurs only when there is an undesirable change to system inputs, the program should investigate and evaluate any above-threshold level for impact to the system. Thus, the trigger values on one tier alert the user of the system that information from the next tier is necessary.

To build a reliable baseline from which to determine threshold levels, several years of monitoring data may be necessary. This multiple year plan assures that the monitoring program fully characterizes the natural, seasonal, and singular fluctuations in the system, such that the user has sufficient confidence in the statistical power of the data. Thus, a monitoring program's threshold levels for the first few years of operation may be changed as additional information is obtained and incorporated into baseline information.

Unfortunately, baseline data for the Sanctuary Monitoring Plan are somewhat fragmented, unavailable, or insufficient, which makes setting threshold levels for system parameters, using statistical analysis, quite difficult. To alleviate this difficulty, the Sanctuary model uses threshold levels from other agencies doing similar monitoring, or it uses thresholds from state and federal

* The concept of using meaningful and detectable change levels to non-numerically describe the severity of a variable's impact is from the *DRAFT Massachusetts Water Resources Authority Effluent Outfall Monitoring Plan: Phase II Post Discharge Monitoring*, MWRA Environmental Quality Department, Boston, MA, January 13, 1995.

regulations. Often these other agencies have set thresholds based on percentages of state or federal regulations. For example, for the levels of heavy metals in fish and shellfish tissues, the MWRA has set warning levels and action levels: the MWRA warning levels are half of the FDA standard, while their action level is the same as that of the FDA (MWRA, 1995b). All of the MWRA thresholds, however, are not based on fixed regulatory values, and in some cases, MWRA has defined its own thresholds based on field studies, observations, and informed scientific opinion. While these latter thresholds are not regulated by federal or state environmental agencies and lack the regulatory enforcement, they may provide future regulatory thresholds. The Sanctuary management should consider all trigger levels, MWRA-derived and otherwise, temporary and should update them as new data become available.

Once baseline data, regulations, or other means define the trigger levels, a program can formulate hypotheses to identify the most probable causes for conditions of above-threshold levels. For any parameter, there may be several possible sources that can perturb the system enough to move the value of the parameter outside of the expected range. Each of these hypotheses creates a link from the parameter that has reached a trigger level to a parameter on the following tier that may explain the change. Thus, one can consider the action of following a link and performing the tests required at the next level as testing a hypothesis. As an example, if there is an increase in a Tier I parameter above the specified threshold level, this indicates that the program should initiate studies in Tier II to identify the cause of the change in Tier I. Then, for each Tier II parameter that connects, or links, to the above-threshold Tier I parameter, there is a hypothesis, which may state that that the change in Tier I is a result of the perturbation in Tier II, that must be proven or disproven. By proving or disproving each of the hypotheses stemming from the Tier I parameter, the program can maximize cost efficiency by targeting those causes associated with the disproven hypotheses; this expedites the identification of the cause and facilitates the progression to Tier III. The Sanctuary management, therefore, must test these types of hypotheses, according to and constrained by the available resources, to evaluate the current situation in the Sanctuary.

Advantages of the Sanctuary Monitoring Strategy

The obvious advantages of this tiered system stem from its modularity. The plan can adapt to expanding knowledge and inputs to the system as well as uncertainty of resources. In addition, by delimiting the natural region into the three broad headings, or classifications, of water column, living resources, and sediment/benthos, the plan characterizes and classifies all of the attributes of the Sanctuary. This approach also allows for future expansion through additional headings, such as human activities, as well as greater potential for subdivision within the classifications at each tier. While it is reasonable to generate a structure with greater detail, it is impractical given the current Sanctuary resources.

Furthermore, the modularity of the plan allows the user to continuously evaluate and pick and choose the items that best suit the program's available resources and current scientific aims, as monitoring direction may change with changing parameters. This multiple entrance approach provides for the most cost-efficient plan. The flexibility of the plan, while providing modular control, also permits top-down and bottom-up operation depending on the situation. Figure 4.4 shows the multiple entrance and vertical flexibility of the Sanctuary monitoring model.

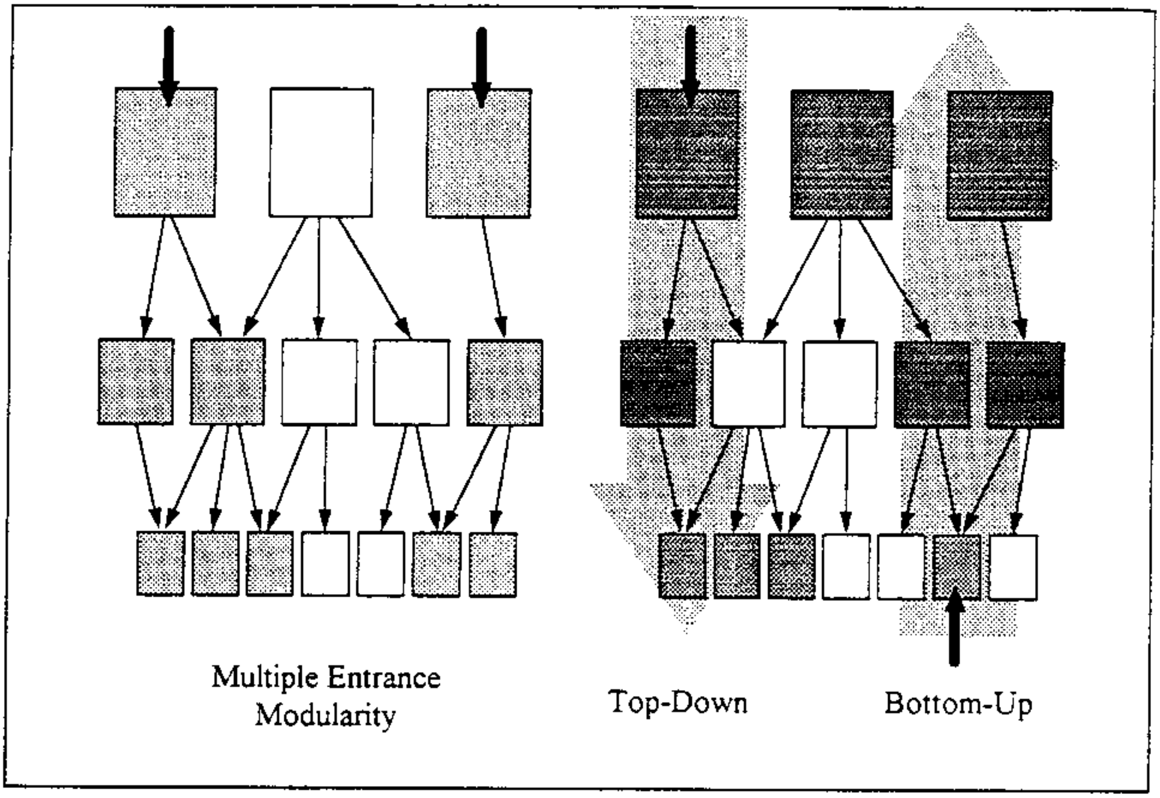


Figure 4.4. Advantages of Tiered System

The tiered approach allows for the biggest gain for the least expense at the first tier. The initial indicators are simple changes in the ecosystem which do not require extensive analysis to recognize or understand. The necessary instrumentation and equipment used in Tier I is relatively inexpensive, or currently available to the Sanctuary, and each measurement has well documented methods and procedures. Tier I parameters act as indicators for many adverse situations, yet they do not require the time and costs of intensively monitoring only a single one of these activities, providing broad coverage for minimal cost. While broad coverage may not appear ideal, the model only considers the false, or disproven, hypotheses, thereby narrowing the breadth of the problem. Finally, other monitoring agencies have already shown the effectiveness and justified the use of many of the indicators that the Sanctuary Monitoring Plan incorporates, further strengthening the model.

Disadvantages of the Sanctuary Monitoring Strategy

The biggest disadvantage of the tiered approach is that it neglects Tier II parameters until Tier I indicates an undesirable condition in the Sanctuary. This means that the program loses the opportunity to establish baselines of data on important Tier II parameters such as nutrients and pathogens. The importance of a baseline for these data is clear to many, but the required costs are too much for any monitoring program to bear. Fortunately, some Tier II baseline data exist from other agencies, but the Sanctuary management must first process these datasets into useable formats.

Another disadvantage of the monitoring plan is that the first tier, in some cases, monitors the *indicators* of changing parameters, and not the parameters themselves. There may be a time lag between a dangerous increase in one of these parameters and the indicator for it. This condition may lead a manager into a false sense of complacency, only to be shocked by a "red flag" that an indicator raises after the possible detrimental effects occur. For instance, the Sanctuary Monitoring Plan recommends the monitoring and measurement of chlorophyll-a. Chlorophyll-a is an indicator of phytoplankton, and it may not provide a measure of the health of the phytoplankton as a physical sample would. A manager may also overlook potential threats that result from a combination of circumstances on Tier I because the structure does not account well for interactive effects. Indicators in two or more fields may not be cause for alarm taken independently, but if considered together, the system may raise a warning flag. For example, an increase in nutrient levels may not be a problem. However, this increase, taken in addition to a decline in the level of dissolved oxygen or increase in chlorophyll-a, may be cause for alarm.

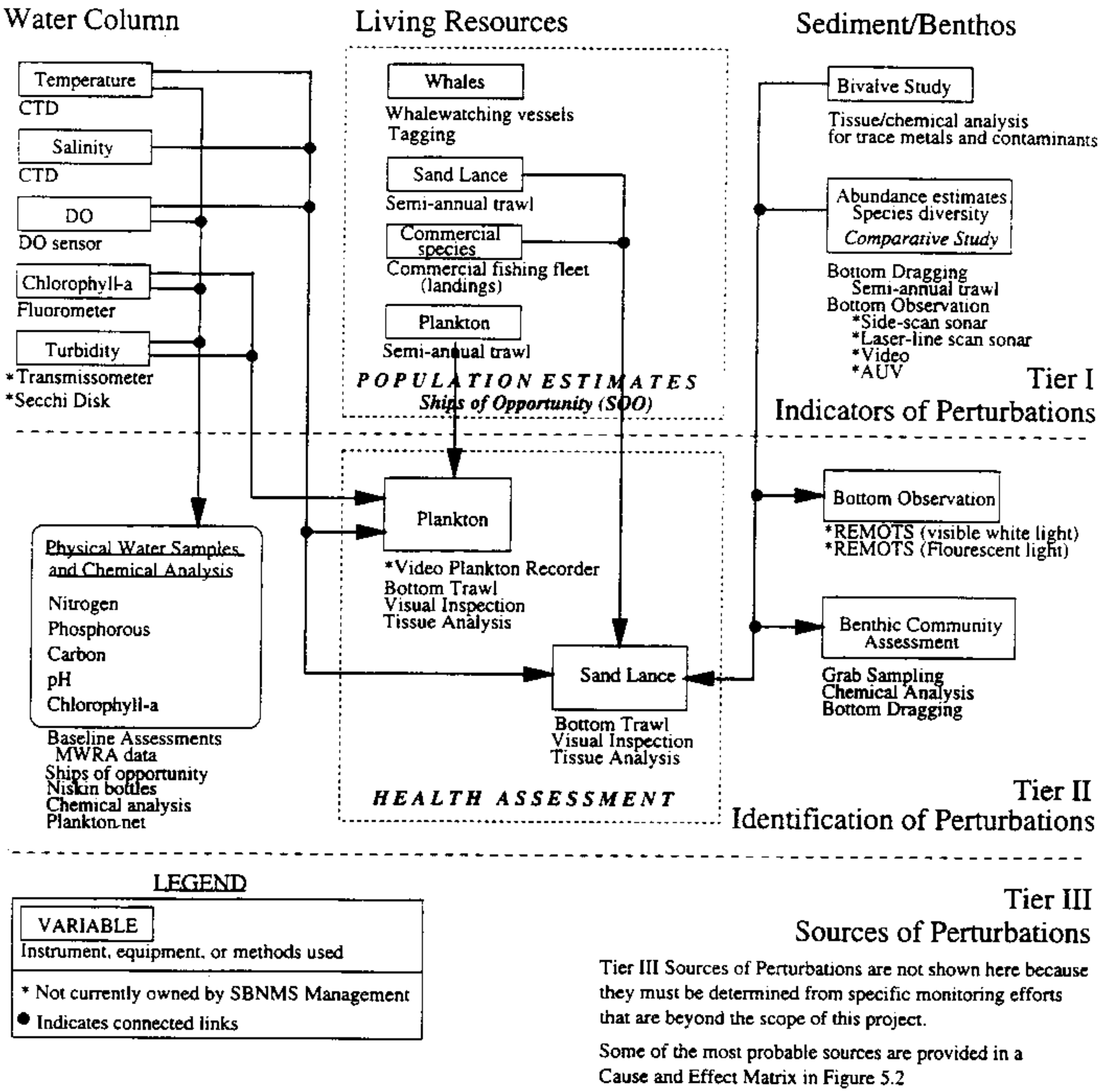


Figure 5.1. Sanctuary Monitoring Plan Model

Details of the Monitoring Plan

This section discusses the three tiers of the Stellwagen Bank National Marine Sanctuary Monitoring Plan. One can further define the generic three tiered structure (Figure 4.3), detailing individual parameters at each tier. Breaking down the first tier into water column, living resources, and sediment/benthos, indicator parameters emerge. The indicators in Tier I help to define the paths to Tier II. Tier II provides methods and collection procedures to identify the perturbations that cause the fluctuations in Tier I and eventually point to possible sources of the perturbation in Tier III. While the Sanctuary Monitoring Plan provides the framework and initial structure for the monitoring of the items in the model, this monitoring can be better tailored to the needs of the Sanctuary management by formulating hypotheses. The Sanctuary Monitoring Plan allows the management to derive these hypotheses based on current concerns and threats to the Sanctuary. Over time, indicators may change as a result of changing conditions in the Sanctuary. Figure 5.1 on the previous page shows the first two tiers of the Sanctuary Monitoring Plan model.

Tier I

Monitoring indicator items at Tier I will provide useful, meaningful, and detectable changes, or flags, of perturbations to the ecosystem. Besides providing flags, Tier I components provide relevant baseline data simply, inexpensively, and consistently. All Tier I items are good indicators of the state of the ecosystem and have been chosen because they are easy to monitor.

Water Column

The Sanctuary Monitoring Plan monitors water column parameters such as salinity, temperature, dissolved oxygen, chlorophyll, and turbidity at the Tier I level (see Figure 5.1).

Salinity and Temperature

Salinity and temperature are two parameters that define the basic water column stratification for chemical, physical, and biological analytical purposes. Both items vary with depth and cause density to increase with depth. Measurements of temperature and salinity can indicate large increases in density where mixing between shallow and deep waters may be inhibited. Temperature and salinity experience seasonal fluctuations, and if they vary markedly from these seasonal levels, the effects can destroy much of the Sanctuary ecosystem since the saturation level of oxygen, necessary for respiration, depends on temperature and salinity. Furthermore, marine organisms inhabit waters within limited ranges of temperature and salinity. If temperature and salinity do change significantly from their seasonal levels, the organisms must move away or die. A change in temperature and salinity indicates a shift in inputs to the ecosystem, most likely an indication of changing sources of water such as unusual inflow from rivers and/or the Gulf of Maine (Hotchkiss, 1995). Changes in temperature and salinity are not likely to be the result of human influences. Because temperature and salinity cannot be controlled or regulated in the marine environment, and they both vary seasonally, there are no trigger, threshold, or typical range levels defined for these parameters. The Monitoring Plan, therefore, uses temperature and salinity data to help in the interpretation of other water column data. The Sanctuary management must measure and monitor temperature and salinity, which may indicate changes in density, help to identify water masses and indicate changes in water inflow, and correlate levels of dissolved oxygen with other water column parameters. Temperature and salinity can be measured using a CTD (Conductivity, Temperature, and Depth), such as that owned by the Sanctuary management, to inexpensively obtain vertical profiles of these two parameters in the water column. A CTD is easy to use and relies on electronic sensors to provide real-time, *in situ* data collection.

Dissolved Oxygen

The measurement of dissolved oxygen (DO) is important for a number of reasons. DO is a requirement for the survival of all of the Sanctuary organisms, as oxygen is critical for the respiration of many living organisms. DO may be related to increased levels of nutrients or other organic matter which may result in increased productivity, creating a high oxygen demand. A rapid decrease in DO, for example, may be indicative of a possible algal bloom. Possible sources of organic matter include the MWRA outfall and the MBDS as well as inflow from the Gulf of Maine. Dissolved oxygen should not be considered an early warning indicator because the resulting level of DO may be an integration of a number of changes to the marine environment. DO can be measured using an electronic sensor, currently owned by the Sanctuary management, making DO an inexpensive indicator of ecosystem-threatening situations.

Chlorophyll-a

Nutrient enrichment in Stellwagen Basin, located just west of Stellwagen Bank and within the Sanctuary perimeter, is a major concern because of the fragility of the ecosystem and the nature of the inputs to the Sanctuary. Because of the increased depth of the Basin, with surrounding bathymetry sloping downwards towards the Basin, it acts as a sink for nutrients, organic matter, and other suspended material, resulting in lower DO values. Chlorophyll-a is the most commonly used indicator of phytoplankton biomass, which, itself, is an indicator of nutrient availablilty and concentrations. The benefit to using chlorophyll-a as an indicator is that there is a direct relation between it and phytoplankton populations, and as such, is a better indicator of possible blooms than DO. The EPA has adopted chlorophyll-a as the standard type of chlorophyll for measurement of algal activities. Chlorophyll-a levels can be measured using a device called a fluorometer, such as that currently owned by the Sanctuary management.

Future considerations for chlorophyll monitoring should include remote sensing, using satellite images to monitor chlorophyll levels as availability and costs of satellite images allow. Government agencies such as NOAA and USGS, are currently using Landsat to measure these levels. In the near future, a new satellite will be launched with an instrument called Sea-viewing Wide Field-of-view Sensor, or SeaWiFS, for broad scale chlorophyll monitoring. Satellite images would enable the management to study chlorophyll concentrations of the entire Sanctuary at an instant in time, however this technology requires simultaneous ground truthing and periodic *in-situ* measurements to be truly accurate. These "snapshots" can be compiled to provide a continual baseline for the area.

Turbidity

Turbidity is a measure of the amount of suspended particles in the water column. It is of concern in Stellwagen Basin because the suspended particles may include organic matter and/or phytoplankton. In addition, high turbidity levels prevent the penetration of light that is necessary for photosynthesis and other essential functions. These are all of interest when attempting to assess the health of the ecosystem. A transmissometer or a Secchi disk can be used to measure turbidity, but each device has its advantages and disadvantages. A transmissometer is an electronic device that uses a beam of light across a specified length of seawater to measure the percentage of transmitted light, or level of turbidity, through the seawater. This device can be attached to a CTD and profiled through the water column providing a continuous picture of the water column. A Secchi disk is a white disk that is lowered from the side of a ship into the water. When the disk disappears from view, the depth at which it reappears upon retrieval to the surface provides an indication of the level of turbidity, or suspended solids, *in the surface waters only*. While the Secchi disk is a fraction of the cost of a transmissometer, the transmissometer provides a much greater level of information about the entire water column. The Sanctuary management should consider the acquisition of either of these devices, depending on availability of Sanctuary management resources, to measure turbidity in the Sanctuary, especially in areas of bottom dragging, riverine input, and basin waters where suspended solids may have higher than average adverse conditions.

Sampling

The Sanctuary management can measure all of these water column Tier I indicators *in situ* using electronic instruments. The management can use the subsequent raw data from the instruments or further process the data for statistical analyses. Additionally, a single well-outfitted instrument, such as that currently owned by the management, which includes a CTD with a DO sensor and a fluorometer, can measure all of these indicators simultaneously. The management should acquire some commercial mathematical software, such as MATLAB or equivalent, to analyze the data.

The Sanctuary management should conduct monthly surveys of Tier I water column parameters to ensure the development of an adequate baseline, providing the detection of seasonal variability as well as significant deviations. During times of high phytoplankton productivity (summer, June through October), the management should increase the frequency of cruises to at least twice a month or even weekly. The management should sample sites throughout the Sanctuary with the primary emphasis on the perimeter of the Sanctuary and a rough interior grid. On the perimeter, greatest focus should be on the northwest corner, which is the highest risk area because of the Sanctuary's proximity to the MWRA future outfall, Gulf of Maine inputs, and the MBDS. The management should use data that have been collected from other agencies and occasionally duplicate all geographically relevant sampling stations that other agencies use in their surveys (especially the two MWRA stations in Stellwagen Basin, see Appendix for maps of MWRA sites) such that the Sanctuary can accurately incorporate all data sets; duplication provides validation of data. Agencies that have conducted similar surveys within Massachusetts Bay and the nearby area are the MWRA, the New England Aquarium, and the Massachusetts Department of Environmental Protection. As knowledge of the water circulation patterns within and around the Sanctuary increases, the management can properly adjust the sampling grid for greater efficiency and usefulness.

The CTD, DO and fluorometer apparatuses benefit from factory calibration as well as verification of the electronic data to physical data samples. To minimize costs, the management may compare duplicated Sanctuary data to MWRA data.

Living Resources

The living resources in the Sanctuary consist of marine mammals, fish, marine fowl, macrophytes, and plankton. Of these five groups, the monitoring plan neglects the marine fowl and macrophytes as potential indicators, and therefore excludes them as items in the tiered structure, because variations in their levels do not appear to have significant impacts on the ecosystem. Further, the remaining three groups, marine mammals, fish, and plankton, only include species that other agencies currently monitor in the vicinity of the Sanctuary. Tier I (see Figure 5.1) focuses on population changes in the indicator species because population data are available from other agencies. The Plan also relies heavily on ships of opportunity, and dovetailing operations with other agencies' cruises, to provide an inexpensive means of sampling data.

Marine Mammals (Whales)

Marine mammals include the humpback, right, and fin whales because these are the three most endangered visitors to the Sanctuary. The Monitoring Plan model excludes dolphins and other marine mammals because their conditions are not as endangered as the whales specified. The management should, therefore, monitor and protect these endangered mammals within the Sanctuary boundaries. While the Sanctuary Monitoring Plan does not use marine mammals as indicator species because of their high variability due to external influences, e.g., while migrating en route to the Sanctuary or once in the Sanctuary boundaries, they should be monitored because of the overwhelming level of public interest in the whales and the availability and volume of whale watching data. The whales may be good indicators of abundant prey species, but their numbers are not consistent enough to serve as a flag or trigger from Tier I to Tier II for the Sanctuary Monitoring Plan.

Prior to the 1980's, people had regularly sighted humpbacks further north in the Gulf of Maine. The shift southward to the Stellwagen Bank area in the mid-1980's is most probably a result of an explosive growth in the sand lance populations due to overfishing of sand lance predator species in the Georges Bank area. The increased sand lance populations attracted the humpbacks to Stellwagen Bank and were responsible for lower numbers of right whales sighted during the mid-1980's because of increased competition for zooplankton. Since the closing of Georges Bank to commercial fisheries and the rejuvenation of commercial fish stocks, the sand lance population has declined, resulting in a northward shift, or return, of the humpbacks to the waters of the Gulf of Maine (Weinrich *et al.*, 1995). While this shift may be cyclic, there are insufficient data to support this hypothesis.

Whale population estimates are available from local conservation groups concerned with the protection of marine mammals, including the Cetacean Research Unit (CRU)* and the College of the Atlantic, Bar Harbor, Maine. One can determine these estimates from whale watch vessel data. Though biased by the vessels' routes, the whale watch data are the most extensive and inexpensive method for measuring whale numbers in the Sanctuary. The populations of the right and humpback whales from daily whale watching excursions are not reliable indicators of the overall condition of the Sanctuary because of their high variability, and the formatted data from the whale watching season serve more as a record, or history, rather than an early indicator. For these reasons, along with a lack of known standardized whale watching and counting methods, the management should not rely on whale data for triggering Tier II events, but merely use the data to compare and possibly correlate with other Tier I data.

Studies from CRU suggest that the best method for determining whale populations is by measuring the mean number per day. Additionally, *WhaleNet* is an electronic bulletin board, available via the Internet and sponsored by NSF, Simmons College, and Wheelock College that provides daily whale watch data from the whale watch vessels (see the Appendix for access instructions to *WhaleNet*). Since whale watch data are abundant, the Sanctuary Manager should establish a relationship with

* MIT does not advocate one marine mammal conservation organization over another, but CRU generously provided information for this monitoring plan.

CRU or other marine mammal conservation groups to facilitate the continuous transfer of whale population estimates.

While not a high priority recommendation, but merely an option, another method that may allow for inexpensive whale monitoring is tagging the whales with radio transmitters or tracking their acoustic patterns using the U.S. Navy's recently declassified SOund SUrveillance System (SOSUS) underwater acoustic array. Tagging is not a task that the Sanctuary management should try to pursue alone, but rather with other national marine sanctuary members along the east coast of the United States and Caribbean. Using radio transmitters or the SOSUS array, migratory patterns of whales can be accurately tracked and studied with less uncertainty and bias.

Sand Lance and Commercial Fish

Within the fisheries, the sand lance remains the key species to monitor because it is the primary food source for the humpback whales and one of the larger competitors of right whales for copepods, a species of zooplankton. Increases in the population of sand lance may indicate an explosive growth in copepods or it may indicate a reduction in the population of sand lance predator fish, the latter most likely due to overfishing. Hence, the management should consider statistically significant levels of change, both up and down, in the numbers of sand lance in the Sanctuary. Prior to initiating a Tier II action, the management should try to quantify any changes in sand lance numbers by comparing them to changes in the commercial species. Sherman *et al.* (1981) and Payne *et al.* (1986) have correlated decreases in commercial predator species with increases in sand lance, and consequently the presence of humpback whales, during the period of the Georges Bank overfishing condition. Therefore, an increase in a predator commercial species should result in a decrease in sand lance and humpback whales, but should result in an increase in right whales to the area.

The Sanctuary monitoring system differentiates the fish stocks in the Sanctuary by length of stays within the Sanctuary boundaries, thereby excluding many migratory species as indicator species. The National Marine Fisheries Service (NMFS) conducts semi-annual bottom trawls of the Stellwagen Bank area as defined by NMFS Statistical Area 514, which includes the entirety of Massachusetts and Cape Cod Bays. The Massachusetts Division of Marine Fisheries (DMF) conducts the nearshore trawls, but NMFS stores and uses the data from those trawls.

NMFS compiles the catch data from the surveys and sorts the catches by species. From these semi-annual surveys, one can establish a baseline with which to compare and determine statistically significant levels of change in sand lance and commercial species such as cod, herring, and flounder populations. While sand lance data are not currently a species that is analyzed because funding does not allow for it, the data are still available for analysis by others. These species may be a portion of the available data sets, and the management should include additional species as necessary. While the sand lance remains an important indicator of benthic health, overfishing, and whale abundance in the Sanctuary, other species may also be important, such as small mackerel (Weinrich, 1995), as conditions change. The NMFS data are free public information and provide an effective baseline from which to monitor. The Sanctuary management should, therefore, establish a relationship with NMFS to facilitate the transfer of population estimate data from the NMFS semi-annual surveys. Other sources of data may be from the commercial fishing fleet landings statistics.

The Sanctuary Manager has already established a data transfer link with NMFS and has proceeded to collect the necessary data.

Plankton

Because plankton are in close contact with the water column and are a primary foundation of the food chain, the management should use these species as indicators. Because of the difficulty in sampling phytoplankton, chlorophyll levels are the most efficient method of determining biomass. To measure levels of zooplankton, the Sanctuary Manager should use data that have been collected during the NMFS semi-annual surveys.

The Sanctuary management should update all NMFS data as available. The Sanctuary Manager has already established a data transfer link with NMFS and has proceeded to collect the necessary data

Sediment / Benthos

Tier I of the sediment/benthos category consists of two items: bivalve study and abundance estimates (see Figure 5.1).

Bivalve Study

The NOAA Mussel Watch Project monitors a suite of contaminants in mussels and oysters at selected sites in coastal and estuarine waters of the United States and the world. On a less-than-annual basis, the projects analyze sediments at Mussel Watch Project sites for contaminants. Bivalve programs are helpful because they use mollusks, which accumulate some contaminants in their tissue at levels many times higher than in the surrounding water. Because mollusks adjust quickly to changes in contamination, they serve as useful indicators of temporal trends in environmental quality. Since they are consumed by people, chemical analyses of mussel and oyster tissues also serve public health interests.

NOAA identifies over seventy chemical pollutants for which to analyze molluscan tissue samples and surface sediments. On a less frequent basis, the programs examine mussels and oysters for disease incidences (presence of neoplasia and *Perkinsus marinus*, Dermo disease). Because no single bivalve molluscan species occupies the entire geographic range monitored by the NOAA program, it samples several different species.

Some collection activities take place in the late fall or winter, while other programs, such as the MWRA, have used the summer months. To minimize the effects of seasonal influences on contaminant concentrations, the programs collect mollusk samples within three weeks of each annual cycle. The sediment and bivalve data include location, date, depth, temperature, salinity, total organic carbon (TOC), total inorganic carbon (TIC), total lipid content, trace metals, PCB, PAH and pesticides. In addition, the bivalve data contain species identification, mean shell length, gonadal index and organics; the sediment data include sediment grain size, wet weights, and dry weights.

The Sanctuary management should either participate in a cooperative effort with MWRA and extend the existing MWRA mussel watch program into Sanctuary waters, or the management should implement an independent caged mussel or bivalve study program within the Sanctuary boundaries. Clearly the former option would be more cost effective to the Sanctuary management. While a bivalve study is rather costly for a Tier I item, it needs to be done only once annually, at most, to provide useful information, and therefore may be as cost efficient as other Tier I studies.

Abundance Estimates and Species Diversity: Comparative Study

Abundance estimates uses two methods to assess the diversity of the benthos: bottom observations and bottom dragging. These two components combine to create a **comparative study**. The first half of the comparative study relies on population data of benthic creatures from observers on fishing vessels and/or NMFS semi-annual trawl by-catch data. The comparative study also relies on the creation of a "no-drag" zone within the Sanctuary with which to compare the dragged area population data. The management should designate a no-drag control area within the Sanctuary for this purpose.

The second half of the comparative study is bottom observations of the benthic region using a variety of sensors such as side scan sonar or laser line scan, both in a disturbed, or dragged, and undisturbed regions. Thus, the two sources of the comparative study are tools to gather information regarding the health of benthic community, in the form of population studies between the two regions. The management should acquire or use some type of bottom observation equipment such as a side scan sonar to monitor benthic populations.

The Sanctuary Manager is in the process of establishing of a no-drag area within the Sanctuary to determine the effects of bottom dragging on the benthos.

Tier II

Tier II components rely on more complex measuring techniques to more accurately isolate and determine the cause of the Tier I flag. This increase in accuracy is expensive and time consuming, and it may not be economically feasible to undertake a Tier II action unless the system raises a flag in Tier I. Tier II items are shown between the two horizontal dashed lines in the Sanctuary Monitoring Plan model in Figure 5.1.

Water Column: Physical Water Samples and Chemical Analysis

All of the Tier II water column parameters require physical sampling and chemical analysis. Physical water sampling gives precision measurements of nutrients within the water column. The management should take samples throughout the water column at the sites specified in Tier I, or wherever Tier I trigger levels are exceeded.

The Tier II physical water parameters include the measurement of nitrogen (PON, DON, and DIN), carbon, phosphorus, silicate, and pH levels of the water in the Sanctuary. Nitrogen is of prime concern because for most marine systems, productivity is limited by this element and the plant biological community is responsive to enhanced levels. Chemical analysis of water samples for carbon isotopes, e.g., ^{14}C, provides a measure of the water quality by distinguishing between natural occuring biogenic sources of organic input, e.g., plankton, and human-related sources of organic input, e.g., sewage (Stumm and Morgan, 1981). Carbon may also provide a measure of suspended organic matter, is important in determining the transport and fate of some chemical contaminants, and may help to determine cause/effect relationships. Phosphorus provides a tracer for effluent relative to different water masses. Silicate may become limiting during times of blooms and therefore controls phytoplankton growth. Sewage effluent is very low in silicate and therefore silicate levels can help determine causes of blooms (natural versus outfall based).

These measurements require large sampling rosettes equipped with Niskin bottles to collect water samples at several depths. The necessary and required support equipment includes a relatively large ship equipped with a heavy duty winch and sheaves system as well as trained personnel. Analyses also require properly trained technicians and well-equipped laboratories. The Sanctuary management does not own any of the required sampling or analytical equipment. Since this equipment is very labor and capital intensive, the management should subcontract all physical water sampling to private consultants; the incurred expenses and personnel requirements prohibit even considering otherwise. There are existing water sampling surveys currently in progress for the MWRA and others, and the management should try to "piggyback" onto these surveys wherever possible. The more data that are available from other agencies can only help Tier II baselines. Note that the MWRA, as part of their Outfall Monitoring Plan, has located two sampling stations for the above nutrients and other nutrients within Stellwagen Basin (see Appendix for map). The management should request these data from MWRA after analyses.

Living Resources: Tissue Analyses and Health Assessment

While Tier I focuses on the population trends of the living resources, Tier II focuses on a health assessment of those resources. Tier II includes tissue analyses of sand lance as well as directed studies of zooplankton.

Sand Lance

The sand lance has played a vital role in the Sanctuary ecosystem, serving as food for humpback whales and several commercial fishery species during the 1980's and early 1990's. While some suggest that there may be other more important preyfish to monitor in the Sanctuary (Weinrich, 1995), the Sanctuary Monitoring Plan has been created from existing reliable studies and may not account for more recent findings, studies, or hypotheses which may suggest species other than the sand lance.

Sherman *et al.* (1981) and Payne *et al.* (1986) have correlated population changes in the sand lance to population changes in some of the commercial species as well as whales. A statistically significant change in the population of sand lance triggers a Tier II action: a Sanctuary management cruise where management personnel perform bottom trawls, supplemental to the semi-annual NMFS surveys, of the Sanctuary to verify the increase or decrease in numbers of sand lance and commercial species. It is likely that increases or decreases in populations of sand lance are caused by envionmental effects rather than human-induced causes. If the management finds that the population of sand lance has decreased significantly at Tier I, a visual inspection for lesions and a tissue analysis, compared with clean and uncontaminated samples, will indicate whether the decrease is due to poor health; water quality and/or sediment quality may also attribute to poor health in sand lance. Relative numbers of male and female sand lance provide information on productivity. Since the sand lance spends a large percentage of its time in the sand, it is more likely to aid in identifying problems in sediment quality than water quality.

Zooplankton

Since zooplankton are in closer contact with the water column than the sand lance, they are more likely to respond to changes faster. The small size of zooplankton also makes them more susceptible to accumulation from lower levels of contamination than would affect the sand lance. Therefore, the zooplankton, the next higher trophic level from phytoplankton, becomes the measure of water quality issues. Since it is likely that a phytoplankton bloom, zooplankton's primary food source, will result in a fairly predictable occurrence and abundance of zooplankton, it is unlikely that a Tier I population estimate threshold for zooplankton will be violated if it incorporates the seasonal variation of phytoplankton; however precise time and location of the phytoplankton blooms are still unknown and vary temporally and spatially depending on temperature and salinity, as well as recent storm activity. Therefore, changes in these water parameters may trigger a Tier II action: a Sanctuary management cruise where qualified personnel perform plankton trawls, filter water samples for phyto- and zooplankton, or possibly use a device such as a video plankton recorder (VPR), from Woods Hole Oceanographic Institution (Davis *et al.*, 1992a,b). The VPR provides video footage of plankton population from which abundance estimates can be calculated. Analyses of the plankton samples may indicate increased levels of contaminants in the water column.

Sediment/Benthos

Bottom Observation

For the two items in Tier II under sediment/benthos in the Sanctuary Monitoring Plan model (Figure 5.1), the choice of method depends on cost as well as background information. The first item relies on the use of one of the two Science Applications International Corporation (SAIC) REMOTS® probes. The REMOTS® system provides photographic information on the health of the sediment layer by plunging a camera-equipped assembly into the sediment and taking vertical sediment profile photographs of the top several centimeters of sediment. One of the probes uses white light to take standard photographs, while the other uses fluorescent light to detect specific contaminants. The vertical profiles from both REMOTS® probes provide information about the *apparent reduction potential depth*, below which the sediment changes to anoxic levels.

Dropped from the side of a ship, the probe equipment allows the optical prism of a camera assembly to enter the bottom at approximately six centimeters per second, using the weight of the assembly to drive the prism several centimeters into the sea floor. The camera trigger trips upon impact with the bottom, activating a time delay on the shutter release. Personnel on the ship can estimate the depth of penetration of the REMOTS® prism using a penetration indicator on the assembly. If the depth is inadequate, the user can adjust it and redeploy the device.

The fluorescent light REMOTS® bombards the sediment in the prism window with fluorescent light, and the imaging system captures the specific illumination of various contaminants in the sediment and compares them with known standards. Proprietary SAIC software allows the measurement and storage of data on twenty-two different variables for each fluorescent light REMOTS® image stored on disk. The user screen shows a summary display so that the user can verify if the stored values in memory are within expected ranges. Because of the limited range of the excitation of the contaminants, this technique requires a prior knowledge of the specific contaminants of concern, data which a program such as the Bivalve study can provide but the abundance estimates cannot.

Though bottom fish are collected in the comparative study in Tier I of sediment/benthos, its Tier I status limits activity to population counts and does not accrue costly tissue analysis. The comparative study within the abundance estimates of Tier I (see Figure 5.1) may trigger the white light REMOTS® item at Tier II. The Monitoring Plan uses the white light REMOTS® to take normal vertical sediment profile photographs in areas where no known specific contaminants exists, but as lower than expected abundance estimates may have suggested at Tier I. Moving from the Tier I Bivalve Study to the Tier II white light REMOTS®, however, does not add a significant increase in knowledge about a specific problem, especially for the cost involved; a more useful method would be to use the fluorescent REMOTS® in the area of the bivalve study to measure the actual levels specific contaminants indicated by the bivalve tissue samples.

Benthic Community Assessment

Benthic community assessment may include grab sampling, chemical analysis, and bottom dragging. Since Tier II of the living resources category focuses on a health assessment (e.g., tissue analyses) of living organisms, Tier II sediment/benthos similarly focuses on the health of the sediments. At this Tier II level, the management should collect sediment cores and analyze them for various contaminants. A typical sediment grab consists of lowering a coring device from the side of a stationary vessel into the sediment to a depth of ten to fifty centimeters. Ship personnel then recover and analyze the core onboard or transport the sample to a laboratory for detailed analysis. Total organic carbon (TOC), clostridium spores, metals, PCB's, hydrocarbons, and Pb_{210} are the basic sediment indicators. Organic contaminants in sediments include PAH, PCB, and coprostanol (fecal sterol used as a sewage tracer). Grab samples cannot be used in areas of finer sediments, large rocks, or cobbles. Grabs are approximately 0.05 m^2 in sample size, and replicates can be used to evaluate temporal differences in benthic communities.

The Tier II benthic community assessment item triggers as a result of the of the comparative study in the Tier I abundance estimates. The management should collect and analyze grab samples only if there is an extreme biological effect requiring this type of excessive expenditure, and the management should not move from the Tier I Bivalve Study to Tier II Benthic Community Assessment (see Figure 5.1) because there is little justification for the extra expenditure of the grab samples over the fluorescent light REMOTS®. The REMOTS® is less expensive because it can confirm the presence of specific chemicals in the environment, and it provides the less expensive alternative; however, it may not provide the level of information about benthic biota that a grab sample can provide. This tradeoff in assessment techniques allows for some flexibility in the Sanctuary Monitoring Plan, relying mainly on a cost effective technique (REMOTS®), but also providing a more accurate and expensive method, if necessary.

Sampling Design Summary

The initial sampling design for Tier I and II parameters has been formulated from various monitoring programs. While only a first iteration, it is necessary for the Sanctuary management to refine this sampling design after it has commenced monitoring the area. Initial monitoring will provide the necessary information to assist the management in deriving specific and useful hypotheses and a robust sampling design. The following table summarizes the sampling design (provided by the specification sheets in the Appendix) for the Sanctuary Monitoring Plan:

PARAMETER	TEMPORAL FREQUENCY	SPATIAL FREQUENCY	SOURCE OF SAMPLING DESIGN
Chlorophyll	monthly (Nov.-May) ~weekly (June-Oct.)	Figure A-1 (MWRA) Stellwagen Basin*	MWRA
DO	monthly (Nov.-May) ~weekly (June-Oct.)	Figure A-1 (MWRA) Stellwagen Basin*	MWRA
Salinity (S)	monthly	Figure A-1 and throughout SBNMS	MWRA
Turbidity	monthly	Figure A-1, and with any CTD casts	MWRA
Physical Water Samples	monthly ~weekly (June-Oct.)	Figure A-1 Stellwagen Basin*	MWRA

PARAMETER	TEMPORAL FREQUENCY	SPATIAL FREQUENCY	SOURCE OF SAMPLING DESIGN
Mussel Watch & Bivalve Study	once per year for 30 to 60 days in summer (MWRA) or late fall (Mussel Watch)	Figure A-3 (Appendix) areas of suspected contamination, perhaps near MBDS or MWRA sites	Temporal: Mussel Watch, MWRA Spatial: NOAA, pers. comm.
Abundance Estimates (bottom trawls)	as required in Tier II	in areas of high dragging, use bottom observation	
Bottom Observation (REMOTS)-->	as required in Tier II quarterly/semi-annual ----(May/August)--->	see Abundance Estimates ---------------------->	---->MWRA
Benthic Community Assessment: Grab Samples, Bottom Dragging	bimonthly or quarterly monthly	depositional areas: basins near Gulf of Maine and MWRA areas of high biological productivity	MWRA
Plankton	1x in each month of: Mar/Apr/Jun/Aug/Nov	6 monitoring stations see also Chlorophyll	NMFS
Sand Lance	I semi-annual trawls II as required	throughout SBNMS	NMFS
Whales	N/A	N/A	N/A

***indicates priority**

The monitoring program should select new monitoring locations (those not managed by other agencies), based on the following considerations:

- Locations of established and new inputs into the ecosystem (e.g., natural or man-made) such as the northwest corner of the Sanctuary
- Ease of sample collection
  distance from port (e.g., samples collected in one work day)
  navigable in most weather conditions
  cost (ship time, etc.)
- Statistical validity (e.g., stratified design, random sampling, tracklines, transects)
- Compatibility with old monitoring data (e.g., selecting a previously, not currently, sampled site)
- Determination of hypotheses

Tier III: Probable Sources

There are several isolated probable sources of perturbation to the Sanctuary, as discussed in the first section. Identification of these probable sources constitute Tier III's sampling approach and may be the most expensive of the studies if initiated. Items in Tiers I and II may be the result of one or more of the sources. The identified sources are as follows:

- MWRA outfall
- Dredged material dumping
- Overfishing
- Bottom dragging
- Water circulation changes
- Gulf of Maine
- Changes in river outflows
- Recreation (Human factor)
- Commercial shipping
- Natural (including seasonal) fluctuations and variations

The Tier I and Tier II levels of the Monitoring Plan provide indicators that allow for differentiation of these sources as well as indications of potential harm to the Sanctuary. Additionally, the format of the system is such that one can use it top-down or bottom-up. This format enables one to identify the most probable indicators given a source, or probable sources given indicators. The Sanctuary Monitoring Plan also incorporates a cause and effect matrix (see section 5.3.1) at the Tier III level for easy cross-referencing of sources and indicators.

Cause and Effect Matrix

The cause and effect matrix, adapted from the National Research Council's *Managing Troubled Waters* (NRC, 1990a) and *Monitoring Southern California's Coastal Waters* (NRC, 1990b), is a schematic representation of the Sanctuary relationships in the three-tiered system. Figure 5.2 shows the matrix at the end of this section. The matrix is a brief, synoptic picture of some of the most probable natural and human sources of perturbation and their effects on the Sanctuary ecosystem. Such a cumulative approach helps to identify the natural resources that are valuable and/or endangered in the Sanctuary. The matrix presents human and natural disturbances, both point and nonpoint sources of contaminants, in a qualitative form, aiming to help the management identify the multiple impacts to the living and nonliving resources of the Sanctuary.

One can use the two-way synthesized matrix for an early, but not detailed, understanding of systemic interactions developed in the Sanctuary ecosystem between the sources and the indicators of the possible perturbations caused by the sources. Thus, the matrix is a foundation for the monitoring program that can evolve to include flow-charts which organize the monitoring objectives according to importance, developing the monitoring program into a dynamic tool for management of the resources.

The selected Tier I indicators of perturbations appear in the top row (see Figure 5.2). The left column lists probable sources of perturbation from Tier III. Entering the matrix from a certain indicator of perturbation at the top can identify all the potential sources of perturbation. In a same manner, one can start from the left of any row and proceed to the top of the matrix.

TIER III: POTENTIAL SOURCES OF PERTURBATION	TIER I: INDICATORS													
	Temperature	Salinity	Dissolved Oxygen	Chlorophyll	Turbidity	Water Sampling	Whales	Commercial Species	Sand Lance	Plankton	Bivalve	Abundance Estimates	Bottom Observation	Benthic Community Assessment
MWRA Outfall	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓
Dredged Material Disposal Site (MBDS)			✓		✓	✓	✓				✓	✓	✓	✓
Overfishing							✓	✓	✓	✓				
Bottom Dragging			✓		✓		✓	✓	✓		✓	✓	✓	✓
Changes in Water Circulation	✓	✓		✓	✓	✓	✓			✓				
Gulf of Maine Inflow	✓	✓	✓	✓	✓	✓	✓			✓				
Riverine Inputs	✓	✓	✓	✓	✓	✓	✓			✓	✓			
Sport Fishing								✓						
Whale Watching							✓							
Commercial Shipping						✓	✓				✓			
Military Activities							✓							
Offshore Oil and Gas Activities					✓	✓	✓				✓			
Sand & Gravel Mining					✓	✓	✓				✓	✓	✓	✓
Natural Fluctuations	✓	✓		✓	✓		✓			✓				

Figure 5.2. Cause and Effect Matrix

Computer Model

Because it is difficult to understand the influence of one indicator on another, the Sanctuary Monitoring Plan incorporates a computer model to facilitate the manipulation and understanding of the compiled Monitoring Plan data. Several separate specification sheets contain this relational information, and to see how a particular Tier I indicator influences another Tier I indicator, one has to read the *Linkages* field on each sheet to find the corresponding items. In essence, one could shuffle papers all day. The computer envisions each indicator (dissolved oxygen, sand lance, etc.) as a separate series of information, but provides the relational information in an easy-to-use package.

The computer model is a tool to manipulate the data in a simple way. *Microsoft Windows* is the platform because of its standing in the market and its availability. *Microsoft Access* is the computer database that contains the Sanctuary Monitoring Plan. It, like *Windows*, is readily available, inexpensive, and suitable to the task.

The underlying goals of developing the model are to have a dynamic, flexible and user friendly database to manipulate the large amount of data. It is highly probable that the relations set in the computer model between indicators will change as the management obtains more information. Therefore, it is necessary for the model to have the capacity to adapt to such changes. Ideally, one would like the model to prompt the user for such changes and rebuild itself without the user needing to know programming or *Microsoft Access'* application development language.

Future development involves developing a user interface to update data in the database. There is also a need to develop an interface that would help build and rebuild the linking of the tiers to one another, which is necessary if the user adds new indicators, or if a current indicator changes the tier on which it stands.

The *Microsoft Access* model uses a push button interface to retrieve the desired information. The user begins by selecting the desired category in which the indicator resides (water column, sediment/benthos, or living resources). From that point the user selects a particular indicator within the chosen category. At any time a user can begin a new selection by clicking on the Top Menu icon at the top of the screen. A user can access the information necessary to make effective monitoring decisions by using the model.

Because it is not feasible to distribute the computer model with this document, the model may be found on the Internet off of the MIT Sea Grant Home page at the following address:

http://web.mit.edu/afs/athena/org/s/seagrant/www/mitsg.htm

User's Guide

The Sanctuary monitoring system incorporates a computer-based tool, based on the three-tiered monitoring system model described in Section 4, for managing the Sanctuary Monitoring Plan. The schematic of this model is reprinted in Figure 7.1, and it may be thought of as a *title layer* for the computer tool, with each box holding a heading that describes the stack of information held below it.

Organization of Information

As described in the text of the report, research for the parameters in Tiers I and II led to the development of specification sheets. These sheets contain information ranging from the expected levels and usefulness of a given parameter to the names of other sources monitoring the parameter in the Stellwagen Bank area. The information on the sheets and the format of the data within the sheets facilitate their entry into the computer model.

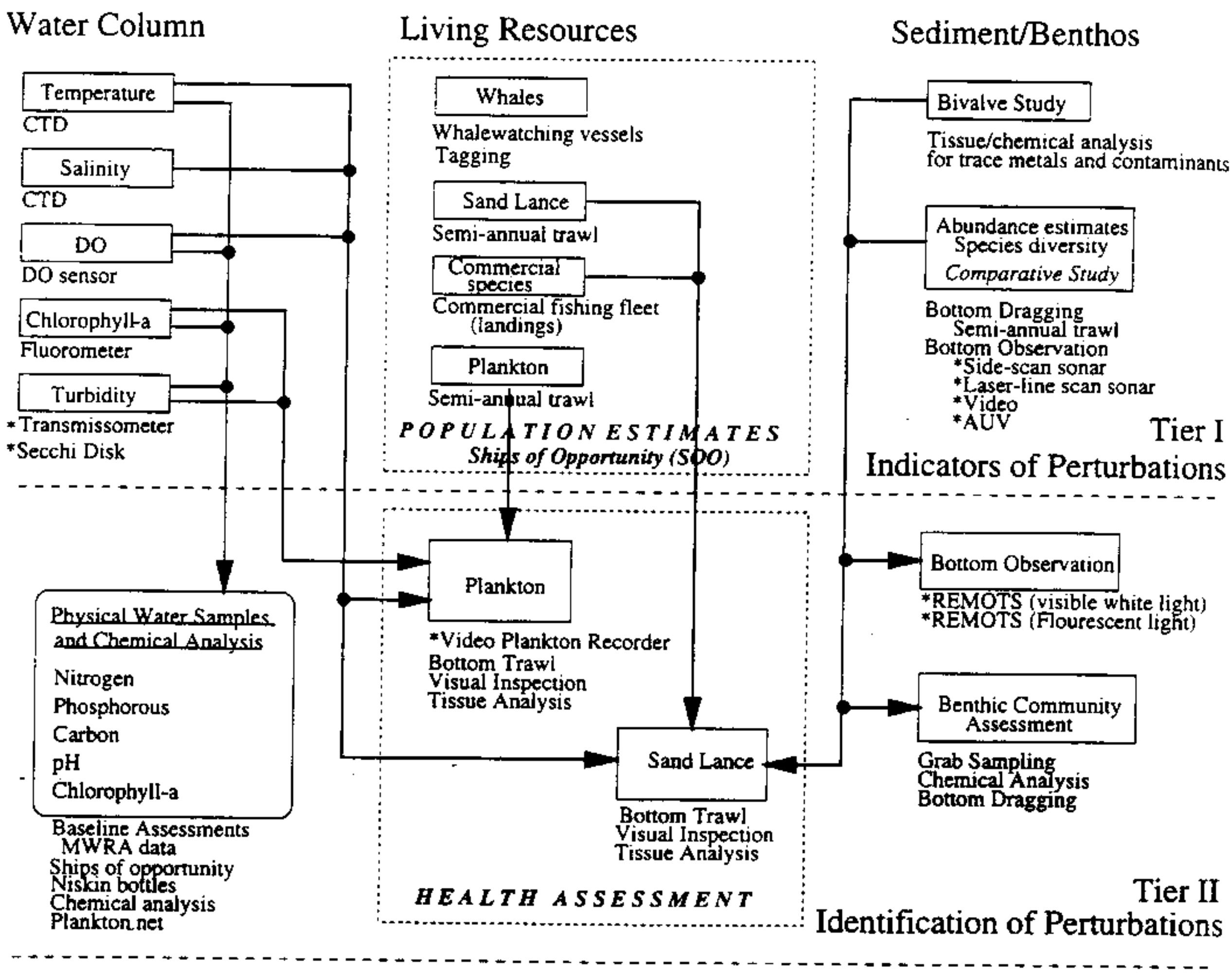
The computer model separates the data for each parameter into groups according to the context in which the data are most likely to be used. This segregation yields two broad classifications: operational-level and background information.

Operational-Level Information

Immediately beneath the title layer is the operational-level layer. The fields displayed at this level lead to the currently available knowledge and information necessary for the monitoring program to function. This information includes the expected ranges of the parameters as well as the trigger levels. The trigger levels alert the operator that information for the next tier is necessary. This layer also makes the links between the tiers of the model.

The operational-level data are all that is necessary for the monitoring system to function once the monitoring program implements methods for data collection and analysis. Essentially, the Manager of the Sanctuary must assure that the collected data are appropriate based on the information given on this level. If not, more information is necessary to give insight into the reason for the deviation; the next tier provides the information that may provide this insight. For any parameter, one can access the related parameters on the following tier by pressing on-screen buttons that appear on the operational-level information sheet.

If the parameter on the display is part of Tier II, the operator can press a button to move up to influential Tier I parameters, also displayed on the operational-level information sheet, allowing for top-down as well as some bottom-up operation.



LEGEND

VARIABLE
Instrument, equipment, or methods used
* Not currently owned by SBNMS Management
● Indicates connected links

Tier III
Sources of Perturbations

Tier III Sources of Perturbations are not shown here because they must be determined from specific monitoring efforts that are beyond the scope of this project.

Some of the most probable sources are provided in a Cause and Effect Matrix in Figure 5.2

Figure 7.1. Sanctuary Monitoring Plan Model

Background Information

Beneath the operational-level layer are one or more background information layers which contain historical monitoring information about each parameter. Perhaps most importantly, this layer provides information about how to monitor the parameter. The operational-level data are only useful if the program is collecting data, and the background information recommends methods and frequencies for data collection. The background layer also provides information to make the monitoring program adaptive with changes to the Stellwagen system. For instance, one might use insight into the selection of a parameter's trigger level to determine if the trigger level is valid as new biological or regulatory information becomes available. This layer also includes such information as other agencies that are monitoring a particular parameter and why, and it offers clarifications or caveats for information appearing on the operational-level layer. The user may obtain background information by pressing the downward button(s) on the operational-level sheet.

Note that the computer model only links the background information sheets to the operational-level sheet of the given parameter. There are no links to other tiers or parameters from background information sheets. Thus, to move from displaying background information for one parameter to displaying information on another, the operator must go back to the operational-level sheet for that parameter where such links exist.

Using the Model

From the previous section, it is clear that the model functions in two capacities; it functions both as a database for reviewing the available information of each individual parameter (both operational-level and background information) separately, and as a monitoring system tool by following the vertical linkages of the system from tier to tier. The monitoring system tool, however, is only as good as the information that supports it. Hence, the operator must periodically update the model with new data.

Monitoring System Tool

The main function of the model is as a tool for monitoring. This section describes the attributes and operation of the computer model in this mode. When the user selects a parameter for examination from the title layer, the model immediately goes to the operational-level of information for that parameter. Specification sheets represent this layer in both the first and second tiers by presenting information necessary for the monitoring of that parameter. For instance, if the user selects **Dissolved Oxygen**, the specification sheet that appears gives information such as the typical range of DO in the Sanctuary waters, the most practical method for monitoring DO, and the accuracy to which a program should monitor DO.

From a management perspective, perhaps the most important piece of information that appears on each operational-level specification sheet is the flag or trigger level for each parameter. As described in the text of this report, once the monitoring system raises a flag, it progresses along the appropriate route to the subsequent tier. This progression is not automatic in the model, but rather is left as a simple operation. This lack of automation serves a purpose, however, by involving the Sanctuary Manager or other user in the decision process, which may be constrained by lack of resources. Hence, the user may choose the best path based on current and available resources.

The computer model provides Tier III information as a list of possible sources for the perturbations that may have caused the fluctuations in Tier I and Tier II parameters. Tier III is self-explanatory, and therefore there are no further background information sheets below the displayed list.

Computer Model Operation

The computer model as described thus far is simply a series of linked data sheets, with the linkages following the model in Figure 7.1. The use of the model assumes the successful acquisition of data for each of the Tier I parameters.

Normal monitoring system operations should consist of assuring that the collected data for Tier I fall within the expected range, and below/above the threshold values, given on the operational-level data sheet for each parameter. While the computer model does not interrogate new data for maximum or minimum values, it does provide a quick reference to threshold levels for the computer operator. Barring any unforeseen introduction of pollutants or other stimuli to the system, this is the only quality assurance step necessary to maintain the accuracy of the system. However, if a perturbation to the system changes one or more of the parameters a significant amount (as defined by the trigger levels), the user should interpret this as a need for more information to understand the change. The necessary additional information is that of the Tier II parameters, which are linked to the Tier I parameter or parameters that have undergone significant change. Ideally, the user should investigate all possible Tier II parameters that are likely to have caused this change, as well as identify the problem areas; however, money, equipment access, or other issues may make certain parameters easier to investigate than others, or may prohibit active investigation completely, leaving the Sanctuary Manager to rely upon data available from other sources.

Though resources may limit the Tier II investigations, the model can accommodate such situations by allowing the operator to select which parameters to follow based on available resources and information. For instance, suppose turbidity (Tier I) levels have increased beyond acceptable levels. This would lead to both chemical analysis of the water column and plankton surveys on Tier II. Chemical analysis would yield more information, but would also incur significant costs. Plankton surveys, on the other hand, may yield limited information, but the user may obtain the information inexpensively through other organizations. On a limited budget, the plankton study data from other agencies provide the most information for the least cost.

Using turbidity as an example again, an increase in turbidity may be due to multiple sources such as river runoff or storms. Other available information may facilitate the decision for action on the part of the Manager. For instance, knowledge of a recent storm and no changes in nutrient sources may give the Manager cause to wait and see if the trend of turbidity increase continues before opting to perform a chemical analysis. There are opportunities for this type of tradeoff at many places in the model, and it is one of the key benefits to the tiered arrangement. One must take indicators seriously, however, and pursue problems as far as possible.

Tier II functions in the same manner as Tier I. If a Tier I flag indicates a need for more information on Tier II, the user should seek that information. As the program collects the Tier II data, the user should assess the quality of the data. If the data are within acceptable threshold levels, and the Tier I indicators recover to acceptable values, the system should return to monitoring Tier I only.

If Tier II data indicate a meaningful change, the user should conduct Tier III studies. The user may initiate a Tier III action by pressing the Tier III button on the operational-level information sheet for the Tier II parameters undergoing change. A Tier II flag indicates that a meaningful change to a system input has occurred, and Tier III gives a list of possible sources for that change. The user should use this list with other information to determine the probable cause of perturbation to the system (e.g., high nutrient loads at the time that the MWRA outfall comes on-line may indicate a problem with the predictions made about outfall performance). The Tier II flag may also indicate that a detrimental change to the biological system of the Sanctuary has occurred, and the user should identify and try to correct this change as soon as possible.

Computer Model: An Example

On starting up the computer model, the screen displays the top menu which contains the three categories of the Sanctuary Monitoring Plan model: **Benthos, Living Resources,** and **Water Column** as in Figure 7.2.

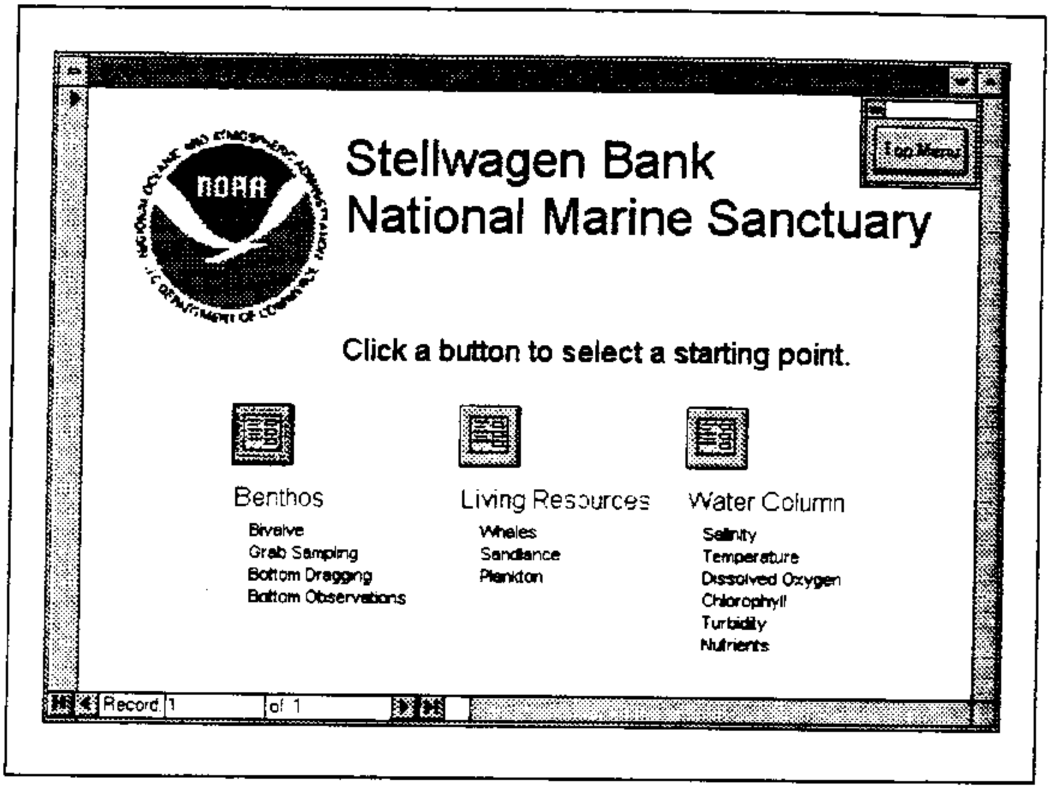


Figure 7.2. Computer Model Top Menu Window

Choosing water column by clicking on the **Water Column** icon with the mouse, the user moves into the Tier I level display. As in the Sanctuary Monitoring Plan model in Figure 7.1, the computer model displays **Salinity, Temperature, Dissolved Oxygen, Chlorophyll, Turbidity,** and **Physical** (water sampling) icons for the Tier I of water column as in Figure 7.3. The user can also return to the top menu by clicking on the **Top Menu** icon.

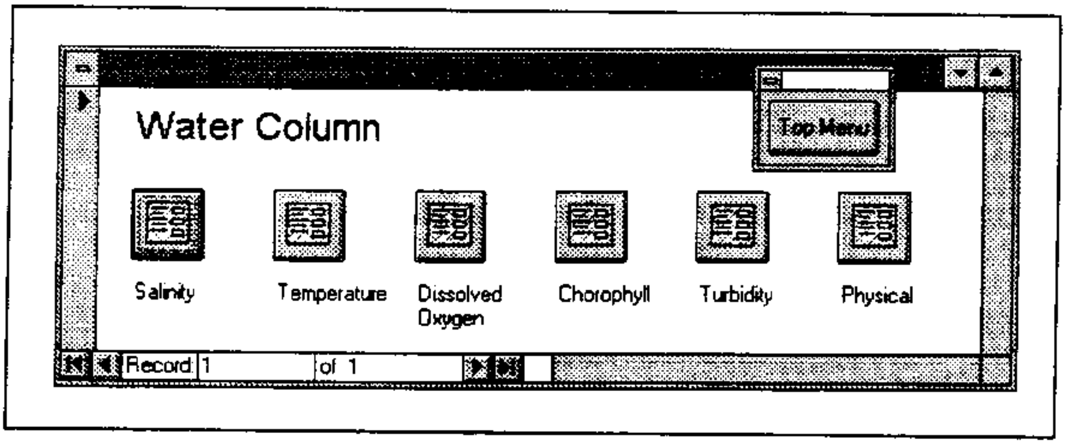


Figure 7.3. Computer Model Title Layer

Clicking on **Dissolved Oxygen**, the user moves into the operational level which displays items such as typical range, accuracy of measurement, and trigger level as well. From this level, the user can move horizontally to other items in Tier I by clicking on **Bottom Dragging** or **Mussel Watch**, or downward to Tier II items by clicking on **Physical Water Samples**, **Plankton**, or **Sand Lance**. There are also buttons, or icons, leading to the specification sheet for dissolved oxygen. As in the previous level, the user can return back to the top menu by clicking on **Top Menu**. To minimize confusion within the computer model, the user cannot return directly to the previous menu, but must return to the top menu. Figure 7.4 shows the operational level for dissolved oxygen.

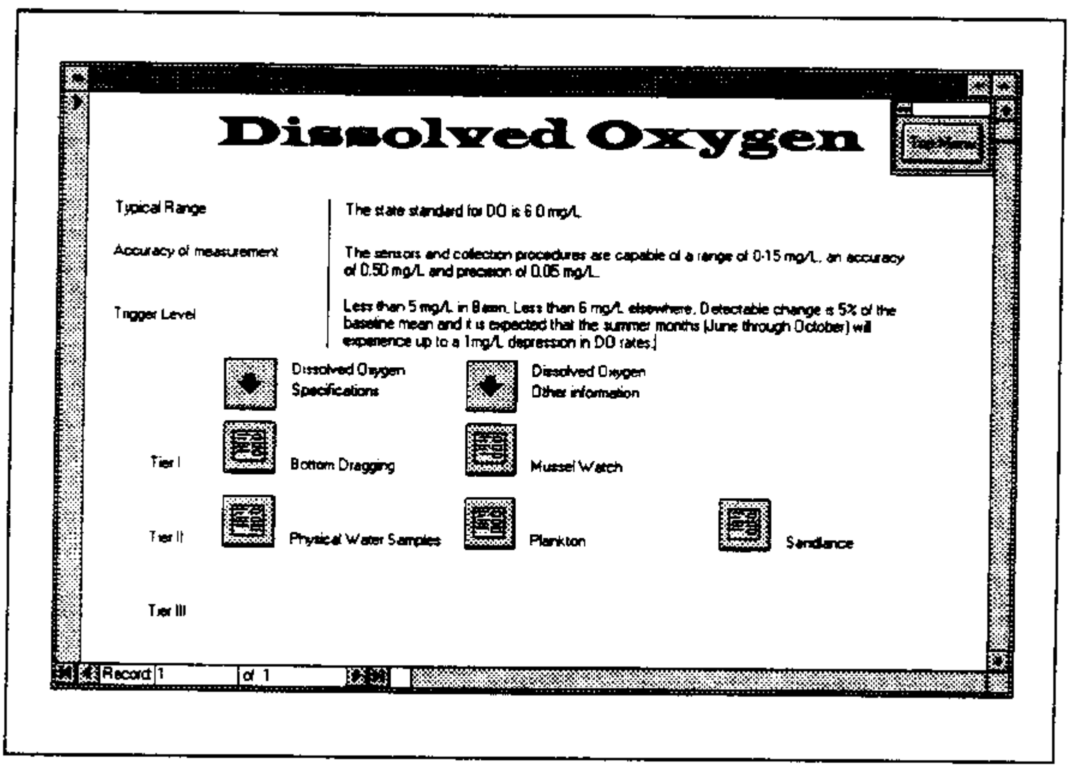


Figure 7.4: Computer Model Operational Level

Clicking on **Dissolved Oxygen Specifications,** designated by a downward arrow within the operational level, the user moves to the specification sheet for dissolved oxygen. There may be two downward arrows indicating that there are two sheets, or pages, or information. The specification sheets only have one icon, an upward arrow, which returns the user back to the operational level. In this case the icon reads *Return to main Dissolved Oxygen sheet*. Figure 7.5 shows the specification sheet for dissolved oxygen.

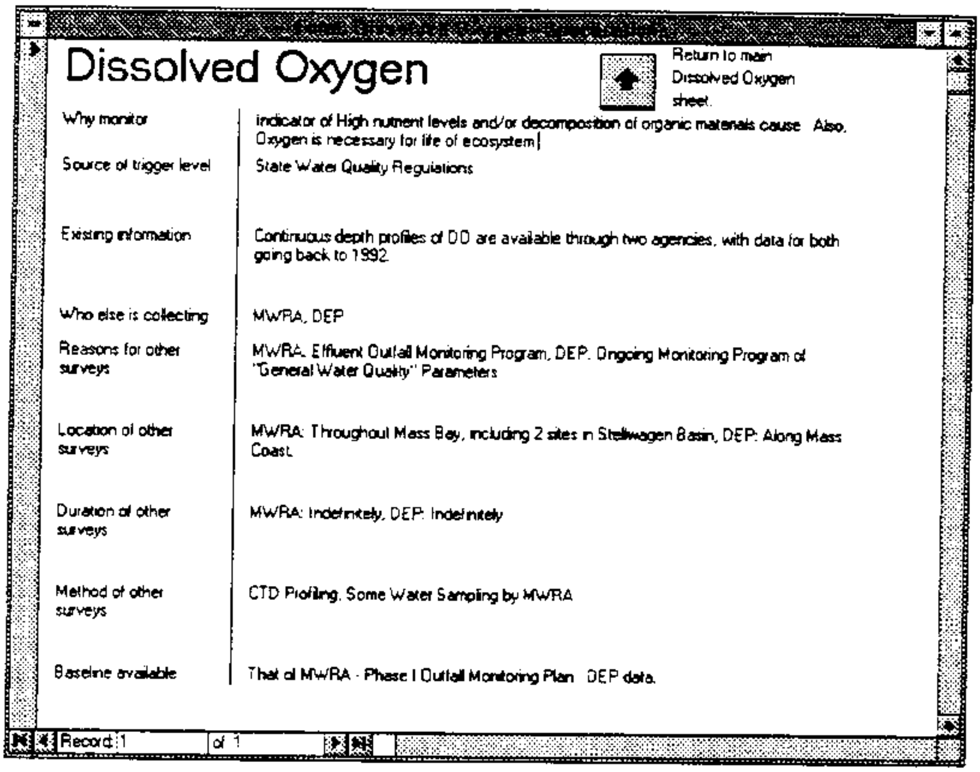


Figure 7.5. Computer Model Specification Sheet for Dissolved Oxygen

Conclusion

The Sanctuary Monitoring System and Plan described in this document are a first attempt at defining an arrangement that will adequately provide timely decision making information to the manager of the Stellwagen Bank National Marine Sanctuary. While there are, perhaps, several more iterations of the system design, this stage of the Monitoring Plan is the most comprehensive to date. As with any design, the internal and external constraints upon the Sanctuary monitoring system produce cost and strategy tradeoffs that have great impacts on the system operation. This section discusses some of these tradeoffs as well as provides some recommendations for the initial implementation of the Sanctuary Monitoring Plan. The main difficulties exist in use of the external data, data management, and setting threshold levels. Benefits include flexibility and cost-efficiency.

Difficulties

There are some weaknesses in the system that may limit its effectiveness when implemented. This section discusses these limitations, and offers suggestions to make the monitoring system a more effective tool for the Sanctuary Manager. Among these limitations are items that result from using externally generated data, the processing of data, and defining threshold levels.

External Data

The first limitation to consider is the use of external data that the plan incorporates from outside agencies such as the EPA, USGS, MWRA, and NMFS. When the end-user of the data, the Sanctuary Manager in this case, has no control over the format and processing of the data provided, there can be a number of problems. The first problem with the use of external data is the discontinuity among different formats and the comparability among data. Additionally, there is an issue of intercalibrating the data from different sources to facilitate integration and comparisons. The Manager has to understand how the provider of the data has chosen the assumptions that drive certain interpretations of the format of the data. Without this information, the Manager may not possess the necessary information to make informed decisions. A second limitation of the external data is the level of quality control of the external studies including calibration and sampling methods and sample storage. If the robustness of the external study is inadequate, it can lead to false conclusions or provide too rough of a model of the ecosystem, and thus provide no useful information to the manager. Finally, for raw and unformatted data, the Manager must invest a significant amount of time to analyze and interpret the data as it pertains to the Sanctuary.

Data Management

A second limitation of the Sanctuary Monitoring Plan is the processing of the data itself, both from internal and external sources. The management must make an investment in the purchase of additional tools to manipulate, analyze, and interpret the new monitoring data. The best data are useless unless there is a way in which the Sanctuary Manager can apply the information to make a reasoned decision. The tools to perform such analysis normally revolve around computer software and an expert opinion of a respected scientist in the field of interest. Since the data may be spread out among different agencies, it is crucial to extend the technological capabilities of data management to include the Internet for easy access to the information and data from these other agencies.

Setting Threshold Levels

In addition to the two limitations described above, a more complex limitation remains an issue: defining threshold values. In the study of any ecosystem, the most complex analysis revolves around how the threats to an ecosystem translate to measurable biological effects. This synergism among the various elements of the ecosystem is the greatest concern, because of the uncertainty of the extent of the impacts. Difficulties exist in setting thresholds when considering the interaction among the various elements of the ecosystem because there are insufficient data from which to draw conclusions about the environment. It is also difficult to observe some cause and effect relationships because of the time lag between exposure and reaction. If it takes twenty years for a cancer lesion to develop on a sand lance, for example, it may not be feasible to have access to everything that has happened within the preceding twenty years that may have been the cause. In addition to these difficulties, the Monitoring Plan must also address the natural variation of extreme events such as storms. Thus, to better understand these effects, one must know the limits and ranges of the natural variations that may provide false indications or mask important results.

Benefits

The goal of the Monitoring Plan described in this document is to protect the integrity and the sustainability of the Sanctuary by providing information about ecosystem variables that will, in turn, provide the manager with decision making tools. The four main benefits of the Sanctuary Monitoring Plan that contribute to this goal are flexibility, cost efficiency, managerial approach, and public accountability and public relations potential.

Flexibility

Recognizing that the ecosystem of the Sanctuary is highly complex and subject to an extensive number of internal and external inter-relationships, coupled with the natural intricacy of the ecosystem itself, the flexibility of the monitoring system is the primary advantage. The multiple entrance implementation scheme is one form of the system's flexibility, helping the user to find answers and links to natural variations in the Sanctuary. The multiple entrance, or modularity, also enables the user to allocate resources according to scientific interest and importance. The conceptual approach and the flexibility of its implementation are a convenient way of treating complex systems with high levels of uncertainty, where a continuous learning process generates the opportunity to test and improve the scientific bases of the Monitoring Plan. The Sanctuary Monitoring Plan sets an initial scientific course of action and systematically checks and adjusts the plan as necessary.

Cost Efficiency

The devised Plan scans the monitoring activities and databases of other agencies and organizations to find information that is pertinent to the Sanctuary. This utilization saves effort, time, and money. The analyses of current monitoring plans from those areas adjacent to the Sanctuary bring valuable data as well as more efficient implementation from monitoring experience. The threshold system allows the manager to concentrate efforts and resources on directly affected species. Since a monitoring plan is a process of continuous learning and action, it produces an intrinsic balance between expenditures in scientific efforts and management actions as well as decision making and the production of scientific information.

Managerial Approach

The broad and comprehensive base of the system allows a link to the past, current, and future research and programs. Its flexible managerial structure allows managers to adapt and improve the system as requirements materialize.

There are many studies available for the area of the Sanctuary, but the information may not be in a format that is easy for the management to use. The Sanctuary Monitoring Plan provides a methodology to build a database that is easy to use, interpret, and establish relations between natural perturbations and ecosystem variations. This practical managerial approach brings an early warning of unnatural perturbations.

Often, programs handle ecosystems in a linear way, where a scientific analysis has set the basis for a management strategy. After the delay in getting its approval and creating the regulations, a program can finally evaluate the ecosystem according to a fixed plan. The Sanctuary Monitoring Plan embodies a dynamic relationship among management, science, and the governing of the Sanctuary. It opens the decision-making process, broadening the scope of the debate and helping the incorporation of non-economic values.

Furthermore, the Sanctuary Monitoring Plan has a different scientific perspective than most other programs: it identifies *indicators* of perturbation and variances in the system as opposed to monitoring the perturbation itself (MWRA similarly monitors for indicators). This indicator and variance information is essential to the continuous process of evaluation and action. One can expect that one indicator might mask another problem of the system, but, because the monitoring system provides for a continuous evaluation of all of the indicators, the management will be able to account for them.

Public Accountability and Public Relations Potential

Public opinion is a critical issue to all projects. The Sanctuary Monitoring Plan is a marketable project that may be used to exert public pressure by providing quantitative data on which to base and reinforce decisions. A public campaign to foster people's awareness and pride for their work on preserving the Stellwagen Bank National Marine Sanctuary may have an impact on fund raising and gaining consensus among different groups upon the courses of action undertaken. Moreover, the Plan establishes a presence in the Sanctuary and creates indirect pressure on those groups that actively work within the Sanctuary boundaries. The Plan also provides quantitative arguments for recommendations to policy makers in charge of issuing the regulatory framework for the Sanctuary and surrounding Massachusetts Bay area.

Recommendations

Model Development and Implementation

1. Identify critical areas of concern in the Sanctuary on which to focus monitoring efforts and formulate hypotheses. When identified, ensure that the sampling design of the monitoring system takes into account the known threats to the health of the Sanctuary.
2. Further develop and refine the Monitoring Plan to meet the goals and objectives of the Sanctuary Management.

Data Collection

3. Gather available data, integrate data into a computer database, and establish a standard format for data. The analysis of the data will also include verification for relevance to the Sanctuary Monitoring Plan (*in progress: The Sanctuary Manager is currently in the process of collecting relevant available data from state and federal agencies and incorporating these data into a single database*).
4. Establish a professional relationship with NMFS and one or more local organizations that are concerned with the protection and conservation of marine mammals. NMFS conducts semi-annual trawls of the bank, and has records of these trawls for the past twenty years. The population data from these trawls may provide the necessary baseline to recognize changes outside of natural variations. The population data from local conservation organizations may help to identify whale behavior patterns within the Sanctuary (*in progress*).
5. Purchase the necessary software to perform data analysis such as MATLAB, or equivalent.
6. Use existing data and identify additional data needs.

Acquisition of Equipment

7. Utilize the Sanctuary management's existing instrumentation as outlined in subsequent sections to perform water column analysis (*in progress*).
8. Acquire bottom observation equipment to conduct benthic studies. Based upon financial capabilities, this can be as inexpensive as a camera, or as costly as a high-resolution sonar suite.
9. Invest in an instrument to measure turbidity. If a transmissometer is cost prohibitive then a Secchi disk is sufficient to ascertain surface water turbidity levels and trends.

Program Integration and Precedents

10. Establish a no-drag control area. As dragging activity increases on Stellwagen Bank, it is necessary to determine if there are detrimental effects. By establishing a no-drag zone, the management can undertake a comparison study to demonstrate the effects of dragging (*in progress*).
11. Integrate a bivalve study in conjunction with an existing program such as the National Oceanic and Atmospheric Administration's (NOAA) Mussel Watch. This type of program provides an excellent indicator of benthic health.

In completing all of the above, it is fundamental that the management places primary focus on the production and development of a database to establish baseline monitoring levels. Baseline data are essential to the development of (marine) monitoring programs because they serve as historical references for environmental conditions. New data are compared with these baseline values to assess the state of the ecosystem. In addition, baseline values are used to test theories and hypotheses. The baseline is also essential to determining trigger levels which lead to a more detailed Tier II monitoring efforts. From these baselines, the Manager can choose more focused hypotheses and test them with an updated and specific sampling design. The time constraint of the semester precluded the creation of effective hypotheses and an advanced sampling design. Furthermore, indicators may change over time because of variations in the marine environment. Thus, the Monitoring Plan should change accordingly to adjust to these natural changes.

The plan for monitoring at the Tier II level is more detailed and costly. The management should evaluate the Tier II scheme after it fully implements and operates Tier I. The evaluation must be timely so that incorporation can commence once the system establishes a complete Tier I baseline.

Future Considerations

The Federal government has already recognized the importance of the Stellwagen Bank area by its designation as a National Marine Sanctuary. In doing so, the Federal government has also mandated that the Sanctuary management set up a monitoring program to protect the living and non-living resources in the Sanctuary. This document is an initial effort to design and develop such a monitoring program to provide the Sanctuary Manager with key decision-making and regulatory information necessary for the protection of the resources within the Sanctuary boundaries. It is but the first step in pulling together all of the information and ideas of those whose work relates to the Sanctuary into a coherent framework and computer database program. The next steps, redefining and implementing, are in the hands of the Sanctuary Manager.

The Sanctuary Manager must continue the iterations of the development process until a feasible and practicable monitoring program is established and can be implemented. The Plan has been designed to accommodate unforeseen external (financial and other) resource fluctuations in the political system. The Manager must evaluate each path to determine which one is the most robust and most reliable in times of uncertainty so that the monitoring program can operate effectively. The Plan does not hard-wire any connections or necessitate any one path through the model, giving the Manager complete control over the monitoring program while providing guidance and alternatives.

Appendix

ITEM	TIER	TYPCIAL RANGE	TRIGGER LEVEL *see below for key to underlined items	SOURCE OF TRIGGER	EQUIPMENT	COST**	LINKS***
Temperature	I	varies seasonally	N/A	N/A	CTD	C/A	Plankton, Sand Lance, PWS
Salinity	I	30 to 34 ppt.	N/A	N/A	CTD	C/A	Plankton, Sand Lance, PWS
Dissolved Oxygen (DO)	I	> 6 mg/L	DO < 5 mg/L, 1 sm. B. DO < 6 mg/L ew. dt: 2 yrs. B., 3 yrs. e.w.	MWRA state stds.	DO sensor	C/A	Plankton, Sand Lance, PWS
Chlorophyll	I	~2 μg/L (ave.) 1 to 8 μg/L (annually)	1) 2x std. for 3 years 2) utt 12 μg/L	MWRA NOAA	Fluorometer	C/A	Plankton, PWS, BCA
Turbidity	I	0.1 to 4.0 m^{-1}	N/A	N/A	Secchi disk Transmissometer	$ $$	Plankton, PWS, Sand Lance, Bottom Obs.
Physical Water Samples and Chemical Analysis	II	Nitrogen: 0.7 to 5.7 μM others: none	100 to 200 % (2-3 x) baseline	MWRA	Niskin bottles, rosette, support vessel, lab	$$ shiptime $$ analysis	Plankton, PWS
Whales	N/A	N/A	N/A	N/A	Whale watching vessels	C/A	Sand Lance, Plankton
Sand Lance I [I] Sand Lance II [II]	I II	N/A	[I] s.s in/decrease population [II] external lesions, mortality	N/A	[I] N/A (NMFS) [II] trawl equip.	[I] C/A [II] $40K/yr	Sand Lance [II], BCA, Bottom Obs.

ITEM	TIER	TYPCIAL RANGE	TRIGGER LEVEL *see below for key to underlined items	SOURCE OF TRIGGER	EQUIPMENT	COST**	LINKS***
Phytoplankton & Zooplankton	I II	N/A	[I] s.s in/decrease population [II] decline in health	N/A	[I] N/A (NMFS) [II] trawl equip., VPR	[I] C/A [II] $$ ship time	Plankton[II], Whales
Mussel Watch & Bivalve Study	I	N/A	Hg: c.CMET>0.8 μg/g ww PCB: c.CMET>1.6 μg/g ww Pb: c.CMET>3.0 μg/g ww	MWRA	cages, analysis equipment	analysis, $60K per year/site	Sand Lance, BCA, Bottom Obs.
Abundance Estimates: Bott. Dragging	I	N/A	decrease in health of dragged area vs. control area	N/A	side-scan sonar, camera	sss: $15K to $35K N/A	Plankton, Sand Lance, Bivalve Study
Bottom Observation: (REMOTS)	II	N/A	no increase > 50 % baseline with > 70% fine grain sediments	MWRA	REMOTS: white & fluorescent	$20K/year (MWRA)	Sand Lance, BCA
Benthic Community Assessment	II	N/A	N/A	N/A	Kynar-coated grab, ship	ship: $$ lab: $300 to $500	Sand Lance, BCA

*utt: upward trend towards
dtt: downward trend towards
sm: summer month
B: Stellwagen Basin
ew.: elsewhere outside of Stellwagen Basin
c.CMET: concentration in caged mussel edible tissue
s.s.: statistically significant
ww: wet weight

**C/A: currently available
$: inexpensive
$$: moderately expensive
$$$: very expensive

***BCA: Benthic Community Assessment
NMFS: National Marine Fisheries Service
VPR: Video Plankton Recorder
PWS: physical water samples

Water Column Specification Sheets

Specification Sheet - Temperature

Monitoring Status: Implement immediately

Typical Range

- Varies seasonally. See Townsend *et al.* (1991) for seasonal values in Massachusetts Bay.

Accuracy of Measurement

- The sensors and collection procedures are capable of a range of -2 °C to 30 °C, an accuracy of 0.015 °C and a precision of 0.01 °C.

Trigger Level

- Not Applicable

Purpose for Monitoring

- Defines water column.

Source of Trigger Level

- This parameter is not a stand alone indicator. Rather, one can use information from the behavior of this parameter in tandem with other Tier I measurements, such as salinity, to narrow the selection of Tier II pursuits when trigger levels are reached.

Existing Information

- Continuous depth profiles of Temperature are available through MWRA, with data going back to 1992. USGS has been characterizing the area since 1992, and will continue to do so at least through 1997 (Joint MWRA-USGS), and until 1999 (Joint Mass Bays-USGS) in National Maine and Coastal Geology Program Plan (Butman, 1996).

Collecting Agent(s)

- MWRA, USGS

Purpose of Collection

- MWRA - Effluent Outfall Monitoring Program
- USGS - Examining Circulation and Transport of pollutants in MA Coastal Waters

Location of Collection

- Throughout Massachusetts Bay, including two sites in Stellwagen Basin (MWRA)

Duration of Collection

- MWRA - Indefinitely
- USGS - At least through 1997 (Joint MWRA-USGS), and until 1999 (Joint Mass Bays-USGS) in National Maine and Coastal Geology Program Plan (Butman, 1996)

Method of Collection

- CTD profiling

Baseline Available

- MWRA - Phase I Outfall Monitoring Plan (MWRA, 1991). USGS Data.

Alternative Methods

- Not Applicable. CTD is a very reliable, inexpensive method.

Can the Sanctuary Manager Do It?

- Yes

Equipment Required

- Sanctuary managment-owned CTD and support ship. A support computer and software is assumed.

Estimated Cost

- No direct cost to the Sanctuary program for collecting data. Instrument calibration and maintenance as well as some analysis are necessary, all of which will require expenses. May be performed by qualified personnel on ships of opportunity (e.g., U.S. Coast Guard, whale watching vessels, USGS, MWRA, etc.) to minimize ship time costs.

Sampling Required

- Monthly surveying should be adequate to ensure that trigger system is functioning properly (MWRA - *DRAFT Contingency Plan*, 1995). Surveys should be taken throughout the Sanctuary as practical. Take temperature readings whenever other CTD-based surveys are conducted.

Notes

Defines water column with salinity. Temperature and salinity cause density to increase with depth, and regulate the saturation of oxygen into deeper waters. Values significantly different from seasonal levels should be carefully cross-checked with other indicators and recent weather patterns for sources of the perturbation such as increased river inflow.

Linkages

- Nutrients (P and N), Plankton, Sand lance

Specification Sheet - Salinity

Monitoring Status: Implement immediately

Typical Range

- Salinity measurements vary from 0 to 35 parts per thousand (ppt.), where a lower value indicates fresher water. Typically, values in Massachusetts Bay vary seasonally, depending on river runoff and precipitation, from 30 to 34 ppt. (Townsend *et al.*, 1991).

Accuracy of Measurement

- The sensors and collection procedures are capable of a range of 0-70 ppt, an accuracy of 0.1 ppt and a precision of 0.01 ppt.

Trigger Level

- Not Applicable

Purpose for Monitoring

- Defines the water column.

Source of Trigger Level

- This parameter is not used as a stand alone indicator. Rather, information from the behavior of this parameter is used in tandem with other Tier I measurements in an effort to narrow the selection of Tier II pursuits when trigger levels are reached.

Existing Information

- Continuous depth profiles of salinity are available through MWRA, with data going back to 1992. USGS has been characterizing the area since 1992 and will continue to do so at least through 1997 (Joint MWRA-USGS), and until 1999 (Joint Mass Bays-USGS) in National Maine and Coastal Geology Program Plan (Butman, 1996).

Collecting Agent(s)

- MWRA, USGS
-

Purpose of Collection

- Location of other surveys
- Throughout Massachusetts Bay, including two sites in Stellwagen Basin (MWRA)

Duration of Collection

- MWRA - Indefinitely
- USGS - At least through 1997 (Joint MWRA-USGS), and until 1999 (Joint Mass Bays-USGS) in National Maine and Coastal Geology Program Plan (Butman, 1996)

Method of Collection

- CTD profiling

Baseline Available

- MWRA - Phase I Outfall Monitoring Plan (MWRA, 1991). USGS Data.

Alternative Methods

- Not Applicable. CTD is a very reliable method, and its current ownership by the Sanctuary Management disqualifies alternative methods.

Can the Sanctuary Manager Do It?

- Yes

Equipment Required

- The Sanctuary management has a CTD and access to boats. A support computer and software is assumed.

Estimated Cost

- No direct cost to the Sanctuary program for collecting data. Instrument calibration and maintenance as well as some analysis may be necessary which will require expenses. May be performed by qualified personnel on ships of opportunity (e.g., U.S. Coast Guard, whale watching vessels, USGS, MWRA, etc.).

Sampling Required

- Monthly surveying should be adequate to ensure that trigger system is functioning properly (MWRA - *DRAFT Contingency Plan*, 1995). Surveys should be taken throughout the Sanctuary as practical. Take salinity readings whenever other CTD-based surveys are conducted.

Notes

Salinity and temperature define the basic conditions of the water column for chemical, physical, and biological purposes. Temperature and salinity cause density to increase with depth, and regulate the saturation of oxygen into deeper waters. Values significantly different from seasonal levels should be carefully cross-checked with other indicators and recent weather patterns for sources of the perturbation such as increased river inflow.

Linkages

- Nutrients (P and N), Plankton, Sand lance

Specification Sheet - Dissolved Oxygen

Monitoring Status: Implement immediately

Typical Range

- DO values from MWRA's *Phase II Post Discharge Monitoring* (MWRA, 1995b) of its nearfield stations range from around 8 mg/L to approximately 12 mg/L, with the lowest values recorded in Stellwagen Basin at 4.63 mL/L (slightly above 6.0 mg/Lin October 1989 (Kelly, 1991). The state standard for DO is 6.0 mg/L.

Accuracy of Measurement

- The sensors and collection procedures are capable of a range of 0-15 mg/L, an accuracy of 0.50 mg/L and precision of 0.05 mg/L.

Trigger Level

- Less than 5 mg/L for one (1) month during summer in Stellwagen Basin
- Less than 6 mg/L for one (1) month during summer elsewhere
- Statistically significant downward trend relative to baseline values for three (3) consectutive years outside Stellwagen Basin and for two (2) consecutive years in Stellwagen Basin.
- Detectable change is 5% of the baseline mean and it is expected that the summer months (June through October) will experience up to a 1 mg/L depression in DO rates.

Purpose for Monitoring

- Indicator of high nutrient levels and/or decomposition of organic materials. Most importantly, oxygen is necessary for life in the ecosystem.

Source of Trigger Level

- State water quality regulations: Massachusetts Marine Water Standard of 6.0 mg/L or 75% saturation (MWRA *Draft Phase II*, 1995, p. 3-8). Trigger levels of 5 mg/L and 6 mg/L from MWRA *DRAFT Contingency Plan*, 1995, p. 25.

Existing Information

- Continuous depth profiles of DO are available through two agencies, with data for both going back to 1992.

Collecting Agent(s)

- MWRA (Massachusetts Bay), DEP (along the coast of Massachusetts)

Purpose of Collection

- MWRA: Effluent Outfall Monitoring Program
- DEP: Ongoing Monitoring Program of "General Water Quality" Parameters

Location of Collection

- MWRA: Throughout Massachusetts Bay, including two sites in Stellwagen Basin (see maps at end of Appendix).
- DEP: Along Massachusetts coast

Duration of Collection

- MWRA: Indefinitely
- DEP: Indefinitely

Method of Collection

- CTD profiling, some water sampling by MWRA

Baseline Available

- MWRA - Phase I Outfall Monitoring Plan (MWRA, 1991). DEP data.

Alternative Methods

- DO may be more accurately measured by collecting water samples and sending off for lab analysis. This method is much costlier, does not return a continuous profile, and may not be fast enough to predict eutrophication events.

Can the Sanctuary Manager Do It?

- Yes

Equipment Required

- The Sanctuary management has a CTD equipped with a DO sensor and access to boats. A support computer and software is assumed.

Estimated Cost

- No direct cost to the Sanctuary program for collecting data. Instrument calibration and maintenance as well as some analysis may be necessary which will require expenses. May be performed by qualified personnel on ships of opportunity (e.g., U.S. Coast Guard, whale watching vessels, USGS, MWRA, etc.).

Sampling Required

- Monthly surveying should be adequate to ensure that trigger system is functioning properly (MWRA - *DRAFT Contingency Plan*, 1995). In times of likely algal blooms (June-October), surveying frequency should be increased, maybe even to weekly. Surveys should be taken throughout the Sanctuary as practical. *Focus should be on Stellwagen Basin, where depth and poor mixing are conditions that may decrease DO below trigger levels.*

Notes

- Water sampling may be required occasionally to calibrate instrument. May be dovetailed with MWRA Basin cruises to save costs.
- Oxygen depletion rate (ODR) may be more of a direct measure of the MWRA effluent impact than DO. It is independent of long term weather patterns, and

it is an indicator of future hypoxia (MWRA *DRAFT Contingency Plan*, 1995, p. 26).:

- MWRA warning level: mean ODR > three times (3x) baseline rate for one (1) month during summer.
- Stellwagen Basin mean ODR > twice (2x) baseline rates for three (3) months during the summer.
- MWRA action level: Stellwagen Basin mean ODR > twice (2x) baseline rates for four (4) consecutive years.
- Related to this is monitoring the summertime mean depth of oxygenated sediments in muddy areas.

Linkages

- Nutrients (P and N), Plankton, Sand lance, Sediment/Benthos

Specification Sheet - Chlorophyll

Monitoring Status: Implement immediately

Typical Range

- The present annual average of chlorophyll is roughly 2 µg/L over the Massachusetts Bay area with a range that varies from 1 to 8 µg/L throughout the year.

Accuracy of Measurement

- The sensors and collection procedures are capable of a range of 0.1-100 µg/L, an accuracy of 50% of the sensor reading and precision of 0.01 µg/L. MWRA design capable of detecting 0.5 µg/L (MWRA, 1995b).

Trigger Level

- Chlorophyll-a concentration annual mean variability greater than two times (2x) the baseline level, for three (3) consecutive years (MWRA, 1995c).
- Statistically significant upward trend relative to baseline level in annual mean chlorophyll-a concentration, for 3 consecutive years (MWRA, 1995c).
- Annual mean chlorophyll-a concentration greater than 12 µg/L (MWRA, 1995c).

Purpose for Monitoring

- Chlorophyll-a is the most common measure of algal biomass, blooms, may be used to predict eutrophication events, and it has been adopted by the EPA for standardizing monitoring systems.

Source of Trigger Level

- MWRA - *DRAFT Contingency Plan* (MWRA, 1995c) p. 27. The MWRA raises an *action* flag if the annual average mean of chlorophyll-a is greater than 15 µg/L.

Existing Information

- Continuous depth profiles of chlorophyll-a are available through MWRA, with data going back to 1992.

Collecting Agent(s)

- MWRA

Purpose of Collection

- Effluent Outfall Monitoring Program

Location of Collection

- Throughout Massachusetts Bay, including two sites in Stellwagen Basin

Duration of Other Survey

- Indefinitely

Method of Other Survey

- CTD profiling, calibrated with water sampling

Baseline Available

- MWRA - Phase I Outfall Monitoring Plan (MWRA, 1991).

Alternative Methods

- Chlorophyll-a may be more accurately measured by collecting water samples and sending off for lab analysis. This method is much costlier, does not return a continuous profile, and may not be fast enough to predict eutrophication or bloom events. Remote sensing using LANDSAT, and SEAWIFS when operational, imaging is possible. MWRA is currently investigating implementing this technology for their Massachusetts Bay monitoring.

Can the Sanctuary Manager Do It?

- Yes

Equipment Required

- The Sanctuary management has a CTD equipped with a fluorometer and access to boats. A support computer and software is assumed.

Estimated Cost

- No direct cost to the Sanctuary program for collecting data. Instrument calibration and maintenance as well as some analysis are necessary which will require expenses. May be performed by qualified personnel on ships of opportunity (e.g., U.S. Coast Guard, whale watching vessels, USGS, MWRA, etc.).

Sampling Required

- Monthly surveying should be adequate to ensure that trigger system is functioning properly (MWRA - *DRAFT Contingency Plan*, 1995). In times of likely algal blooms (January to March and June to October), surveying frequency should be increased, maybe even to weekly. Surveys should be taken throughout the Sanctuary as practical. Focus should be on Stellwagen Basin, where depth and poor mixing make hypoxia likely.

Notes

Water sampling may be required occasionally to calibrate instrument. May be dovetailed with MWRA Basin cruises to save costs.

Linkages

- Nutrients (P and N), Plankton

Specification Sheet - Turbidity

Monitoring Status: Implement as soon as equipment becomes available

Typical Range

- Usually defined in terms of beam attenuation. Typical values in Massachusetts Bay are 0.1 m^{-1} to 4.0 m^{-1}

Accuracy of Measurement

- The sensors and collection procedures are capable of a range of 0 to 40 m^{-1}, an accuracy of 0.20 m^{-1} and a precision of 0.05 m^{-1}. Battelle states a precision of 0.01 m^{-1} for the MWRA Phase I, 1991.

Trigger Level

An increased level of turbidity for TBD weeks, with emphasis on Stellwagen Basin. This trigger can be refined upon some initial baseline studies.

Purpose for Monitoring

- Turbidity, or beam attenuation, is a measure of the amount of suspended solids in the water column. It also provides an indication of the mixing and sediment transport. This item may be useful for monitoring bottom dragging operations.

Source of Trigger Level

- TBD

Existing Information

- Continuous depth profiles of turbidity are available through MWRA, with data going back to 1992. USGS has been characterizing area from 1992, and will continue to do so at least through 1997 (Joint MWRA-USGS), and until 1999 (Joint Mass Bays-USGS) in National Maine and Coastal Geology Program Plan (Butman, 1996).

Collecting Agent(s)

- MWRA
- USGS

Purpose of Collection

- MWRA - Effluent Outfall Monitoring Program
- USGS - Examining Circulation and Transport of pollutants in MA Coastal Waters

Location of Collection

- Throughout Massachusetts Bay, including two sites in Stellwagen Basin (MWRA)

Duration of Collections

- MWRA - Indefinitely
- USGS - At least through 1997 (Joint MWRA-USGS), and until 1999 (Joint Mass Bays-USGS) in National Maine and Coastal Geology Program Plan (Butman, 1996)

Method of Collection

- CTD profiling

Baseline Available

- MWRA - Phase I Outfall Monitoring Plan (MWRA, 1991). USGS Data.

Alternative Methods

- Secchi disk (Townsend *et al.*, 1991) for surface waters only.

Can the Sanctuary Manager Do It?

Yes

Equipment Required

- The Sanctuary management has a CTD with a transmissometer and access to boats. A support computer and software is assumed.

Estimated Cost

- No direct cost to the Sanctuary program for collecting data. Instrument calibration and maintenance as well as some analysis are necessary which will require expenses. May be performed by qualified personnel on ships of opportunity (e.g., U.S. Coast Guard, whale watching vessels, USGS, MWRA, etc.), especially secchi disk measurements.

Sampling Required

- Monthly surveying should be adequate to ensure that trigger system is functioning properly (MWRA - *DRAFT Contingency Plan*, 1995). Surveys should be taken throughout the Sanctuary as practical. Take turbidity readings whenever other CTD-based surveys are conducted.

Notes

- Townsend *et al.*, 1991, suggests that increased water input from rivers and the Gulf of Maine may increase particulates in the water column, thereby increasing the beam attenuation value. Particulates may include large quantities of nutrients, thereby increasing the phytoplanton biomass, or chlorophyll, measurements (p.75).

Linkages

- Nutrients (P and N), Plankton, Bottom Observation.

Specification Sheet - Physical Water Samples and Chemical Analysis

Monitoring Status: Implement as required

Nutrients Include

- Nitrogen (N and DIN), Phosphorous, Carbon (C)

Other Items

- pH

Typical Range

- No defined NPDES or MWRA limits exist for the nutrients, but MWRA NPDES permit requirements exist for pH levels. Average yearly nitrogen levels for the area range from 0.7 μM to 5.7 μM.

Accuracy of Measurement

- The sensors and collection procedures are capable of a precision of nitrogen of ±1%, a precision of carbon of ±5%, a precision of phosphorus of ±4%.

Trigger Level

- 100% to 200% of baseline levels for nutrients (DIN).

Purpose for Monitoring

- Indicator of high nutrient levels, and correlation exists between nitrogen levels and temperature and between nitrogen and chlorophyll, or plankton, abundance.

Source of Trigger Level

- MRWA, *Draft Report: Optimization of Water Column Monitoring: Statistical Treatments* (Hunt *et al.*, 1995), pp. 57-59.

Existing Information

- MWRA has collected data since 1992 on these physical water quantities.

Collecting Agent(s)

- MWRA

Purpose of Collection

- MWRA: Effluent Outfall Monitoring Program

Location of Collection

- MWRA: Throughout Massachusetts Bay, including two sites in Stellwagen Basin

Duration of Collection

- MWRA: Indefinitely

Method of Collection

- Water sampling, laboratory analysis.

Baseline Available

- MWRA - Phase I and II Outfall Monitoring Plan.

Alternative Methods

- None.

Can the Sanctuary Manager Do It?

- Yes.

Equipment Required

- Niskin hydrocast bottles or GO-FLO bottles for collection of physical water samples from a ship or boat.
-

Estimated Cost

- May be performed by qualified personnel on ships of opportunity (e.g., U.S. Coast Guard, whale watching vessels, USGS, MWRA, etc.).
-

Sampling Required

- Monthly surveying should be adequate to ensure that trigger system is functioning properly (MWRA - *DRAFT Contingency Plan*, 1995).

Notes

- Information on physical water samples is somewhat limited. Few regulations or standards exist for trigger levels.
- MWRA has set warning and action levels for the annual total nitrogen loading from the effluent. These values are, respectively, 12,500 and 14,000 tons (MWRA *DRAFT Contingency Plan*, 1995).

Linkages

- Temperature, DO, Chlorophyll-a, Turbidity

Living Resources Specification Sheets

Specification Sheet - Whales

Monitoring Status: Implement immediately

The Stellwagen Bank National Marine Sanctuary is the temporary home to many migratory marine mammals, most notably, the humpback, fin, and right whales. Of these, the right whale is the most endangered, numbering 300-500 animals in the Northern Atlantic stock. These are followed closely by the humpbacks, numbering 5,500, and the fin whales numbering 3,590 to 6,300 (1990 estimates, NMFS, 1990, as referenced in SBNMS, 1993). These whales pass through the Sanctuary seasonally, feeding on sand lance and copepods, and in some cases calving in the Sanctuary. The humpbacks frequent the bank from early March or April to mid November; the right whales, from late winter/early spring through July and then back through in October; and the fin whale, from April to October.

Because of this regular seasonal migration through the bank, whale watching has boomed in the area. Whale watching is a multimillion dollar ($17M) tourism industry in New England. More than forty vessels make approximately 6000 trips to the bank carrying over one million passengers (SBNMS, 1993). These trips take place mostly during the summer and fall months, providing ample sampling frequency during the whales' residency on the bank. As the trips leave hourly (at least) during season, availability is not a problem, when considering the whale watching vessels as a resource for monitoring the whale populations.

Since 1976, marine naturalists have ridden whale watch vessels to photograph and try to identify the whales in the bank. Using 35-mm Pentax MX or LX cameras equipped with 200-,300-,or 400-mm lens, motor drive, and recording databack, and using black and white film rated at ISO 400, several thousands of photographs have been taken. These photographs are analyzed and compared with existing photos for distinctive markings on the flukes, fins, or bodies. A North Atlantic Humpback Whale Catalog currently resides at the College of the Atlantic in Bar Harbor, Maine (Clapham and Mayo, 1987). Other agencies involved in the photographic identification of the whales include Manomet Bird Observatory observers on NMFS/NEFC R/V's (Payne, *et al.*, 1986), Cetacean Research Unit (CRU), and the New England Aquarium.

Though biased by the whale watching vessels' routes, the whale watch data are one of the most extensive in the world. For this reason, it is felt that the reliability of identification and local population estimation is high, while the reliability of the estimates of the North Atlantic populations are medium to low. From 1979 to 1985, 348 humpbacks were identified from photographs (44 females with a total of 72 calves. Of these, observers saw twelve females with two calves and another eight females were seen with three calves. Reproductive rates are approximately 0.3 - .43 calves per mature female per year (Clapham and Mayo, 1987).

Payne *et al.*(1986) have determined a positive correlation between the numbers of sand lance and the numbers of right, humpback, and fin whales, using fisheries data from 1978 to 1982 and available whale watch data from same period. In the southwestern corner of the Gulf of Maine, from 1978 to 1982, there was an increase in humpback whales observed per kilometer. This whale increase followed an increase in sand lance density between 1978 and 1981 (Note that a significant decrease in sand lance occurred in 1982). In addition, it is known that sand lance are abundant in sandy, shallower areas, which corresponds to the location of the whale sightings which showed an increase from 1978 to 1981 and a decrease in 1982 (Payne *et al.*, 1986).

This increase in whale populations (in the mid-1980's) in the southern Gulf of Maine coincided with a decrease in populations at Mt. Desert Rock, ME. Prior to the 1980's, people had regularly sighted the humpbacks further north in the Gulf of Maine. The shift southward to the Stellwagen Bank area in the mid-1980's is most probably a result of an explosive growth in the sand lance populations from overfishing of sand lance predator species in the Georges Bank area. The increased sand lance populations attracted the humpbacks to Stellwagen Bank and was responsible for lower numbers of right whales sighted during the mid-1980's. Since the closing of Georges Bank and the rejuvenation of commercial fish stocks, the sand lance population has declined, resulting in a northward shift, or return, of the humpbacks to the waters of the Gulf of Maine (Weinrich *et al.*, 1995). While this process may be cyclic, there is insufficient data to support this hypothesis.

From these studies, 1982 to 1994, correlations have been drawn between the sand lance and other species in the Stellwagen Bank area (Sherman *et al.*, 1981). As the adult sand lance population in the bank decreases, the copepod population increases, since sand lance eats the copepod, further resulting in an increase in right whales to the bank, which also prey primarily on copepods, and a decrease in humpbacks to the bank, due to the decrease in sand lance. Conversely, as the adult sand lance population increases, the copepods population decreases, causing the number of right whales to the bank to decrease and the numbers of humpbacks to the bank to increase. While the fluctuation in sand lance populations in most probably due to the fishing activity in the Georges Bank area, the fluctuation in the number of whales observed in the bank can be attributed to the number of sand lance and copepods available.

Tier I involves the collection of whale watch data to monitor the trends in whale activity in the area. Tagging and/or tracking using the U.S. Navy SOSUS array may be an alternate method that would provide unbiased whale estimates.

References: Clapham and Mayo, 1987; Clapham *et al.*, 1993; Payne *et al.*, 1986; Payne *et al.*, 1990; Jossi *et al.*, 1995; Weinrich *et al.*, 1995.

Electronic Access Instructions to WhaleNet

WhaleNet is available on the Internet and may be accessed on the World-Wide Web (WWW), through gopher, or via telnet:

- gopher://whale.simmons.edu
- http://whale.simmons.edu
- *telnet>* connect vmsvax.simmons.edu
  username> environet [enter "environet" for the username]
  password> simmons [enter "simmons" for the password]
  Bulletin> select whalenet [enter "select whalenet" at the first *Bulletin>* prompt]
  Bulletin> 1 [for introductory message]
  Bulletin> dir [for directory]
  Bulletin> help [for help]
  Bulletin> ex [to exit]

To post an electronic message to *WhaleNet*, send email to:
whalenet@vmsvax.simmons.edu

Specification Sheet - Sand Lance

Monitoring Status: Implement immediately (Tier I), as required (Tier II) pending samping design

One of the primary considerations for monitoring the living resources of the Sanctuary is the maintenance of the marine mammal population. Whales have become an icon of the devastation occurring marine ecosystem as a whole, as such, they have the tendency to easily evoke human emotions. Since many of the whales which frequent the bank are endangered, monitoring the population of whales serves as an indicator of the bank's health while also keeping the bank in the public's eye as a whale feeding area. With whale-watching as an every increasing source for the economy, it would seem that all interested parties are served by maintaining an environment suitable to whales.

Two sources of food standout as important for the whales: sand lance and zooplankton. Since sand lance primarily feed on zooplankton, they become an important trophic link in the Sanctuary ecosystem. In addition to whales, they are an important prey of haddock, hake, yellowtail flounder, cod, and mackerel.

The sand lance is also an opportunistic species filling the void of an over-fished ecosystem which has been depleted of tertiary predators including herring and mackerel. Sherman *et al.* (1981) have documented herring and mackerel declines corresponding to an increase sand lance abundance.

There have been studies to correlate the frequency of skin tumors in populations of flatfish with environmental factors. Since the sand lance behavior includes burying itself in the sediments, it is possible to correlate sediment pollution to sand lance skin tumor frequency.

Existing analysis of population data is somewhat old and only provides a relative relationship. The National Marine Fisheries Service (NMFS) has conducted semi-annual bottom trawls for the past 20 years. A professional relationship needs to be established in order to acquire the existing data and to provide a means for the exchange of future data. Acquisition of existing data will provide a necessary data base to allow a determination of what exactly is a significant change in the population.

The first tier of monitoring should be the acquisition of data from NMFS. The second tier should involve the sampling of sand lance to investigate for skin lesions and perform tissue analysis to investigate any bio-accumulation. MWRA spends approximately $40,000 annually on flounder histopathology and another $40,000 annually on tissue analyses and chemistry (MWRA *Phase I* (1991), Estimated Costs, p. 43).

References: Covill, 1959; Sherman *et al.*, 1981 ; Meyer *et al.*, 1979 ; Scott, 1973.

Specification Sheet - Phytoplankton - Zooplankton

Monitoring Status: Implement immediately for Tier I, as required for Tier II

Existing Information

1. Nutrients and Massachusetts Bay (An update of eutrophication issues)
2. Nutrients and Massachusetts Bay (A synthesis of eutrophication issues)
3. Spawning strategies of fishes in relation to circulation, phytoplankton production, and pulses in zooplankton off the northeastern U.S.
4. Stellwagen Bank National Marine Sanctuary (Final Environmental Impact Statement/ Management Plan)
5. The videoplankton recorder (VPR) : design and initial results

Format of Existing Information (Dates/Who Analyzed/Long term or Short Term)

1. 1991-1993 / MWRA
2. Fall 1989-summer 1990 / MWRA
3. 1977-1980 / National Oceanic and Atmospheric Administration
4. July 1993 / NOAA
5. 1992 / Davis, Gallager, Berman, Haury, Strickler (WHOI).

Collecting Agent(s)

- NOAA
- MWRA

Location of Collection

- The information from reports 1, 2 and 3 was collected at 46 stations throughout Massachusetts and Cape Cod bays.

Purpose of Collection

- To define variations in the principal indicators (such as chlorophyll, nitrogen and silica ratios of nutrients) and also to analyze the seasonal variations and correlation with fish populations.

Method of Collection

- Phytoplankton biomass estimates may be obtained using a CTD equipped with a fluorometer or using a video plankton recorder (VPR). Rosette water samplers and vertical net tows (25 μm mesh) from 0.5% light level to the surface may also be used (Townsend *et al.*, 1991). Sampling of zooplankton may be accomplished using vertical net hauls of 80 centimeter diameter, 160 μm mesh, plankton nets from the surface to 35 meters and back (Townsend *et al.*, 1991).

Estimated Cost & Time Required

- Costs include ship time and sampling equipment as well as analyses costs. Phytoplankton may be analyzed with the physical water samples.

Necessary Baseline and Red Flags

- Initial baseline is provided by MWRA reports. The red flags are also provided by MWRA reports but should be checked periodically.

Can the Sanctuary Manager Do It?

- Yes, with appropriate equipment.

Purpose of Monitoring

- Information may indicate correlation between plankton variations and fish populations as well as productivity of the Sanctuary. Additionally, analyses of plankton samples may indicate contamination of water column.

Sampling Required (Frequency/Spatial Distribution)

- Given seasonal variations, sampling should occur one time in each month of March, April, June, August and November. This frequency allows the program to characterize the blooms of the phytoplankton. A six station spatial distribution seems to be the optimal.

Notes

- Because of the small size of phytoplankton, it is easily contaminated from the collection vessels or nets. Generally for phytoplankton biomass levels, one can monitor chlorophyll using a fluorometer, which is much less expensive than mobilizing trawling equipment and resources. Gelatinous, small, and fragile zooplankton may be missed with traditional sampling methods. See Turner *et al.* (1989) for discussion.

Other Factors

- Phytoplankton and Zooplankton
- Light
- Chlorophyll-a
- Physics (mixing ,stratification, advection)
- Nutrients and food levels

Linkages

- Tier I plankton population studies to Tier II plankton in-depth studies.
- From Tier I: temperature, salinity, DO, chlorophyll-a, turbidiy

Sediment/Benthos Specification Sheets

Specification Sheet - Mussel Watch / Bivalve Study

Monitoring Status: Historical data - requires development

Existing Information

- Hydrocarbons, PCB and EDDT in mussels and oysters
- Histopathological studies of mussels and oysters
- Trace materials, toxins and petroleum hydrocarbon content
- Contamination of Gulf of Maine Coastline Mussels

Format of Existing Information (Dates/Who Analyzed/Long term or Short Term)

- 1976-1978 / Mussel Watch EPA/Long-term
- 1976-Present/Mussel Watch NOAA/Long-term
- 1977-Present/CA State Water Resources Control Board/Long-term (ref. only)
- 1974-Present/ME Department of Marine Resources

Trigger Levels

- Trigger levels exist for various contaminants including mercury (Hg), PCB, and lead (Pb). In general, warning levels are 50% and action levels are 80% of U.S. FDA Action Limits except for lead, which is based on EPA risk assessment of lead in drinking water:
- **Warning Levels:**
  - Annual mean Hg concentration in caged mussel edible tissue (CMET) > 0.5 μg/g wet weight.
  - Annual mean PCB concentration in CMET > 1.0 μg/g wet weight.
  - Annual mean Pb concentration in CMET > 2.0 μg/g wet weight.
  - Statistically significant upward trend relative to baseline in annual Hg, PCB, or Pb in CMET for three (3) consecutive years.
- **Action Levels:**
  - Annual mean of Hg in CMET > 0.8 μg/g wet weight.
  - Annual mean of PCB in CMET > 1.6 μg/g wet weight.
  - Annual mean of Pb in CMET > 3.0 μg/g wet weight.

Source of Trigger Levels

- MRWA *DRAFT Contingency Plan*, 1995, pp. 44-45.

Collecting Agent(s)

- EPA /NOAA/CA SWRCB/ME DMR
-

Current Location of Collected Data

- Woods Hole Oceanographic Institution-MIT
- EPA Region I Laboratory
- CA SWRCB (for reference purposes only)
- ME DMR

Location of Collection

- Coast (East and West)
- California Coast (for reference purposes only)
- Gulf of Maine

Purpose of Collection

- All of the data was collected to comply with the National and International Mussel Watch Program to establish trends of contamination of the mussels in urban waters.

Methods of Collection

- Throughout each area of concern, the natural mussels/oysters were sampled and the tissues analyzed for various contamination levels.

Alternative Methods

- Another choice of an animal species to determine the effects of anthropomorphic effects on the marine environment.

Necessary Baseline and Red Flags

- The red flag to trigger a Tier II action is a noticeable change in the health of the samples. A baseline is already available in the data for the studies indicated.

Can the Sanctuary Manager Do It?

- Yes.

Equipment Required

- Manager has indicated that it is possible to obtain the use of an ocean going vessel which is the main platform required to perform such a program. Cages for the various samples are also necessary as well as tissue analyses.

Estimated Cost & Time Required

- Cost is approximately $60,000 per site per year. This amount may change if NOAA can be persuaded to fund SBNMS as a site. MWRA allocates $10,000 annually for the caged mussel chemistry (MWRA *Phase I*, 1991, Estimated Costs, p. 43).

Purpose for Monitoring

- The issues addressed indicate the effective way in which the mussels/oysters can provide a snapshot of the accumulation of various contaminants in the ecosystem.

Sampling Required

- The mussel watch program allows the individual scientist to establish a sampling program to suit the particular study. The spatial distribution varies, but sampling frequency for all sites is annually (see Notes below). For a site the size of SBNMS, two sites are recommended, with 30 elements per site.

Notes

MWRA's caged mussel program is an annual sixty (60) day deployment. California program information included for reference purposes only

Linkages

- Analysis of the Tier II benthic environment in which the mussel samples exist.
- Combines with bottom dragging and observation in Tier I to form a comparative study from which Tier II items follow.:
  - Bottom Observation, Benthic Community Assessement: Grab Sampling, Sand Lance
  - The justification for these linkages is provided by the analysis of the individual reports which indicate the inputs to their models and proposed causes and effects.

Other Factors

- NOAA representative, Mr. Tom O'Connor indicated that it may be more feasible to substitute scallops for mussels in analysis due to prevalence of scallops in area. That raises questions of compatibility between data sets that he believes may be resolvable . Additionally, there are not many naturally occurring mussels in the area, but it may be possible to cage some other mussels that will survive, as Mr. John Sowles of the Gulf of Maine Monitoring Committee has done. Finally, due to the location of SBNMS so far from the coast, additional pressure would have to be brought to bear on NOAA to choose SBNMS as a site. The close location of the dredge site and the outfall will probably sway opinion to favor the inclusion.

Specification Sheet - Abundance Estimates: Bottom Dragging

Monitoring Status: Historical data - requires development

Existing Information

CSIRO Division of Fisheries (Sainsbury *et al.*, 1993) conducted experiments in two fishing zones. They closed one zone off to bottom trawling and left the other open to such activities. In the zone which was closed to trawling for the duration of the experiment, there was an increase in both the combined populations of *Lutjanus* and *Lethrinus* and an abundance of both the large and the small epibenthic organisms. Within the zone in which trawling continued throughout the experimental period, the opposite trends were observed. There was a steady decrease in the catch rates of *Lutjanus* and *Lethrinus* and an associated decrease in the two sizes of epibenthic organisms.

Format of Existing Information (dates, who analyzed, long or short term)

- Format unknown. Dates of survey 1986 to 1991.

Collecting Agent

- CSIRO Division of Fisheries, Hobart, Australia

Location of Collection

- Australia, North West Shelf Fishery (tropical fishery, large number of species, commercial interest in small portion, biology of species unknown)

Purpose of Collection

- Concern about destruction of habitats which are necessary for sustaining many fish resources. Great need for sustainability of marine resources.

Method of Collection

- "Adaptive Management" approach, attempts to develop a reasoned empiricism by managing the resource in a way which permits accelerated identification of the response of the resource to exploitation and provides guidance to the selection of long term management options.
- CSIRO personnel collected the data using a 35mm camera system with two illuminating strobes, fitted to the head rope of the trawl gear. The system took a color photograph every twenty-four (24) seconds for the duration of each thirty (30) minute trawl. CSIRO personnel identified habitat types based on the presence or absence of large epibenthic organisms (> 25cm along major axis). To determine the effects of the trawl gear on the epibenthic organisms, CSIRO personnel placed a video 8 camera in an underwater housing and attached it to the headline of the trawl gear. They positioned the camera so that it looked down and back towards the footrope. The field of view encompassed the ground gear and an area of around three (3) to four (4) meters both in front and behind.
- Habitat mapping requires sidescan sonar imagery to show the distribution of sediment types, bedforms, bottom roughness and seabed disturbance caused by fishing gear and tidal and storm currents. Sediment samples are also

necessary coupled with video observations. High resolution seismic profiling and echo sounding surveys provide information on the height and distribution of sand waves and rock outcrops, the thickness of surfacial sediments and the relative hardness and slope of the seafloor. Visual observations of the seabed using video equipped samplers, ROV's and submersibles are essential for interpreting sidescan sonar and seismic data and for documenting substrates and species assemblages in various habitats

Estimated Cost and Time Required

- The study in the North West Shelf Fishery lasted 5 years. A long time period is necessary as effects on a ecosystem are difficult to monitor if conclusive evidence is sought (establishing a baseline etc.) The cost of the Sanctuary monitoring plan's proposed comparative study depends on the cooperation of the fishermen and the cost of the sidescan sonar ($15K - $35K) to image the bottom.

Alternative Methods

- Evaluation of information for management can be done under the "certainty equivalent" approach: a best model is weighted against alternative evaluations of the data available leading to other management options.

Necessary Baseline and Red Flags

- The comparative study during the first few years will determine the baseline and red flags.

Can the Sanctuary Manager Do It?

- Relatively easy to implement.

Purpose for Monitoring

- If dynamics of marine communities are poorly understood, it is hard to determine the effects of bottom dragging. However, results from habitat type identification showed that *Lutjanus* and *Lethrinus* lived in habitats with large epibenthic organisms, while *Nempiterus* and *Saurida* favored open, sandy habitats. Bottom observations may indicate the effects of bottom dragging on the benthos, and it may determine whether such activities are beneficial or detrimental to the benthic ecosystem.

Sampling Required (Frequency/Spatial Distribution)

- 393 observations were made in the North West Shelf Fishery over five years. Bottom observations may be contained to those areas of intensive bottom dragging. Frequency may begin elevated (daily to weekly), and it may settle somewhat as the management gains insight into the effects of bottom dragging.

Other Factors

- The following comments are additional information pertaining to bottom dragging:

- Stellwagen Bank is covered by large expanses of sand, gravelly sand and shell deposits on its crest and upper flanks and by boulder fields and mud on its lower flanks. These bottom types provide a variety of habitats for groundfish, scallops, lobsters, sand lance and other species.
- Concerns expressed about beam trawl impact on habitat have to do with the amount of repeated tows or fishing effort, to which a particular area may be subject.
- The studies performed were not done on surfaces similar to that of Stellwagen Bank, nor were the species the same.
- Stokesbury and Himmelman (1993), as referenced in Coonamesett Farm (1995), have studied large and small scale distribution of scallops in two unfished scallop beds. Large scale distribution was strongly associated with substrate type; gravel and gravel/sand. Small scale distribution was contagious in clumps. High fertilization success within clumps has been evidenced, therefore disturbance of these aggregations may decrease reproductive success.

Habitat Impact

- Habitat impact is related to substrate type, sediment size, current velocity, the organisms present and the gear being used.
- Gear parameters include gear type, weight and frequency of use.
- Today, there is enough evidence indicating that fishing can change the species complex in an area, either by altering the physical habitat, or by selectively destroying sessile organisms that occupy the habitat. The destruction can be due to harvesting and subsequent removal of sessile species, sediment resuspension, mechanical contact with the gear or physical movement of substrate. In most cases, however, it is most difficult to separate out the long-term impacts of fishing from natural processes and other human induced impacts.

Sediment Resuspension

- In high energy environments, heavy fishing pressure may alter the bottom by continually suspending and flushing finer sediments away.
- Bottom dragging has both positve and negative impacts on the benthos as well as some unknown impacts. Working the bottom attracts predators to feed on exposed benthos. Sediment resuspension can increase the rate of benthic pelagic nutrient flux which could lead to plankton blooms which can have positive or negative effects. This may lead to higher production of certain species that feed on the exposed benthos, however, there may be more detrimental effects:
- Introducing previously trapped pollutants into the water column, smothering eggs and small organisms, retarding metabolic functions in filter feeders, altering the ecosystem structure, destroying habitat, changing behavior, etc. Sediment resuspension caused by working the bottom can create anaerobic turbid conditions capable of killing scallop spat. Resuspended sediment also decreases the feeding efficiency of filter feeders.

- Fahraeus-Van Ree (1990), as referenced in Coonamesett Farm (1995), has concluded that cloudy water resulting from otter trawling may negatively influence the physical and chemical interactions between cod males and females as well as the interactions between eggs and milt. Also, newly released eggs are adhesive thus suspended sediment can easily cover the egg membrane resulting in metabolic disturbance and eventual cell death. Cod larvae moving down in the water column to the bottom may be negatively impacted by suspended sediment in that it can diminish their chances of locating prey organisms as the are the visual feeders at this point in life. They may also have respiratory difficulty if sediment covers their epithelia hindering gas exchange.
- Stevens (1987), as referenced in Coonamesett Farm (1995), concluded that sediment clouds generated by towed fishing gear have the potential to kill scallop spat. Suspended sediment at lower levels decreases scallop feeding efficiency inhibiting growth and survival. Metamorphosis of larvae may be affected by sediment resuspension as well. Resettling of sediment can cover surfaces preventing spat settlement on those surfaces. Studies in New Zealand on reseeded scallop beds found 20% survival of spat on untowed beds versus 0.8% survival on beds open to trawling. The relative roles of sediment suspension and mechanical damage resulting in this mortality is unknown.

For other references see Coonamesett Farm (1995), Jenner *et al.* (1985), ISNF (1985) including New England references Valentine and Lough (1991) and Spurr (1977).

Specification Sheet - Bottom Observation: REMOTS® & Redox Potential Reduction Depth

Monitoring Status: Implement as required (equipment, sampling design needed)

Existing Information

- MWRA has performed measurements in their benthic monitoring study (Blake *et al.*, 1993), starting in 1992.

Format of Existing Information

- 10 stations were sampled in May and August of 1992, four of these within the Sanctuary boundaries. As such, these are considered short term observations. Samples were processed at the SAIC Environmental Testing Center in Narragansett, Rhode Island.

Trigger Level

- The sediment redox potential depth (RPD) will not decrease by more than 50% of the baseline condition in muddy areas (> 70% fine grained sediments)

Source of Trigger Level

- MWRA Draft Phase II (MWRA 1995a): *Hypothesis 29*, p. 3-11. MWRA (1995b): *Hypothesis B5*.

Collecting Agent

- Science Applications International Corporation, Woods Hole, Massachusetts.

Location of Collection

- Nearfield stations located around the proposed outfall diffuser site, farfield stations located primarily on west border of sanctuary (see map).

Purpose of Collection

- Determination of baseline conditions before operation of new outfall diffuser. As another indicator parameter of the intensity of biological activity within the upper sediment column, the apparent redox potential depth allows the determination of the depth to which mixing occurs in the benthic environment. Deeper mixing is generally associated with more intensive biological activity.

Method of Collection

- Sediment samples were collected using the Ted Young grab technique, employing a 0.1 square meter Kynar-coated grab with Teflon panels. Two samples were taken at each site, and divided into subsamples to ensure sample purity. These measurements are made using REMOTS image analysis system and interpreted using a SPARCstation computer by a senior-level scientist.

Estimated Cost and Time Required

- Approximately 3 to 4 samples could be collected within a day outing, for sites located in close proximity. A boating platform would be required with accurate navigation equipment, along with the use of REMOTS imaging equipment, which may incure a substantial financial burden for an extended monitoring program. The interpretation of raw data from the equipment will also require trained labor for reliable analysis. This interpretation of the data will require on the order of two weeks to perform. MWRA spends approximately $20,000 annually, for one time per year at 15-20 sites, on sediment profile camera imaging (MWRA *Phase I* (1991), Estimated Costs, p. 43).

Necessary Baseline and Red Flags

- The amount of biological productivity depends upon many factors, including temperature and the availability of nutrients in the benthic environment. The seasonal variations in these factors suggest that tri-weekly or monthly samples be taken in order for the requisite resolution to be determined for statistical analyses to be credible.

Can the Sanctuary Manager Do It?

- The client will most likely not be able to perform these measurements with internal labor resources, as the equipment requires experienced personnel to properly deploy. The interpretation of the raw data will also require skilled labor familiar with the manner that the data is collected.

Sampling Required

- Because of the high capital investment required to deploy and interpret data from the REMOTS equipment, monthly measurements will most likely not be possible. Therefore, quarterly or biannual outings are suggested to determine characteristic redox potential reduction depths at specific sites within the sanctuary which may be at risk to contaminants affecting biological productivity.

Notes

- See the specification sheet for dissolved oxygen.

References

Williams and Rhodes (1994), Germano *et al.* (1994), Fredette *et al.* (1986).

Specification Sheet - Benthic Community Assessment: Grab Samples: Clostridium spores

Monitoring Status: Implement as required (equipment, sampling design needed)

Existing Information

- MWRA has performed measurements in their benthic monitoring study (Blake *et al.*, 1993), starting in 1992.

Format of Existing Information

- 10 stations were sampled in May and August of 1992, four of these within the Sanctuary boundaries. As such, these are considered short terms observations. Samples were processed at the SAIC Environmental Testing Center in Narragansett, Rhode Island.

Collecting Agent

- Science Applications International Corporation, Woods Hole, Massachusetts.

Location of Collection

- Nearfield stations located around the proposed outfall diffuser site, farfield stations located primarily on west border of sanctuary (see map at end of Appendix).

Purpose of Collection

- Determination of baseline conditions before operation of new outfall diffuser. *Clostridium* spores are useful indicator parameters of sewage contamination because of their longevity in oceanic environments.

Method of Collection

- Sediment samples were collected using the Ted Young grab technique, employing a 0.1 square meter Kynar-coated grab with Teflon panels. Two samples were taken at each site, and divided into subsamples to ensure sample purity. Samples were stored at reduced temperature until analysis was performed at SAIC.

Estimated Cost and Time Required

- Approximately three to four samples could be collected within a day outing, for sites located in close proximity. A boating platform would be required with accurate navigation equipment, along with the one-time investment in the sampling equipment. The laboratory analyses would be relatively expensive, on the order of $300-$500, and requiring three to five days to complete.

Necessary Baseline and Red Flags

- The yearly variations which inevitably occur, from the variation of freshwater inflow from the Gulf of Maine and effluent from the MWRA outfall will need to be documented in order for meaningful deviations to be statistically significant. Once a stable range of *Clostridium* spore populations has been documented at the sampling locations, outliers from this range should be retested and then noted as red flags if successive tests determine the location is in fact a statistical outlier.

Can the Sanctuary Manager Do It?

- The client will be able to collect the samples if access to a boating platform is available. The analyses of the samples should be performed by competent laboratory specialists, such as SAIC of Narragansett, Rhode Island.

Sampling Required

- Samples should be taken at bimonthly or quarterly periods in order to determine the seasonal variations associated with varying outfall intensities. These measurements should be taken in depositional areas (basins) located in nearest to the outfall or Gulf of Maine inflow.

Notes

- Silver (Ag) is also a good sewage tracer (MWRA, 1995b).

Linkages

- Bottom Observation, Bivalve Study

References

Bothner *et al.* (1994)

Specification Sheet - Benthic Community Assessment: Grab Samples: Total Organic Carbon

Monitoring Status: Implement as required (equipment, sampling design needed)

Existing Information

- MWRA has performed measurements in their benthic monitoring study (Blake *et al.*, 1993), starting in 1992.

Format of Existing Information

- 10 stations were sampled in May and August of 1992, four of these within the Sanctuary boundaries. As such, these are considered short terms observations. Samples were processed at the SAIC Environmental Testing Center in Narragansett, Rhode Island.

Collecting Agent

- Science Applications International Corporation.

Location of Collection

- Nearfield stations located around the proposed outfall diffuser site, farfield stations located primarily on west border of the Sanctuary (see map at end of Appendix).

Purpose of Collection

- Determination of baseline conditions before operation of new outfall diffuser. Total Organic Carbon is a useful measurement of the biological activity in an area, as organic matter decomposes into various carbon by-products.

Method of Collection

- Sediment samples were collected using the Ted Young grab technique, employing a 0.1 square meter Kynar-coated grab with Teflon panels. Two samples were taken at each site, and divided into subsamples to ensure sample purity. Samples were frozen and sent to the Geochemical and Environmental Research Group of Texas A&M University for analysis according to NOAA's Status and Trends program.

Estimated Cost and Time Required

- Approximately three to four samples could be collected within a day outing, for sites located in close proximity. A boating platform would be required with accurate navigation equipment, along with the one-time investment in the sampling equipment. The laboratory analyses would be more expensive, on the order of $750, and requiring three to five days to complete.

Necessary Baseline and Red Flags

- The amount of biological productivity depends upon many factors, including temperature and the availability of nutrients in the benthic environment. The seasonal variations in these factors suggest that tri-weekly or monthly samples be taken in order for the requisite resolution to be determined for statistical analyses to be credible.

Can the Sanctuary Manager Do It?

- The client will be able to collect the samples if access to a boating platform is available. The analyses of the samples should be performed by competent laboratory specialists.

Sampling Required

- As mentioned above, it is recommended that samples be taken at least once a month in areas of high biological productivity in order to understand the seasonal variations in benthic activity. Significant deviations should be confirmed by additional sample, and if found consistently outlying, then further investigation should be undertaken to determine the causal factor in reduce biological productivity.

Linkages

- Bottom Observation, Bivalve Study

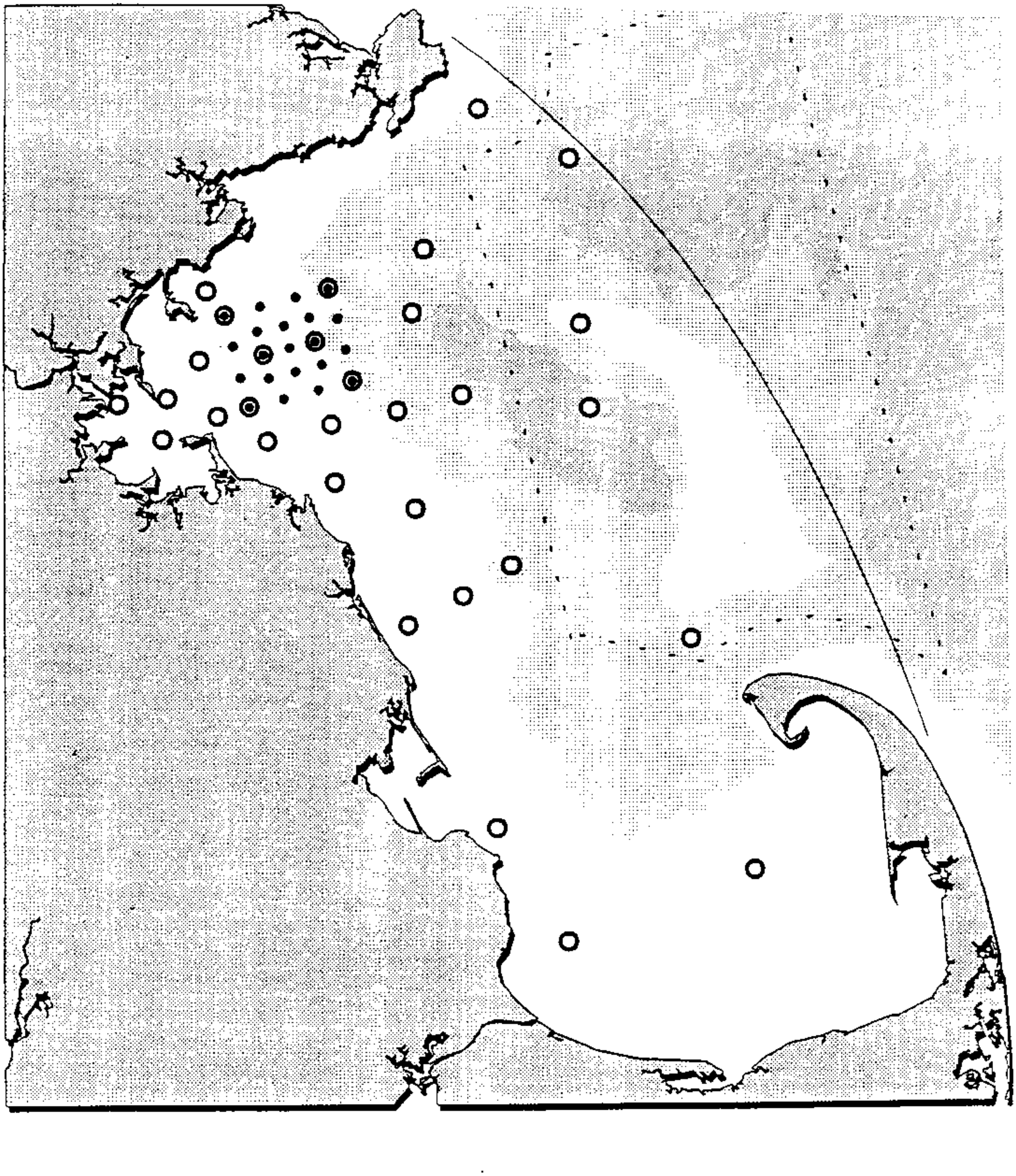


Figure A-1. MWRA Water Quality Monitoring Stations
(courtesy of MWRA; from MWRA, 1995b)

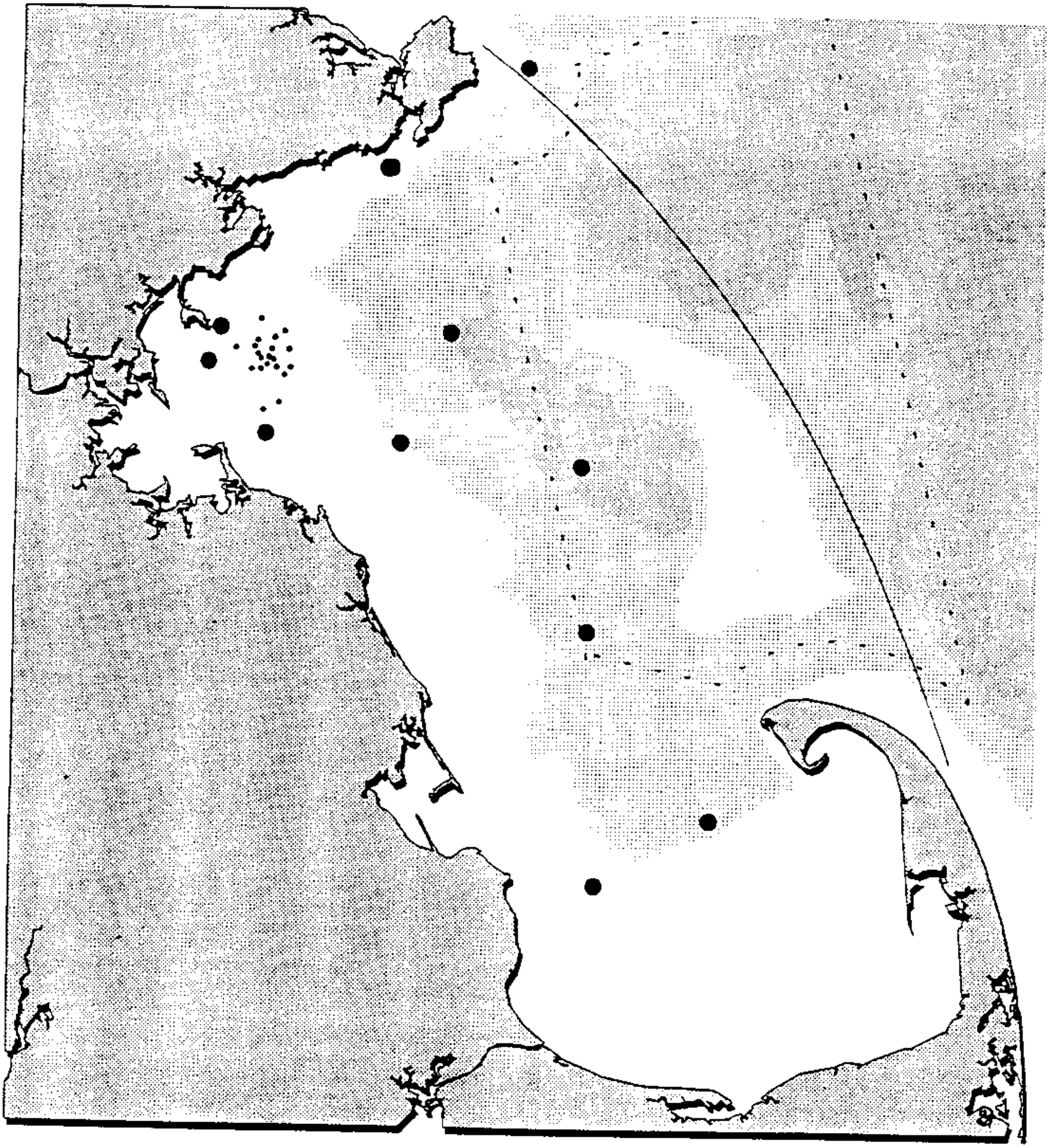


Figure A-2. MWRA Benthic Monitoring Stations
(courtesy of MWRA; from MWRA, 1995b)

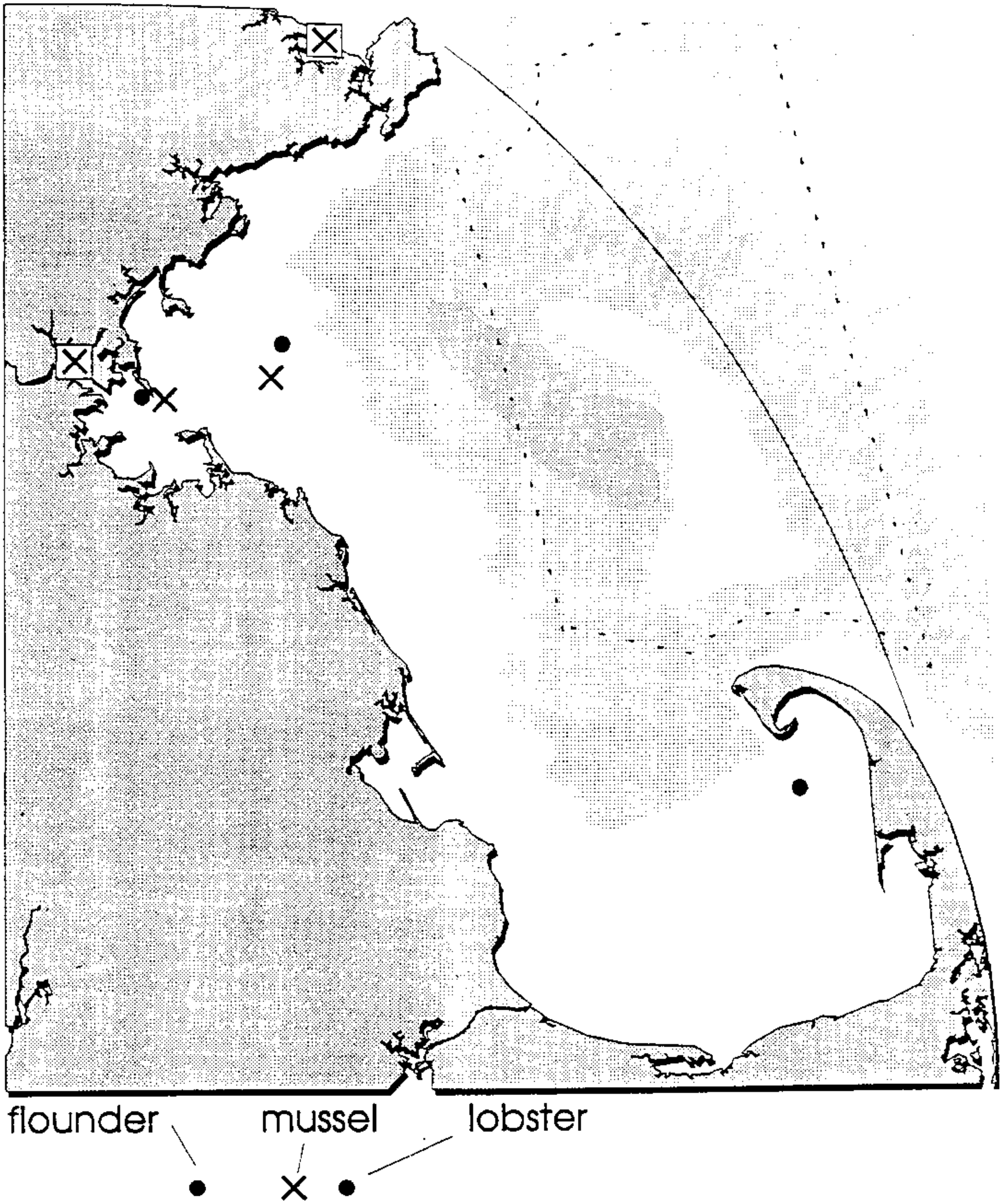


Figure A-3. MWRA Fish & Shellfish Monitoring Stations (courtesy of MWRA; from MWRA, 1995b)

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