Using Science in the Management of Massachusetts Bay and Boston Harbor

Judith McDowell and Judith Pederson

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AN ADAPTIVE MANAGEMENT APPROACH: INTEGRATION OF SCIENCE INTO MANAGEMENT DECISIONS FOR MASSACHUSETTS BAY AND BOSTON HARBOR

A Special Session of Coastal Zone 97: The next 25 years

Convened by

Judith McDowell, Director WHOI SG
and
Judith Pederson, MIT SG

Co-sponsored by

Massachusetts Institute of Technology Sea Grant College Program
and
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AN ADAPTIVE MANAGEMENT APPROACH: INTEGRATION OF SCIENCE INTO MANAGEMENT DECISIONS FOR MASSACHUSETTS BAY AND BOSTON HARBOR

A one day Symposium, a *Ten-year Review of Management Issues and Scientific Studies in Massachusetts Bay and Boston Harbor*, is scheduled for Monday, July 21, 1997 at the Plaza Ballroom of the Park Plaza Hotel. This Massachusetts Bay Symposium highlights scientific studies that support and are integrated into management decisions affecting coastal and marine resources in the Massachusetts and Cape Cod Bays and Boston Harbor. The Massachusetts Bays Symposium is being held in conjunction with the Tenth International Symposium on Coastal and Ocean Management, Coastal Zone 97: The Next 25 years.

AGENDA

8:30 AM	Introductions Judith McDowell, WHOI Sea Grant and Judith Pederson, MIT Sea Grant
8:45 AM	*Integrating Science and Management: The Massachusetts Bays Program Experience* Judith Pederson, MIT Sea Grant College Program
9:10 AM	*Trigger Planning Tightens the Relationship between Monitoring and Pollution Abatement: The Massachusetts Water Resources Authority Contingency Plan* Michael S. Connor, Michael Mickelson, Kenneth E. Keay, Leo Sommaripa, and Mary Robbins, Massachusetts Water Resources Authority
9:35 AM	*Tracer Studies of Freshwater and Sediment Transport in Boston's Inner Harbor* E.Eric Adams, Massachusetts Institute of Technology and Keith D. Stolzenbach, University of California Los
10:00 AM	Break
10:15 AM	*Predicting Sediment Transport and the Fate of Contaminants in Massachusetts Bay* Bradford Butman, Richard P. Signell, Michael H. Bothner, and Jeffrey H. List, U. S. Geological Survey
10:40 AM	*Metal Concentrations in Surface Sediments of Boston Harbor - Changes with Time* M. H. Bothner, M. Buchholtz ten Brink, and F.T. Manheim, U.S. Geological Survey
11:05 AM	*Sediment/Water Exchange of Contaminants in Boston Harbor: Estimating Clean Up Times (no abstract)* Phillip Gschwend, Massachusetts Institute of Technology
11:30 AM	*The Merrimack River: Its Importance as a Source of Contaminants to the Gulf of Maine*

Marie Studer, Earthwatch, Gordon Wallace, UMass/Boston, and Jerome Cura, Menzie-Cura Associates, Inc.

11:55 AM	Lunch
12:55 PM	*Overview of the Physical Environment of Massachusetts and Cape Cod Bays* George B. Gardner, University of Massachusetts/Boston
1:20 PM	*Benthic Metabolism and Nutrient Cycling in Boston Harbor Massachusetts, USA - A Decade's View* Anne Giblin, Charles Hopkinson, and Jane Tucker, Marine Biological Laboratory
1:45 PM	*Nutrients in Massachusetts Bay - A Decade's View* Theodore C. Loder III and Robert D. Budrow, University of New Hampshire
2:10 PM	*"Recovery" of Boston Harbor Benthos: Infauna, Carbon-Nitrogen Cycling and Sediment-Water Column Exchanges* Brian Howes, UMass/Dartmouth, David R. Schlezinger, Boston University, and James A. Blake, ENSR
2:35 PM	Break
2:50 PM	*Benthic Community Monitoring in Boston Harbor: Do Observed Community Changes Equal Recovery from Pollution?* Kenneth E. Keay, Massachusetts Water Resources Authority, James A. Blake, ENSR, Eugene D. Gallagher, UMass/Boston, Brigitte Hilbig, ENSR, Roy K. Kropp, Battelle Ocean Sciences, Donald C. Rhoads, Science Applications International Corporation
3:15 PM	*Food Resources and Foraging Imperatives of the Northern Right Whale, Eubalaena glacialis, in Massachusetts and Cape Cod Bays* Charles Mayo, Center for Coastal Resources
3:40 PM	*Examining Historical Changes in Biota of Plum Island Sound* Robert Buchsbaum, Massachusetts Audubon Society
4:05 PM	*Fisheries Resources in Massachusetts Cod Bays* H. Arnold Carr, Massachusetts Division of Marine Fisheries
4:30 PM	*The Wellfleet Harbor Project - Successes of the Minibays Approach* George Heufelder, Barnstable County Health Department

An Adaptive Management Approach: Integration of Science into Management Decisions for Massachusetts Bay and Boston Harbor

Judith Pederson, Massachusetts Institute of Technology Sea Grant College Program
Judith McDowell, Woods Hole Oceanographic Institution Sea Grant Program

A Ten-year Review of Management Issues and Scientific Studies in Massachusetts Bay and Boston Harbor

Since the mid 1980s when Boston Harbor was deemed one of the dirtiest Harbors in the U.S., considerable research and monitoring efforts have gone into understanding processes and developing management approaches to improving water quality in Boston Harbor and Massachusetts and Cape Cod Bays. Initial studies focused on identifying and quantifying point and nonpoint sources of pollution, understanding the physical and biogeochemical process of the bay and the transport, fate and effect of contaminants, and examining pollution impacts on living resources in the Bays. This session reviews ten years of research in Massachusetts Bay and Boston Harbor and highlights scientific studies that support and are integrated into management decisions affecting coastal and marine resources.

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INTEGRATING SCIENCE AND MANAGEMENT: THE MASSACHUSETTS BAYS PROGRAM EXPERIENCE

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Key words: Massachusetts Bay, Management, Contaminants, Decision-making

Centuries of dumping human and industrial wastes into Boston Harbor has left a legacy of pollution and ecosystem degradation. Although required to bring wastewater treatment to a secondary level in compliance with the Clean Water Act, the Commonwealth appealed the decision through a waiver process in the Clean Water Act and delayed any upgrade for nearly a decade. The state was denied the waiver and forced to pay settlement funds that were used to conduct studies that would enhance understanding pollution impacts on the system.

Using these settlement funds, the Massachusetts Bays Program (MBP) was established and eventually become a National Estuary Program. The program's research and outreach activities focused on the Massachusetts and Cape Cod Bays ecosystem as a whole. The process for establishing a research program that addressed management concerns involved bringing together stakeholders, managers and scientists to identify the management questions and develop a research plan to address these concerns. Given the limited state of knowledge, studies initially focused on characterizing (and quantifying) sources of contaminants, physical oceanography, the transport, fate and effect of contaminants and a socio-economic study of Massachusetts Bay resources. Subsequent studies focused on data gaps, especially poorly defined sources and distribution of contaminants. Through various committees, such as local governance, citizen's advocacy network, technical advisory committee and a management committee, the program has been successful in integrating scientific information into local and state management decisions.

Because Boston Harbor is ranked among the most contaminated in the country, the MBP research agenda focused, in part, on the effects of contaminants on living resources (Table 1). These studies included improved quantification of sources, the effects of contaminants and PAH on individual organisms and on populations. The data provided background for a major monitoring program in Massachusetts Bay to examine the effectiveness of secondary level treatment of a major wastewater treatment facility contributed to the refinement of point and nonpoint sources for specific contaminants and are relevant to development of sediment quality criteria that is under review at the state. The integration of research studies with management issues has furthered our knowledge and improved decision-making and policy development.

Table 1. Part List of Massachusetts Bays Program Funded Research.

Researchers	Date	Title
Dan Golomb David Ryan Nelson Eby Jeffrey Underhill Terry Wade Stephen Zemba	1995 MPB-96-01	Atmospheric Deposition of Toxic Metals and Polynuclear Aromatic Hydrocarbons and Nitrogen onto Massachusetts Bay Parts I and II
Jeffrey L. Hyland Helder Costa	MPB-95-03	Examining Linkages Between Contaminant Inputs and their Impacts on Living Marine Resources of the Massachusetts Bay Ecosystem through Application of the Sediment Quality Triad Method.
Judith McDowell Damian Shea	1996	Population Processes of Mya arenaria from Contaminated Habitats in Massachusetts Bays
Anne McElroy Michael Shiaris Judith McDowell Brian Howes John Molongoski	1995 MBP-95-02	Bioavailability and Biotransformation of Polycylic Aromatic Hydrocarbons in Benthic Environments of Coastal Massachusetts
Menzie-Cura	1991 MBP-91-01	Sources and Loading of Pollutants to Massachusetts Bay. Massachusetts Bays Program
Menzie-Cura	1995 MBP-95-04	Organic Loadings from the Merrimack River to Massachusetts Bay
Menzie-Cura	1995 MBP-95-06	Measurements and Loadings of PAH in Storm Water, Combined Sewer Overflows, Rivers, and Publicly Owned Treatment Works Discharging to Massachusetts Bays
Michael Moore Roxanna M. Smolowitz Dale F. Leavitt John J. Stegeman	1995 MBP-95-05	Evaluation of Chemical Contaminant Effects in the Massachusetts Bays

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TRIGGER PLANNING TIGHTENS THE RELATIONSHIP BETWEEN MONITORING AND POLLUTION ABATEMENT:

THE MASSACHUSETTS WATER RESOURCES AUTHORITY CONTINGENCY PLAN

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Michael J. Mickelson, Massachusetts Water Resources Authority
Kenneth E. Keay, Massachusetts Water Resources Authority
Leo Sommaripa, US Peace Corps, Ivory Coast
Mary Robbins, Massachusetts Water Resources Authority

Key Words: Monitoring, Trigger Planning, Indicators

The Massachusetts Water Resources Authority (MWRA), which provides water and sewer service to greater Boston, is currently developing a plan to link the results of its monitoring program directly to the environmental protection of Massachusetts and Cape Cod Bays when effluent discharge moves from Boston Harbor into Massachusetts Bay. The impetus for and direction of the plan comes from regulatory review in connection with the Endangered Species Act. In cooperation with regulatory agencies, MWRA has written a Contingency Plan whose underlying structure serves as a model for making monitoring a tool that can be actively used to improve the health of the environment and inform the public, and is not just another isolated study. The Contingency Plan not only includes descriptions of potential modifications to the treatment plant, but also addresses the more difficult question of establishing how and when an alternative would be chosen and used.

MWRA evaluated seven categories of impact of coastal discharges of treated sewage: nutrients, organic material, toxic contaminants, pathogens, solids, floatables, and plant performance (so that systemic problems with the plant can also be identified). The Contingency Plan identifies approximately thirty water quality characteristics monitored by MWRA that are indicators of relevant environmental problems. These indicators are called "trigger parameters" because when they exceed threshold levels established in the Plan, they automatically trigger specific MWRA responses; the thresholds set quantitative boundaries for acceptable environmental change. Thresholds are either "caution levels" or "warning levels," depending on the degree of risk they indicate. Caution levels provide early indication of unanticipated environmental change, well before environmental health is compromised. If a parameter's trigger value reaches the warning level, no significant impact has occurred, but environmental conditions have moved sufficiently far from the baseline that it would be prudent to respond in order to prevent significant impact. This quantification of different levels of environmental risk is key to determining when and how to respond to environmental change.

To complement the thresholds, the Contingency Plan describes what corrective actions could be taken to reduce the impact of MWRA effluent. The Plan does not include fully developed engineering blueprints. Instead, it describes the kinds of technologies available and matches them to the environmental problem.

The implementation process connects monitoring results to response (Figure 1), integrating the monitoring program into evaluation and improvement of treatment plant performance. Regularly published reports of monitoring results include comparisons with thresholds to determine whether there are any exceedances. If there were a threshold exceedance, a series of steps takes MWRA in five months through a preliminary investigation and proposal for expanded monitoring and development of corrective action. The proposal, which includes target dates for each step of the response, is subject to peer review by an oversight group and an outside visiting committee.

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Regular monitoring, reviewing, and reporting

Develop Contingency Plan

Develop and implement outfall monitoring plan

Regular meetings of Outfall Monitoring Task Force (OMTF)

Early review of all monitoring data (ASAP)

Technical reports on effluent, water, benthos, and fish (annual)

Public reporting such as Wastewater Performance Report (quarterly), and http://www.mwra.com

Outfall Monitoring Overview Report (annual) details results, exceedances, actions, and revisions to monitoring plan and contingency plan

Actions taken when threshold exceeded

If warning level exceeded:

- accelerate reporting
- notify OMTF
- notfy treatment plant operations staff

If there is any exceedance:

- convene special meeting of OMTF to confirm exceedence and determine cause.
- notify plant staff
- summarize actions in the Wastewater Performance Report

If any exceedance is caused by MWRA discharge:

- the subsequent Wastewater Performance Report describes plant performance, expanded monitoring, and modifications to MWRA operations.

If the exceedance caused by MWRA discharge is for a warning level:

- develop a Response Plan

TRACER STUDIES OF FRESHWATER AND SEDIMENT TRANSPORT IN BOSTON'S INNER HARBOR

E. Eric Adams, Massachusetts Institute of Technology
Keith D. Stolzenbach, University of California Los Angeles

Key Words: Freshwater, Sediment, Deposition, Residence Time

As part of an interdisciplinary study of the transport and fate of sewage contaminants (Stolzenbach and Adams, eds., 1997), particularly those emanating from combined sewer overflows (CSOs), several field studies were conducted in Boston's Inner Harbor.

The first study concerned the residence time of water and suspended particles in Fort Point Channel, a sub-region of Boston Harbor containing a major CSO and highly contaminated sediment. Residence times were determined during three field surveys from 1989-1991 by measuring the disappearance of fluorescent tracers from the water column. Flushing by advective movement was quantified using Rhodamine WT dye, a dissolved tracer which has negligible interaction with suspended sediment. The fate of suspended particles was inferred from measured concentrations of fluorescent yellow pigment particles which were initially well mixed with the dye and which have a size range and settling velocity comparable to the sewage particles of interest. Dye and particle concentrations were measured by fluorescent spectroscopy of water samples obtained throughout the channel over a week following tracer introduction. Results indicated that channel water is replaced on a scale of 1 to 2.5 days, depending on tidal amplitude and phase during tracer release, and the magnitude of freshwater inflow. The characteristic time for particle removal was 0.5 to 1 days, reflecting additional loss by deposition. The implied particle deposition rate of 2-5 m/d is an order of magnitude faster than observed in laboratory settling columns suggesting that removal of suspended tracer particles from Fort Point Channel during our surveys may have been the result of scavenging by a bottom "fluff" layer. This finding is consistent with our previous observation of particle deposition in Salem Sound, MA, and in controlled laboratory studies of particle aggregation at the sediment water interface.

The fluorescent yellow paint also served as markers to determine overall sediment burial rates in the channel. To this end, three cores were taken in 1993 and 1994 from the floor of the channel and sectioned in 1 cm intervals to identify vertical bands of high paint concentration. Paint particles were counted and sized manually using a fluorescent microscope in order to determine the mean burial rate, the particle size distribution and the total mass recovered in the core. The experimentally determined burial rate estimated from the two peaks of particle concentration in the three cores (n=6) ranged from 0.5 to 4.0 cm/yr with a mean of 2.4 cm/yr. Such rates are consistent with other estimates made from Pb-210 measurements and from measured variations over time in channel bathymetry. If representative of deposition over the whole channel, these rates suggest a net import of sediment equal to more than ten times the rate of sediment discharged directly to the channel.

During July 1992 the second dye study was conducted in which approximately 500 pounds of 20% Rhodamine WT dye were released over a period of 5.5 hours into the Charles River just upstream of its entrance to the inner harbor at theNew Charles River Dam. Dye concentrations were recorded throughout the Inner Harbor over the following six days. After the first day, dye was found to be reasonably well mixed laterally, but showed decreasing concentrations with depth and distance toward the mouth. The mean residence time of Charles River water in the Inner Harbor, computed from the time variation of total dye recovery, was 3.75 days. Freshwater inflow to the Inner Harbor during this period averaged about 4 m3/s and the 3.75 day residence time corresponds approximately to earlier observations by Bumpus for this flow rate, who used the fraction fresh water approach. Fecal coliform are often used as indicators of sewage pollution. Reported half-lives of fecal coliform, determined by calibrating models to field measurement in Boston Harbor, fall in the range of 0.2 to 0.7 days--significantly shorter than the mean inner harbor residence time. This suggests that most bacteria entering the inner harbor with the Charles River inflow, or from nearby CSOs, die by the time they reach the Outer Harbor.

The results of both sets of field studies were used in the calibration of 2 and 3-dimensional models to simulate the transport of CSO contaminants through Boston's Inner Harbor.

Stolzenbach, K. D. and Adams, E. E. (eds) Contaminated Sediments in Boston Harbor Marine Center on Coastal Water Quality, MIT Sea Grant College Program (1997).

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PREDICTING SEDIMENT TRANSPORT AND THE FATE OF CONTAMINANTS IN MASSACHUSETTS BAY

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The transport and accumulation of sediments in the Massachusetts Bays is determined principally by the residual circulation, major storms, the bathymetry, and the geometry of the semi-enclosed basin. The mean current, driven principally by the along-shore coastal current in the western Gulf of Maine, proceeds in a counterclockwise direction around Massachusetts Bay. Superimposed on this residual flow pattern are tidal, density, and wind-driven currents that can alter the direction and speed of residual flow on a daily basis. Northeast storms generate large swell that propagate into Massachusetts Bay from the Gulf of Maine. The oscillatory currents associated with these waves cause resuspension of bottom sediments in water depths less than about 50 m over areas exposed to the northeast, principally along the western shore of Massachusetts Bay. The near-bottom currents associated with the northeast winds are to the south and offshore and carry the resuspended material southward toward Cape Cod Bay and offshore into Stellwagen Basin. The area to the west of Cape Cod is sheltered from the large swell associated with northeasters, and the waves are rarely large enough to resuspend the sediments in the deep Stellwagen Basin. Sediments that are transported to these two areas from the western side of Massachusetts Bay, by the residual circulation or the storm-driven currents, are less likely to be resuspended again, and thus these areas are long-term sinks for fine sediments and associated contaminants. This conceptual model is supported by direct observations of currents and sediment resuspension during storms, wave and 3D current modeling, by the observed accumulation of fine grained sediments in Cape Cod Bay and Stellwagen Basin, and by the lack of fine sediment along the western shore of Massachusetts Bay. The model is also consistent with the distribution of silver and *Clostridium perfringens* spores, most likely input to the Massachusetts Bays from Boston's sewage system. The role of internal waves, a potential mechanism for resuspending sediments in Stellwagen Basin in the summer, remains to be determined.

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METAL CONCENTRATIONS IN SURFACE SEDIMENTS OF BOSTON HARBOR - CHANGES WITH TIME

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Key words: Boston Harbor, sediments, metals, time trends, contaminants

The concentrations of metals in surface sediments of Boston Harbor have decreased during the period 1977-1993. This conclusion is supported by analysis of: (1) surface sediments collected at monitoring stations in the outer harbor between 1977 and 1993; (2) metal concentration profiles in sediment cores from depositional areas of the harbor; and (3) historical data from a contaminated-sediment database, which includes information on metal and organic contaminants and sediment texture. The background and matrix-corrected concentrations of lead (Pb) measured in the surficial layer (0-2 cm) of cores decreased by an average of 46% ± 9% among four locations in the outer harbor during the 16 year period. Chromium (Cr), copper (Cu), mercury (Hg), silver (Ag), and zinc (Zn) exhibited similar trends.

Results from this study are supported by historical data that were compiled from diverse sources into a regional sediment database. This sediment database contains approximately 3000 samples; of these, about 600 samples were collected and analyzed for Cu, Hg, Pb, and Zn in Boston Harbor surface sediments between 1971-1993. The database indicates that, in Boston's Inner Harbor, the concentrations of these four metals also decreased with time. The concentrations of metals within each year-class in the database are highly variable. In the case of the Inner Harbor, the reduction in this variability and average contaminant concentration appears to parallel a reduction in industrial and other point sources that has occurred since the early 1970's after the U.S. EPA NPDES discharge permit system was established.

The decreases in metal concentrations that are observed in more recent years parallel a general decrease in the flux of metals to the harbor, such as: (1) ending of sewage sludge discharge to the Harbor in December, 1991; (2) greater source reduction (e.g. recovery of silver from photographic processing) and closing or moving of companies; (3) improvements in wastewater handling and sewage treatment; and (4) diminishing use of lead in gasoline beginning about 1973. Despite the general decrease in metal concentrations in Boston Harbor surface sediments, the concentrations of Ag and Hg measured at some outer harbor stations in 1993 were still at, or above, the level associated with frequent adverse effects to marine organisms (guidelines are: Ag 3.7 ppm, Hg 1.17 ppm, Long and others, 1995). Concentrations of the other metals listed were in the range considered to occasionally induce adverse biological effects.

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THE MERRIMACK RIVER: ITS IMPORTANCE AS A SOURCE OF CONTAMINANTS TO THE GULF OF MAINE

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Gordon Wallace, The University of Massachusetts at Boston
Jerome Cura, Menzie-Cura and Associates

Key Words: Merrimack River, metals, polynuclear aromatic hydrocarbons, Gulf of Maine, Massachusetts Bay

The Merrimack River is New England's fourth largest river basin and the fifth largest river discharging to the Gulf of Maine and one of the is more heavily populated and industrialized than larger watersheds in Maine and Canada. contaminants discharged to the Merrimack Estuary.

Although the Merrimack does not discharge directly into Massachusetts Bay, a fresh water plume attributed to the Merrimack has been observed in the Bay by Butman (1975) Gardner et al., (1986) hypothesized that the Merrimack was a major source of metals to the Bay. In addition, it has been estimated that the Merrimack River may contribute about 50% of the freshwater entering the Bays system (Geyer et al., 1992). Therefore, knowledge of the metal flux from the Merrimack River to its estuary and, potentially to the Gulf of Maine and Massachusetts Bay systems, is a necessary component of the management of these resources.

A two-year geochemical study of the Merrimack River was undertaken to determine the behavior of selected dissolved and particulate metals in the river system and the flux to the Merrimack Estuary and assess the potential flux to the Gulf of Maine (Studer, 1995). The River was sampled at the most downstream, freshwater location at Newburyport, MA. Anthropogenic and seasonal influences on water column metal concentrations, distribution and fluxes were observed. The magnitude of the spring transport, and the large percentage of metals in the dissolved form throughout the year, indicates that metals may be efficiently transported to the Gulf of Maine and impact the near-shore environment.

During sample collection for metal analysis, flow varied by a factor of 30 between the highest and lowest flow sampled. Most dissolved metal concentrations fluctuated within a factor of 5 and did not show strong trends with flow. The greatest variability in concentrations of most dissolved metals occurred under low-flows. The greater variation at lower flow reflect both the result of anthropogenic perturbations of the system and in-stream processes. Variability in particulate metal concentrations observed over the flow range was greater than for dissolved metal concentrations, and no systematic relationship between concentration and flow were observed.

Riverine dissolved and particulate metal flux from the Merrimack River were estimated using results from the flux versus flow relationships from linear regression analysis. Assuming that metal transport through the estuary is conservative, the Merrimack River becomes an important source of metals to coastal waters. Even under low-to average-flow conditions, the potential flux from the Merrimack can be substantial, and becomes much more significant during the spring high-flow conditions. It was estimated that 35-75% of the annual total metal and 70% of the annual TSM flux occurs during the spring months of March, April and May. The relative contribution of dissolved and particulate metals to the estuary changes with flow. On an annual basis, approximately 65% or more of the Al, Fe, and Pb is delivered to the estuary in particulate form, while 80% or greater of the annual Cu, Mn, Ni and Zn flux is introduced in dissolved or colloidal form. Approximately 60% of the annual Cd flux is in the dissolved/colloidal form. The predominance of dissolved or colloidal forms is of importance in assessing the efficiency of transport of metals in the Gulf of Maine watersheds and coastal waters.

Riverine metal flux from the Merrimack River is comparable in magnitude with the metal flux entering Massachusetts Bay in sewage effluent. Under average river flow conditions, the estimated Cu river flux is roughly 50% of the input entering Massachusetts Bay from the Massachusetts Water Resources Authority (MWRA) treatment plant (Alber and Chan, 1993). Estimates for the riverine Zn flux is approximately equal to that contributed by the MWRA treatment plant and Pb river flux is double the sewage flux. During high-flow conditions, the Merrimack River discharges 2-6 times the amount of metal released from the treatment plant.

In 1992, a one year study was conducted to quantify and assess the significance of loadings of organic contaminants from the Merrimack River to Massachusetts Bay (Menzie-Cura, 1995). The river was sampled four times under various flow and seasonal conditions. At the time of sampling, the Merrimack River Estuary was a strongly stratified, salt wedge estuary. The concentrations of organic compounds below the pycnocline are generally low, relative to concentrations in the thin (often less than one meter deep), well-mixed surface layer.

The measured total polycyclic aromatic hydrocarbons concentration in Merrimack River freshwater discharge ranged by a factor of four, from 120 mg/l to 460 mg/l, with the highest concentrations observed in samples collected in the spring. Assuming that the water from the Merrimack River reaches Massachusetts Bay for approximately half the year, a loading estimate from the River to the Bay of 1,000 kg/year is calculated.

The predicted PAH concentrations in northern outer Massachusetts Bay (based on measured concentrations in the Merrimack River, dilution of the Merrimack River plume, and conservation of mass of PAHs) agree well with measured concentrations in northern outer Massachusetts Bay. However other sources of PAHs, including atmospheric deposition, are also known to contribute significantly to the overall loading. The estimated total loading of PAHs to Massachusetts Bay from all sources is 14,000 kg/year. The total loading from the Merrimack River and rivers draining into Massachusetts Bay is approximately 29% of the total, with the Merrimack contributing as much as 8% of the estimated total PAH loading. These results emphasize the importance of the Merrimack River as a source of organic contaminants to the coastal zone and that it should be considered in the long-term management plan of the Gulf of Maine/Massachusetts Bay system.

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OVER VIEW OF THE PHYSICAL ENVIRONMENT OF MASSACHUSETTS AND CAPE COD BAYS

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Key words: Massachusetts and Cape Cod Bays, Physical Oceanography

At the largest scale, Massachusetts and Cape Cod Bays are dominated by regional oceanographic processes in the Gulf of Maine, within which they are embedded. In particular, most of the fresh water received by the Bays enters in a southward flowing coastal current which carries river discharges from the Merrimack River (which enters the Gulf approximately 30 km north of Massachusetts Bay) as well as from more remote rivers entering along the coast of Maine. Circulation of the surface waters within the Bays is generally from north to south, representing in effect a portion of this coastal current. In contrast with a very open connection between the Gulf and the Bays within the upper 30 meters of the water column, the deeper waters are isolated by Stellwagen Bank, which forms much of the eastern boundary below that depth. During the winter months, the water column is well mixed, and water properties throughout the Bays are similar to, though somewhat colder than, those in the Gulf. From approximately April to October, however, there is sufficient stratification to partially isolate the deeper water. During this stratified period, the temperature and salinity of the deep water evolve slowly, through diffusion and episodic advective events, from initial conditions set at the time of stratification. Dissolved oxygen concentrations decline significantly over this period due to respiration, at times approaching levels of concern. I will illustrate these processes using data I and others have acquired over the last several years. I will also briefly discuss the vertical transport processes active during the stratified period. These processes are important in determining the nutrients available for phytoplankton production.

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BENTHIC METABOLISM AND NUTRIENT CYCLING IN BOSTON HARBOR, MASSACHUSETTS, U.S.A.

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Key Words: Benthic fluxes, nutrients, denitrification, sediments, decomposition

To gain insight into the importance of the benthos in carbon and nutrient budgets of Boston Harbor and surrounding bays, we measured sediment-water exchanges of oxygen, total carbon dioxide (DIC), nitrogen (ammonium, nitrate+nitrite, urea, N_2O), silicate, and phosphorus at several stations in different sedimentary environments just prior to and subsequent to cessation of sewage sludge disposal in the Harbor.

Measurements were made at three primary stations: (1) BH08 which was representative of sandy substrate; (2) BH02 which was more typical of reworked environments; and (3) BH03, the former sludge disposal site which should represent the extreme of depositional areas. These stations were sampled from 1 to 5 times a year for three years. At least one annual cycle was obtained from each station.

The ratio of the average annual DIC release to O_2 uptake at three primary stations ranged from 0.84 to 1.99. Annual average DIC/DIN flux ratios were consistently greater than predicted from the Redfield ratio, suggesting substantial losses of mineralized N. The pattern was less clear for P, as some stations showed evidence that the sediments were a sink for P while others appeared to be a net source to the water column over the study period. In general, temporal and spatial patterns of respiration, nutrient fluxes and flux ratios were not consistently related to measures of sediment oxidation-reduction status such as Eh or dissolved sulfide. The colonization of the sediments of BH03, the former disposal site, by large numbers of benthic infauna had a profound effect on sediment chemistry and metabolism.

To calculate the importance of organic matter decomposition in the sediments to the carbon budget of Boston Harbor, we used average annual DIC fluxes from stations BH03, BH02, and BH08. We assigned these rates in proportion to the relative areal extent of depositional (51%), reworked (29%), or erosional (20%) sediments in Boston Harbor. We excluded 1993 BH03 data because we felt the very high rates at the sludge disposal site during this year, when benthic infaunal abundances peaked, were probably not representative of the depositional areas in the Harbor as a whole. Weighted average sediment respiration was 56 mmol C m^{-2} d^{-1} in Boston Harbor.

Levels of primary production have been estimated to be 325 gC m^{-2} y^{-1} (74 mmol C m^{-2} d^{-1}) in Boston Harbor. Sewage effluent and other sources provide an additional 200 gC m^{-2} y^{-1} (46 mmol C m^{-2} d^{-1}) to Boston Harbor. Comparison

of loading to sediment respiration indicates that about 46% of the total organic matter entering the harbor from sewage and primary production is mineralized on the bottom. This percentage is nearly twice as high as that reported from other estuaries. The reasons for such a high percentage of the decomposition to occur on the bottom is presently unexplained. It is possible that our sampling may have been biased towards more metabolically active sites. Measurements at other less frequently sampled sites, T4, R4 and T7, suggest that the primary sites, with the exception of BH03 in 1993, are representative of the region. It is possible that the sediments are currently out of equilibrium with inputs and that organic matter which was stored during decades of dumping is now being decomposed. Alternatively, the recent increases in animal abundances throughout the harbor may have enhanced the capture of organic matter to sediments through filter feeding.

In spite of the role of the benthos in carbon cycling, it is less of a factor in N and P cycling in Boston Harbor. Although remineralized nitrogen from the sediments could supply a major portion of the phytoplankton demand for N (40%) and P (29%), the absolute contribution of N and P from the benthos is small compared to the allochthonus inputs. At the present time new nitrogen and phosphorus inputs to the Harbor are an order of magnitude greater than the benthic flux of N and P and external inputs exceed phytoplankton N and P requirements.

The regeneration of Si from sediments can supply a significantly greater fraction of the Si required to support primary production than N or P regeneration supports primary production. On average, benthic silica fluxes could supply more than 60% of the Si requirements for primary production assuming that the production was completely dominated by diatoms. Currently, silica inputs to the harbor from wastewater discharge are considerably lower than N inputs; with an average N/Si ratio 3.44 (Hunt et al. 1995). In contrast, annual average N/Si release ratios from the sediments ranged from 0.53 to 1.15. However, benthic fluxes are four times lower than Si inputs from wastewater.

The high rates of anthropogenic nutrient inputs to Boston Harbor greatly exceed the capacity of the sediment to remove nutrients through denitrification and/or burial. The average area weighted value we calculate for N removal from the Harbor using DIC/DIN ratios is 4.0 mmol m^{-2} d^{-1}, suggesting that denitrification about 17% of the nitrogen load of the Harbor. Although this estimate of N removal in the harbor is somewhat higher than direct N_2 flux measurements, it supports the conclusion that the majority of the nitrogen entering Boston Harbor is exported to Massachusetts Bay. The areal average of the P fluxes from the three primary stations indicated there was no net removal of P from the Harbor during 1992-1994. Sediments served as a net source of P releasing an average of 0.22 mmol m^{-2} d^{-1}.

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NUTRIENTS IN MASSACHUSETTS BAY - A DECADE'S VIEW

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Key Words: Nutrients, nitrogen, phosphorus, silicate, chlorophyll

In the summer of 1987, the Massachusetts Water Resources Authority (MWRA) began a systematic study of nutrient components in Broad Sound, a coastal area outside of Boston Harbor, to gather information useful for its outfall siting decisions. Several periodic studies continued during this phase, funded by the MWRA and others, until 1992, when the Harbor and Outfall Monitoring Program began. Detailed studies have been carried out in this area since then. This program will continue for the next several years until well after the new outfall is operational, sometime during 1998.

Because of the sporadic nature of the data collected prior to 1992, the focus of this work will be on trends in nutrient changes during the past 5 years, with longer term trends discussed wherever possible. During this time period, the concentration ranges of the individual nutrients have not changed appreciably, though there has been an increase in the total mass of some nutrients over time. For example, the amounts of inorganic nitrogen (nitrate + nitrite + ammonium) during the February to December periods, have nearly doubled during that time period (1992-1996), while there were only slight increases in phosphate and silicate. The average fluorescence varied by almost a factor of 2 during this time period, but no trends were apparent. These changes do not appear to be related to increases in the nutrient sources, but interannual changes in the timing of phytoplankton blooms, especially the spring bloom (including stating dates, bloom length, and extent), coupled with timing of the spring water-column stabilization. Thus these interannual changes are mostly affected by variations in weather (winds, temperature, and light) and freshwater input from both local and farfield rivers.

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"RECOVERY" OF BOSTON HARBOR BENTHOS: INFAUNA, CARBON-NITROGEN CYCLING AND SEDIMENT-WATER COLUMN EXCHANGES

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Key Words: Sediment Metabolism, Infaunal Communities, Denitrification, Nutrients, Oxygen Uptake

Monitoring of sediment carbon and nutrient cycling is currently providing sensitive indicators of the changing ecological health of Boston Harbor. Results from studies of the sediment-infauna complex within Boston Harbor provide an example of the non-linear responses of marine systems to changes in organic matter loading rates and the need for direct measurements.

Rates of sediment oxygen uptake were measured along the organic matter gradient from Boston's Inner Harbor to Stellwagen Basin. These data were coupled with seasonal measurements of water column - sediment exchanges of nutrients (primary nitrogen), sediment oxidation, and porewater chemistry. In addition, parallel measurements of denitrification were conducted at two stations within Boston harbor (high versus low infaunal density).

Rates of total sediment community respiration, while showing significant inter-annual variability, appear to be increasing in portions of Boston Harbor. Seasonal measurements of carbon and nitrogen cycling in surficial sediments indicate that rates of organic carbon and nitrogen remineralization and denitrification were higher in 1995 than reported in each of the previous years of monitoring. Concurrent with the changing rates of diagenesis has been rapid colonization of Harbor sediments by infauna, particularly the development of dense amphipod mats (*Ampelisca* and *Leptocheirus*). Continued monitoring through 1996 suggests that "depuration" of sediment nutrients and oxidation debt is relatively rapid following infaunal recolonization.

Ampelisca are pollution sensitive, deposit feeding amphipods capable of building mats several centimeters thick, and reaching densities of over 100,000 individuals m^{-2}. The widespread colonization of Harbor sediments by this infaunal complex has increased both the degree of sediment oxidation and rates of sediment/water column exchange through bioturbation and burrow ventilation. While populations continue to show cyclical variations, the amphipod mats appear to be more persistent from year to year (1989-1996). The expanded distribution and reduction of interannual variations in the *Ampelisca* complex are likely related to improving water quality, particularly in the northern region of Boston Harbor, due to cessation of sludge discharges and/or contaminant reduction measures.

Remineralization rates and denitrification were significantly enhanced in areas densely colonized by amphipods (North of Long Island > Hull Bay > North Harbor) compared to areas with lower total infaunal densities (Quincy Bay). Infauna affected carbon mineralization directly through their metabolism and indirectly through their irrigation of the surficial sediments. The result was increasing oxidation of surficial sediments and higher rates of nitrification/ denitrification. Sediments were heavily colonized by amphipods (*Ampelisca* and *Leptocheirus*) from May through August. The dense amphipod mats began to break up in August and were virtually gone by the October sampling. The nearly linear increases in community respiration with temperature measured at both stations when the mats were present (March-August) contrasted strongly with the much lower rates in October when the mats were senescent, but temperatures remained high. The influence of the infaunal community upon organic matter turnover is seen in the five fold (Long Island) and two fold (North Harbor) higher rates of oxygen uptake at similar temperatures when the amphipod community was present.

Similarly, interannual comparisons showed large increases in measured rates of sediment oxygen uptake and denitrification in Boston Harbor (1992-1996). In contrast to 1995 and 1996, the *Ampelisca* complex was only infrequently encountered during previous monitoring. In all cases data from 1992-1994 (SOD: Giblin et al. 1995; denitrification: Nowicki In Press) showed significantly lower rates than those in 1995, except where amphipod mats were noted by the earlier studies. Inter-annual comparisons at the more stable Massachusetts Bay stations yielded similar rates of biogeochemical cycling in all years. It appears that with the dense colonization of Harbor sediments during 1995, rates of carbon mineralization and denitrification within Boston Harbor were more than two fold higher than in previous years. The extent to which the higher rates were the result of "mining" of sediment deposits versus increased trapping of water column particles requires further study. However, rates of denitrification and community metabolism declined and sediment oxidation began to increase in 1996 suggesting that the labile organic matter pool of the sediments may be declining under continued bioturbation.

These results suggest that a positive feed-back loop exists whereby improving habitat quality results in increased persistence and abundance of infaunal populations. Increased sediment irrigation by infauna results in accelerated rates of organic matter and nutrient cycling and subsequent removal from Harbor sediments leading to improved habitat. This accelerated nutrient depuration of Harbor sediments suggests that the use of static analysis (which assumes proportional responses) in predicting future rates of change in habitat quality may be inappropriate in the Boston Harbor system.

It appears that nitrogen and carbon dynamics within the Harbor and transport to Massachusetts Bay may be very dynamic under changing environmental quality.

The temporal nature of these biological mediating effects and their potential role in accelerating nutrient removal from the Harbor will be elucidated by the continued monitoring of this system.

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BENTHIC COMMUNITY MONITORING IN BOSTON HARBOR: DO OBSERVED COMMUNITY CHANGES EQUAL RECOVERY FROM POLLUTION?

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Keywords: Benthic community monitoring, recovery, indices, sediment profile imaging.

Benthic community sampling carried out by the Metropolitan District Commission (MDC) in the late 1970s and early 1980s documented highly degraded conditions persisting through much of the Northern and central parts of greater Boston Harbor, a legacy of decades of untreated and under-treated sewage discharges. While samples taken in the southern parts of the outer Harbor contained communities showing affinities to those collected in undisturbed offshore regions, samples from the north Harbor were quite different. Much of that area was characterized by sparse, depauperate assemblages of tubificid oligochaetes and the pollution tolerant polychaetes *Capitella* spp. and *Polydora cornuta*. The sampling also indicated episodic populations of tube-dwelling amphipods of the genus *Ampelisca*, but these communities appeared to be both spatially restricted and short-lived.

Starting in the late 1980s, MWRA began an ambitious program of infrastructure improvements designed to bring the region's sewage treatment into compliance with the Clean Water Act. One of the early major improvements was ceasing, in December 1991, the discharge of approximately 35 dry tons/day of digested sewage sludge into the Harbor.

As part of a monitoring program designed to track the effects of this and other treatment improvement projects on the Harbor environment, MWRA initiated preliminary benthic community monitoring in 1989, and an ongoing intensive sampling program in late summer 1991. The monitoring consists of twice-annual (April and August) sampling at eight faunal stations distributed throughout the Harbor, where both quantitative faunal samples and samples for grain size and other bulk sediment analyses are collected. The August survey is complemented with a 60-station reconnaissance survey which has used both sediment profile imaging and rapid, semi-quantitative processing of normal faunal grabs. This two-pronged monitoring approach provides us with detailed information on changes occurring at a few key Harbor locations, while simultaneously providing high- resolution spatial information allowing us to extrapolate results to the Harbor as a whole.

Results of the sampling through 1991 were consistent with the MDC surveys of a decade before. Starting in April and August 1992, however, a series of substantial changes have occurred in the benthic communities being monitored. Significant decreases were seen in sediment concentrations of sewage tracers, concurrent with significant increases in benthic species richness, especially in (but not restricted to) north Harbor stations. Species composition also changed dramatically, with many sites formerly dominated by an oligochaete/*P. cornuta/Streblospio benedicti* assemblage containing a more diverse assemblage dominated by high abundances of *Ampelisca abdita* and other amphipods.

This change is fully evident in the results of the reconnaissance surveys. Evidence of dense *Ampelisca* tubemats was seen at about 18% of soft-bottom stations sampled in 1989 and 1990, restricted primarily to the central and southern parts of the Harbor. Begininning in August 1992 the areal distribution of *Ampelisca* mats increased dramatically, such that by 1994 and 1995 persistent, dense *Ampelisca* tubemats were found in about 60% of stations (Table 1). Concurrent improvements have also been seen in other indicators of sediment status, for example in apparent Redox Potential Discontinuity (Table 1).

The changes we have seen are fully consistent with the initial stages of recovery of benthic communities from pollution. The extent to which they are a response to treatment improvements has been a subject of some debate within the project team. In this talk we will address the question through the use of recently developed multivariate analyses of community structure.

Table 1: Changes in abundance of *Ampelisca* sp. tubemats and Apparent RPD in Boston Harbor sediments.

Year	% of stations with dense *Ampelisca* mats (# of stations)	Mean Apparent RPD, cm (std.dev.)
1989-90	18 (92)	1.2 (0.9)
1992	42 (62)	2.0 (0.8)
1993	45 (49)	2.4 (1.9)
1994	60 (50)	1.8 (1.2)
1995	58.3 (59)	2.8 (2.1)

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FOOD RESOURCES AND FORAGING IMPERATIVES OF THE NORTHERN RIGHT WHALE, *EUBALAENA GLACIALIS*, IN MASSACHUSETTS AND CAPE COD BAYS

Charles Mayo, Center for Coastal Studies

Because the Northern Right Whale is one of the rarest large mammals on earth a variety of conservation strategies involving direct causes of mortality, ship strike and entanglement, have been devised. A third and usually less considered area of concern which deserves attention, that of habitat qualtiy is the subject of this paper.

Right whales seasonally visit the Bays between mid-December and late April to forage on dense patches of calanoid copepods of the genera *Calanus*, *Pseudocalanus*, *Centropages*, and *Temora* and on cypris stages of barnacles. The Bays are recognized as one of the few places on earth where surface foraging activities, known as "skim feeding" can regularly be observed.

By summarizing the data collected in the Bays over the last 12 winters, information on the characteristics of the zooplankton patches releasing foraging behavior of right whales has been obtained. From collections in the feeding path of skimming right whales we have determined that a feeding threshold of 4000 organisms/M3 in the size range determined by experiment to be captured by whale baleen controls the fine-scale foraging behavior of the whales. By applying this value as a crudemeasure of the acceptability of the Bays to the surface foragning of the whales it has been possible to characterize the quality of the Federally designated Right Whale Critical Habitat. From such analysis applied to the last 12 years of plankton collections throughout the Cape Cod Bay we have determined that 4.1% of the surface collections are in areas with zooplankton concentrations exceeding the feeding threshold, while 2.9% of the surface has a great enough concentration of zooplankton to exceed our calculated basic caloric requirements for a foraging whale. While much of the Bays appear unacceptable to right whales, the small areas where dense though ephmeral patches of zooplanton are found includ micro patches (<50 cm diameter) with densities exceeding 2.0 x 107 organisms/M3.

The use of these foraging "acceptability measures," their extension to recent stuides of subsurface foraging, and their potential application to management of the Right Whale Critical Habitat will be discussed.

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EXAMINING HISTORICAL CHANGES IN THE BIOTA OF PLUM ISLAND SOUND

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Key Words: Living Resources, Massachusetts Bay, Estuary, Fish

In 1992, the Massachusetts Audubon Society received funding from the Massachusetts Bays Program to carry out a five year examination of water quality, living resources, and land uses of the Plum Island Sound region and to use this information to develop a long term management plan. A major focus of the Plum Island Sound Minibay Project was in collecting information on the present status of estuarine fish, birds, and vegetation and using this information to assess long term biological changes.

The estuarine fish surveys were carried out in collaboration with the Woods Hole Ecosystems Center's Land Margin Ecological Research project. We used the Massachusetts Division of Marine Fisheries (DMF) 1968 estuarine monograph on the Parker River/Plum Island Sound as a source of historical information. Over a 16 month period in 1993-1994, we carried out monthly sampling at the exact same stations as those sampled in 1965 by DMF and used very similar methods. We found higher abundance of individual fish and greater species richness in 1993-1994 compared to the 1965 study, both overall and in most individual sampling stations. The two most abundant species we collected, Atlantic silversides (*Menidia menidia*) and mummichog (*Fundulus heteroclitus*) accounted for greater than 90 percent of the individuals and biomass in our samples. Although silversides and mummichogs were also the dominants in the DMF study, they were about ten and five fold higher in population in 1993-1994 than in 1965. There were no obvious patterns in other species of fish. We suspect that the tremendous increase in the two major species of "bait fish" are a result of regional trends that are not specific to Plum Island Sound, since the Sound itself and its surrounding watershed have remained relatively undeveloped over the past thirty years.

To examine the historical trends in bird populations in the Plum Island region, we compared the bird populations present from 1930 through the1950s as reflected in the field notebooks of the renowned ornithologist, Ludlow Griscom, with information compiled from recent surveys carried out by the Parker River National Wildlife Refuge. The most reliable historical information indicated that three of four shorebird species (i.e., greater yellowlegs, semipalmated sandpipers, and black-bellied plovers) have declined in numbers between the 1950s and the 1990s and a fourth (semiplamated plovers) has remained about the same. Three of five waterfowl species have increased, with mallards showing the most dramatic increase. Common terns have declined substantially. The changes in bird numbers, like those for fish, reflect trends throughout New England.

The focus of our vegetation studies has been the invasion of the salt marsh by the common reed, *Phragmites australis*, particularly in areas that have been altered by tidal restrictions. We have set up a number of permanent transects through areas of salt marsh that are transitional between *Spartina* spp. and *Phragmites*. These transects will be used to follow future changes, if any, in the distribution of *Phragmites*. In research we are currently carrying out with the Jackson Estuarine Laboratory of the University of New Hampshire, we are examining the causes and ecological consequences of *Phragmites* invasions of the salt marsh.

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FISHERIES RESOURCES IN MASSACHUSETTS BAY

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Key Words: Fish, fishery, stock decline, regulation

Massachusetts Bay has supported an increasingly active variety of recreational and commercial fisheries during this century, but in particular, in the most recent years. The recent sharp increase in fishing activities are a result of a combination of circumstances including a high concentration of people, suitable harbors, an improved economy, and increase marine-related technology.

The technology coupled with the economy has advanced the interest, ability, and capability of both the recreational and commercial fisherman. This has resulted in more people having means to acquire equipment and tackle that allows them to increase fishing pressure per unit time over an increasing period of the year. Once- occasional recreational fishermen that rented their skiff from a marina, now have watercraft and navigational equipment that encourage them to go more offshore. Commercial fishermen have increased their vessel size, improved their hauling capability and navigation to permit them to fish more gear in areas they dare not fish in prior years.

As the fishing pressure increased, targeted marine species declined in abundance. Three species are presented as an example and they echo the abundance trends or resultant landings of most of the other popular marine species in Massachusetts bay. Atlantic cod annual abundance indices in Massachusetts and Cape Cod Bays dropped more than threefold between 1983 and 1996. Winter flounder indices in the same waters, after a two significantly abundant periods in the early 1980's, remained low in abundance since 1987. Lobster landings in the main Boston Harbor-Massachusetts Bay statistical area reflected an increase in 1979 from about 2.1 million pounds to over five million pounds in 1990, but precipitantly declined to less than three million pounds in 1995.

Two species that are exceptions to the declining abundance trend are striped bass and Atlantic mackerel. The striped bass did sharply decline in the 1980's, but severe conservation measures, concomitant with appropriate studies on the species dynamics, appears to have resulted in a successful return of abundance for this species. The mackerel is also a species of importancetoday, especially to the recreational fishermen.

Two invertebrate species provided a basis for new commercial fishing opportunities. The sea urchin and the hagfish, normally species of low interest, became commercially significant because of international demand. Boston Harbor and Beverly-Salem Harbors dominated the sea urchin fishery which began during 1992, peaked in 1995 and then sharply declined. The hagfish deepwater fishery was brief but a viable alternative to the depressed traditional fisheries. Both species provided a opportunistic fishery for lobstermen, gillnetters and divers during the time when these fishermen's income were depressed because of low catches in traditional fisheries and resulting increased regulations.

These two opportunistic fisheries presented concern to managers. The sea urchin fishery prompted several studies that focused on population dynamics, culture, and the impact of harvesting techniques. The hagfish fishery was of less interest, probably because it occurred further offshore and targeted a species of little interest to conservationists. Gear conflict between the fixed hagfish gear and the mobile dragger fishermen was the most important issue in the hagfish fishery.

Managers and biologists considered causes of the declines and initiated some studies to better define appropriate actions. Increased regulations resulted; these included reduction or eliminating fishing during certain time periods increasing closed areas and limiting certain gear designs and types.

The future requires more study of impacts of certain gear types on the targeted species and the environment. This work would be done in tandom with the examination of other man-made and natural factors. Fishing effort must be reduced. Fishing must become more selective for targeted and non-targeted marine species and fishing gear must be designed to be less impacting on the marine habitats.

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THE WELLFLEET HARBOR PROJECT: SUCCESSES OF THE MINIBAYS APPROACH

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The Wellfleet Harbor Project, part of the Massachusetts Bays Program, Minibays Projects is a five-year multi-faceted program of research, outreach, implementation, and local involvement. The efforts of the project were guided by a local management committee comprised of nearly all boards and committees concerned with the resources of the Harbor. In the initial years of the project, the extent of the Wellfleet Harbor watershed was determined through extensive hydrologic investigations. Concurrently, tidal flushing characteristics of the harbor were determined. Combined with the assessment of nitrogen inputs from the watershed, these studies served as the basis for preliminary nitrogen management strategies.

A water quality monitoring program that focuses on nutrients and bacteriological indicators has been in place since 1992. This monitoring program serves to validate and confirm the nitrogen loading assessments. Nutrient sediment-flux studies were conducted in one area suspected as being impacted by land-based anthropogenic sources, and have yielded surprising indication of the importance of natural sources of bioavailable nitrogen. This information is currently being integrated in the subwatershed management plan.

Small research efforts supported under the Project were extremely successful in helping to form an overall management plan for the harbor. In year two and three of the project, an oyster cultch effort identified the most productive oyster set areas of the harbor as well as resulting in a recruitment of over 20 million oysters. This project leaves a legacy of information invaluable to oyster fishery. Anticipating the need for nitrogen reduction in some of the subwatersheds, another small research effort ensued involving the installation of five alternative on-site septic systems. These systems are presently in various stages of evaluation and serve to supplement the state's database on alternative technologies. The installation of these systems has also cultured a familiarity with alternative on-site septic systems by the Board of Health and Conservation Commission, which now requires them in sensitive areas.

As the grant-supported portion of the Wellfleet Harbor Project draws to a close, the Town of Wellfleet has expressed its commitment to continue the water quality monitoring of the harbor, and continue in the more intensive study of embayments identified by the project as nitrogen sensitive. The Project will leave a legacy of accessible information in the form of a publically-available computer site on which all the work supported by the grant, and all previous studies in the area can be accessed.

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