Long Island Sound Research Conference Proceedings

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Preface

This book began as a collection of abstracts submitted for presentation at the Long Island Sound Research Conference convened at Southern Connecticut State University in late October, 1992, the first in a series. Authors of both oral and poster presentations were invited to submit extended abstracts following the conference to be considered for publication in this proceedings volume. Conference organizers agreed that the proceedings would be published, alternating years, by the Communications components of the Sea Grant Programs of Connecticut and New York. The volume celebrates a renewed interest in Long Island Sound, a valuable estuary of national importance, by pulling together a wide range of multidisciplinary research that should help to fill the wide gaps in our knowledge to date.

The organization of the volume parallels that of the sessions presented at the conference. Manuscripts are grouped into categories under the topic headings of Geology and Biochemistry, Hydrodynamics and Sediment Transport, Habitat and Ecosystem Preservation and Restoration , Ecologically Significant Organisms, Marine Fisheries, and Water Quality. In addition, there is an initial chapter of plenary papers that provides valuable historical and scientific background information and a final section comprising a "mixed bag" of poster papers.

As editor of the proceedings this time around, I have taken some liberties with manuscripts and figures in order to present a consistent format. Any errors or omissions are strictly my responsibility. Addresses for authors have been included with each paper, and readers are urged to contact them directly for further information.

The preparation of this volume benefitted greatly from the watchful eyes and helpful hands of Dolores Chambers, Karen Massaro, Eleanor Minikowski, Nancy Monahan, and Ken Sherwood. Publication would not have been possible without the efforts of Sue McNamara and the Long Island Sound Foundation, the support of the Connecticut Sea Grant Office, and the funding provided by United Technologies.

It is the sincere hope of the conference organizers that the biennial conferences and resulting proceedings volumes contribute to the sharing of information that may be useful in illuminating future management issues in Long Island Sound and other estuaries that provide similar resources. More information on the evolution and philosophy of the conference(s) can be found in the first plenary paper, by Dr. Harry Haakonsen. We hope you enjoy the science of the Sound.

Margaret A. Stewart Van Patten
October, 1993

Contents

Marine Fisheries

Ecologically Significant Organisms in LIS

Habitat and Ecosystem Preservation and Restoration

Water Quality

Conference Schedule

Friday, October 23, 1992

9:00 - 10:45 **Long Island Sound Research: Special Session**

"Evolution of the Long Island Sound Research Conference"
H. O. Haakonsen (Southern Connecticut State University)

"Research on Long Island Sound: An Historical Perspective"
D. Squires (University of Connecticut)

"Aquaculture in China: Parallel Applications of LIS"
C. Yarish (University of Connecticut)

11:00 - 12:00 **Long Island Sound Research : Special Session**

"Long Island Sound: A Multidisciplinary Perspective"
T. Callinan (Connecticut Troubador)

"DAX: Severe Weather Forecasting Research and its Relationship to Long Island Sound"
M. Goldstein (Western Connecticut State University)

1:00 - 2:30 **Plenary Session**

Welcome - A. Pinciaro, Academic Vice President (SCSU)

"LIS Research Conference: History and Future"
H. O. Haakonsen (Southern Connecticut State University)

"Fisheries and Marine Resource Management: Issues on Long Island Sound"
E. M. Smith (CT DEP, Bureau of Marine Fisheries)

"Physical Oceanography of Long Island Sound: an Ecological Perspective"
B. L. Welsh (University of Connecticut)

2:45 - 3:45 **Hydrodynamics and Sediment Transport**

"Fine Grained Sediment Transport in Long Island Sound: Transport Modeling Considerations"
W. F. Bohlen (University of Connecticut)

"Hydrodynamic and Suspended Sediment Variations During the Passage of Hurricane Gloria over Eastern Long Island Sound"
K. Howard-Strobel, Y. Wang, and W. F. Bohlen (University of Connecticut)

"Observations of the Hydrography and Circulation in Block Island Sound"
J. O'Donnell (University of Connecticut)

2:45 - 3:45 **Marine Fisheries**

"Long Island Sound Fishing Resource Abundance in Relation to Dissolved Oxygen"
D. Simpson and P. Howell (CT DEP Marine Fisheries)

"Biological Baselines of Plankton Populations in Long Island Sound: What We Know and Don't Know"
D. M. Monteleone, D. J. Lonsdale, and W. T. Peterson (Marine Science Research Center, SUNY Stony Brook)

"Using the Marine Recreational Fisheries Statistics Survey (MRFSS) to Calculate Catch Estimates for Long Island Sound"
R. Salz (NY DEC, Div. of Marine Resources)

4:15 - 5:15 **E Map - A Regional/Management Perspective**

Panel Presentation by J. O'Connor, J. Paul, and A. McElroy

Saturday, October 24, 1992

9:00 - 10:00 **Water Quality**

"Twenty-five Years of Dredged Material Disposal Site Monitoring in Long Island Sound: A Long-term Perspective"
T. J. Fredette and P. G. Kullberg (U.S. Army Corps)

"Results from Three Years of Sampling Activities for EPA's Environmental Monitoring and Assessment Program in Long Island Sound"
J. F. Paul *et al.* (U.S. EPA)

"Pelagic Biological Processes Influencing Hypoxia in Western Long Island Sound"
T. H. Anderson and G. T. Taylor (Marine Sciences Research Center, SUNY Stony Brook)

"Spatial and Temporal Trends of Dissolved Oxygen in the East River and Western Long Island Sound"
T. M. Brosnan and A. Stubin (NY DEP Mar. Sciences)

9:00 - 10:00 **Ecosystem Preservation and Restoration**

"Assessment and Management of Connecticut's Piping Plover and Least Tern Populations"
J. Victoria (CT DEP, Wildlife Section)

"Biotic Changes at the Barn Island Tidal Marshes (Stonington, CT): Sea-Level Rise and Restoration"
R. S. Warren, P. E. Fell, and W. A. Niering (Conn. College)

"Watershed Protection: A Regional Approach"
A. W. Bamberger (Westchester Land Trust)

11:00 - 12:00 **Geology and Biogeochemistry**

"Geologic History of Long Island Sound"
R. S. Lewis and N. F. Neff (LIS Resource Center)

"Post-Glacial Stratigraphy and Rates of Sediment Accumulation in Three Eastern Connecticut Coves"
C. Arnold, P. Patton, and N. A. McLoughlin (CT Sea Grant Advisory Program and Wesleyan University)

"Porewater Transport in Western Long Island Sound and its Relation to the Benthic Community Structure"
E. C. DeAngelo (Dept. of Marine Science, University of Connecticut)

11:00 - 12:00 **Ecologically Significant Organisms in LIS**

"Benthic Ecology of Long Island Sound: A Short History, a Tentative Model, and a Benthoscape Approach"
R. N. Zajac (University of New Haven)

"Contaminants in Scaup Ducks Wintering on Long Island Sound"
J. S. Barclay, C. R. Perkins, and G. Chasko (UConn and CT DEP)

"Population Genetics of Kelp Species from Lomg Island Sound to Newfoundland"
C. Neefus, R. Ekert, A. Mathieson, and C. Yarish (Univ. of New Haven and UConn)

"Reproduction of the Macroalga *Laminaria longicruris* de la Pyl. in Long Island Sound"
M. S. Van Patten and C. Yarish (CT Sea Grant and UConn)

1:30 - 2:30 **Hydrodynamics and Sediment Transport**

"Estuarine Circulation and the Effects of Dredging on the Housatonic River Estuary"
P. C. Patton, A. S. Polonsky, and M. I. Alanen (Wesleyan University)

"Lateral Hydrographic Variability in Eastern LIS"
L. M. Huzzey (U.S. Coast Guard Academy)

"Evidence of Helmholtz Resonance in LIS and its Response to a Rise in Sea Level"
R. J. Chant, R. E. Wilson, and H. J. Bokuniewicz (Mar. Sci. Cen., SUNY Stony Brook)

1:30 - 2:30 **Habitat Preservation and Restoration**

"Three Years of Marsh Restoration in Mumford Cove, Groton, Connecticut"
P. M. Capotosto (DEP, Mosquito & Vector Control Section)

"The Application of Geographical Information Systems (GIS) to the Management of Long Island Sound and its Coast: How Do We Organize and Optimize?"
S. Prisloe and R. N. Zajac (Univ. of New Haven)

"Effects of Nutrient Enrichment of Kelp (*Laminaria longicruris*) from Long Island Sound"
C. A. Penniman and C. Yarish (Central Conn. State Univ. and UConn)

2:30 - 3:30 **Water Quality**

"A Comparison of the Norwalk and Saugatuck Estuaries With Respect to Dissolved Oxygen Levels and Benthic Juvenile Fish"
R. B. Harris and P. Fraboni (Harbor Watch)

"Sediment Toxicity in Long Island Sound Embayments"
S. B. Bricker (NOAA/ORCA)

"Relationships Between Bacterial Abundance and Selected Hydrographic and Seston Measures at Three Long Island Sound Sites, 1987-1988"
G. H. Wikfors, W. J. Blogoslawski, and R. Goldberg (NOAA, NMFS, Northeast Fisheries Science Center)

2:30 - 3:30 **Geology and Biogeochemistry**

"Atmospheric Deposition to Long Island Sound"
D. R. Miller (UConn)

"Contaminants in the Quinnipiac River-Estuary and Other Sources Entering New Haven Harbor"
G. L. Wheeler, Y. Tokuz, G. Wang, and M. Bessa (Univ. of New Haven)

"Biological Nutrient Removal During Cold Weather: The Key to LIS Water Quality Improvements"
J. A. Lauria (Malcolm Pirnie, Inc.)

3:30 - 4:30 **Plenary Session**

"A Research Agenda Based on the Long Island Sound Study"
M. Tedesco, Director (EPA Long Island Sound Office)

Presiders:

Ambrose Anorua	Southern Connecticut State University
Norman Bender	Connecticut Sea Grant Marine AdvisoryProgram
Karen Chytalo	NY Department of Conservation
William Green	Guilford Shellfish Commission
Rolf Martin	Southern Connecticut State University
Edward Monahan	Connecticut Sea Grant College Program
Jeffrey Shepherd	Sacred Heart University
Robert Whitlatch	The University of Connecticut

Plenary Sessions

Evolution of the Long Island Sound Research Conference

H. Haakonsen, *Director, Center for the Environment, Southern Connecticut State University*

The Long Island Sound Research Conference (LISRC) was convened in response to a recommendation by the Long Island Sound Assembly (LISA) that a forum be established to foster the exchange of scientific research findings related to the Sound. In an effort to design a conference format that would adequately address the research community, a committee was established with representation from the Sea Grant Programs and other scientific research centers in New York and Connecticut. In addition, the Connecticut Department of Environmental Protection and the New York Department of Environmental Conservation were invited to participate in the planning process.

The LISRC Planning Committee started to work on the conference design in February, 1992. The make-up of the committee provided for lively discussion and creative thinking. Progress was made quickly and the format of the conference began to take shape. In March, a call for papers was sent to a list of investigators identified from an assortment of lists on file with agencies represented on the planning committee. Scientists were invited to submit abstracts for poster sessions or contributed papers. In the early months of planning, it was difficult to determine the detailed structure of the meeting, since there was no way of assessing the response that would be generated by the call for papers.

In early May, abstracts were distributed for review and in mid-summer participants were advised of the status of their presentations. From the abstracts submitted, 30 were selected for presentation as contributed papers and 14 for presentation as posters.

Research papers presented during the two-day conference focused on water quality, habitat preservation and management, geology and biogeochemistry, living marine resources, marine fisheries, and hydrodynamics and sediment transport. The structure of the meeting provided opportunities for formal presentations and informal discussions. Research findings were presented during plenary meetings, concurrent sessions, poster discussions, and a panel presentation. The conference was the first of a series of biennial research meetings. In an effort to guarantee the opportunity to share the results of the broad spectrum of scientists involved in Long Island Sound research, the planning committee enlisted the support of several corporations. United Technologies, Inc. responded by contributing $5,000 to the general fund for operating the conference. Frank MacAbee, corporate Vice President for Environmental Affairs stated that UTC was committed to fostering a better understanding of the complex ecosystem of Long Island Sound and in encouraging more students to seek careers in science and environmental studies. The grant provided the necessary support to permit the conference to proceed.

During the planning process the committee determined that it would be important to introduce high school and university students to persons and processes involved in research on Long Island Sound. To enhance the understanding of science by high school students, high school teachers were invited to bring two of their students to the conference under sponsorship of corporate grants. A special session on Friday morning introduced students to the scope and structure of Long Island Sound research. The featured presenters included meteorologist, Dr. Mel Goldstein; aquaculture specialist, Dr. Charles Yarish; the distinguished marine scientist, Dr. Donald Squires; and the Connecticut Troubadour, Mr. Tom Callinan.

In an effort to give a broad overview of important Long Island Sound issues, plenary sessions were integrated into the program. These sessions involved a discussion of "Living Marine Resources, Processes and Trends" by Mr. Eric M. Smith (CTDEP); "Physical Oceanography of Long

Island Sound" by Dr. Barbara L. Welsh, (UConn); and "A Research Agenda Based on the Long Island Sound Study" by Mr. Mark Tedesco (EPA-LIS Office). The plenary sessions were very well-received. The plenary presentations provided a framework for reference throughout the conference.

Since E MAP strategies are now receiving a great deal of attention, a panel was convened to discuss the impact of E MAP on Long Island Sound research and management. The panelists included Dr. Joel O'Connor (USEPA), Dr. John Paul (USEPA), and Dr. Ann McElroy (NY Sea Grant Program). The panel outlined the utility, strengths, and weaknesses of E MAP concepts as they are applied to LIS. The panel presentation was extremely effective and stimulated a lively discussion.

In addition to studying the environment of Long Island Sound scientifically, a folk group, the Morgans, presented a concert of environmental music. The conference and concert were designed to focus public attention on the environmental, economic, and ethical factors affecting Long Island Sound. Based upon the evaluations submitted by conference participants, the goal was met.

In response to the positive feedback from the presenters and participants, the planning committee has endorsed the concept of a biennial conference focused on Long Island Sound research. In 1994, the conference will be in New York State and will return to Connecticut in 1996. Proceedings of the Long Island Sound Research Conference will be published early in the spring following each of the conferences.

Understanding The Sound

D. F. Squires, *Department of Marine Sciences, University of Connecticut*

Less is known about Long Island Sound than about most other major estuaries in the United States because, comparatively, it has been the subject of less research than the others. One wouldn't expect that neglect for, after all, at least a dozen universities are located close to the Sound and a several of those have or have had marine research programs of consequence. There is also a major federal laboratory located on the Sound and such laboratories are usually an asset, providing a continuous stream of new information. And, Long Island Sound is a heavily utilized resource in one of the most densely settled areas of the nation, suggesting a receptive audience for new information.

A Brief History of Research on Long Island Sound

One way the scope of knowledge about the Sound may be assessed is by analysis of the scientific literature by discipline (i.e. what proportion of publications deal with biology, geology, etc.?), by distribution in time (i.e. what was published when?) and by kind of research (i.e. was the research about the Sound or did it utilize the Sound only as a laboratory?). One starting point for such a study is the bibliography of Long Island Sound prepared in 1985 by Ralph Lewis and Nancy Coffin which lists 1,175 titles published between 1830 and 1984[1]. Because that bibliography includes not only the traditional articles in scientific journals and books, but also the "grey literature" or less widely distributed technical and data reports, it is of especial value.

From the Lewis and Coffin bibliography I determined the following distribution of titles by discipline of the subject matter[2]:

Subject Discipline	Number of Titles*	Proportion of Total
General	269	14%
Environmental	303	16%
Biological	547	29%
Geological	563	30%
Oceanography	191	10%

*Adds to more than 1,175 because of inclusion of some publications under more than one discipline, i.e. chapters in books were separately listed by discipline.

By subjective comparison with similar analyses of scientific literature, it would appear that biological literature is under-represented while the geological component is, by contrast, somewhat larger than would be expected. (A more anticipated balance would have something like 40% biological, 20% oceanography, 15% environmental, 15% general and 10% geological.) And, most importantly, the oceanography component is small—after all, the bibliography is of Long Island Sound literature! In part, as Ralph Lewis has advised me, that bias results from the greater familiarity the compilers had with the literature of geology. Nonetheless, it remains obvious that the category "oceanography" is under-represented.

To learn who had done what kind of research—and when it had been done—a count was made, by decade, of titles listed in the Lewis and Coffin bibliography. Then, by talking with people with long memories, some personality was added to the structure that had emerged from that count. The pattern shown in Figure 1 is one of a gradual increase in number of titles published over the period from 1830 to 1920, followed by a remarkable increase, particularly after the Second World

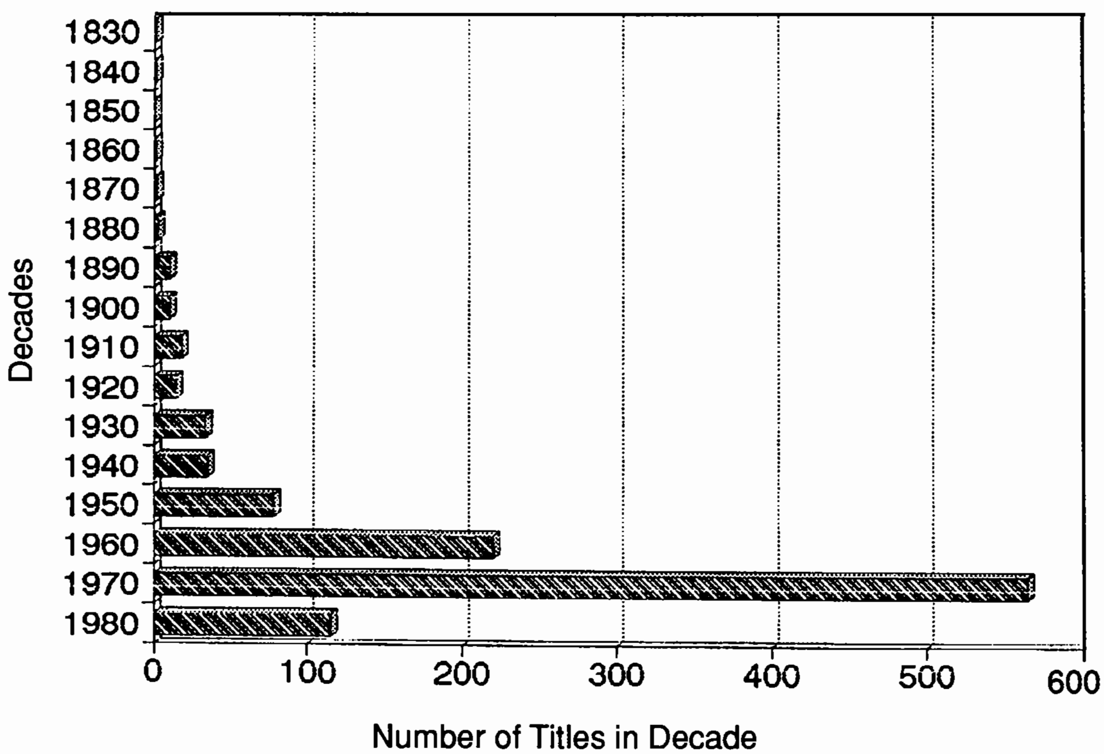

Figure 1. Distribution of research titles by decade in which published.

War. In part that paucity of older literature may reflect a lesser effort by the compilers to pursue the more inaccessible literature of the past. But it definitely reflects the fact that prior to the 1940s, there were fewer institutions performing research with far fewer people.

Early studies of the Sound, beyond that of its mapping by the Coast and Geodetic Survey, were undertaken at Yale University which soon established a tradition, lasting to the present, of contributing steadily to the understandings of Long Island Sound. At first it was the interests of James Dwight Dana in the geology of Long Island Sound and its environs. Professor Richard Flint followed with his studies of the glacial and other geology of the surrounding region which continued until the

1960s. But the pace for oceanographic studies was slow and not until the 1930s did the number of titles listed per decade show a sharp increase. The stimulus in that decade was the monetaryencouragement given by the federal government to the states to undertake biological surveys. Those studies of wildlife, and to a lesser extent, fishes, resulted in a freshet of publications by the state departments of conservation often in collaboration with academic institutions. The increased number of publications of the 1930s was sustained during the 1940s by Victor Loosanoff at the Milford Laboratory.

The Milford Laboratory had been formed in 1931 by the U.S. Bureau of Commercial Fisheries (now called the National Marine Fisheries Service) and had as its mission research in support of the Sound's shellfish industry, particularly Connecticut's oyster fishery. Through his research publications, Loosanoff, a giant in the field, established that laboratory as a national, even international, center for the study of shellfish. Through subsequent years, the laboratory has undertaken research of broader aspect, but its focus has always remained principally on the shell- and fin-fisheries of the Sound.

The Post-War Research Boom

The otherwise slow but steady rise in the number of publications already described is marked by the veritable explosion of titles in the 1960s, a number which doubled again in the 1970s. The responsible factors for this burst of activity lay far beyond the region of Long Island Sound. During the Second World War, the United States government had, for first time in the nation's history, fully mobilized the academic community for research and development related to the war. Vannever Bush[3], who led that effort, established a system of grants and contracts by which academic capabilities could be obtained by the government and the costs to the academic institutions involved reimbursed. That system was retained after the war in a multiplicity of federal agencies which made grants or contracted for, academic research. This new relationship between government and academia made it financially possible for university scientists to undertake research of a scale limited before to out-of-pocket expenses or to the largesse of a patron or an industry. Expansion of universities and colleges during the 1960s to meet the flood of post-war babies—now of college entrance age—enlarged the pool of researchers who could participate in that research. But this count of titles is only a crude measure of productivity. What we might seek is some indication of research leadership and continuity.

During the 1960s it was the initiative of a group of scientists at Yale, working within the Bingham Oceanographic Institute, which came to full flower. Dr. Gordon Riley, whose name is perhaps best known for the oceanographic surveys of Long Island Sound he conducted in the 1950s had actually commenced publication in the 1940s, but it was the continuing stream of papers and monographs by him and his associates, including Sally Richards, Robert Conover, G.B. Deevey, Peter Wangersky and others, which swelled our knowledge of the Sound. Riley was principal author of 23 publications and co-author of many others during the period of the 1940s to 1960s.

Again, in the 1970s there was a veritable explosion of research on Long Island Sound. Why? In part it was a consequence of the work by the Yale group which had stimulated interest in this body of water, but also it was a consequence of the growing awareness of the importance of the oceans by our nation. John F. Kennedy, a newly elected President in 1960, had a deep personal interest and commitment to the ocean—he used the word "oceanography" four times in his inaugural address—and through that interest he stimulated the development of a federal ocean program[4]. That stimulus was furthered by a series of "Governor's Conferences on Oceanography" at the state level in 1965. Emerging from those conferences was the inauguration of marine research and education programs at state universities all around the nation's coast. In 1967 the University of Connecticut formed its Marine Sciences Institute and located it at a former Coast Guard Training Base at Avery Point, Groton. That Institute incorporated the Marine Biological Station at Noank, Connecticut, which had been formed by biology Professor John S. Rankin, Jr. in 1954. In New York, the nascent State University of New York at Stony Brook, became the locus of the State University system's marine activity. The Marine Science Research Center, as it was called, started in 1968 as a research institute, but was soon broadened to include graduate programs in marine sciences. From these new research institutes and their many new, young researchers came a veritable torrent of publications.

Other institutions formed marine programs or centers. But competition for research funds was fierce and many fell by the wayside. For example, the short-lived New York Ocean Science Laboratory at Montauk, Long Island, became a physical reality in 1971 and for several years before its demise, conducted surveys of the eastern Sound.

Also an outgrowth of the federal ocean program was the National Sea Grant College Program carried out through academic institutions in the coastal states. Modelled on the land grant college system which had created modern agriculture, the Sea Grant colleges were to assist the states in the development and wise use of their coastal resources through research, education and extension outreach programs. In 1971 New York started its Sea Grant program with the creation of the New York Sea Grant Institute which brought together the intellectual resources of the State University of New York's many campuses and those of Cornell University. Connecticut's Sea Grant program was somewhat slower in getting underway, commencing with a marine advisory program in 1974 and adding a continuing research function only in 1984.

The trail-off in titles in the decade of the 1980s, shown in Figure 1, is an artifact of data collection—Lewis and Coffin searched only a small portion of that decade's output. I don't have data, but would be surprised if the decade of the 1980s were not about the same as that of the 1970s.

The Federal Government's Interest

Concern for the condition of Long Island Sound, which was by then beginning to show signs of wear and tear, led to Congressional hearings in the early 1970s. And from those hearings, a study, the first Long Island Sound Study, was conducted under the auspices of the New England River Basins Commission from 1971 to 1975. Under the name "People on the Sound" that study led to the publication of 23 reports as well as many working papers, almost all prepared by federal agencies. "People on the Sound" was a planning study and as such did very little original research. Most of its work was an assessment of conditions based upon the meager information then available. Its lack of impact has been variously attributed to "little coordination and quality control among the 20 federal agencies that prepared the work"[5] or as being "little more than an aggregation of pieces rather than a coherent plan."[6]

An Absence of Research Continuity

But all of this effort has been to little avail, for we still knew little about Long Island Sound. Why? Ralph Lewis, Connecticut's associate state geologist, observed that most of the research done prior to 1980 related to specific coves or embayments of Long Island Sound, and not the Sound itself. Bill Wise, director of the Living Marine Resources Institute at Stony Brook, opined that many of the biological studies undertaken by researchers at the Marine Sciences Research Center at Stony Brook utilize the Sound as a laboratory—the Sound was a site for research, not a subject of research.

When the present Long Island Sound Study commenced in 1985 a decision was made to emphasize research on the processes occurring in the Sound. The need for Sound-wide data was immediate. And, there was very little of it. Gordon Riley's work in the 1950s provided the earliest snapshot of conditions in Long Island Sound, but by then the great post-Word War II surge in human populations around the Sound had already commenced. After Riley's work, there was little until the surveys by Douglas Hardy and Professor Peter Weyl of Stony Brook's Marine Sciences Research Center in the early 1970s.

One study of long duration, but of narrow geographic scope, which has taken place in the Sound has been that of the dredged material disposal sites in the central Sound. In the early 1970s, concern about the disposal plans for the polluted substrate to be dredged from New Haven Harbor led to a U.S. Army Corps of Engineers study of possible disposal sites. A group at Yale under the leadership of Robert Berner, Robert Gordon, Donald Rhoads, and Karl Turekian, composed of graduate students, post-docs, and undergraduates, had been in place at the time of the Corps' initiative. The research was supported mainly by the Department of Energy and in part by the National Science Foundation, and was aimed at understanding the sedimentology, geochemistry, and geophysics of Long Island Sound. The graduate students at that time included Henry Bokuniewicz, Robert Aller, and Kirk Cochran, now all faculty at the Marine Sciences Research Center at Stony Brook. In 1980, the results of that research were brought together in a special issue of the journal *Advances in Geophysics*[7] edited by Turekian and Gordon.. Others involved in the Sound disposal site (DAMOS) project included W. Frank Bohlen and Lance Stewart of the Marine Sciences Institute, University of Connecticut.

But as Yale's faculty had moved to other research fields, leadership for research on the Sound was picked up by the public universities; The Marine Sciences Research Center at SUNY at Stony Brook, with a rapidly expanding faculty, has contributed the largest share of Long Island Sound research since the 1980s. Following on Douglas Hardy's important surveys of the western Sound in the early 1970s have been numerous studies including those of Professors Henry Bokuniewicz on geological processes, Kirk Cochran on geochemical processes, Bob Aller on chemistry/organism relationships, and Bob Wilson and Malcolm Bowman on physical oceanography.

In the early 1970s, Connecticut's Bureau of Marine Fisheries and the University of Connecticut cooperated in a number of long term studies of lobster, alewife and other species. These were conducted by Professor John "Stubby" Rankin's group at the Noank Marine Biology Laboratory, including Lance Stewart and William Lund among others. Another of those Noank researchers was Dr. Sung Feng whose productive work using shellfish to monitor the presence of pollutants in Long Island Sound helped to initiate present concerns for its water quality.

Why has Long Island Sound Research Not Flourished?

From these musings, one may construct an anecdotal answer to the question: Why has there not been more extensive research on Long Island Sound? The answer seems to be that there has not been a continuing stream of research funding which permitted the development of a program with long term goals. With the exception of the dredged material disposal study, sponsored by the U.S. Army Corps of Engineers and the fishery investigations by the University of Connecticut funded through the Connecticut Department of Environmental Protection, there have been few long term studies. What has been undertaken has been the result of episodic funding commitments by a variety of federal agencies and with only token support from the states.

In the last few years the second, six year long, spectacularly underfunded, Long Island Sound Study has been carried out. Some new research has been undertaken. While that study alone has spawned over 70 reports and resulted in issues of the journals *Estuaries* [8] and *Coastal Research*[9] dedicated to Long Island Sound topics, much more basic research has been identified as being needed.

Taking the Pulse of the Sound

A top priority, however, is a monitoring program. Such a program should, if well designed, serve not only to assess the Sound's health on a year-to-year basis, but also provide a means of measuring slow, gradual changes which may creep up on us in the future. To gain an understanding of how a waterbody is changing over time, it is necessary to have a history of surveys which have measured its physical, chemical and biological characteristics over a long span of time. By reviewing those data, change may be identified. The means are not precise, but represent the best tool available. But surveys are expensive to conduct because they exact heavy, continuing, operational costs of both ships and personnel. If conducted over a period of time, utilizing standardized techniques of measurement, continuity of funding is required—and such continuity of funding is often absent from our system.

As the present Long Island Sound Study got underway, it became apparent that the kind of data base which existed for many other estuaries would be hard to find for Long Island Sound. In 1986 the National Oceanic and Atmospheric Administration (NOAA) sought to determine the number and kind of surveys made of water quality parameters or of biological distributions in the Sound[10]. It identified a total of 71 data sets representing the voluntary response from those institutions and individuals solicited identifying such data sets. Those sets have been characterized as being of short duration (surveys of less than two years) or long (longer than two years) and of local (embayments or less than one-third the area of the Sound) or wide geographic coverage. The results are:

Type of Survey	Number of Surveys	Percent of Total
Long duration and wide coverage	8	11%
Short duration and wide coverage	12	17%
Long duration but of local coverage	16	23%
Short duration and local coverage	35	49%
Total	71	100%

What was found was exactly the wrong thing: Most of the surveys looked at a particular waterbody for only a period of several months or, at most, a whole year. While such surveys may answer specific questions, they have limited use in depicting a comprehensive picture of how Long Island Sound works or in establishing a baseline from which change may be measured. Most such surveys are undertaken by governmental agencies, particularly by local and state governments, for administrative purposes, not for research understandings.

But, this analysis is fraught with problems. First of all, governmental bodies are more apt to respond to requests for information about the data sets they possess than are academic scientists while the latter may, in fact, have more. Secondly, response rates from all quarters to such requests are usually low. Monitoring surveys are best undertaken by governmental units, for it is difficult for academic scientists to raise the funds necessary for their conduct and to sustain the effort. Most granting agencies, for example, will not support survey type investigations. For long term surveys, stability of funding over long periods of time is required, and is often possible only by agencies of government. For example, New York City's Department of Environmental Protection has surveyed the waters of New York Harbor for over 100 years and in doing so has created one of the longest and most useful data sets there is. Unfortunately for Long Island Sound, their jurisdiction ends at the westernmost Sound. The Interstate Sanitation Commission (ISC) was formed by New York and New Jersey in 1936 because of concern for water quality in New York Harbor. In 1941 Connecticut joined the ISC and surveys of western Long Island Sound were initiated and continue to the present[11].

Since the early 1980s Connecticut's Department of Environmental Protection has undertaken Sound-wide fishery surveys of particular species. By the mid-1980s the Marine Fisheries unit had expanded those surveys to multiple species occurring at the 40 sampling stations visited between April and November each year. In 1991, those surveys were further expanded to include water quality parameters at each of those stations. The department plans to continue its monitoring of both water quality and fisheries as long as funding permits. At present, it is the only Sound-wide monitoring going on.

Communicating Research Results

Research results are usually quickly disseminated through the research community because there are established, and recognized, means of doing so. But carrying that information to two other groups, governmental agencies and the public, is less well done. The gap has been recognized for some time and remedial efforts are in place. For example, the National Sea Grant College Program recognized the need for wide dissemination of research results and caused the Marine Advisory Service to be a component of every state Sea Grant program. Analogous to the Cooperative Extension System, the Marine Advisory personnel work at spreading the word through publications, through the media and through meetings and other personal contacts. The system works well when it is effectively used, as, for example, by the Long Island Sound Study. Too often, however, parochialism inhibits the effective use of this capability.

Academic scientists, by and large, are not great communicators of their research to the public. The system in which they work has been very slow to recognize the importance of such activities in the career advancement of faculty. One of the ways in which academics communicate is through the writing of books of semi-technical content which may then be used by the broader public as reference tools. There have been few such productions about Long Island Sound: *The Urban Sea: Long Island Sound* [12] was published in 1976 and *The American Mediterranean: An environmental, economic and social history of Long Island Sound* [13] appeared in1974. More recently, Connecticut's Department of Environmental Protection assisted in sponsoring Peter Patton and James Kent's recent book *A Moveable Shore: The Fate of the Connecticut Coast* [14] The Department's Natural Resources Center also produced *Long Island Sound: An Atlas of Natural Resources* [15] (1989) and *A History of Connecticut's Coast* [16] (1982). Long Island Sound's Keeper, Terry Backer put funds from environmental fines to work and published *The Sound Book* [17] in 1993.

Also important in communication of research are the Long Island Sound conferences held annually. One of those is to be a regular event called by Connecticut's Department of Environmental Protection for the purpose of reviewing the research it funds. Academic institutions have also sponsored conferences dealing with the Sound.

The Future?

It is not at all clear where the money to support a major Long Island Sound research program will come from. Without a large federal program supporting Sound-wide research, available funds will largely support only for localized studies. Marine research appears, at present, to not be of highest priority in Washington circles. Should this be the case, larger scale research on Long Island Sound processes, research of great importance, can only be pieced together through consortial funding. Such endeavors require great leadership and constant, devoted, attention to beat back parochial institutional interests and squabbling. Were the resources of the Connecticut and New York Sea Grant College programs to come together and provide not only such leadership, but also research support, and Connecticut's Long Island Sound Research Fund to also participate, the requisite—and long-term—research support might be assembled.

But on the Sound's northern shore there are hopeful signs. Connecticut's Department of Environmental Protection initiated its Long Island Sound Research Fund in 1992 with a stated mission of supporting basic research on the Sound at about one million dollars a year. Despite the financial exigencies of the 1990s, that fund, unique to the northeast, has been continued. In 1993 that initiative will be augmented by more directed activities funded by Connecticut's Long Island Sound license plate program.

Acknowledgments

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Footnotes

[1] Lewis, R. and N. Coffin, 1985. Long Island Sound. A *Bibliography*. State of Connecticut, Department of Environmental Protection, Natural Resources Center, Marine Program. DEP Bull. No. 8. 99 pp. This publication is still available from the Natural Resources Center, Department of Environmental Protection, Hartford, CT. A current, and more complete, catalogue of the technical literature on Long Island Sound has been compiled by the Long Island Sound Resource Center. Including about 2,800 titles, it has broader coverage particularly of other than geological literature. Unfortunately it is accessible only at the Resource Center in computer file form.

[2] "General" includes titles of such breadth that a predominant discipline could not be determined. "Environmental" includes those titles suggestive of content of broad disciplinary coverage, but more focused than "General." "Oceanography" includes titles dealing with physical, chemical and, to some extent, biological processes. In no instances was the text of the citation examined—reference was made solely by title.

[3] Vannevar Bush was President Roosevelt's scientific advisor through the wartime period. See Bush, V., 1945. *Science: The Endless Frontier*. A report to the President by Vannever Bush, director of the Office of scientific research and development. U.S. Govt. Printing Off., Washington, D.C., July 1945.

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[6] Koppelman, L.K., P.K. Weyl, M.G. Gross and D.S. Davies, 1976. *The Urban Sea: Long Island Sound*. Praeger Publ. Co., New York, NY. 223 pp.

[7] *Advances in Geophysics*, Vol. 22, 1980.

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[9] *Coastal Research* Spec. Issue # 11, Fall, 1991.

[10] Collins, E. and G. Heimerdinger, 1986. *Data characteristics for Western Long Island Sound*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data and Information Service. June 1986. National Ocean Data Center informal report No. 2. Unpaginated.

[11] The Interstate Sanitation Commission's jurisdiction extends eastward from New York Harbor to a line drawn from Port Jefferson, Long Island to New Haven, Connecticut.

[12] Koppelman, L.K., P.K. Weyl, M.G. Gross and D.S. Davies, 1976. *The Urban Sea: Long Island Sound.* Praeger Publ. Co., New York, NY. 223 pp.

[13] Weigold, M. 1974. *The American Mediterranean: An Environmental, Economic and Social History of Long Island Sound.* Kennikat Press, Port Washington, NY. 228 pp.

[14] Patton, P.C. and J.M. Kent, 1992. *A Moveable Shore. The Fate of the Connecticut Coast.* Duke Univ. Press, Durham, N.C. 143 pp.

[15] Anonymous, 1989. *Long Island Sound: An Atlas of Natural Resources.* Connecticut Department of Environmental Conservation. 52 pp.

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Aquaculture in China: Parallel Application to Long Island Sound

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The People's Republic of China (PRC) is faced with the enormous task of providing food for a population exceeding 1.15 billion people. A scarcity of arable farmland has necessitated alternative activities for increased food production. The People's Republic of China is now one or the world's leaders in aquaculture production. Prawn (shrimp), blue mussels, various seaweeds (mostly kelp), scallops (both native and introduced species from the U.S.) and freshwater fish (Mostly carp), are among the species cultured. Clams, oysters, and abalone are also cultivated. In this summary, we will attempt to give an overview of the aquaculture of seaweeds and scallops in the People's Republic of China and discuss implications for Long Island Sound.

General description of seaweed cultivation industry in the People's Republic of China

The annual output of seaweed (*Laminaria, Porphyra, Gracilaria, Gelidium, Eucheuma,* etc.) is about 250,000 metric tonnes in dry weight (1.25 million tonnes if fresh weight), with an estimated value exceeding $300 million. Farming area for seaweed cultivation is approximately 13,500 hectares. *Laminaria* production is about 88% of the harvest (i.e. fresh weight). The *Porphyra* harvest is about 6% fresh weight and other seaweeds total 6% of the harvest. About 70% of seaweed is directly used as food or vegetable, 25% as raw material for industry and 5% in food processing.

Kelp (known as "haidai") has been artificially cultivated in China since the 1950s. The kelp industry, based on the aquaculture of Laminaria japonica, makes use of three techniques: (1) indoor sporeling culture in greenhouses; (2) raft (long-line) culture in which young sporophytes on ropes are hung in the sea to mature; and (3) artificial fertilization with manure. Seventeen large sporeling centers are capable of delivering 6.4 billion germlings to meet the needs of the kelp industry, which farms more than 13,500 hectares of nearshore waters. The annual harvest of 250,000 dry metric tons of kelp has an estimated value of over $250 million.

Porphyra (known as "nori") culture in China began in 1959. The main culture technique is raft culture in the tidal waters in the temperate shores of the PRC. The total culture area of this red seaweed in approximately 6,700 hectares, with an annual output of 15,600 tonnes. The output of *Porphyra* per hectare is 2,400 kg, predominately for food production.

The artificial cultivation of *Gracilaria* takes place in ponds located in Guangdon and Hainan Provinces, in the south of the PRC. Culture area is 2,000 hectares, with an annual yield of 3,000 tonnes. *Eucheuma* is experimentally farmed in Hainan Province with an annual output of 300 tonnes.

General description of integrated culture of scallops with *Laminaria* in China

Culture of *Laminaria*

Meiospores of *Laminaria* are collected on seed string frames in indoor pools at the kelp nurseries (greenhouses) in mid-June. Germlings are maintained there during the summer until the temperature in the open sea drops beneath 20°C (about 100 days in the nursery). Input sea water is cooled to 5-10°C with a turnover of fresh seawater every five days. One frame can provide 50,000 seedlings and one square meter of pool can provide 200,000 seedlings. In October the frames are brought to the intermediate culture raft and kept there until the middle of November when the length of the seedlings reaches 10 cm. Afterwards, the frames are brought back to the greenhouses and the seedlings will be detached from the frame and inserted into culture strings (10 seedlings pre string). The culture strings are brought back to the culture raft between November and December. In some oligotrophic areas, *Laminaria* will be fertilized regularly with manure or slow release fertilizers. The harvest will follow after 11 months. Average output of *Laminaria* is 18 tonnes per hectare. With indoor sporeling culture techniques, *Laminaria* is able to grow up from spore to commercial size blade in less than a year. Usually *Laminaria* will take two years to grow under natural conditions.

Culture of the bay scallop, *Argopectin irradians*

Long-line technology from the kelp industry has been adopted for use in scallop aquaculture, thereby reducing infrastructure costs. Bay scallops (*Argopectin irradians*) were successfully introduced to China from northeast America in 1982. Surprisingly, an industry exceeding 120,000 metric tonnes (fresh weight) annually has been developed from 26 scallops.

Parent scallops are brought back from the culture rafts to indoor nurseries in March. They are cultured in indoor tanks with temperature increases from 1 °C to 15 °C (1 °C increase/day) and fed a mixture of *Isochrysis galbana*, *Pyramimonas spp.*, and *Platymonas spp.* (about 20,000 cells per ml). The temperature of the sea water is kept below 20 °C. After spawning in April, the larvae are cultured in indoor tanks and attached to an adherent medium. By the end of May, larvae have grown to a size of 0.35-0.45 mm and are transferred from nursery tanks to lantern nets. The larvae will be cultured in large tanks if the temperature in open sea is not high enough. During this intermediate culture period, the larvae will be scattered and the lantern nets will be changed 2-3 times until the larvae reach commercial size (average shell length >5mm) by the middle of July. At this stage the juvenile scallops will be sold to culture farms. Normally the scallops will be cultured on the long-line culture rafts from July to December. The same culture raft will be used on which the *Laminaria* were originally grown. About 100 lantern nets, spaced 1m apart, with 250 scallops in each net (10 shelves per lantern net, each with 25 scallops) will be hung on the culture raft. The scallops will be harvested by the middle of December. The average output is 75 metric tonnes.

Advantages of integrated culture of kelp and bay scallops

It is very efficient for a nursery to raise both juvenile *Laminaria* and bay scallops. The nursery is used for scallops from March to May, and for *Laminaria* from June to October. There is no conflict between the two breeding programs and infrastructure costs are reduced in a shared aquaculture program.

At some culture farms, there is some conflict in utilizing the same culture raft for both bay scallops and *Laminaria*. By the end of November, sporelings of *Laminaria* are ready for transplant to culture strings suspended from the long-lines of the culture raft although the scallops are still being cultured on these rafts. To solve this problem, some scallops (usually 15%) are harvested to leave space for *Laminaria*. The *Laminaria* sporelings will be suspended from these rafts at higher densities (usually two time the norm). After the scallop harvest, the *Laminaria* lines will be thinned out to the proper density. In late spring and early summer, only *Laminaria* is cultured on the raft. If the farm has a reservoir for intermediate culture of scallops, there will not be any problem with space on the culture rafts. If a site for intermediate culture is not available, then some Laminaria will be harvested ahead of time to leave some space for the scallops. Intermediate culture of the scallops occupies less than 3% of the total culture raft from May to July.

There are many advantages of multiculture. It greatly increases the income of *Laminaria* farmers and ultimately reduces the need for chemical fertilization in oligotrophic areas. Water quality has improved in eutrophic regions where there has been an integrated approach to scallop and *Laminaria* aquaculture.

Long Island Sound Situation

It is estimated that the New England bay scallop fishery has declined 80% due to recruitment failures and brown-tide blooms. The Connecticut scallop industry has gone from production highs in the 1940s of 50,000 bushels to less than 10 bushels today! Farming bay scallops offers a viable alternative to natural harvests that are intimately tied to water and habitat quality. Currently, there is no aquaculture of kelp in New England.

A demonstration long-line scallop and kelp farm could be deployed in the waters of Long Island Sound. Farms should be monitored for scallop and kelp survival and growth, as well as fouling of scallop nets. Meat and water quality characteristics of the scallops should be collected to determine optimum meat yields. Integrated kelp culture should proceed following a Chinese model farm. A cost-benefit analysis of capitol labor and production costs should be determined for the suggested integrated aquaculture program. Cultivation of the kelp will improve the water quality in the vicinity of the demonstration farm, and ultimately shellfish production would be increased.

Fisheries and Marine Resource Management: Issues on Long Island Sound

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It is my pleasure today to describe some of the biological resources of the Sound, their uses, and some of the issues and problems facing us as we approach the end of the 20th century.

Connecticut has a storied history of maritime uses. From the whalers of the last century to the nuclear submarines constructed today, coastal Connecticut has had intimate ties to the sea. One of the principal ties has been to our fisheries. I'd like to describe some of our fishery resources and how they're fished for before we discuss trends and perspectives.

The lobster is one of the most valuable of the natural resources fished for in the Sound, yielding on the order of 3.5 million pounds at a value of ten million dollars each year at the dockside. It is also one of the most heavily exploited marine resources along the Atlantic coast making it doubly important to marine resource managers. Lobsters are taken principally with pots, or traps, from small vessels, anywhere from skiffs to 42' fiberglass vessels.

The oyster has become the most valuable marine resource harvested from the Sound in the past five years. Oysters are taken principally by dredge from leased or franchised beds which are cultivated by the owner or lease holder in a manner not unlike farming. Landings have quadrupled since the mid-1980s and, in value, are worth over 25 million dollars each year.

Historically, Connecticut fishery resources have supported large vessel fisheries such as menhaden purse seining, but more traditionally, the fleet has been comprised of small to medium sized bottom trawlers typified by many of the vessels one sees today in the port of Stonington. Even there, the gradual transition has been from 50' wooden vessels to 70-90' steel trawlers. Often maligned, it is important to recognize the bottom trawl fishery for its role in society as the major producer of seafood for the non-fishing, seafood-consuming public.

Without doubt, the largest fishery on the Sound is the recreational finfish fishery, also known as saltwater sportfishing, or marine angling. Almost 10% of Connecticut's citizens and an equally large number of New Yorkers participate in this fishery each year, fishing for winter flounder, striped bass, summer flounder, tautog, scup, and principally, bluefish, both as "snappers" or young of the year, and adults. We've always known this was a large and important fishery, as well as a valuable one, supporting many businesses that supply the sport fishery. What has become more obvious in the past five to ten years is the magnitude of the impact of the sport fishery on marine resources. In the Sound, many finfish species are now taken in greater numbers each year by the recreational fishery, than by the commercial.

What are some of the trends in landings? The following two tables provide some insight into the relative magnitude of the fisheries in Connecticut.

Table 1. Connecticut Sport Fishery Landings from Long Island Sound (lbs)

	1987	1988	1989	1990	1991
All finfish	15,700,000	7,200,000	12,400,000	6,200,000	10,800,000
Bluefish	12,300,000	4,300,000	9,600,000	4,800,000	8,400,000
Winter flounder	1,100,000	900,000	600,000	400,000	500,000

Table 2. Connecticut Commercial Fishery Landings from Long island Sound (lbs)

	1987	1988	1989	1990	1991
Lobster	1,500,000	1,800,000	1,900,000	2,300,000	2,400,000
Finfish & squid	1,000,000	700,000	600,000	900,000	800,000
Oysters*	4,300,000	8,700,000	15,500,000	23,400,000	33,400,000
Hard Clams*	4,800,000	2,500,000	5,700,000	9,000,000	9,900,000

What are some of the trends in our living marine resources and how do we identify them? Marine biologists of the department's Fisheries Division conduct a number of "fishery-independent" monitoring programs intended to determine abundance, distribution, growth, and mortality rates of important resources, from which population dynamics can be determined and stock conditions evaluated. Larval and juvenile lobsters are sampled, as well as adults in the commercial fishery. The Department's research vessel *JOHN DEMPSEY*, constructed in 1990 to a design specified by Department staff, has been used since then to monitor fishery resources and water quality associated with the multi-agency and university "Long Island Sound Study."

One of the interesting finfish trends that has become apparent in the past five years is the restoration of the sea herring resource. A victim of foreign overfishing in the 1970s, the sea herring resource collapsed and went into recruitment failure which lasted over ten years. Since the late 1980s the resource has begun to recover and our survey efforts have documented a steadily increasing biomass. This bodes well for sea birds, marine mammals, and pisciverous (or "fish eating") fishes which prey on herring, and also for fishermen who may once again fish for herring as a fishable resource.

Environmental assessment became almost a "buzzword" in the late 1980s but it took the Long Island Sound Study to refocus our attention on the environmental quality of the Sound. One of the principal research results, and management problems identified, was that of hypoxia, or low dissolved oxygen levels. It was found that oxygen in late summer declined to levels which caused living marine resources to either evacuate the western part of the Sound, or to perish. This has become one of the principal goals of the Study, to improve water quality to sustain year round populations of endemic living resources. At the same time, there are other management problems confronting us, for example, the disposal of waste, trash, and other refuse in marine waters. The trend in this fact is extremely disturbing: a few short years ago, the amount of refuse and trash disposed of at sea exceeded the magnitude of all U. S. commercial seafood landings. With the advent of the MARPOL (Marine Pollution) Treaty, and greater environmental awareness on the part of those using our coastal seas, one can only hope that this statistic will be reversed and that open water trash disposal will become virtually nonexistent.

In marine fishery management, we often speak in acronyms, the briefer the better. The most common and conventional one is F. Management of fishing mortality (fishing rate is identified as "F"), is the principal challenge facing marine fishery managers. Whether due to problems of gear selectivity or simply too much fishing pressure, managers are now confronting the problems of excessive fishing pressure with more direct controls, such as effort reductions, moratoriums, quotas, etc. From the discard mortality in trawl fisheries to hooking mortality in sport fisheries, the field of "fishery conservation engineering" is now addressing these problems to increase the escapement of juvenile fish or species which should not be taken because of the need to conserve them.

Connecticut and New York have been very involved in "interjurisdictional fisheries management" for many years, through the Atlantic States Marine Fisheries Commission and Regional Fisheries Management Councils established by Congress for the purpose of managing offshore fisheries under extended fishery jurisdiction (the so-called "200 mile limit law"). Interjurisdictional fisheries management is of critical importance when you realize that most heavily exploited marine fisheries under extended fishery jurisdiction (the so-called "200 mile limit law"). Interjurisdictional fisheries management is of critical importance when you realize that most heavily exploited marine fishery resources are migratory, and fished for by fishermen from a number of different states. These endeavors have become some of the most pressing and important facing the two states.

Finally, what are some of the issues facing users of living marine resources? Certainly, a perennial favorite is competition, whether between different commercial fishing groups, or between sport and commercial fishermen, for fishing space, or the right to take a particular species. These become some of the most aggravating and divisive of the issues facing marine resource managers, but also, some of the most important.

Public access is another important issue. Gradually over the years, many fishing opportunities have been eliminated, whether by the loss of commercial dock space for commercial seafood producers, or the loss of shoreside fishing sites for recreational fishermen. In either case, it represents a loss of opportunity for those who would harvest renewable natural resources for public and personal benefit.

Habitat protection once was an extremely important consideration; then, for years, it seemed to lie dormant. Over the past several years, however, it seems to have gone through a rebirth, with state and federal agencies becoming more aggressive in habitat conservation activities, and importantly, with an interested and informed public providing the impetus for habitat conservation and restoration programs. As an example, Connecticut has lost about 30% of its original tidal wetlands to development. Such areas are of critical importance as spawning and nursery habitat for renewable fish and shellfish resources. The public has come to recognize that it is important that we husband what remains and restore what can be restored and there are many fine examples of public and private ventures which do just that.

The issue of contaminants and their effects on our fisheries has become an important one in the last ten years. There is the obvious issue of seafood safety, that is, the potential impacts on the health of human consumers of fishery resources. Then, there is the more subtle issue of the effects of contaminants on the biology of living resources. Marine ecologists are gradually coming to realize that the initial concerns about seafood safety may be less important than the concerns over the health of the living resources themselves. As just one example, winter flounder from industrialized areas with high sediment contaminant levels have been shown to have impaired growth rates and reproductive physiology, an effect analogous to that produced by DDT decades ago in fish-eating seabirds like the osprey. However, the edible tissue of winter flounder is free of contaminants and safe to eat. It is a question of protecting the flounder rather than the human who eats the flounder. Unfortunately, little is known of the effects of contaminants on most species and little is being done to investigate such questions.

Regrettably, we've ignored the benefits of fish and seafood in our diets. Seafood is a low fat, high protein component of a healthy diet. Omega-3 fatty acids contained in fish have been shown to diminish the risk of cardiovascular disease, one of the leading causes of death in Americans. Instead however, we've continued to be preoccupied with concerns about consumer health. While a justified consideration, all too often the consumer is unnecessarily alarmed about seafood-based health and safety issues. One of the most notable examples occurred a few years ago in a New York Times advertisement showing a whole fish on a dinner plate with a hypodermic needle and syringe hanging from its gill cover. The words in the ad were irrelevant. The message was clear. "Eat fish, get AIDS." We don't need that. It will take a responsible press, a proactive government, and an informed constituency to counter such misinformation.

Physical Oceanography of Long Island Sound: an Ecological Perspective

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"... the generalities of relative richness of an ecosystem and its component parts are largely explainable in terms of a handful of environmental factors of a mainly physical nature: radiation, vertical circulation, the nutrient pool, depth of water, and the character of bottom sediments."
—*Gordon A. Riley, 1972*

Introduction

This paper addresses physical oceanographic aspects of Long Island Sound with respect to its latitude, its bathymetry and its hydrography. These attributes control the environmental factors of radiation, vertical circulation, depth of water, character of bottom sediments, and fundamental distributions of nutrients as cited by Riley. In turn, these factors determine the Sound's ecological structure, which includes its rich mix of northern and southern species, its rich mosaic of habitats, and its trophic design.

While natural forces provide the fundamental conditions which determine the Sound's ecology, there are at least two ways we humans are modifying their effects. (1) On a local scale, the growth of our populations along the shores of the Sound and its tributaries has increased total amounts of nutrients and dissolved organic loadings and changed their source distributions (Fig. 1A). (2) On a global scale, our burning of fossil fuels is increasing the carbon dioxide in the atmosphere and our release of chlorofluorocarbons is affecting the ozone layer, alterations which will influence the ecology of the Sound by altering the quantity, quality and balance of radiant energy. These global, longer-term effects will ultimately have much greater consequences on the character of the Sound, but they are beyond the scope of this presentation. The increase in nutrients and dissolved organics, while it is happening worldwide, produces local eutrophication. In Long Island Sound, eutrophication is manifest in the depletion of dissolved oxygen in bottom waters during the summer, and the measurement of dissolved oxygen provides a convenient parameter for linking the physical oceanography of the Sound to its ecological state.

Our Place under the Sun

By virtue of its latitude (41° N), Long Island Sound lies in the most dynamic climatic belt in the world for marine systems. The tilt of the earth on its axis changes solar radiation intensity dramatically and moves us into and out of the northern wind belt over the annual cycle. As a result, mean monthly water temperatures range from -1°C to 22°C, and winds vary from strong northwesterlies in winter, which thoroughly mix the water column and produce robust exchanges with offshore waters, to gentle southwesterlies in summer, which, combined with thermal heating, results in a seasonally stratified water column. Thermal stratification begins in late March (Riley 1956). It becomes seasonally permanent about mid-June in western areas, aided by the narrowness and orientation of the basin and a deep reservoir of bottom water which may be as much as 8°C cooler than that at the surface. It persists until late August or early September, when shorter days bring greater atmospheric cooling at night, and daytime heating becomes insufficient to counteract the mixing forces of tides and wind (Welsh and Eller 1991).

The combination of a dynamic temperature range and a voluminous deep water reservoir which is warmer in winter and cooler in summer accommodates a rich ecological mix of endemic species whose centers of population lie to the north and the south. Lobster and winter flounder, for example, are boreal species which live at the southern end of their temperature range. They utilize the deeper waters as a refuge from higher inshore temperatures in summer, while the blue crab, a mid-Atlantic species, survives by moving into deeper waters to escape winter cold. In addition a number of coastal migrants, such as menhaden and bluefish, come and go with the appropriate seasons.

Legacy of the Glacier

This deep water refuge, east-west orientation and other topographic characteristics are a legacy of the glacier. It scooped out a basin which is relatively smooth and spindle-shaped in outline, with its long axis lying parallel to the coastline (Fig. 1A). Below the surface, however, sills and reefs cut across the main axis, dividing it into a series of basins (Fig. 1B). The greatest depth lies to the east, at the main opening with the sea, but the greatest cross-sectional volume lies in the broad Central Basin (Fig 2).

In contrast to the irregular axial topography, cross-sections of these basins are mostly smooth and U-shaped, so that deep water extends nearly shore to shore. Shallow water resides mostly within 80 or so estuaries which line the north shore and several large embayments along the western half of the south shore. These small individual systems nearly triple the linear saltwater shoreline. They are ecologically diverse, provide protective nursery areas, and contribute directly to the quality of life and the socio-economics of the region, but their small size and accessibility make them highly vulnerable to anthropogenic impact such as the polluting effects of runoff and direct discharges.

The Sound is a sediment-poor system because the glacier scraped away surficial sediments from the drainage basin to the north and deposited them on the shelf south of Long Island (Lewis and Stone 1991). Consequently, very little sediment is carried in by rivers, and annual net deposition is less than 1 mm, 50%-75% of which is contributed from the ocean (Kim and Bokuniewicz 1991; Koppelman *et al.* 1976). Resuspension rates are high, however, fostered by turbulence produced when currents flow across the irregular topography along the main axis (Fig. 1B). Fine sediments are winnowed and broadly distributed. About 56% of the bottom, comprising most of the central and western basins, is covered by soft mud (Kim and Bokuniewicz 1991), which somewhat limits the benthic fauna of that region. There are coarser sediments to the eastward, however, and rocky outcrops throughout the basins and along the shorelines, providing a mosaic of hard- and soft-bottom habitats which enhance the overall floral and faunal richness of the system. There is little hard bottom to the south, for instance, and Long Island Sound is the southern extension for a variety of attached macroalgae such as the kelp, *Laminaria longicruris* (which is also another example of a plant population living at the edge of its temperature range (van Patten 1992).

A Sound and an Estuary

The hydrography of the Sound reflects its character as both a sound and an estuary. At its head is the East River, a tidal strait, connecting to the Hudson-Raritan system. The major freshwater sources lie unconventionally along the northern flank and over 80% of the freshwater enters the eastern basin almost directly across from its main opening to the sea (Fig. 1). The water entering through the East River is only about 6-8 ppt fresher than that at the Race, but the gradient is sufficient to impart a weak gravitational circulation which combines with the dominant tidal forcing at the Race to produce a complex residual circulation (Fig. 3). The dominant feature is a Sound-wide counterclockwise gyre which carries offshore water from the Race westward along the northern flank and brackish water from the East River eastward along the southern flank. The pattern is interrupted, however, by the irregular bottom topography mentioned above (Fig. 1B), which short-circuits the flow along the way. The result is a series of counterclockwise gyres along the main axis and several

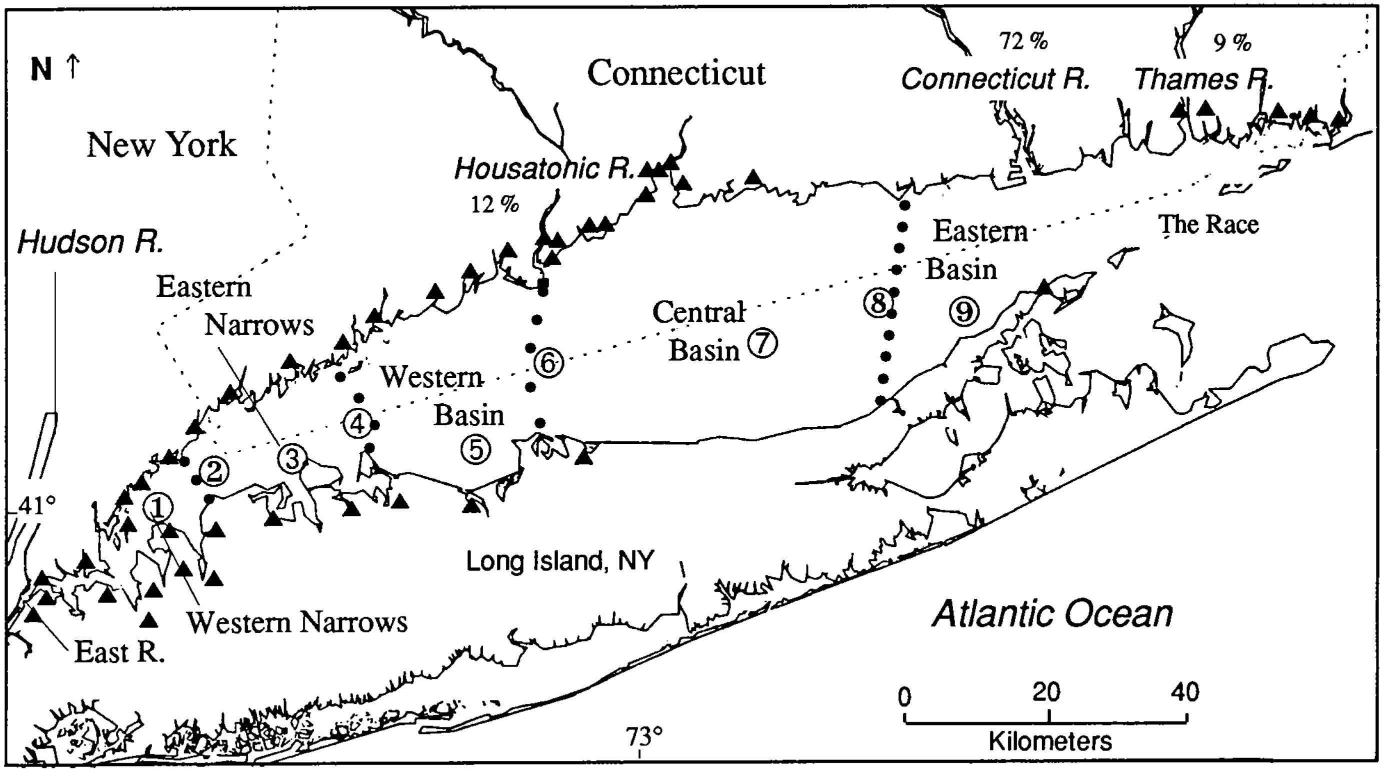

Figure 1A. Map view of Long Island Sound, showing distribution of major rivers and their contribution in terms of percent of total freshwater inflow, and the distribution of sewage treatment plants (▲) relative to the various basins, sills, and partial barriets (reefs). The numbers refer to the features shown in Figure 1B (next page).

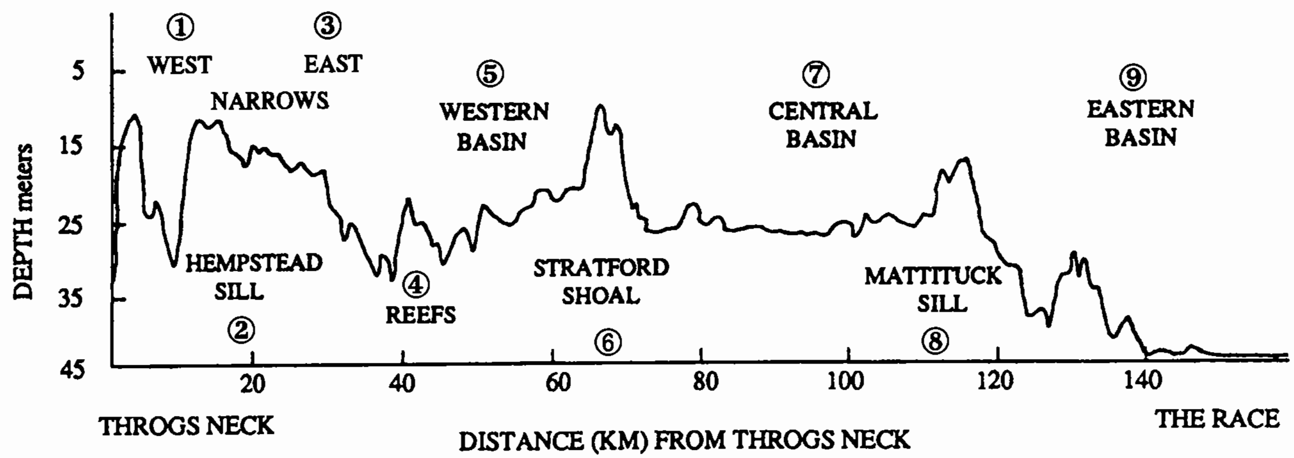

Figure 1B. A profile of bathymetry along the mainstem of Long Island Sound, from Throgs Neck (East River entrance) to The Race. Full Scale = ten nautical miles.

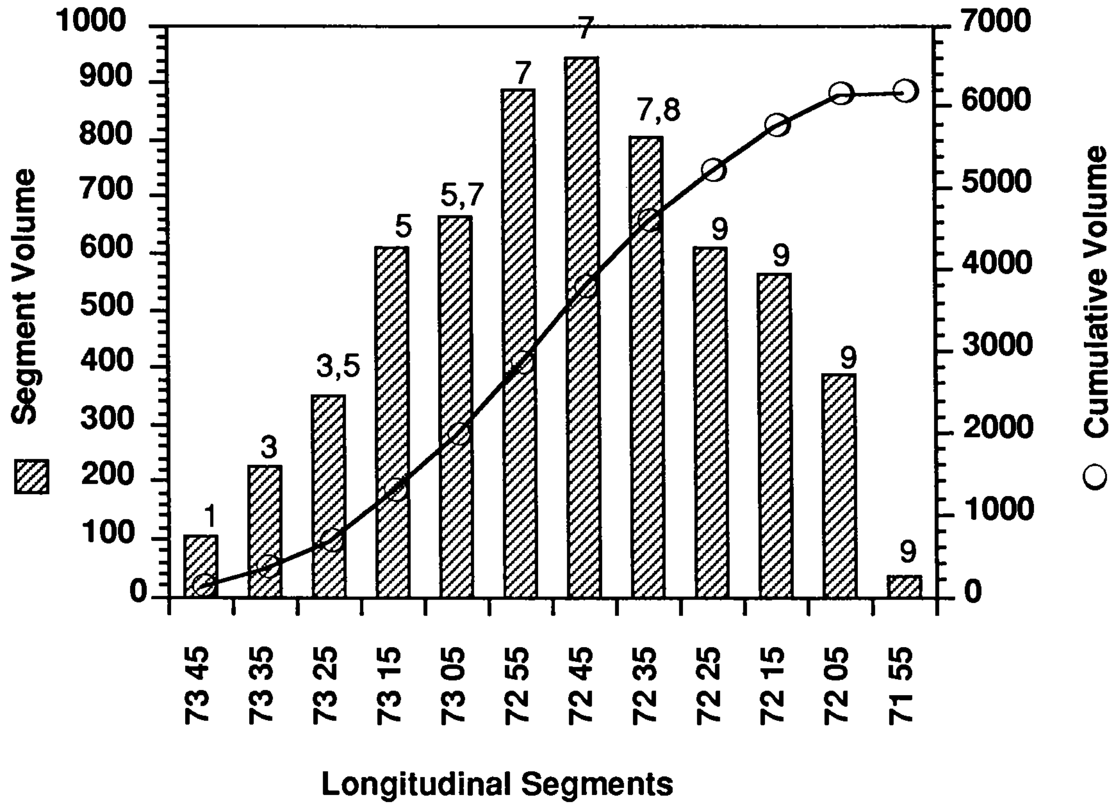

Figure 2. Volume distribution in Long Island sound at mean low water. Segments are based on decades of longitude and designated by the midpoint. Volumes were calculated from Riley (1952). Volume units are $m^3 \times 10^7$. Numbers over the bars refer to the physiographic features defined in Fig. 1.

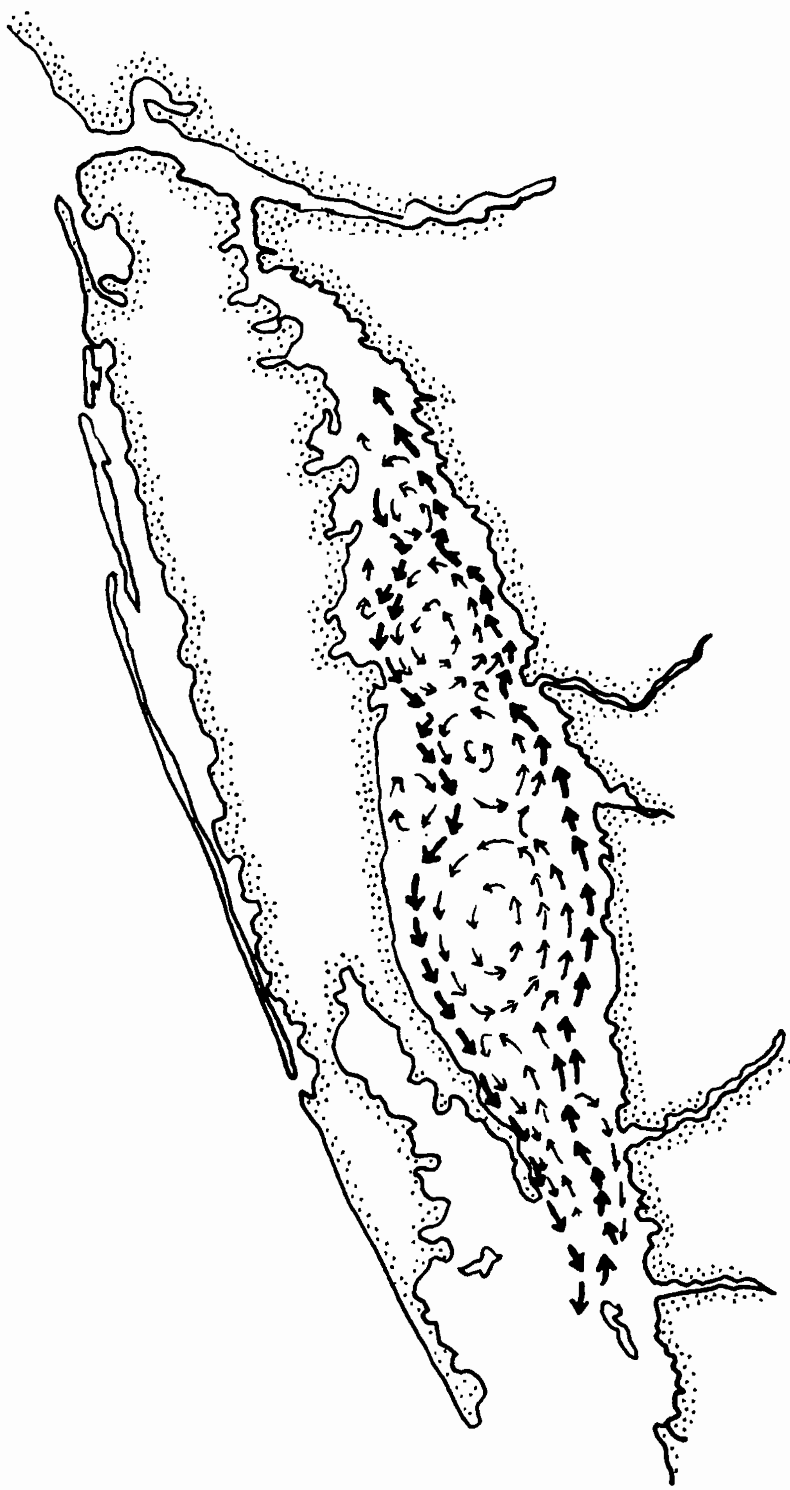

Figure 3. Residual circulation in Long Island Sound. Heavy arrows delineate the main gravitational gyre inward along the north shore and outward along the south shore. Lighter arrows are smaller gyres caused by bottom topography. After R. Wilson (pers. comm.). Full Scale = ten nautical miles.

small clockwise gyres along the flanks (R. Wilson and D. Pritchard, personal communication). A similar pattern consisting of 3 gyres for the main axis was suggested by Riley (1952), but the direction of rotation for Riley's central gyre was clockwise. Supporting evidence is fragmentary, but theoretical considerations would argue for the development of residual gyres in a basin such as Long Island Sound where strong tidal currents interact with an uneven bottom topography (J. O'Donnell, personal communication).

Some Ecological Consequences

These spatial and temporal patterns and their magnitude and persistence are not well known, but their potential influence on trophic structure and eutrophication processes is great. Gyres increase residence times, and thereby enhance the retention of plant and animal populations as well as nutrients and organics of natural or anthropogenic origin. They also provide epicenters for biological activity through organic accumulation (clockwise gyres produce downwelling) or production (counterclockwise gyres produce upwelling). All of these effects increase the richness of a system, but such linkages have been only marginally explored (cf. Bowman 1988).

The pattern of inflow along the northern shore has been more thoroughly documented (R. Wilson, pers. comm.). Through this mechanism, nutrients and organics entering from the Housatonic, Quinnepiac and small streams along the CT shore become entrained and transported westward, further enriching the waters off the heavily urbanized western half of the Sound. Riley (1952) found substantial evidence for westward residual flow in the Central Basin, and there is recent speculation that a substantial portion of nutrients and organics from the Connecticut River may either flow directly westward or become entrained by physical or biological mechanisms within the gyral patterns of the eastern basin and eventually transported westward (J. O'Donnell, pers. comm.).

This speculation warrants further research, because the Connecticut is the single largest riverine contributor of nutrients (>70%) and organics (82 % measured as BOD) to the Sound (Farrow *et al.* 1986). It has previously been assumed that, since most Connecticut River water flows directly out of the Sound through the Race, its nutrients and organics could have little influence on enrichment occurring to the west of Mattituck Sill (Fig. 1). It has also been assumed that enrichment in the central and western basins results from urban enrichments from the East River and western shoreline. In terms of total loadings, however, the rivers are larger contributors than sewage treatment plants with respect to nitrogen (49% vs. 38%) and BOD (53% vs. 22%), and they contribute about one-third as much phosphorus. (This analysis does not include atmospheric deposition.) Inorganic nitrogen in riverine flow is dominated by the nitrate-nitrite faction, while sewage treatment effluents are dominated by ammonia. There is indeed a strong gradient for ammonia, which reflects the high STP densities to the west, but there is an opposing gradient for nitrate-nitrite, which reflects riverine enrichment to the central basin (Fig. 4A, 4B). Opposing gradients of phosphate (Fig. 4C) lend further support for two enrichment sources, a more easterly one from the rivers and a more westerly one from STPs. The sedimentation of finer grain sizes in central and western basins discussed earlier suggests another mechanism for westward transport of organics: adsorption to new and resuspended fine-grained materials.

People Push the System

The STP effluents are obviously a human intervention, and so is a large proportion of riverine nutrient and BOD loadings, being derived from agricultural runoff and STP effluents upstream. Such loadings enrich surface waters and contribute directly and indirectly to respiration in bottom waters of the western and central basins, which, during the period of summertime stratification causes a cumulative oxygen depletion in those bottom waters (Welsh and Eller 1991). The area of greatest depletion lies in the far western basin where it is undoubtedly related to STP inflows from the East

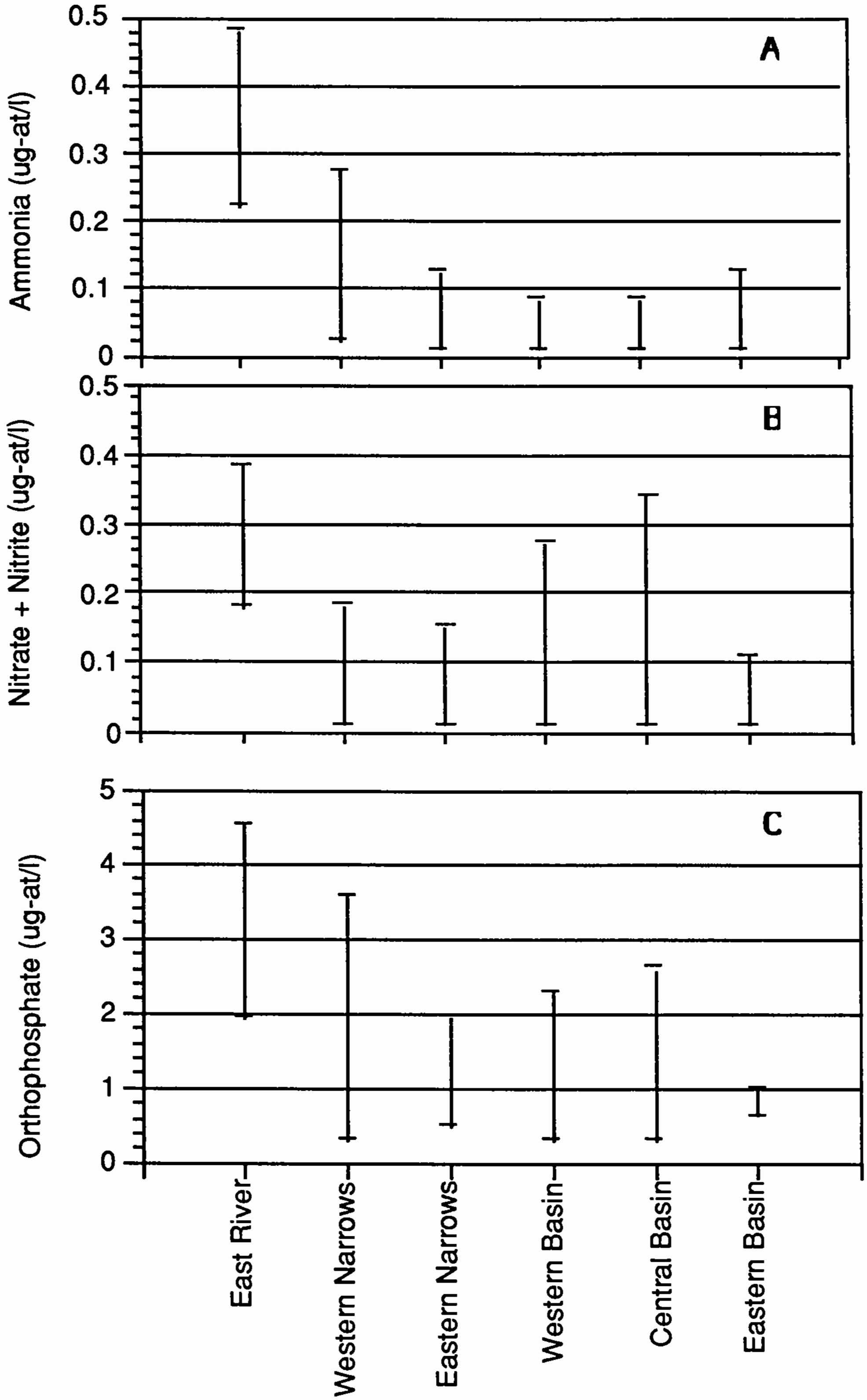

Figure 4. West-to-east gradients of ammonia (A), nitrate-nitrite (B), and phosphate (C). Values are maxima and minima by physiographic basin. Unpub. data from Hydroqual, Inc.

River and communities along the western flanks. There are also isolated areas of intensified depletion along the flanks of the central basin (Fig. 5), which probably reflect the contributions of local rivers and may also reflect residual drift to the westward from more easterly sources.

We originally assumed that severe oxygen depletion would be limited to western areas where most STP plants are located (Fig. 1A). There should then be a dilution effect to the east, because of the large volume of water below the pycnocline in the Central Basin (Fig. 2), and the fact that the entire water column below the pycnocline is well mixed by turbulent flow across the uneven topography of the main axis (Fig. 1B). The broad, deep basin of the Sound should thus provide a deep reservoir of cold well-oxygenated water at the beginning of each summer which would buffer the deep water system against the respiratory demands during its hydrodynamic isolation by stratification. Recently, however, we seem to be reaching the limits of this buffering capacity. In the mid-1950s oxygen levels were always well above 3 ppm in the central basins and much of the western basin (Riley, unpub. data). Recent studies indicate levels reaching <1 ppm in these basins; in some cases there are lobes of drawdown on the flanks of the system which are isolated from the main mass of low-oxygen water stretching eastward from the western sectors, which may be associated with local riverine sources (Fig. 5). There is also evidence of associated changes in community composition which is increasing respiration within the water column itself (Welsh in press). With substantial additions of nutrients from rivers along the northern flanks, there is no reason to think that the easterly advance of the seasonal oxygen deficit will continue to be constrained by dilution within the Central Basin.

Oxygen depletion in the deep water can be expected to exclude species which have lived there, especially those that use the deep water habitat as a thermal refuge, because they may already be stressed by living at the edge of their temperature range.

Conclusion

Long Island Sound lies at a thermally dynamic zone where it becomes stratified in summer and mixed in winter. It is a glacially scoured, sediment poor system with a large, deep water reservoir, low sedimentation rates, high resuspension and dispersal rates, and soft mud covering more than 50% of its bottom area. Hydrologically, it is both a Sound and an estuary, resulting in residual current regimes which import and retain sediments and organisms.

The temperature regimes in the Sound, the thermal refuge provided by its deep bottom-water reservoir, and its mosaic of hard- and soft-bottom habitats supports a rich ecological mixture of endemic species, many of whose natural population centers lie to the north and south. Its diversity is further enhanced by seasonally migratory fishes.

As a result of its physical attributes, Long Island Sound has a large volume of cold, well-oxygenated, deep water at the beginning of every summer season. In the past, oxygen supplies in the deep water "buffer" have been sufficient to handle the burden of summer metabolism. By virtue of the interaction of its circulation patterns with human development, however, Long Island Sound has become eutrophied, changing the biological patterns of oxygen production and consumption, such that we may now be losing that natural deep water buffering capacity.

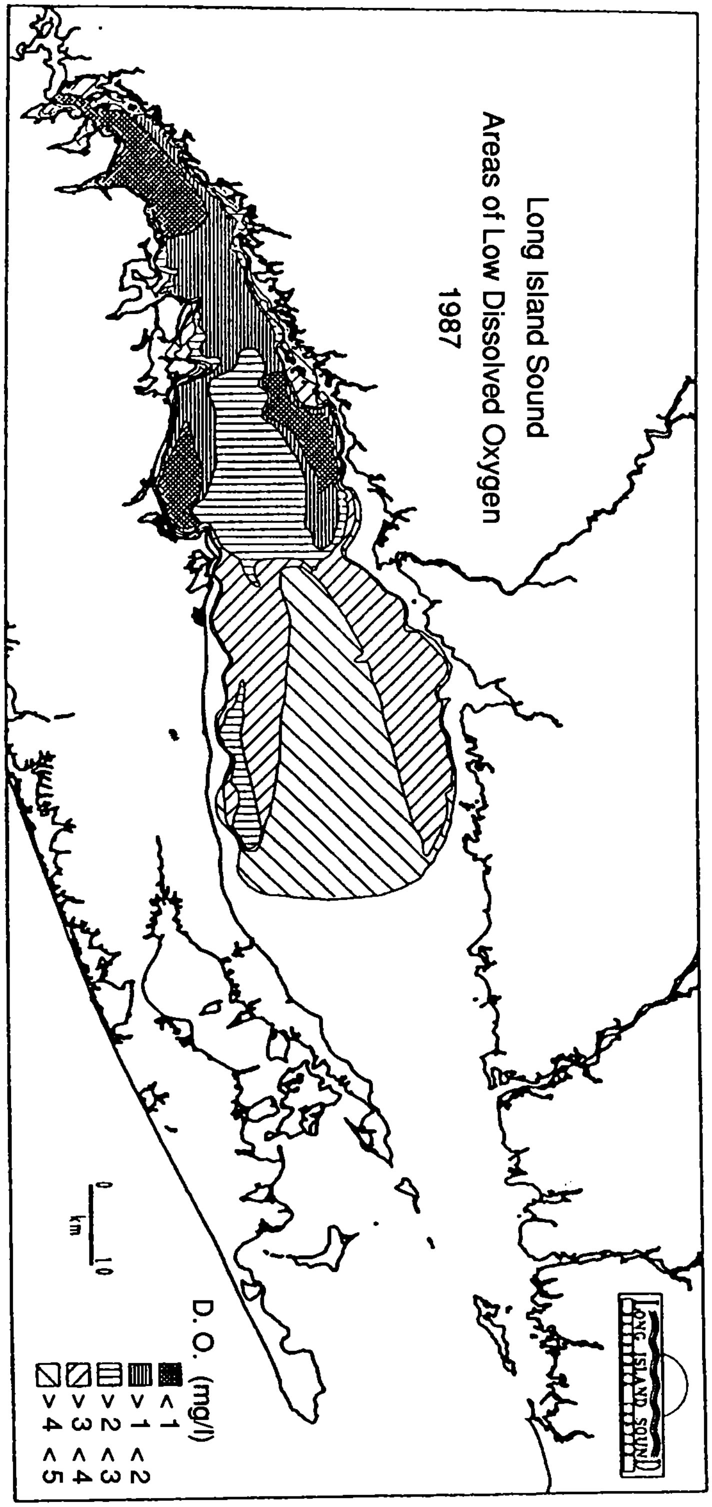

Figure 5. Seasonal lows for dissolved oxygen in bottom waters during the summer of 1987. From Welsh et al. (in press).

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Geology and Biogeochemistry

Geologic History of Long Island Sound

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Abstract

A systematic study of the geology of Long Island Sound (LIS) has been conducted over the past ten years. Knowledge gained from onshore regional geologic studies has been combined with 3500 km of high-resolution seismic reflection profile data, vibra-cores, and video images of the sea floor to better understand the geologic history of the basin. Glacial deposits overlie and nearly fill an inner lowland which is floored by crystalline rocks in the north and is bounded to the south by an irregular scarp cut in the Cretaceous coastal plain strata. The thick glacial section consists of sediment that was deposited in glacial Lake Connecticut during the systematic retreat of the last (late Wisconsinan) ice sheet. Lacustrine fans and submerged moraines mark former positions of the ice margin in the LIS basin. The lake spillway was located at the lowest along the Roanoke Point-Fishers Island-Charlestown moraine in the vicinity of The Race. Lake levels fell as the spillway was erosionally deepened, and gradually the lakebed became subaerially exposed. Extensive deposition associated with the draining of glacial Lake Hitchcock (through the Connecticut River valley), followed by a continuation of marine sedimentation have significantly reshaped the modern LIS basin. Reshaping of the basin is also taking place where tidal currents are reworking and transporting glacial and postglacial deposits.

Depositional History of the Long Island Sound Basin

Cretaceous strata of the coastal plain sedimentary wedge once extended north across the Long Island Sound (LIS) area and covered the older bedrock for some distance into southern Connecticut (Lewis and Stone, 1991). The formation of an inner lowland floored by Paleozoic crystalline rocks was the result of stream erosion aided by multiple ice advances. These erosive forces combined to remove the inner portion of the coastal plain sedimentary wedge and re-expose the underlying crystalline bedrock.

During the glaciations, scouring of bedrock and coastal plain strata occurred, and materials dislodged from Connecticut and the evolving lowland itself were incorporated into the drift deposits associated with each ice advance. Till (unstratified material of mixed boulder to clay-sized sediment), end moraines (assorted material built up at the front of the glacier) and meltwater sediments (stratified sand and gravel) were deposited on Long Island and in the glacially modified lowland. Deposition of thick end moraines (Roanoke Point-Fishers Island- Charlestown moraine) effectively transformed the inner lowland into a closed basin.

The terminal position of the late Wisconsinan ice sheet (Fig. l) marked by the Ronkonkoma-Shinnecock-Amagansett moraine belt (Sirkin, 1982), was probably occupied at about 21,000 years ago. The ice margin subsequently retreated to a more northerly position marked by the Harbor Hill-Roanoke Point-Fishers Island-Charlestown moraine belt (Fig. 1). By about 19,000 years ago, the ice front began to recede from this inner morainal position (Stone and Borns, 1986), and deglaciation of the southernmost part of the LIS basin was initiated. Meltwater was impounded in the long, narrow basin between the moraine to the south and the retreating ice margin to the north. This resulted in the formation of glacial Lake Connecticut (Stone *et al.*, 1985). Lake Connecticut water levels were controlled by a spillway across the lowest point on the inner moraine (The Race, Fig. 1).

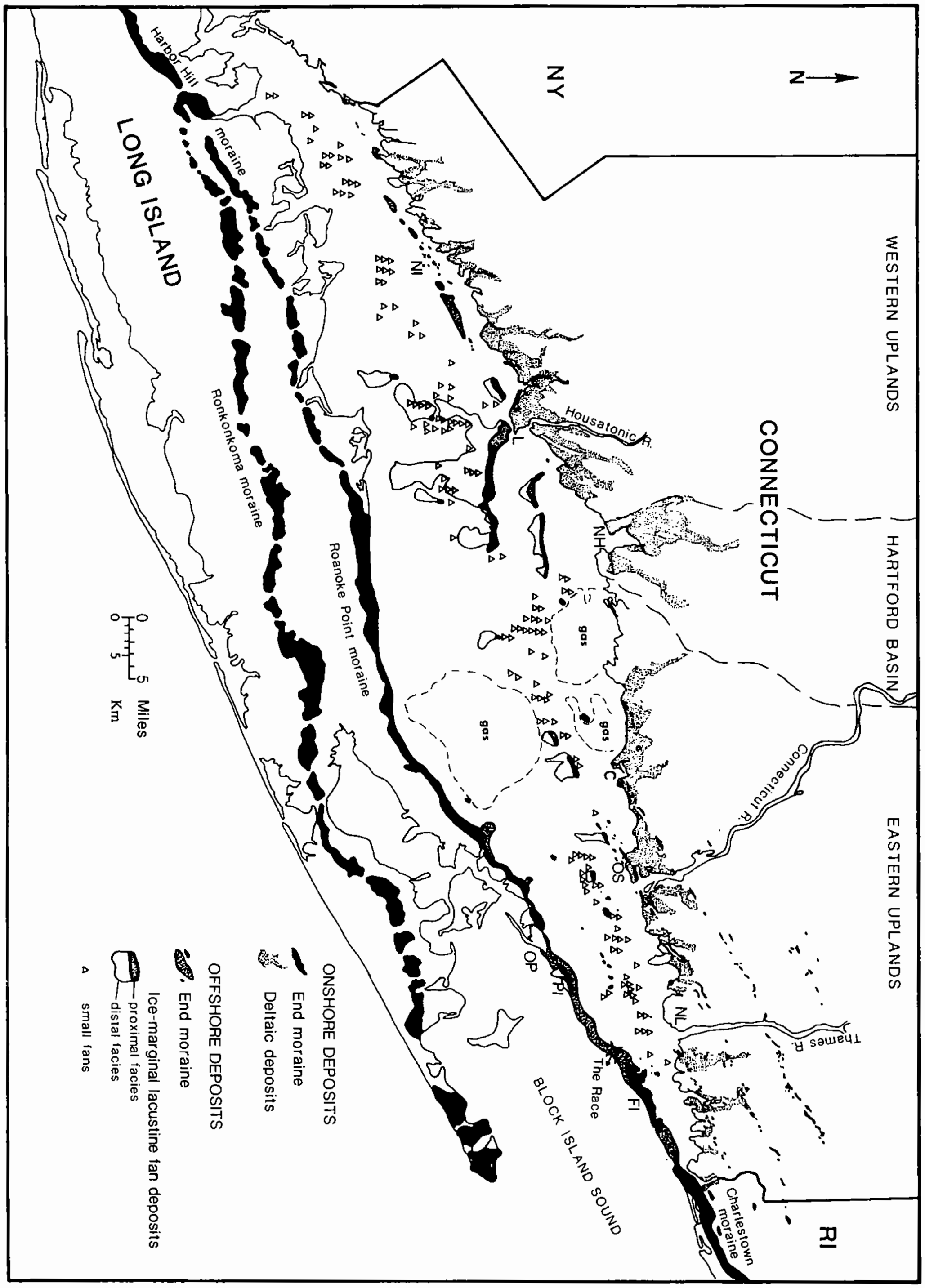

Figure 1. Map showing submerged end-moraine deposits and ice-marginal lacustrine-fan deposits of glacial Lake Connecticut (from Stone and Lewis, 1991). NI, Norwalk Islands; NH, New Haven; FI, Fishers Island.

Northward retreat of the ice margin through the LIS Basin is recorded by a series of lacustrine (lake)-fans built on the lake bottom, overlying bedrock, coastal plain sediments, or older drift (Lewis and Stone, 1991). These fans were deposited along ice-front positions by sediment-laden meltwater issuing from beneath the ice. Fans occur locally throughout the basin, but are more numerous and extensive in the wide central Sound (Fig. 1). Also interpreted as stratified meltwater deposits laid down during ice retreat in Lake Connecticut are extensive varved (seasonally layered) lake clay sediments up to 150 m thick (Fig. 2).

By about 17,600 years ago, the ice sheet had established a recessional position along the Norwalk Islands (NI, Fig. 1) (Stone and Borns, 1986). As the ice retreated out of the lake onto higher ground, meltwater flowed down bedrock valleys and built deltas into the lake near the present coastline (Fig. 2). Deltas built in front of the mouth of the Connecticut River indicate that lake levels had lowered only a few meters from the initial spillway altitude by the time of this deposition (Lewis and Stone, 1991).

As deglaciation progressed, the topography of the Central Lowland (Hartford Basin) (Fig. 2), produced a lobe of ice extending southward from New Haven that lingered the longest in the lake. As this ice lobe retreated out of the lake, a complex of deltas was built in the Milford-New Haven area. The lake had lowered about 10 m by this time. These deltas are extensive both on land and offshore (Fig. 2). It is clear from continuous internal reflectors indicating stratigraphic equivalence that in the deep central basin much of the varved lake-clay sediments settled out in the lake concurrently with the Milford-New Haven area delta building (Lewis and Stone, 1991).

A much thinner section of varved lake clay overlies the section that is stratigraphically equivalent to the New Haven deltas and provides evidence that the lake continued to exist as the ice margin retreated northward (Lewis and Stone, 1991). During this time, the level of glacial Lake Connecticut continued to lower due to erosion at the spillway. As shoreward portions of the lakebed were subaerially exposed, streams locally entrenched older, higher-level delta deposits and redeposited coarser material farther out into the lake basin. The gradually shrinking glacial lake may have lasted another 1,000 years. By about 15,500 years ago, the lake was completely drained and the lakebed was subaerially exposed. A channel system associated with on-land streams, which developed on the lakebed as the lake drained, exited the basin through the former spillway notch at The Race.

Incision of the drained Lake Connecticut lakebed by the channel system took place before relative sea level reached sufficient height to enter the basin. A rising base level produced by encroachment of the sea caused fluvial aggradation in the channels. Fluvial deposition was followed by estuarine deposition as marine waters entered the basin via the channel system. Continued sea-level rise caused the estuaries to migrate up the channel system; the transgressing surf zone followed. Wave action planed across the estuarine deposits and the surrounding, higher-lying lakebed initiating the formation of a time-transgressive wave-cut unconformity. The postglacial marine transgression entered the LIS basin as soon as relative sea level reached the altitude of The Race notch, possibly as early as 15,000 years ago.

Slightly earlier, about 16,000 years ago, glacial Lake Hitchcock began to occupy the upper Connecticut River valley and was an efficient sediment trap for the largest drainage system entering the LIS Basin (Stone and Ashley, 1992). The initiation of upward land movement (glacio-isostatic rebound) in response to "unloading" caused by the removal of the weight of the retreating ice from southern New England may have been the impetus for the draining of glacial Lake Hitchcock. Stone and Ashley (1992) argue that the lake-draining began about 14,000 years ago. As Lake Hitchcock drained, more and more of the lakebed was progressively exposed, and a very large amount of sediment became available to the developing Connecticut River. This lakebed material was eroded and supplied to the LIS basin. Over the course of approximately 1,500 years, an extensive, progradational, marine delta and associated finer-grained distal sediments essentially filled the broad central part of the evolving estuary (Lewis and Stone, 1991). Eventually, with continued

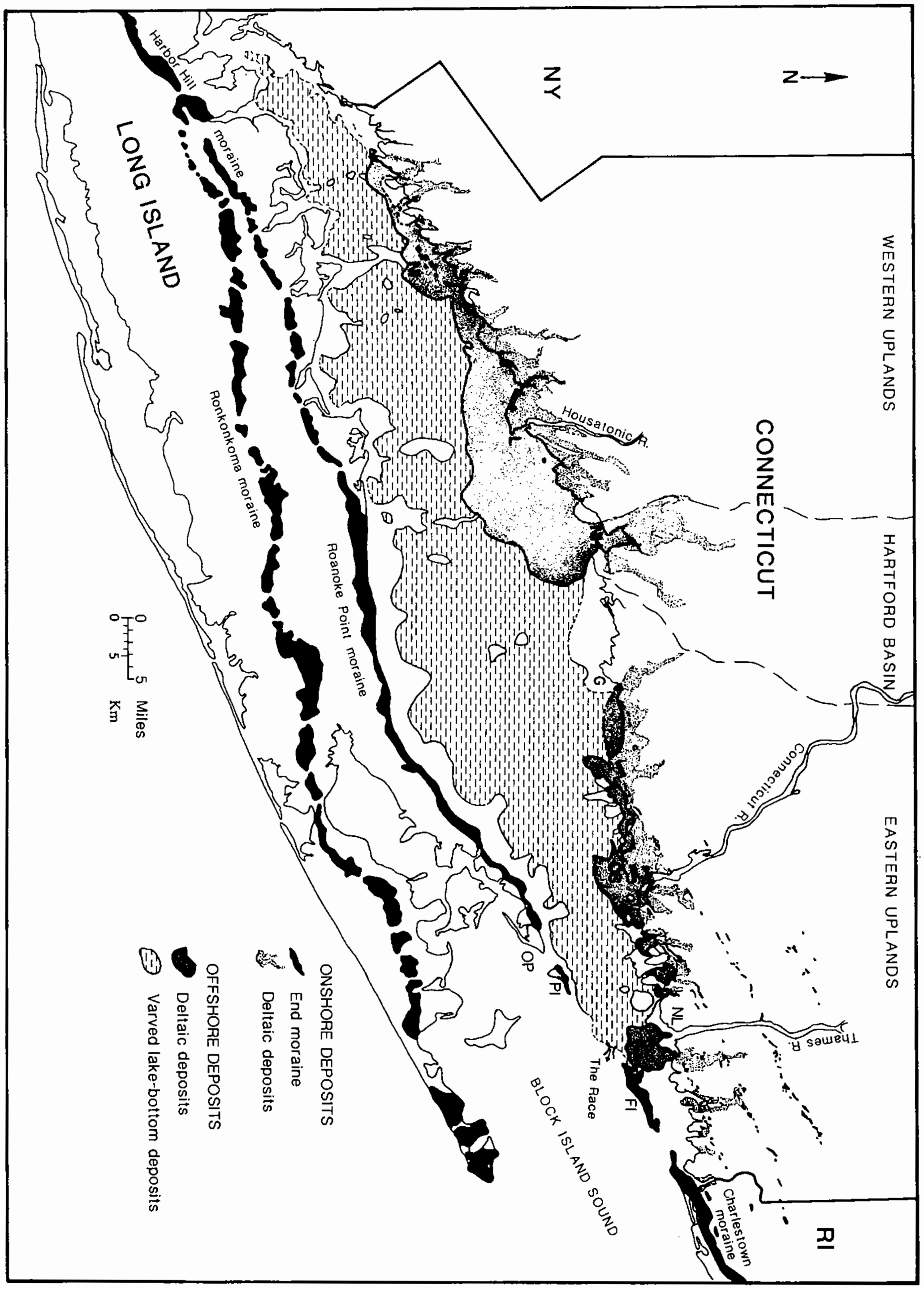

Figure 2. Map showing deltaic and varved lake-clay deposits of glacial Lake Connecticut (from Lewis and Stone, 1991).

relative sea-level rise, sediment supply from the Connecticut River lessened and became finer grained. Laminated fine-grained marine sediments were laid down onlapping the marine delta and record complexities in the continuing marine transgression.

As the tides extended their reach throughout the basin, typical marine processes prevailed. Finer-grained sediments began to accumulate in quiet-water areas, and tidal currents began to reshape the configuration of constricted high-energy areas. Tidal currents eventually began to dominate the patterns of erosion, reworking and sedimentation in the eastern Sound. Since then, extensive erosion and reworking of Pleistocene and lower Holocene deposits has occurred. The LIS basin is still adjusting to its new role as an arm of the rising sea.

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Post-Glacial Stratigraphy and Rates of Sediment Accumulation in Three Eastern Connecticut Coves

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Introduction

The sedimentary stratigraphy of three coves in eastern Connecticut was examined to: (1) describe the post-glacial geomorphic evolution of these nearshore areas in relation to the geologic history of the greater Long Island Sound basin as it is currently understood, and (2) analyze the depositional history of the coves, particularly with respect to the widely-held belief that railroad causeway constrictions along the coves have greatly increased sedimentation rates in the last 130 years.

The three coves — Mumford Cove in Groton, Quiambaug Cove in Stonington, and Wequetequock Cove in Stonington — are all narrow, elongate embayments along the relatively sheltered coastline of Fisher's Island Sound. The coves are bordered by glacio-deltaic and glacio-fluvial deposits (Stone *et al.*, 1985) and the axes of the coves occupy the position of meltwater streams that drained the Wisconsin glacier as it retreated.

The drainage basins of the major tributaries to the coves range from 11 km^2 (Mumford) to 31 km^2 (Wequetequock). During the 1860s railroad bridges in the eastern coastal area previously supported by pilings were converted to riprap causeways with greatly reduced tidal openings. The three coves studied were chosen in part because of the differing potential for impact from the causeways: Wequetequock is bisected by a causeway, Quiambaug is impacted by both a railroad causeway and a similar constriction from a roadway bridge, and Mumford is without man-made constrictions.

A total of 29 vibracores, up to 8 meters in length, were taken from the open water and fringing salt marshes of the three coves. The stratigraphy of the cores was described, and selected samples were analyzed for total organic content (loss on ignition), water content, and concentration of certain heavy metals. Radiometric dating of selected horizons is in progress; to date, seven Carbon-14 (^{14}C) samples and one Lead-210 (^{210}Pb) sample have been analyzed.

Post-Glacial History

The cores show a fairly consistent succession of stratigraphic facies, which can be divided into lower and upper units representing two distinct depositional environments separated by an erosional unconformity.

The lower unit shows an oxidized, coarsening upward sequence from laminated silt and clay, to well-sorted sand, to coarse-grained sand and gravel, overlain in some cases by a weathered soil profile. This sequence is interpreted as follows. Fine-grained deltaic sediment deposited into glacial Lake Connecticut during deglaciation was overlain by well-sorted glacio-fluvial sediment prograding over the delta plain. This deltaic sequence was incised by streams during the draining of the lake to form narrow stream valleys with gravel-bed channels and flanking stream terraces. This interpretation of the cove stratigraphy is consistent with the geologic history of the greater Long Island Sound basin as inferred from seismic reflection profiles (Lewis and Stone, 1991).

Above this late Pleistocene/early Holocene sequence there is an abrupt change to an upper unit consisting of sediments deposited under reducing (marine) conditions. This unconformity is marked by a layer of gray, reworked gravel. A peat layer of varying cohesiveness commonly lies above the gravel, followed by up to 5 meters of organic-rich, fine-grained gray to black marine mud.

The gravel layer is interpreted as a lag deposit laid down during the high-energy environment accompanying the marine transgression of the LIS basin; this sequence is consistent with interpretations of similar facies in borings in the Narragansett Bay area (Peck and McMaster, 1991). ^{14}C dates from the overlying peat layer in a series of Quiambaug Cove cores show a progression of the marine inundation up the cove axes, with the onset of marine mud deposition at about 5,000 years before present (BP) at the mouth, 3,900 years BP at the center, and only 1,700 years BP at the modern cove head. The marine mud layer, which in each cove forms a wedge that thickens toward the cove mouth, represents a long history of low-energy deposition virtually unchanged from the marine transgression to the present

Rates of Sediment Accumulation

Long term sediment accumulation rates for the marine mud were estimated by using the radiocarbon-determined ages of the basal peat section as the beginning date for deposition. Three different compaction scenarios used to calculate the length of the sediment column had little effect on the accumulation rates. Seven ^{14}C samples analyzed to date result in accumulation rates ranging from 0.3 to 1.6 millimeters per year (mm/yr), with an average of 1.1 mm/yr. This rate is very similar to estimates made for Long Island Sound (Kim and Bokuniewicz, 1991; Benoit *et al.*, 1979) and Narragansett Bay (Peck and McMaster, 1991).

Historic accumulation rates remain problematic. No recognizable horizons (such as a sand layer from the 1938 hurricane) were discovered that would allow an unambiguous estimate of recent rates; however, limited ^{210}Pb dating and metals concentration data have been collected. To date, the one ^{210}Pb sample analyzed (Quiambaug Cove) shows an excess ^{210}Pb profile that equates to a sediment accumulation rate of about 3.5 mm/yr for the last 70-80 years. Age dating by the ^{210}Pb method can be misleading where significant bioturbation occurs (Benniger *et al.*, 1975). However, x-ray and CAT-scan images of the core showed no evidence of biological disturbance, and present day conditions in the coves are characterized by sparse benthic fauna (Crawford, personal communication).

Analyses of 32 metals were done for the ^{210}Pb core. The concentrations of lead, copper, and zinc showed sharp decreases at a depth of about 30 cm. Similar profiles have been interpreted by others (Varekamp, 1991) as being indicative of anthropogenic pollution. Using the 3.5 mm/yr accumulation rate determined for the same core by ^{210}Pb analysis, the 30 cm depth equates to an onset of such pollution at about 100 years ago, which is in general agreement with Varekamp's estimate for the Connecticut River area.

Discussion

There is not enough evidence at this point to distinguish between long and short term sediment accumulation rates. We plan additional ^{210}Pb dates and metals profiles. In addition, ^{14}C dates from organic material positioned within the middle of the marine mud sequence will provide intermediate ages that may help to define any inflection point in the rate of marine mud accumulation.

It is interesting to note that the range of estimated sediment accumulation rates in the area (about 0.5 - 4.0 mm/yr) is virtually identical to the range of estimates for relative sea level rise (van de Plassche, 1989; Patton and Horne, 1991). This suggests that contrary to anecdotal evidence on the part of cove-area residents, the water depth in these coves has been relatively constant over historic time. This appears to be supported by inspection of old maritime charts of the area, which show no discernible changes in cove depths over the last 100 years. We suspect that the historic growth of large sandy flood tidal deltas due to increased current velocities induced by the causeway constrictions, which are certainly noticeable obstructions to boating, may be the source of the local perceptions about shoaling.

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Porewater Transport in Western Long Island Sound and its Relation to the Benthic Community Structure

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Western Long Island Sound sediments act as both a source and sink of dissolved constituents through the exchange of sediment porewater and bottom water. Bacterial decomposition of organic material draws down oxygen levels and regenerates nutrients such as nitrogen, phosphorous and silica. The rates of release of these materials and other dissolved constituents from the sediments is a necessary inclusion in any attempt at calculating water column mass balance, or modelling a concentration dependent process.

Transport of dissolved constituents in sediment porewater is a function of both physical mixing parameters (e.g. diffusion and advection) and chemical reactivity (e.g. redox reactions, and adsorption/desorption). In addition, both of these factors may be enhanced by biological activity in the sediments. Consequently, it is often difficult to separate the effects of physical flux parameters and chemical reactions.

The determination of physical transport parameters and the effects of biological enhancement, requires an unreactive dissolved analog. Rn-222, an inert radioactive gas produced in sediments by the decay of its parent Ra-226, is an ideal tracer of porewater transport over short time scales ($t_{1/2}$=3.85 days). Comparisons of measured Rn-222/Ra-226 disequilibrium to that caused by molecular diffusion allows the quantification of rates of biological porewater irrigation.

Hypoxia, periods of low dissolved oxygen (< 3 ppm) in the water column, has afflicted western Long Island Sound during the summer months for several years. This paper discusses the use of Rn/Ra disequilibrium in the assessment of the effects of hypoxia on benthic infaunal activity. The benthos were expected to respond to hypoxia in one of three ways: 1) ignore hypoxia and maintain high rates of bioirrigation; 2) remain alive but slow activity or go into stasis until hypoxia was relieved, reducing the rate of bioirrigation; or 3) migrate from the area or die off, thus reducing irrigation to simple molecular diffusion.

Two study sites were chosen in Western Long Island Sound. One site was located south of the Thimble Islands (41° 12' 30" N, 72° 46' 36"W), while the other station was situated at mid-Sound off Greenwich CT, (40° 57' 38"N, 73° 35' 18"W). The stations were chosen so that one, the Greenwich station, would lie within the hypoxic zone, while the other station would serve as a control for hypoxia. Temperature and Dissolved Oxygen (DO) were measured in the water with a CTD and YSI temperature/oxygen probe to determine the presence and extent of a thermocline and hypoxia.

Two sediment cores were collected from each station monthly from June 1991 through September 1991. Cores were collected with a weighted, wire-operated box core (15.2cm x 15.2cm x 51cm) which penetrated approximately 25cm into the sediments. Upon recovery of cores, inspection of the sediment surface and the clarity of bottom water trapped in the core indicated minimal interface disturbance during the coring process. The cores were sectioned in 1cm - 5cm intervals to a depth of 20cm; one-half of each section being used for Rn/Ra analysis, the other for biological assessment.

Small subsamples for porosity analysis were collected from the half of the core reserved for Rn/Ra analysis. The remainder of the section was placed in 500ml glass circulation vessels containing 100ml of seawater. Each vessel was immediately sealed with tops fitted with inlet and outlet ports, and a rubber O-ring to make an airtight seal. Sample volume was determined by displacement.

These samples were analyzed for Rn-222 by the method of Mathieu *et al.* (1988). The samples were flushed with He for one hour and shaken several times to create a slurry. Rn-222 was trapped on cold, activated charcoal tubes, then transferred to ZnS-coated Lucas cells for counting. All samples were stripped of Rn-222 and counted within 24 hours of collection. Following circulation, the samples were resealed to allow the in-growth of secular equilibrium, and reflushed to determine Ra emanation (i.e., Rn-222 production rate).

Samples reserved for biological assessment were fixed in 10% formalin. Later the samples were sieved through a 300μ screen and the residue was resuspended and preserved in ethanol and Rose Bengal. The benthic infauna were picked from the residue, identified, and enumerated under a dissecting microscope.

The temperature of the bottom water above the sediment surface ranged from 13.4°C at the Greenwich station in June to 21.7°C at the Branford station in August. The lowest DO at the Branford station was 4.2 ppm, recorded in July. DO at the Greenwich station dropped below hypoxic levels in July and reached a minimum of 2.3 ppm in August. Sediment porosity (cm^3 H_2O per 100 cm^3 bulk sediment) showed little variation with depth and averaged 30%. This allowed for the inclusion of constant porosity in the radon transport model.

At the Greenwich station, Rn-222 activity profiles showed subsurface minima at depths ranging from 2.5cm to 12cm. At depths below the subsurface minimum Rn-222 activity reaches an asymptotic value of 85 dpm/l. No such asymptote is reached at the Branford station where the injection depth is at or near the bottom of the core. Radioequilibrium with Ra-226 is not reached at either station. The disequilibrium may be the result of an analytical artifact created by slurrying the samples. (Slurrying the samples alters the radio-decay recoil (distance and direction that the daughter atom follows after decay of the parent) geometry of the sediments.) In a slurry jar more Rn-222 atoms will enter the porewater rather than recoiling into the crystalline structure of adjacent sediment grains (Key *et al.*, 1979). The Rn-222 flux was calculated for each core from the measured Rn-222 deficiencies. At both stations the lowest flux values were found in August (0.46 dpm/cm^2 at Branford; 0.09 dpm/cm^2 at Greenwich) and the highest values were recorded in September (0.68 dpm/cm^2 and 0.60 dpm/cm^2 at Branford and Greenwich respectively).

The benthic community comprised three major groups: annelids, bivalves, and crustaceans. At all times of the season annelids dominated the benthos of the Branford station. The majority of the infauna was contained in the top 8 cm of sediment with the exception of large chaetopterid polychaetes whose thick parchment tubes extended to depths between 15cm - 20cm. Infaunal density decreased from 5.14 indiv/cm^3 in June to 1.36 indiv/cm^3 in August, then increasing again in September to 6.28 indiv/cm^3. In addition, no chaetopterids were collected during the August sampling period.

The benthic infauna at the Greenwich station was composed almost entirely of annelids and bivalves. Overall infaunal density showed a pattern of decline and recovery similar to the Branford station, from 4.8 indiv/cm^3 in June to 0.75 indiv/cm^3 in August. In June and September annelids dominated the benthos. Infaunal depth distributions show the greatest number of animals at the sediment surface between 0-1cm then decreasing exponentially to 8 cm. The July and August sampling periods, when hypoxic conditions prevailed, are marked by a shift in dominance towards the bivalves. The benthos of the August core is composed almost entirely of bivalves. A small peak in animal density is present 1cm lower in the sediment than during oxic periods, with the animals still limited to the top 8 cm of sediment.

In order to quantify the biodiffusion and bioadvection parameters, the model constructed by Benoit *et al.* (1991) was fit to the Rn-222 data. The model,

$$0 = \frac{dC_1}{dt} = D_b \frac{d^2C_1}{dz^2} + \omega \frac{dC_1}{dz} - \lambda C_1 + \lambda C_{eq} \quad (1)$$

$$0 = \frac{dC_2}{dt} = D_s \frac{d^2C_2}{dz^2} - \lambda C_2 + \lambda C_{eq} \quad (2)$$

where
C_1 = Rn-222 concentration in the upper layer
C_2 = Rn-222 concentration in the lower layer
C_{eq} = equilibrium Rn-222 concentration
D_b = enhanced biodiffusion coefficient
D_s = corrected molecular diffusion of Rn-222 in sediments
ω = bioadvection velocity
λ = Rn-222 decay constant
z = depth

utilizes the diagenetic equation and is broken into two boxes. l) the upper layer (eq. l) - in which porewater irrigation is controlled by both the random movement of biodiffusive organisms (D_b) and the unidirectional pumping of bioadvective tube-dwellers (ω). The bottom boundary of the upper layer is demarked by a subsurface Rn-222 minimum. The minimum indicates the level at which low Rn-222 activity seawater is injected at depth when sedentary polychaetes irrigate their tubes. 2) the lower layer - below the subsurface minimum is characterized by little or no infauna. The only porewater transport mechanism in this layer therefore is molecular diffusion (D_s).

Model estimates of enhanced diffusion ranged from lX-8X greater than the corrected molecular diffusion rate of Rn-222 in sediments at the Greenwich station; while the range at the Branford station was 3X-25X. Both stations displayed the same pattern of low values of D_b in June and August and high values in July and September.

Bioadvection velocities calculated for the Branford station were greater than those calculated at Greenwich by nearly an order of magnitude. Branford values ranged from 2.57 cm/day to 0.51 cm/day and the Greenwich station varied from 0.95 cm/day to 0.02 cm/day. Bioadvection varied in a pattern similar to the biodiffusion at the Branford, high in July and September and low in June and August. However, the same relationship was not observed at Greenwich. At the hypoxic station calculated bioadvection velocities decreased steadily through August, then rose to its highest value in September.

The presence of the large chaetopterids and tubes at Branford makes the relation between the transport parameters and total infaunal less clear. In August when the benthic organisms were less abundant and no chaetopterids were found, D_b and ω were also at their lowest. However, in July when the second smallest population size occurred, D_b and ω peaked. It was in July that the only intact chaetopteride was collected. During June and September cores were collected containing tubes occupied by commensal crabs with only pieces of chaetopterids.

The data reveal a relationship between the transport parameters and the size of the benthic community. At the Greenwich station there is a clear trend in which both biodiffusion and bioadvection increase linearly with the population size, except for the sample with the largest population size. This sample was collected in June when the water temperature was only 13°C. The water temperature during all other collection periods was 19°C or warmer. Although the six degree difference in temperature should have a negligible effect on the molecular diffusion rate, it could

BENTHIC COMMUNITY STRUCTURE
GREENWICH STATION

Figure 1

Figure 1A

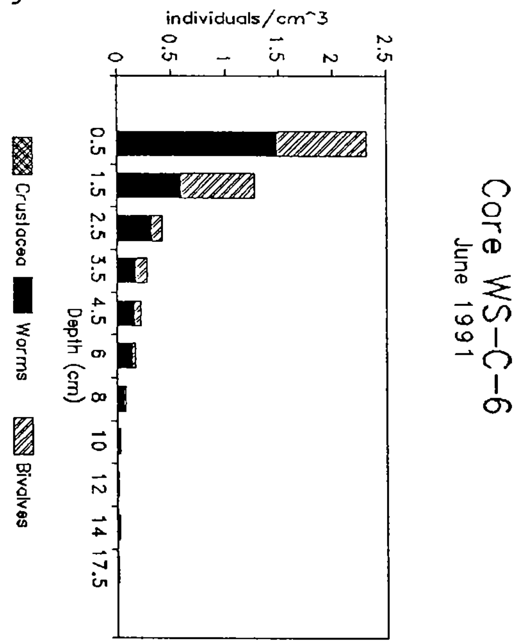

Figure 1B

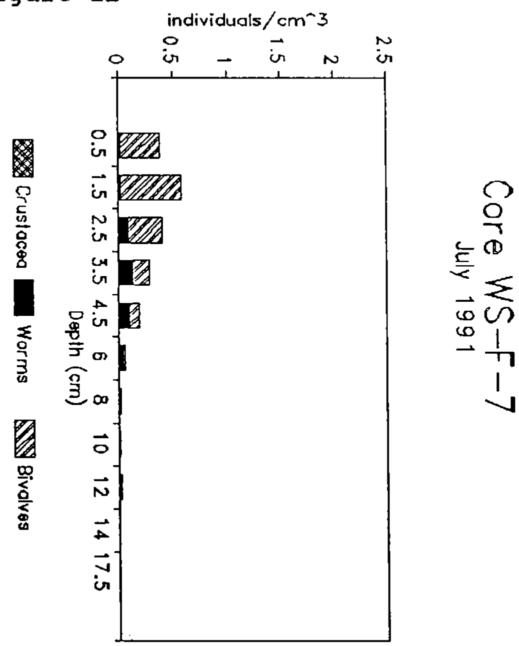

Figure 1C

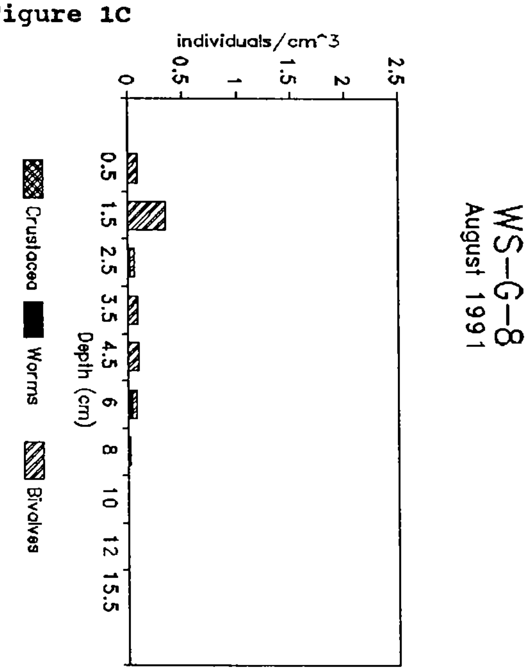

Figure 1D

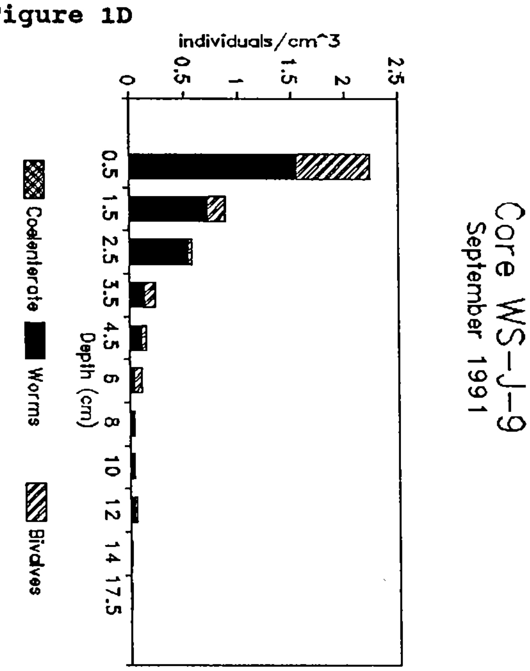

Figure 1 - Changes in the benthic community structure (indiv/cm^3 vs. depth cm) can be seen throughout the summer season for a station within the hypoxic zone. Beginning in June (la) annelid worms dominate the benthos. As hypoxia sets in in July and August (lb & lc) the annelids are reduced to almost zero leaving only the bivalves. Post-hypoxia in September is marked by a return of the annelids.

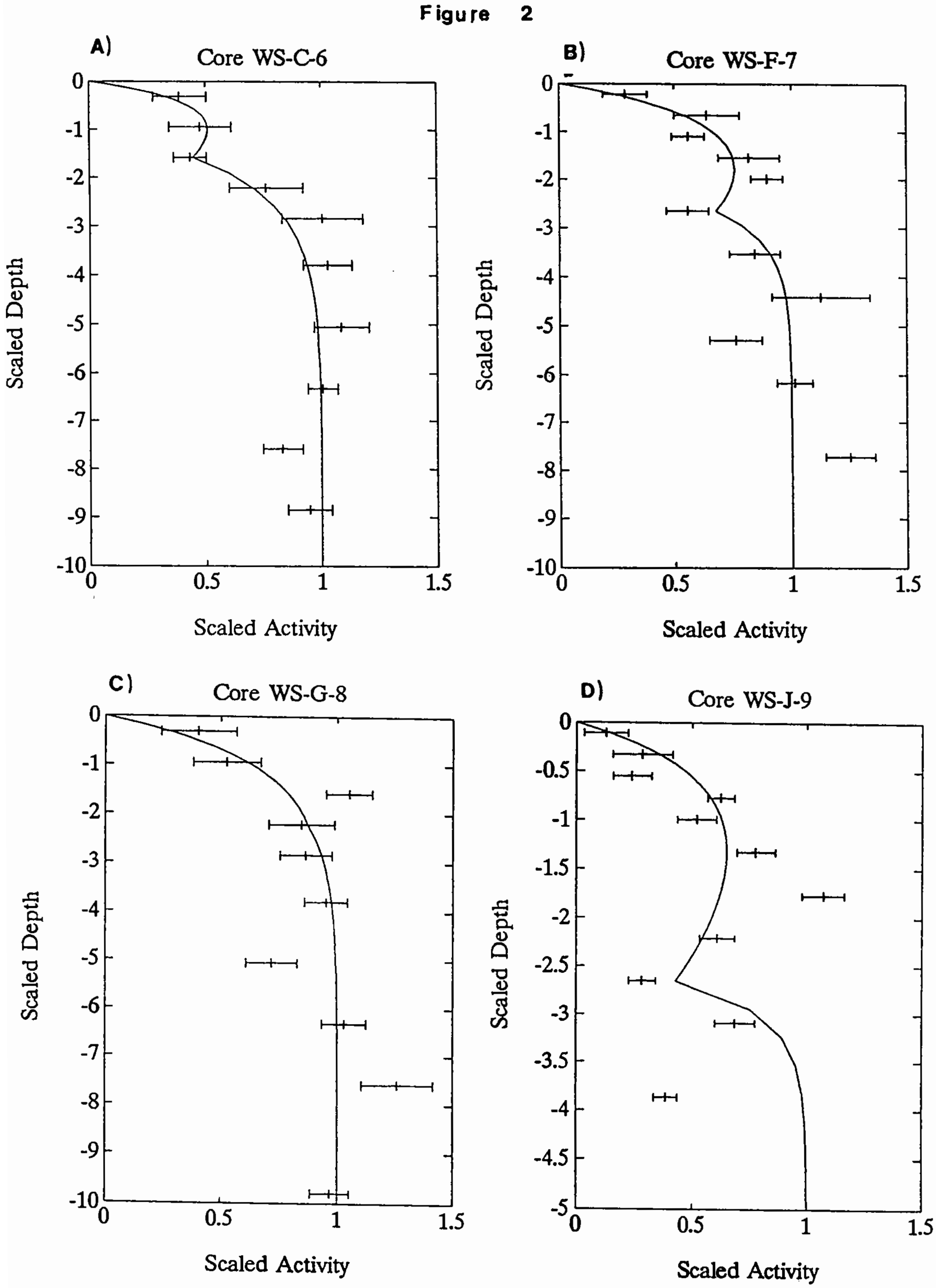

Figure 2 - Obs. Rn-222 activity (error bars) and model generated profiles (solid lines) for four sediment cores collected at the Greenwich station from June 1991 (2a) through September 1991 (2d). The depth axis is scaled to the injection depth and the activity axis scaled to the equilibrium production value. The location of the Rn-222 minima can be related to the bottom of the irrigation tubes.

affect the activity of the benthic infauna. Even though there is a large extant population in June, infaunal motility and burrowing activity may be decreased due to the cold temperature.

Assuming that polychaetes act primarily as bioadvectors, and bivalves as biodiffusers, then the depth of the subsurface Rn-222 minima can be related to the vertical location of polychaetes in the core. In core WS-C-6 (Fig. la) the majority of the polychaetes were found in the top three sections of the core at a depth of 2.5 cm, the same depth as the Rn-222 minimum (Fig. 2a). In the July core WS-F-7 (Fig. lb) polychaetes thin out and disappear from the upper sections, shifting the peak range from 0-2.5 cm to 3.5-6 cm. The Rn-222 minimum also shifts to 6cm and is of a smaller magnitude. Finally in August when the polychaetes all but disappear and only a few bivalves remain (Core WS-G-8, Fig. lc), no Rn-222 minimum (Fig. 2c) is observed resulting in a profile similar to molecular diffusion.

Hypoxia in Western Long Island Sound reduces the number and changes the species composition of the benthos. As DO decreases animals less adapted (polychaetes) either migrate out of the area or die off, leaving the bivalves which are able to close up and wait for reoxygenation. Changes in the benthos are reflected in Rn/Ra disequilibrium which can be quantified in terms of biodiffusion and bioadvection parameters.

Acknowledgments

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Atmospheric Deposition to Long Island Sound

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Introduction

In 1985, the U.S. Environmental Protection Agency funded research, monitoring, and the assessment of water quality for the Long Island Sound (LIS). The ultimate purpose of the study was to implement a comprehensive conservation and management plan for LIS (Long Island Sound Study, 1990). One area that has received special attention is the low dissolved oxygen levels (hypoxia) that has impacted the western half of LIS. The LIS Study has determined that excess nitrogen loading is the major contributor to hypoxia and that atmospheric deposition is one of the sources. The goal of this study was to determine the nutrient loading to the surface of LIS. This was accomplished by setting up two wet and dry deposition monitoring sites along LIS and measuring the deposition of sulfur, phosphorus and nitrogen.

Site Description and Instrumentation

The first site is located at the Sherwood Island State Park in Westport. The monitoring tower and instrumentation are situated in a grassy area about 100 meters from the Sound. The second site is at the Hammonasset State Park in Madison. The tower and instrument shelter lie about 500 meters from the Sound, surrounded by small shrubs and marsh grasses.

There are three components to the monitoring site. These include a wet deposition collector, two filterpacks to monitor the dry deposition, and meteorological instruments to determine the dry deposition velocity. A wetness sensor on the wet deposition collector insures that the bucket is exposed only during precipitation.

Two three-stage filterpacks are used to collect the dry deposition samples. The first filterpack contains a Teflon®, nylon and treated cellulose filter. These filters are analyzed for sulfate, nitrate, ammonium, sulfur dioxide and nitric acid vapor. The second filterpack contains a Teflon® filter to collect particulate phosphate. Both filterpacks are maintained at a flow rate of 3 liters/minute.

Various meteorological instruments are employed on a 10- meter antenna tower. Wind speed, wind direction, temperature, humidity, net radiation, precipitation, and surface wetness are monitored every 10 seconds and output into 1-hour averages and statistical quantities. These values are input into a dry deposition inferential model to estimate deposition velocities. Deposition velocities are multiplied by the atmospheric deposition to determine the dry deposition flux.

Analysis

Analysis of the following chemical species have been conducted: nitrate ($N0_3^-$), sulfate(SO_4^{2-}), sulfur dioxide (SO_2), ammonium (NH_4^+), nitric acid (HNO_3), total phosphorous (PO_4^{2-}) and total dissolved nitrogen (TDN). Samples are collected every Tuesday at the sites and then returned to the Environmental Research Institute (ERI) at the University of Connecticut for analysis.

For a complete guide to the laboratory procedures, refer to "Quality Assurance Plan for Measurement of Atmospheric Dry Deposition to LIS" (Miller and Nikolaidis 1992).

Deposition Velocities and Fluxes

Deposition velocity is defined as the flux divided by the pollutant concentration and expressed as cm/s. It can be thought of as the inverse of resistance to the flow of the pollutant to the surface. The total resistance is broken down into three components: 1) R_a, aerodynamic resistance, 2) R_b , laminar layer resistance and 3) R_c, the canopy or surface element resistance. All three resistances are calculated using the meteorological parameters from each site. The deposition velocity can thus be expressed by: $V_d = 1/(R_a + R_b + R_c)$

The deposition velocities are estimated using a dry deposition inferential model initially developed by Hicks *et al.*(1985). They have used this method to monitor dry deposition at 12 sites across the country since 1985 (Hicks *et al.* ,1991). The EPA has also concurrently set up a network of over 50 sites nationwide (Edgerton and Lavery, 1991). For a complete discussion of the model refer to Hicks *et al.* (1987).

The deposition flux is defined as the concentration multiplied by the deposition velocity for each chemical pollutant. The filters are retrieved on a weekly basis, thus concentration was determined as a mean weekly value. Deposition velocities were determined on an hourly basis and were averaged for the week. These two values were multiplied to calculate the flux. Wet deposition flux is determined by multiplying the concentration by the precipitation total. Both fluxes are expressed as kg/ha (except phosphorous = grams/ha).

Results and Discussion.

Monitoring of the sites began on January 28, 1991. Table 1 is the quarterly summary for the dry, wet, and total deposition for nitrogen, sulfur and phosphorous. The quarters are broken down by 13 week periods beginning on February 5, 1991. Nitrogen deposition is dominated by wet deposition at both sites, whereas for sulfur, the dry and wet values exchange dominance during two quarters. Phosphorous was almost entirely in the wet form. Because we were measuring only phosphorous particles which were generally less than two microns in diameter, it is likely that significant larger particles were being neglected in the calculation of the dry deposition.

Table 2 is a summary sheet of the data, making direct comparisons between different nutrient species for a one year (52-week) period. (Note that some of the chemical species were monitored for less than 52 weeks). All fluxes are expressed in terms of nitrogen, sulfur, or phosphorous. From table 2, it is shown that wet nitrogen contributed 66.3% and 68.0% of the total nitrogen deposition at Hammonasset and Sherwood Island respectively. HNO_3 was the major dry deposition component and nitrate the major wet component. For sulfur, 48.8% was wet deposition at Hammonasset and 57.5% was wet at Sherwood Island. For phosphorous, deposition was almost entirely dominated by the wet component. Hammonasset was 92.9% wet phosphorous and Sherwood Island was 88.2% wet phosphorous.

The dry nitrogen deposition was dominated by HNO_3 deposition because of two factors. The estimated deposition velocities of the particulate species NO_3^- and NH_4^+ were much less than that of HNO_3 and the atmospheric concentrations of NO_3^- and NH_4^- were also less than HNO_3 on average. Dry sulfur loading has a similar relationship between the particulate SO_4^{2-} and gaseous SO_2 states. In terms of sulfur, the atmospheric concentrations of sulfur dioxide were over twice that of sulfate. Considering that deposition velocities of sulfur dioxide were two to five times higher than sulfate, this results in the sulfur dioxide dry deposition greatly outweighing that of the particulate sulfate. It is well known that sulfur dioxide concentrations are higher during the winter, but due to lack of vegetation, deposition velocities are very low during the winter over terrestrial areas, resulting in generally higher summer deposition rates (Meyers *et al.* ,1991). Deposition velocities to

TABLE 1. Quarterly Deposition Summary: Nitrogen, Sulfur and Phosphorous.

Dry Deposition 1991-1992		Hammonasset			Sherwood Island		
		kg/ha	kg/ha	gr/ha	kg/ha	kg/ha	gr/ha
Qrt.	Date	NITROGEN	SULFUR	PHOSPHUR	NITROGEN	SULFUR	PHOSPHUR
1	Feb. 5	.54	2.32	.41	.67	2.16	.40
2	Apr. 30	.80	1.16	1.65	.60	1.15	1.87
3	July 30	.74	1.54	.81	.52	1.17	.77
4	Oct. 29	.97	4.82	.68	.66	2.31	.72
Total	Year	3.05	9.84	3.55	2.45	6.79	3.75

Wet Deposition 1991-1992		Hammonasset			Sherwood Island		
		kg/ha	kg/ha	gr/ha	kg/ha	kg/ha	gr/ha
Qtr.	Date	Nitrogen	Sulfur	Phosphur	Nitrogen	Sulfur	Phosphur
1	Feb. 5	.98	1.67	7.08	.82	1.97	9.26
2	Apr. 30	2.54	4.20	13.22	2.07	3.61	10.24
3	July 30	1.58	2.08	17.94	1.49	2.23	6.48
4	Oct. 29	.90	1.40	7.96	.86	1.37	1.95
Total	Year	6.00	9.36	46.20	5.24	9.18	27.93

Total Deposition 1991-1992		Hammonasset			Sherwood Island		
		kg/ha	kg/ha	gr/ha	kg/ha	kg/ha	gr/ha
Qtr.	Date	Nitrogen	Sulfur	Phosphur	Nitrogen	Sulfur	Phosphur
1	Feb. 5	1.52	3.99	7.49	1.50	4.13	9.66
2	Apr. 30	3.34	5.36	14.87	2.67	4.76	12.10
3	July 30	2.32	3.62	18.75	2.00	3.40	7.25
4	Oct. 29	1.87	6.22	8.64	1.53	3.68	2.67
Total	Year	9.06	19.20	49.75	7.69	15.98	31.68

TABLE 2. Estimated Loading to Long Island Sound for Nitrogen, Sulfur and Phosphorous

	NITROGEN LOADING (AS N)					SULFUR LOADING (AS S)			T-PHOS (AS P)	
	DRY DEPOSITION KG/HECTARE			WET KG/HECTARE		DRY (KG/HECTARE)		WET KG/H	DRY G/HEC	WET G/HEC
	HNO_3 52 WEEKS	NO_3^- 52 WEEKS	NH_4^+ 42 WEEKS	NO_3^- 52 WEEKS	NH_4^+ 38 WEEKS	SO_4^{2-} 52 WEEKS	SO_2 52 WEEKS	SO_4^{2-} 52 WEEKS	PO_4^{2-} 42 WEEKS	PO_4^{2-} 52 WEEKS
HAMMON SHERWOOD	2.65 2.12	.033 .028	.37 .31	4.38 3.70	1.63 1.53	.60 .56	9.24 6.24	9.36 9.18	3.55 3.75	46.20 27.93
% of Total HAMMON SHERWOOD	% 29.2 27.6	% .4 .4	% 4.0 4.0	% 48.3 48.1	% 18.0 19.9	% 3.1 3.5	% 48.1 39.0	% 48.8 57.5	% 7.1 11.8	% 92.9 88.2
	TOTAL NITROGEN KG/ HECTARE-YEAR					TOTAL SULFUR KG/HEC-YEAR			TOTAL T-PHOS G/HEC-YEAR	
HAMMON SHERWOOD AVERAGE	9.06 7.69 8.37					19.20 15.98 17.59			49.75 31.68 40.72	
	MULTIPLY EACH BY THE AREA OF THE SOUND (3.37 x 10^5 Hectares) TO CALCULATE TOTAL LOADING TO LONG ISLAND SOUND									
ANNUAL ESTIMATE	NITROGEN = 2821 METRIC TONNES (3103 TONS)					SULFUR= 5929 METRIC TONNES (6521 TONS)			PHOSPHOROUS= 13.7 MT (15.1 TONS)	

sea water are dependent on the mean wind speed and it appears that sulfur deposition into LIS may actually peak during the winter.

By multiplying the surface area of LIS by the average of the Sherwood Island and Hammonasset fluxes, one can estimate the atmospheric nitrogen, sulfur, and phosphorous loadings to LIS. For the first year, our study estimates the nitrogen loading to be 2821 metric tonnes. The LIS Study (1990) estimated that for 1989, 6,182 metric tonnes of nitrogen were deposited. Our study estimated sulfur deposition to be 5,929 metric tonnes/ year to LIS. Phosphorous was the nutrient least deposited to LIS. Estimated deposition was only 13.7 metric tonnes which is about 200 times less than that of nitrogen and 430 times less than that of sulfur. Plant life requires phosphorous on a scale 16 times less than that of nitrogen. It is widely assumed that nitrogen is the limiting growth factor for oceanic ecosystems as opposed to phosphorous for terrestrial regions. This study did not take into account the atmospheric deposition to the LIS watersheds. It may be wise to add an estimate from the atmospheric deposition to the LIS watershed to complete the model.

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Contaminants in the Quinnipiac River-Estuary and Other Sources Entering New Haven Harbor

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Introduction

New Haven Harbor is one of the major commercial harbors in New England and consists of approximately 8 square miles of shallow embayment north of the breakwater at Long Island Sound. The harbor is fed by the Quinnipiac, Mill, and West Rivers which drain 166, 40 and 37 square miles respectively of highly industrialized land. NOAA studies have ranked New Haven Harbor among the top 20 most contaminated of the 177 sites in its national survey of mussel tissue for PAHs and PCBs (NOAA 1989). Sediments adjacent to the mussels, however, were among the lowest in both contaminants and fine grain content of all the NOAA sites (NOAA 1988). This finding of contaminated mussels in essentially clean sand raised questions regarding the sources and modes of transport of these contaminants.

A number of studies have quantified metal contaminants in the rivers feeding New Haven Harbor, but very little data was available on PAHs, PCBs, and other organic contaminants in the sediments of these rivers. Previous studies that did include organics had sampled less than 12 sites and focused on areas of suspected high concentrations (Dunbar, 1984, Hall *et al.*, 1985)

The major objectives of our work are to characterize and quantify the organic contaminant loads contributed by these three rivers and to assess the modes of transport of the contaminants from the sources to the shellfish. We present here data on the general distribution of PAHs and PCBs in the sediments of the three rivers, including 66 samples taken over the 12 lower miles of the Quinnipiac River; 11 samples from the lower 3 miles of the West River; 16 samples taken over the lower 2 miles of Mill River and 5 from the Route 95 Quinnipiac River Bridge area.

Methods

All analyses were conducted at our state certified laboratory using the following EPA protocols: (l) extraction by sonication in CH_2C1_2 by RCRA 3550 method, (2) cleanup by florisil chromatography using RCRA 3620 method, (3) PAHs by capillary column GC (FID detection) using RCRA 8010 method, (4) PCBs by packed column GC (ECD detection) using RCRA 8080 method, (5) identity confirmation by ion trap GC-MS using RCRA 8270 method, (6) total hydrocarbon by CF_3C1_3 extraction and FTIR using EPA 413.2 method and (7) soil grain size analysis by sieves using ASTM D421 method.

A computer data base using dBase IV has been created containing sample collection details, location description, sediment type, particle size analysis data, and the quantitative and qualitative analytical results for PCB, PAH and total hydrocarbons. All sample locations have been detailed on USGS maps.

Characterization of Sediments

We found several distinct types of sediments ranging from coarse sand typical of mid-stream locations with strong currents, to mud with high fine grain content typical of the wetlands and ponds adjacent to the river. Two river-bend-sand-bar sites contained fine sand and silt typical of low current catch basins. Several areas of the Mill River have an extremely fine grain gelatinous ooze type sediment with high plasticity.

Samples of each type of sediment were sifted through a series of ASTM sieves and characterized for the % particles in the following size ranges: >600µm, 600 - 300µm, 300 - 75µm and 75 - 12µm. Results of the particle size analyses for the different sediment types is given in Table 1. The values given are the averages of a number of sites with similar sediment.

Since the sediment types differ widely in fine grain content, it is expected that the ability of these sediments to adsorb organic contaminants such as PCB and PAH, will also be markedly different. Sites were chosen so as to sample a wide variety of land use and environmental conditions. Several samples were taken from *different locations* with *similar* types of sediment with the object of distinguishing hot spots from values generally representative of widely dispersed contaminants for the given type of sediment.

Table 1. Particle Size Distribution for Various Sediments

Sediment Type	# of sites	% > 600µm	% 600-300µm	% 300-75µm	% 75-12µm
Mid stream sand	26	81.8	16.1	1.4	0.7
Riverbend siltbasin	2	37.8	20.5	15.8	25.9
River pond mud	25	26.8	14.2	30.2	28.8
Wetlands mud	16	4.7	19.3	22.3	53.7
Mill River "Jello"	9	5.9	2.9	13.5	77.7

Distribution of PAH's

Thirteen individual PAH's were individually quantified and results summed to give a total PAH concentration. PAH's were found in all samples and ranged from 0.80 ppm to 224. ppm. Results presented in Table 2A give the *average total* PAH levels (ppm) for various types of sediments. For this comparison, wetlands mud and river pond mud samples were combined in a single category. Sites that differed by more than two standard deviations from the average were not included in the average but were grouped in a separate class of *hot spots*. We believe the *average* values are typical of the levels of widely dispersed PAHs in these sediment types. As expected, the average values are higher for the fine grain sediments than for the sandy ones. The *hotspots* values probably represent sources of PAH's, although in no case did we sample an obvious spill or direct discharge site. Both sand and wetlands samples near the Upjohn Co. landfill are the highest values on the Quinnipiac River. In general, the West and Mill Rivers have considerably higher average values in all sediment types than the Quinnipiac River. The highest values found were hotspots on the Mill and West Rivers. These were actually sand/gravel sediments and not located near known NPDES sites. We find these sites hard to explain, except by postulating that they have been used as recent illegal dump sites.

Table 2A - Average and Hot Spot PAH Levels

Sediment	AVE SITES	N (ave)	HOT SPOTS	N (hot)
Q-River Sand	1.46 ± 0.2	18	5.15 ± 1.31	8
Q-RiverMud	7.66 ± 0.7	31	27.1±4.6	9
W-River Sand	19.2 ± 5.3	2	224.0	1
W-River Mud	15.3 ± 5.3	5	35.5 ± 4.0	3
M-River Sand	9.87 ± 2.4	4	50.8 ± 3.3	4
M-River "Jello"	41.8 ± 4.2	4	82.5 ± 11	4

Table 2B - Average and Hot Spot PCB Levels

Sediment	AVE SITES	N (ave)	HOT SPOTS	N (hot)
Q-River Sand0.010 ± 0.007	18	0.77 ± 0.6	8	
Q-RiverMud	0.350 ± 0 .13	22	2.71 ± 8.6	18
W-River Sand	0 nd	2	0.19	1
W-RiverMud0.06 ± 0.03	5	0.43 ± .20	3	
M-River Sand	0.51 ± 0.30	4	5.20 ± 1.9	4
M-River "Jello"	0.56 ± 0.18	4	3.05 ± .60	4

Tables 2A, 2B: Values are in ppm and are averages of samples from N sites. The ranges ± are SEMs. The detection limits were 0.1 ppm for PAH's and 0.005 ppm for PCB's.

Distribution of PCBs

Our data shows that PCB's are not as ubiquitous in the river sediments as are the PAH's. PCB's were undetected (< 0.005 ppm in 12 sandy and 10 fine grain mud sediments). Average values which exclude hot spots but include 0 for the undetected sites are given in Table 2B. Average values are considerably higher in the mud and wetlands samples than in the sandy sediments of the Quinnipiac and West Rivers. The river-bend silt deposits have a large fine grain content but show a much smaller entrapment of PCBs than they do for PAHs. The larger standard deviations of the Mill River samples indicates that there are several closely located hot spots in this river and it is more difficult to make a clear distinction between average and hotspot values.

PCB hotspots on the Quinnipiac are located in wetlands adjacent to the Upjohn Co. landfill and two river ponds just north (upstream) of Upjohn near the RT. 40 bridge. We have studied these areas in some detail, finding that the *surface* bottom sediment in the ponds is largely Aroclor 1260, whereas deeper sediments (4-12 inches) contain a mix of the lighter molecular weight PCB congeners. We have done separate PCB analyses on the different particle size fractions of these sediments and found the Aroclor 1260 largely associated with the larger particles (>600µm), which in this case are partly decayed leaves and sticks, whereas the pattern of lighter molecular weigh congeners found below the surface sediment is largely associated with the fine grain (<75µm) particles. These results suggest either: (a) that the surface Aroclor was deposited at a more recent time (different source ?) than the PCB congeners below it; or (b) that the congeners of Aroclor 1260 differ in their rates of penetrating the sediment since lighter congeners are 10^3-10^4 times more soluble than heavier ones (Makey, 1983). The fact that 75% of the surface sediment Aroclor 1260 was bound to sticks and leaves even in the presence a high (30% < 75μm) fine grain sediment argues that the Aroclor absorbs almost irreversibly to plant biomass since it did not equilibrate with the adjacent fine grain soil.

Assessment

In assessing the "hotspot" data given above it should be emphasized that at no time did we sample at a known point source such as a NPDES discharge or a known spill site. Had we done so, values 10 - 100 greater could have been measured. The "average" values given above are representative of *large areas* of river bottom or associated wetlands. The "hotspot" values given are representative of *smaller areas* of several acres in size and may be located in the vicinity (within 100 meters) of a point source. At the completion of our sampling program we intend to integrate a moving average of the contaminant levels with appropriate areas on maps to produce an estimate of the total load of these contaminants that exists in the river sediments. The distribution of the total contaminant load among sediments types will also be known and may be useful in predicting the future fates of these contaminants.

In sampling the Mill River, and the confluence of the Mill and Quinnipiac Rivers (at Rte. 95), we repeated the six locations studied by Hall and coworkers (1985). These workers reported PCB's were *undetected* at five of the six locations and a level of 0.20 ppm at one location. In our hands in 1992, PCBs were found at all six locations and range from 0.25 to 3.5 ppm. It would therefore appear that PCB contamination in this area has increased. In addition, we have sampled at 5 points in a transect under the Rte. 95 bridge at the confluence of the rivers and New Haven Harbor. These samples show that both PCB and PAH contamination decrease west to east and correlate with the content of black "jello" sediment typical of the lower Mill River. These analyses may be relevant to future dredging operations in this area.

Current and Future Work

The measurement of sediment contaminant levels as we have reported here is the first step in assessing the putative detrimental effects of sediment contamination. The *bioavailability* of contaminants vary enormously with the types of sediment and depends on such physical properties as equilibrium partitioning, pore water concentrations and adsorption-desorption rates (Adams *et al.*, 1992). To begin addressing questions of contaminant transport, we have begun measuring PAH and PCB levels of plankton in the Quinnipiac River. Adsorption/desorption studies on the sediments we have collected are also planned.

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Biological Nutrient Removal During Cold Weather: the Key to Long Island Sound Water Quality Improvements

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The control of nutrients, particularly nitrogen, into Long Island Sound, is a key environmental factor in preserving the Sound's water quality and preventing the detrimental effects of hypoxia on its ecosystem. In a project applicable to all Wastewater Treatment Plants along the Sound, the city of Norwalk, Connecticut has developed an aggressive biological treatment program to reduce its nitrogen contribution to the coastal ecosystem from the city's 15 million gallons per day wastewater treatment plant.

Norwalk first determined the best method of biological nutrient removal (BNR) for the cold-weather climate of the Northeast, since previously BNR has been applied only in warm-weather areas. A first-of-its-kind demonstration project was designed, comprised of four pilot plants each with different total nitrogen removal efficiencies. Installed and operated under simultaneous conditions at the Norwalk Wastewater Treatment Plant for over a year, the treatment processes studied included:

- Sequencing anoxic/oxic reactors (turning aeration on, then off in a portion of the aeration tank)
- Anoxic/oxic reactor retrofit into the existing plant
- Anaerobic/anoxic/oxic process
- Five-stage Bardenpho process
- Downflow denitrification filters

This project concluded that BNR is effective for controlling nutrient discharges from Wastewater Treatment Plants on the Connecticut, New York, and Northeast coast, under a variety of temperatures and process operating scenarios. Although application of these processes must be based on site-specific conditions, the study has provided data to support the detailed engineering design of BNR facilities in colder climates.

The program's greater significance is its role in developing BNR processes with general applicability to all secondary facilities operating under cold weather temperature conditions, similar to the northeastern United States. In fact, the pilot plant results will be used as a model for nitrogen removal performance and estimated construction costs for upgrading 21 treatment plants which now discharge effluent into Long Island Sound. This project earned First Prize in the New York Association of Consulting Engineer's 1991 Excellence in Engineering competition, and First Place for Community Relations programming in the New York International Association of Business Communicators 1992 awards program.

Hydrodynamics and Sediment Transport

Fine Grained Sediment Transport in Long Island Sound: Transport Modeling Considerations

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Abstract

In the classic view, sediment transport is the result of material eroded by flow-induced shear stress from an in-place, semi-consolidated bed. Quantitative estimates of mass flux are typically based on field flow and laboratory sediment measurements. Low energy flow and/or bulk sediment properties favoring resistance to erosion are generally assumed to be conditions representative of negligible transport. Field observations at a number of locations in Long Island Sound indicate that this view is overly simplistic. In many areas mass transport in the vicinity of the sediment-water interface is dominated by the alternate resuspension and settling of an assemblage of loosely aggregated organic and inorganic materials often referred to as "fluff". Time series observations using bottom mounted instrument arrays provide clear indication of the dominance of these processes over a wide variety of hydrodynamic conditions. Erosion of the underlying sediment column is limited to periods of extreme boundary shear stress seldom observed in water depths exceeding 15 to 20m. Even this limited erosion can be further reduced during periods of benthic biological activity. Fluff displacements directly affect contaminant transport, both to and from the sediment column, modify local sedimentation rates, and alter interfacial hydrodynamics. Despite its importance, however, the mobile resuspension layer is often neglected in the specification of system sediment transport characteristics and usually excluded from the governing algorithms used in the numerical modeling of mass and contaminant transport in the Sound and similar estuarine systems. A more comprehensive physical view of the estuarine transport system is recommended.

Introduction

In the classic view, transport of either cohesive or non-cohesive sediments is the result of material erosion by flo- induced shear stress from an in-place, semi-consolidated bed. A progressive increase in velocity and associated boundary shear stress above some threshold value is expected to result in progressive erosion. Alternatively, a decrease in shear stress should favor deposition. The mass of material displaced is typically estimated using an empirical formula relating boundary shear stress to erosion rate. The majority of these formulations are based on laboratory empirical data and require specification of the physical, and, in some cases, the chemical, characteristics of the upper layers of the sediment column. These latter data are usually obtained by laboratory analysis of field samples.

In the case of cohesive sediments, the variations in sediment characteristics have resulted in erosion rate formulae that display a variety of forms (e.g. Krone, 1962; Parthenaides, 1965; Fukuda and Lick, 1980; and Mehta, 1986). Although applied in several numerical modeling studies, none of these formulae has been rigorously verified through field observation. An early effort by Lavelle, *et al.* (1984) yielded in-situ erosion rates similar to those observed in the laboratory studies but raised questions concerning transport at low shear stresses. A replot of some of the Lavelle data shows relatively minor resuspension over a wide range in velocity. A progressive increase in suspended material concentrations, presumed to be indicative of interfacial erosion, is associated with velocities in excess of 30 cm/sec (Figure 1). The data suggest that significant amounts of sediment may be transported prior to any measurable erosion of the underlying sediment column.

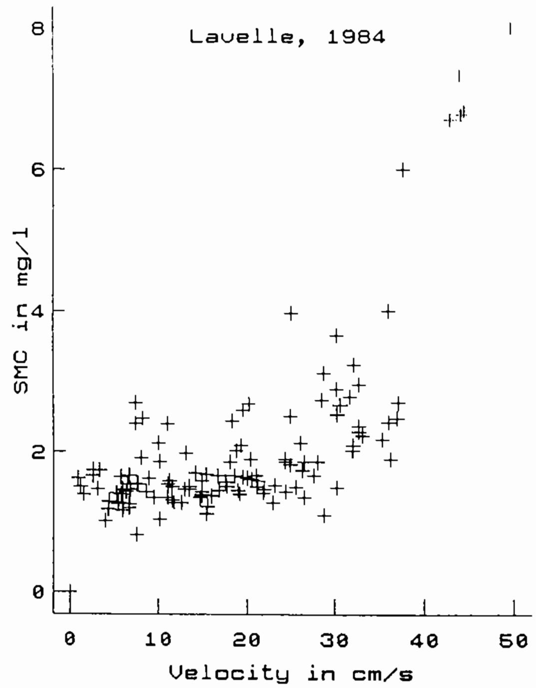


Figure 1: Suspended material concentrations and concurrent speed. From Lavelle, *et.al.*, 1984.

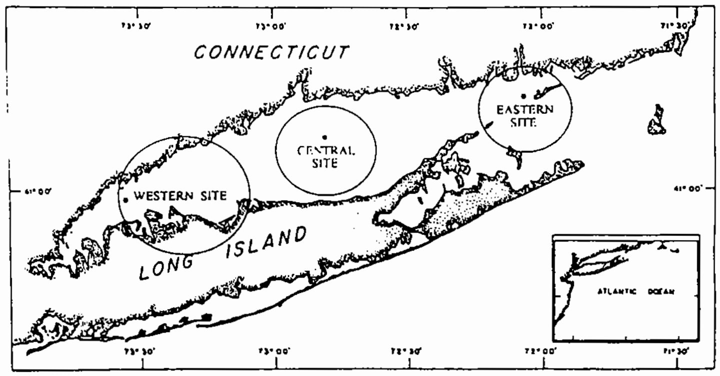
To examine the extent to which the results of Lavelle *et al.* (1984) are applicable to Long Island Sound, in-situ data obtained during a series of investigations over the past ten years have been reviewed. The following provides a summary of the results of this review.

Methods and Procedures

Since 1980, time series observations of near-bottom suspended material concentrations and concurrent hydrographic conditions have been obtained at selected sites in western, central and eastern Long Island Sound. These data were obtained using bottom-mounted arrays of instruments deployed for varying periods of time ranging from weeks to years. The typical array was free-standing and self-contained and included several optical sensors (red-light transmissometers and/or back-scattering probes) to monitor suspended material concentrations, water temperature and salinity sensors, and a two-axis electromagnetic current meter. All units were positioned to sample conditions approximately 1m above the bottom. Systems were usually programmed to burst sample all instruments four (4) times each hour for periods of approximately 90 sec. Data were internally recorded in digital format and retrieved for subsequent analysis during periodic servicing. A more detailed description of these arrays, including calibration procedures, is provided in Bohlen (1982).

Results and Conclusions

Array observations in the western Sound at a site in approximately 20m of water south of Greenwich, Connecticut (Figure 2) show evident variations in near-bottom suspended material concentrations during each tidal cycle. Typical concentrations during the observation period in 1986-1987 varied between 4 and 10mg/l with values displaying only limited seasonality. In contrast to the classic view, concentrations at 1m above the bed decreased with increasing velocity. Maximum concentrations occurred at minimum velocities, indicative of progressive settling of materials initially dispersed upwards from a reservoir along the sediment-water interface. The dominance of this alternate resuspension and deposition results in a functional dependence between velocity and material concentrations that stands in marked contrast to that of Lavelle, *et al.* (1984) (Figure 3).



LONG ISLAND SOUND – STUDY AREA

Figure 2: Long Island Sound showing locations of instrument array deployments, 1980-1990.

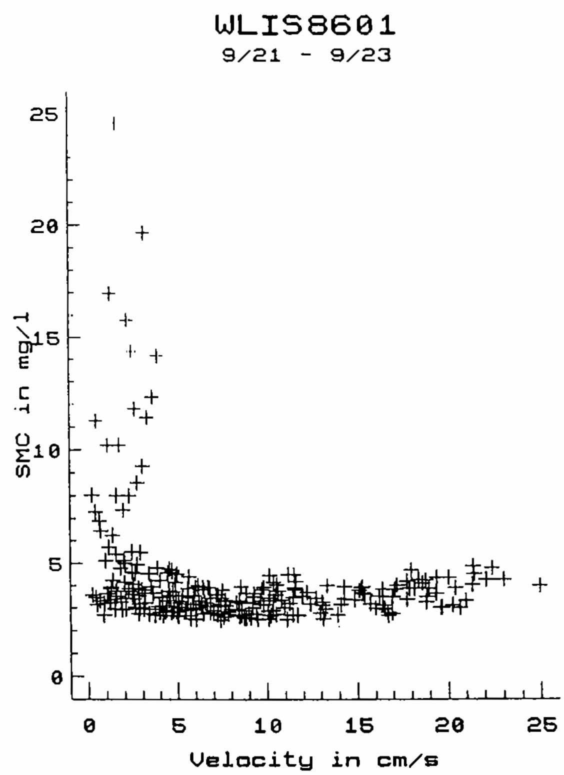


Figure 3: Suspended material concentrations and concurrent speed at a site in western Long Island Sound.

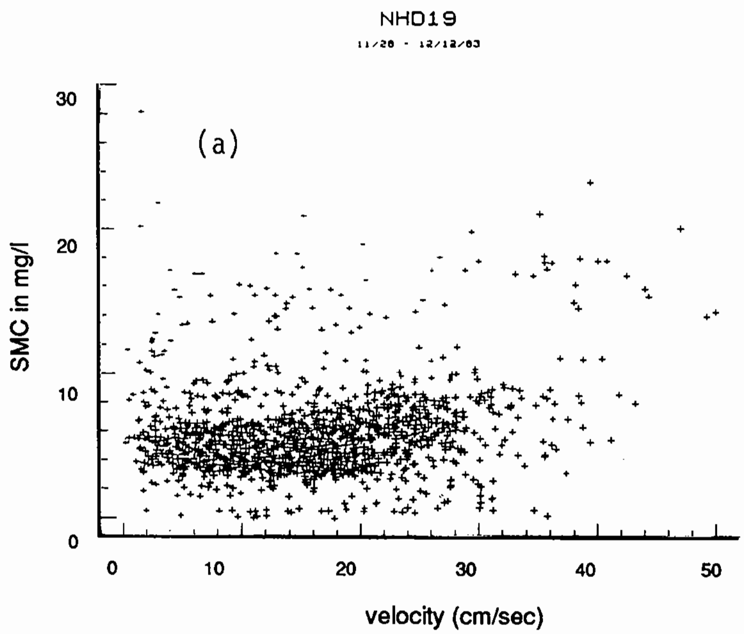
Moving to the central Sound, at a site in 20m of water approximately 10km south and east of New Haven (Figure 2), near-bottom concentrations again display a progressive variation over each tidal cycle with values ranging from 5 to 10mg/l during a yearlong series of observations in 1984. In contrast to the response observed in the western Sound, suspended material concentrations at this station increased progressively with increasing velocity. Examination of the functional dependence between velocity and material concentrations indicates that despite this trend the system remains dominated by alternate resuspension and deposition of materials from a reservoir above the interface. Measurable erosion of the underlying interface is confined to periods of maximum velocity typically associated with spring tidal conditions and/or aperiodic storm events (Figure 4a-4b).

In the eastern Sound, observations at a site in approximately 20m of water near the dredged material disposal area (Figure 2) show material concentrations varying progressively with velocity. Values are relatively low and during the 1980-1990 period typically ranged between 1 and 5mg/1. Although concentration variations are in-phase with tidal velocities at this station the data provide essentially no indication of measurable erosion of the underlying interface (Figure 5a). The observed variations in near-bottom concentrations appear dominated by a combination of alternate resuspension/deposition and advective transport of materials from a far-field source(s). The response is consistent with the relatively high-energy nature of the eastern Sound.

Erosion of the sediment-water interface in the eastern Sound does occur intermittently but at a significantly lower frequency than observed in the central Sound. At the eastern site spring tides do not result in an evident increase in material concentrations. Interfacial erosion at this site appears confined to periods of extreme shear stress induced by the passage of aperiodic storm events. Observations during and after Hurricane Gloria in September, 1985 show a functional dependence between velocity and suspended material concentrations similar in form to that observed during spring tidal conditions at the central Sound station (compare Figures 5b to 4b). The discrete nature of the response displayed during the hurricane provides further indication of the erosion resistance of the sediment-water interface at the eastern Sound station.

Discussion

The variety of near-bottom time-series data provide clear indication that in all deep (O(20m))and many shallow water areas the suspended material field in Long Island Sound is dominated by alternate resuspension and deposition of materials from a mobile layer of materials just above the sediment-water interface. Erosion of the interface and the underlying sediment column is limited to periods of above average shear stress which in many usually occurs only during the passage of high energy storm events. Recent analyses by Kim and Bokuniewicz (1991) indicate that the mass of material participating in this suspension-deposition cycle exceeds that introduced from all source areas by more than two orders of magnitude. Against this background, the influence of storms and similar aperiodic resuspension events appears relatively small involving the displacement of very thin (O(mm)) layers of sediment. The data indicate that efforts to model sediment transport in such a system cannot simply rely on specification of mass erosion from the static sediment column but must also include supplementary expressions sufficient to detail the mass of material resident within the mobile layer and participating in the resuspension-deposition cycle. At present this appears best accomplished by a selective series of site specific in-situ observations using systems similar to the bottom-mounted arrays employed in the studies reviewed above. Simple reliance on laboratory data does not appear sufficient.



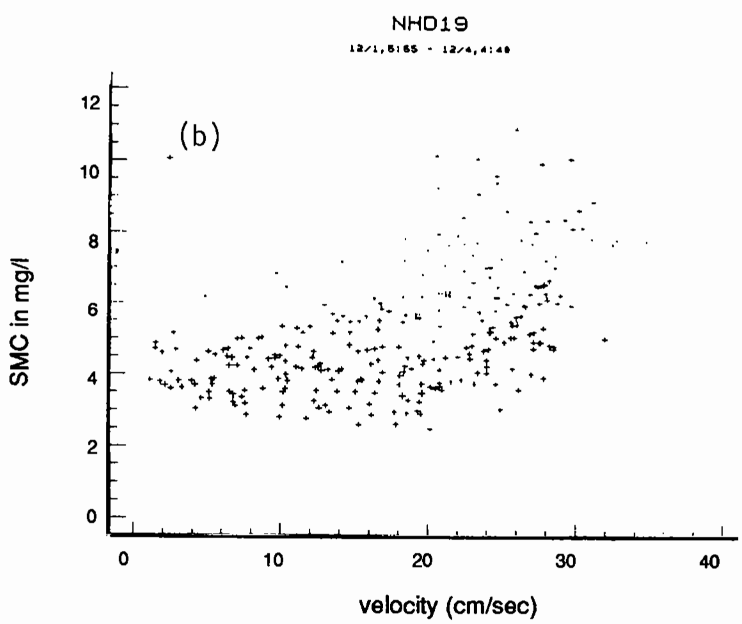


Fig 4a. Suspended material concentrations and concurrent speed at a site in central Long Island Sound - Observations over a range of average and above average flow conditions.

Fig. 4b. Suspended material concentrations and concurrent speed at a site in central Long Island Sound - Spring tidal conditions. Selected from the total record shown in Fig. 4a.

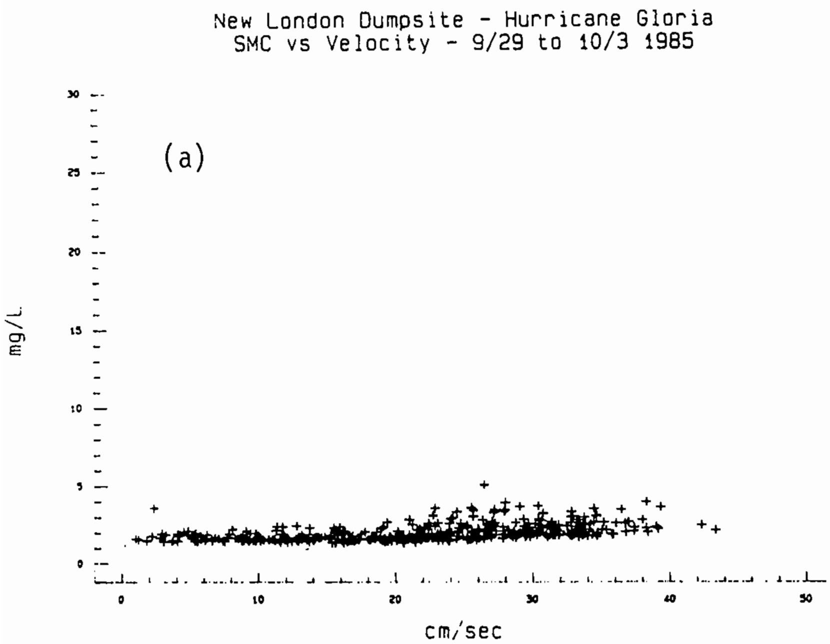


Fig. 5a. Suspended material concentrations and concurrent speed at a site in eastern Long Island Sound - Average tidal conditions prevailing after the passage of Hurricane Gloria.

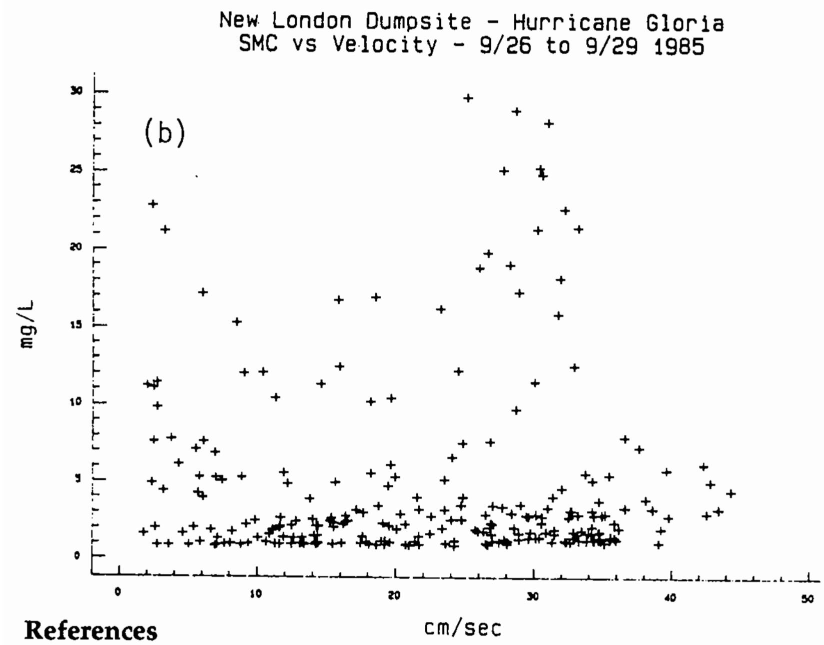


Fig 5b. Suspended material concentrations and concurrent speed at a site in eastern Long Island Sound during the passage of Hurricane Gloria.

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Hydrodynamic and Suspended Sediment Variations During the Passage of Hurricane Gloria Over Eastern Long Island Sound

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Abstract

In September 1985, the passage of Hurricane Gloria was recorded by a bottom-mounted instrument array deployed within a dredge material disposal site in Eastern Long Island Sound at a depth of 25 meters. We review these data, with emphasis on variations in wave field and sea level, and present it with meteorological and tidal height data collected at several locations surrounding Long Island Sound. The time series collected reveal several interesting occurrences: 1) a 7-second local wind wave with a duration of 6 hours and a 12-second swell with a duration of 48 hours, 2) a greater than 1 meter sea level rise in the Sound due to storm surge and wave setup, 3) a 'relaxation' event which suppressed a flood tide, followed by a 'rebound' of landward flow 12 hours later, 4) meso-scale horizontal mixing, inferred from the temperature data, which lasted for 42 hours, and 5) two spikes in suspended material concentrations, one due to local resuspension induced by wave-current interaction, and a second spike, 15 hours later, a result of offshore advection of inshore materials. Gloria's effects were relatively complex, covering a range of temporal and spatial scales. Differences in the timing and magnitude of storm events, as well as the perturbations they may cause, obviates their unpredictability and ultimately confounds the typically simplistic assumptions used in storm modeling.

Introduction

Storms can create extreme hydrodynamic disturbances, *i.e.*, sea level rise, elimination of tidal reversals, alteration in the residual current field, destratification due to mixing or increased stratification due to run off. The flux of sediment into and through estuarine basins, during storms, can also be quite significant. In this paper, we chronicle the hydrodynamic and suspended sediment response at a depth of 25 meters in Eastern Long Island Sound during the passage of Hurricane Gloria on September 25th, 1985.

The study area (Figure 1), is located within a dredged material disposal site in the eastern portion of Long Island Sound, approximately 2 nautical miles south of the Thames River. Circulation in this region is dominated by the semi-diurnal lunar tide; the tidal range is 0.75 meters. Data collected during ambient conditions show current speeds ranging from 20-40 cm/sec at the site, and an average salinity of 30.5 ppt.

Hurricane Gloria started near the Cape Verde Islands on September 16, 1985 and maintained a westward track across the tropical Atlantic (Figure 1). Headed northwest toward the continental U.S., the storm intensified. On September 24th, just east of the Bahamas, the central pressure fell to a low of 919 millibar. Gloria's central pressure weakened to 942 millibar as it brushed by Cape Hatteras after midnight on September 27th. The atmospheric pressure records (Figure 2a) from Brook Haven National Laboratory, Upton, New York showed that the center of the hurricane passed over Western Long Island Sound at 1300 on September 27th with a pressure just under 970 millibar. Meteorological time series from Bridgeport and Avery Point, CT and Brook Haven, NY indicate that the passage of Gloria took less than six hours, with the most intense period lasting only two hours.

Precipitation measured during this period totals only 15 mm (0.6 inches). At the peak of the storm, some meteorological data was lost due to local power failures. Data recorded up to the loss of power show wind speeds at Avery Point of 39 m/s (87 mph), while at Brook Haven the top speed was 31 m/s (70.5 mph). Winds were out of the southeast as Gloria approached, then shifted to the south as the center passed over Long Island Sound, and finally, swung southwest as the storm headed toward northern New England. The hurricane became extratropical over New England later that evening (Case and Gerrish, 1986).

Methods

The hydrodynamic and suspended sediment variations were recorded by a bottom-mounted instrument array, DAISY (Bohlen, 1982). The array was equipped with a ParoScientific "digi-quartz" pressure sensor, a Marsh-McBirney two-axis electromagnetic current meter, a KVH compass, two thermistors, a SeaBird Electronics Model 4 conductivity probe and two red-light nephelometers with a 10 cm pathlength. For wave analysis, the pressure sensor sampled every 0.5 hours for 1024 seconds with a sampling frequency of 2 Hz. The pressure data for tidal analysis was collected every 15 minutes. The remaining sensors were sampled every 15 minutes for a duration of 192 seconds.

Hourly sea level data were obtained from six stations, maintained by NOAA's National Ocean Service, surrounding Long Island Sound for the period of 15 September to 15 October, 1985. These stations include Bridgeport (BP) and New London (NL) in Connecticut and Montauk (MT), Port Jefferson (PJ), Willets Point (WP) and the Battery (BT) in New York State (Figure 1).

The derived current directions were confirmed using principal axis analysis, assuming the dominant current component is along the major axis of Long Island Sound. The 180° phase ambiguity was resolved by cross referencing the directional data with the tidal measurements. Harmonic analyses were applied to current and sea level data for anomaly estimates. Wave period and height were resolved from the pressure measurements using linear wave theory (SPM, 1984; Dyer, 1986) and spectral analysis techniques.

Results

Waves. A significant amount of wave energy (Figure 2b), estimated as the area under the curve of the resulting power spectrum, was 'felt' by the pressure sensor located at over 20 meters depth. Spectral analyses of the high frequency (2 Hz) pressure measurements reveal a bimodal distribution during the passage of Hurricane Gloria, indicating that both local wind wave and far-field swell are important. The local wind waves have a period of 7 seconds with a pronounced growth in wave height at 10:00 hours on September 27th. The wave height reached a peak at noon and then slowly decayed, by day's end on September 27th the local wind generated waves were almost undetectable by the bottom sensor.

The longer period swell was first detected at noon on the 26th, 24 hours prior to the passing of the hurricane center. We speculate that the swell was introduced to Long Island Sound through the east end, while the hurricane was to the south of the region. These swells have periods of about 12 seconds, with the height gradually increasing to a peak at noon on the 27th when wind speeds reached their maximum. The height of the swell gradually decayed over the next 24 hours.

At the peak of the storm, the estimated surface wave height was 2.85 meters, with a wave period of 7.7 seconds. However, with the presence of both local wind waves and far-field swell, the actual seas might have exceeded 3 meters. In the presence of a bimodally distributed wave spectrum, wave-wave interactions and wave-current interactions complicate the estimation of significant wave height and the associated bottom shear stresses using linear wave theory.

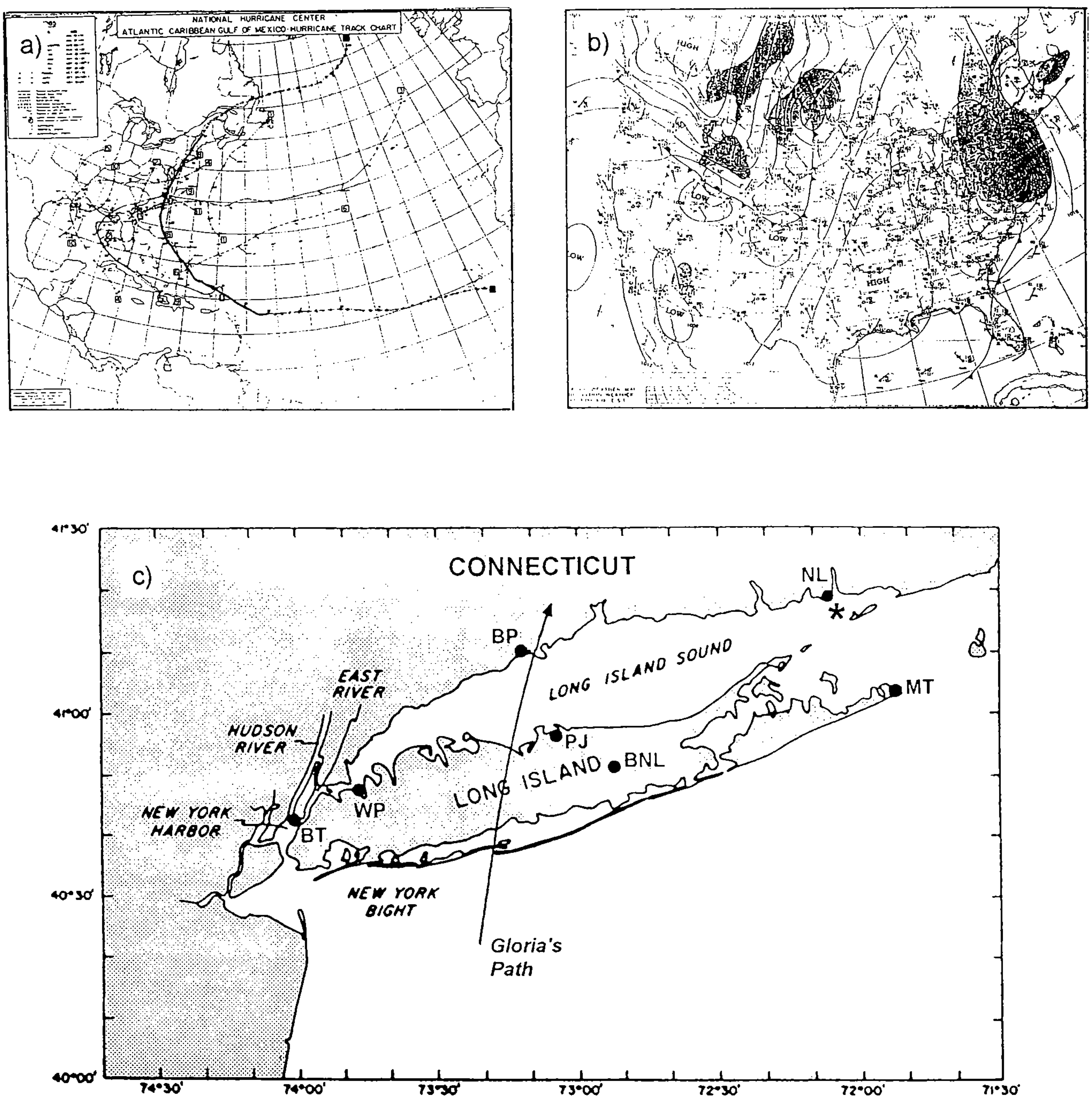

Figure 1: a) Hurricane Gloria's track from Cape Verde to New England, b) isobars over New England during Gloria, c) the instrument array location (indicated by *), sea level stations and meteorological stations and Gloria's path through Long Island Sound.

Tides. The hourly tidal height data from the six stations surrounding the Sound show an almost simultaneous rise in sea level. This indicates a basin-wide response of the system to storm surge and wave setup. Sea level data, after detiding, indicate a 95 cm sea level rise at Montauk and the instrument site (Figure 2c), a 146 cm sea level rise at New London, about 130 cm at Bridgeport and Port Jefferson, 142 cm at Willets Point, and 172 cm at the Battery. About 40 cm of the sea level rise can be accounted for by the storm surge resulting from falling atmospheric pressure (40 millibar). We estimate the cross-sound wind setup to be about an order of magnitude less than that due to atmospheric pressure reduction. Other major components of sea level rise are wave setup and the local geometry, the magnitude of these contributions have not yet been explored. Twelve hours after the passage of Gloria, the tidal height time series show a 'rebound', which is a common phenomena.

Currents. Current data, after tidal removal, show an along-Sound seaward (eastward) flow, immediately after the passage of the hurricane center (Figure 2d). This can be explained as a result of the relaxation of setup waters during the storm augmented by the westerly component of the south-west winds. This seaward flow lasted for six hours with a maximum speed of 35 cm/second. Following this seaward flow event was a compensatory landward (westward) flow with a peak velocity of 30 cm/second over a period of six hours. The eastward relaxation event occurred during the flood tide which as a result was suppressed. Likewise, the westward flow coincided with the ebb tide, reducing ebb current velocities.

Time series of the cross-sound velocity component indicate that a weak near-bottom southbound current developed during the storm. This suggests that the cross-sound wind setup created a two-layer circulation pattern. A similar occurrence has been reported by Tyagl and Hanes (1989) during a storm off a Louisiana barrier island.

Hydrography. The temperature time series (Figure 2e) displays a clear tidal signal with approximately a 1°C difference between ebb and flood waters during ambient conditions. The temperature difference between flood and ebb waters reduced to 0.2° C at 08:00 on the 27th of September. We infer that warmer shelf water was mixed into the Sound during the flood tide. During the next 42 hours this parcel of mixed water was transported back and forth at the study site with the tidal signal diminishing to 0.1 °C. The original nearly 1°C tidal signal was not re-established until 02:00 on September 29th, suggesting that relatively intense meso-scale horizontal mixing had occurred.

Suspended Sediment Concentrations. The response of the suspended material field has previously been described by Fredette, et *al.* (1989) and SAIC (1989). An increase in the suspended material concentration from 2 to 16 mg/l was observed, a result of wave-current interactions resuspending sediments at the sediment-water interface during the passage of the hurricane (Figure 2f). Concentrations dropped to pre-storm levels after the storm had passed and remained low for several hours. Fifteen hours after the storm passage, another high concentration event occurred in which concentrations reached 30 mg/l. This concentration has been attributed to the offshore advection of nearshore sediments suspended during the storm.

Discussion & Conclusions

Hurricane Gloria was a relatively short-lived, 'dry' event. Winds were out of the south, across the Sound, a direction with limited fetch. The maximum storm surge occurred at low tide and the storm induced setup and relaxation flows opposed the tidal currents. Opposing flows would reduce the bottom shear stress at the bed, limiting the amount of erosion that could occur from the sediment bed. As a result, the overall sedimentation impact within eastern Long Island Sound appears to have been relatively minor. Tropical storm Agnes, for comparison, which struck the mid-Atlantic region

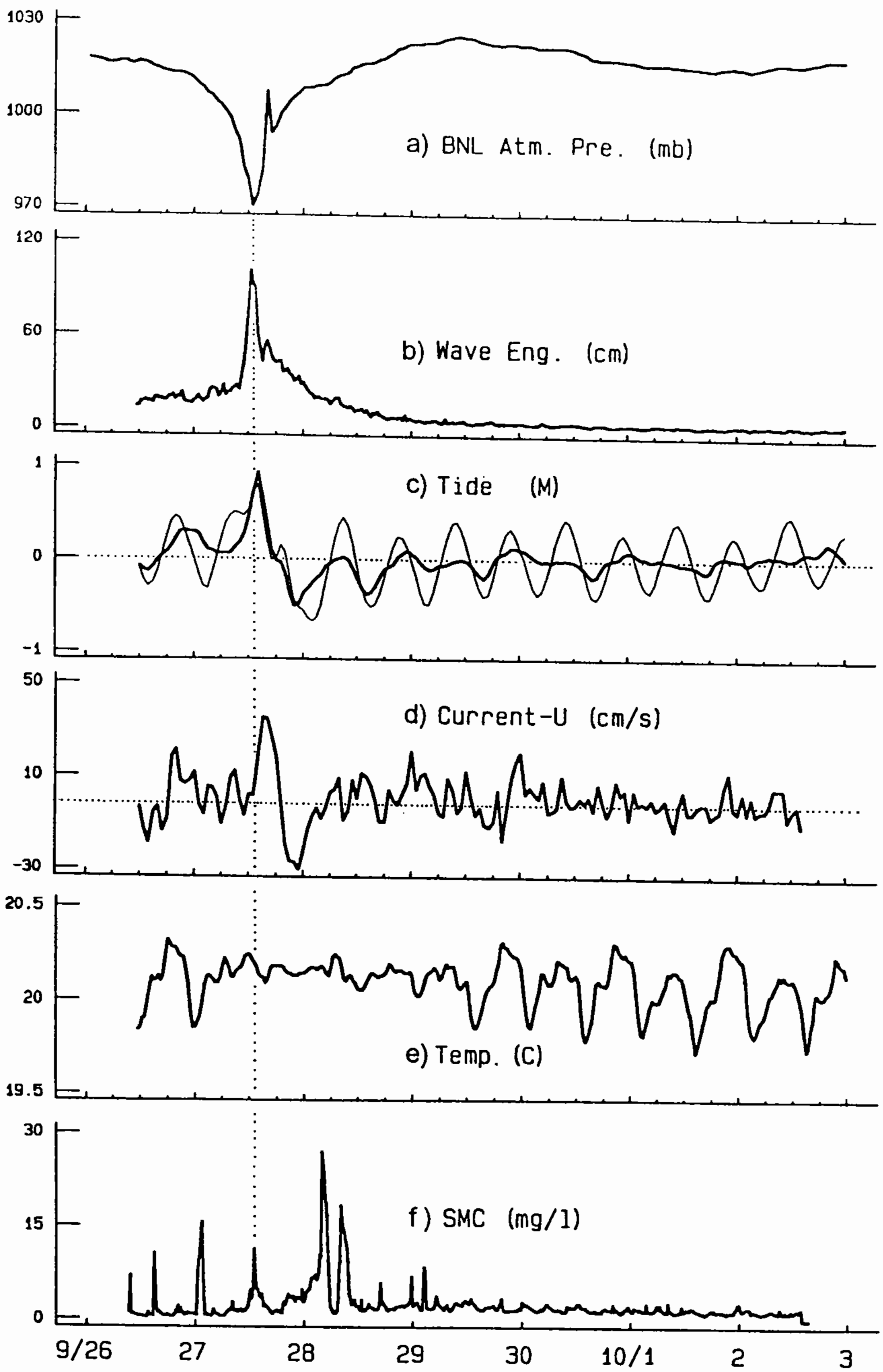

Figure 2: Time series data show that: a) a 40 cm atmosphere pressure drop at 1300 (EST), 27 September, 1985 (Data from Brook Haven, Upton, NY); b) bottom wave energy, derived from the area under the curve of the power spectrum; c) measured tidal elevations (thin line) and after tidal removal (thick line); d) along-Sound current component after tidal removal; e) water temperature; f) suspended material concentrations.

in June of 1972, was a very 'wet' event with 305-457 mm of precipitation over a 3-day period. Suspended material concentrations reached three orders of magnitude higher than ambient conditions; abnormally high suspended sediment concentrations were observed for a month. The erosion and deposition caused by Agnes 'aged' the Chesapeake Bay by 50 years (Zabawa and Schubel, 1974). Recently, Bohlen *et al.* (1992) compared the amount of material resuspended at several sites during storm events with the amount of material resuspended throughout the Sound during each tidal cycle. They concluded that the amount of material in suspension in eastern Long Island Sound, associated with Gloria, was indeed small relative to the mass in suspension during each tidal cycle.

Hurricane Gloria's effects in the eastern Sound were relatively complex, covering a range of temporal and spatial scales. Despite this complexity in the hydrodynamic and suspended sediment response, Gloria's impact was short-term and minimal. Differences in the timing and magnitude of storm events, as well as the perturbations they may cause, obviates their unpredictability and ultimately confounds the typically simplistic assumptions used in storm modeling.

Acknowledgments

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Observations of the Hydrography and Circulation in Block Island Sound

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Introduction

The exchange of water and associated material between large estuaries and the adjacent continental shelf is of obvious environmental importance. It is well established that the buoyant surface water exits the estuary and that mixing within the estuary requires water to flow in at the bottom(Bowden, 1983). In large estuaries like the Delaware Bay, Long Island Sound, and Buzzards Bay the stratification is weak so that the internal Rossby deformation radius, $R=(gD\Delta\rho/\rho)^{1/2}/f$, (where g is the acceleration of gravity, ρ and $\Delta\rho$ are the scales of the mean and the vertical variation of the density, D is the vertical scale of the stratification and f is the Coriolis parameter) may be of the same order of magnitude as the width of the mouth. This is, in fact, a good definition of "large". In these situations, the exchange flow is affected by the Coriolis acceleration and may have a fully three-dimensional structure.

Recent observations of the flow at the mouth of the Delaware Bay (Pape and Garvine, 1982; Masse, 1988 and 1990; Garvine 1991; Wong and Munchow 1992; Munchow, 1992), have established that the near surface residual outflow from the estuary is concentrated on the right side of the estuary (looking offshore), that it is vertically well-mixed nearshore and more stratified in the deeper regions offshore, and that the brackish outflow turns to the right as it exits the estuary. Subsequently, it forms a coherent alongshore jet which carries the effluent away from the estuary. Munchow (1992) has examined the dynamics of this region and concluded that in addition to the horizontal pressure gradient and Coriolis acceleration, bottom friction and convective accelerations are important to the dynamics of the "turning region" of the outflow, whereas the coastal current is geostrophic at first order. The inflow has been considered theoretically by Masse (1988 and 1990) and directly observed by Garvine (1991) and Munchow *et al.* (1991) and it is clear that the inflow velocity is weak compared to the outflow but occurs over a significant fraction of the cross section of the estuary mouth.

The outflow from Long Island Sound (LIS) and the hydrography and circulation in Block Island Sound (BIS) has not been adequately studied. Bowman and Esaias (1981) used tidal current predictions and bathymetry to estimate the distribution of the tidal mixing parameter of Simpson and Hunter (1974) in LIS and BIS and compared it to the observed surface to bottom density difference in salinity in the fall of 1978. The correlation of these results suggest that tidally-induced vertical mixing determines the hydrography in the shallow areas.

The most extensive set of published observations of the exchange between LIS and the coastal ocean was obtained by Paskausky and Murphy (1976). They repeatedly deployed both surface and bottom "Woodhead drifters" at a large number of stations throughout LIS and characterized the seasonal variability of the resulting velocity estimates. They found that the return rate for surface drifters was always lower than that for bottom drifters, which is obviously consistent with a persistent outflow from the Sound. However, for one drifter deployment (June, 1973) in eastern LIS, the recovery rate was particularly good. Most of the drifters that were recovered were found on the south shore of Long Island and were grounded by a period of strong southeasterly winds. The trajectories of these drifters suggested that the outflow from LIS formed a coastal current which had a speed of order 10 cm/s.

This paper reports the results of a pilot observation campaign to directly observe the characteristics of the outflow from Long Island and Block Island Sound. We hypothesize that flow is analogous to that at the mouth of the Delaware Bay with significant across-Sound variations in the hydrography and current structure. The details of the observational methods are discussed in the following section and then section 3 describes the results. Our preliminary conclusions and a summary are provided in section 4.

The Observations

Figure la shows the region of this investigation and the relative locations of Montauk Point, Watch Hill, and Block Island. This area is relatively deep, up to 60 m in central BIS, with shoals around Montauk and Block Island. The tidal regime is energetic (speeds of order 1 m/s) and principally semi-diurnal with significant contributions from the M2, S2, N2 and Kl constituents.

On the second and third of May, 1990, we used the R.V. UCONN to visit the stations shown by the filled circles in Figure la and recorded the vertical structure of conductivity and temperature with a Seabird Instruments SBE 19 CTD. During this period the weather was overcast with light and variable winds. We began the observation program at Station N2 near maximum ebb at the Race and completed the section two hours later. We then observed the hydrography on section O during both the late flood and early ebb, and repeated section N during the two hours spanning the maximum flood. On the second day (May 3rd), we repeated observations along section N at late ebb and section O during the maximum flood. We then steamed south from Montauk along section R and then west along section S during the ebb.

On the first day of the measurement campaign we also deployed four drifting buoys with near surface drogues (shown in Figure ld) approximately midway between Watch Hill and Montauk. These buoys were equipped with LORAN navigation systems, data loggers and VHF transmitters. They were programmed to locate themselves every 15 minutes, to store and then broadcast their positions so that we could track them from the R.V. UCONN in real time and ultimately retrieve them. Two of these instruments malfunctioned soon after deployment and will not be discussed.

In the following section we will also refer to current observations obtained by a bottom-mounted, upward looking 600 kHz acoustic Doppler current profiler deployed in 30 m of water by NOAA-NOS during the Long Island Sound Oceanography Program at the station indicated as S16 on Figure la. This instrument operated from the 30th of December, 1988 until the 23rd of January, 1989 and provided current observations at lm wide bins between 2 and 25m above the instrument which was approximately lm above the seabed.

The Results

Though these hydrographic sections were acquired rapidly enough to be regarded as synoptic, we did not obtain sufficient repetitions to adequately represent the tidal evolution of the hydrography. The data do show characteristics that seem to persist throughout the tidal cycle and in this report we only focus on these features.

Three vertical cross-sections from Watch Hill Point, Rhode Island to Montauk (section N) showed that the most buoyant (freshest) water consistently occurred near Montauk and the least buoyant (most saline) near Watch Hill. Vertical stratification was weak near both coasts and stronger stratification appeared in the deeper water, especially in the northern portion of the transect. A representative density section from Montauk to Block Island (O) is shown in Figure 2a. This displays a structure similar to that observed along the Montauk-Watch Hill section, with well-mixed, denser, saltier, water near Block Island and well mixed, fresher water near Montauk. These patterns are consistent with those outlined in the work of Bowman and Esaias (1981) though this data has higher spatial resolution in BIS and shows that there is little stratification near Watch Hill and Block Island.

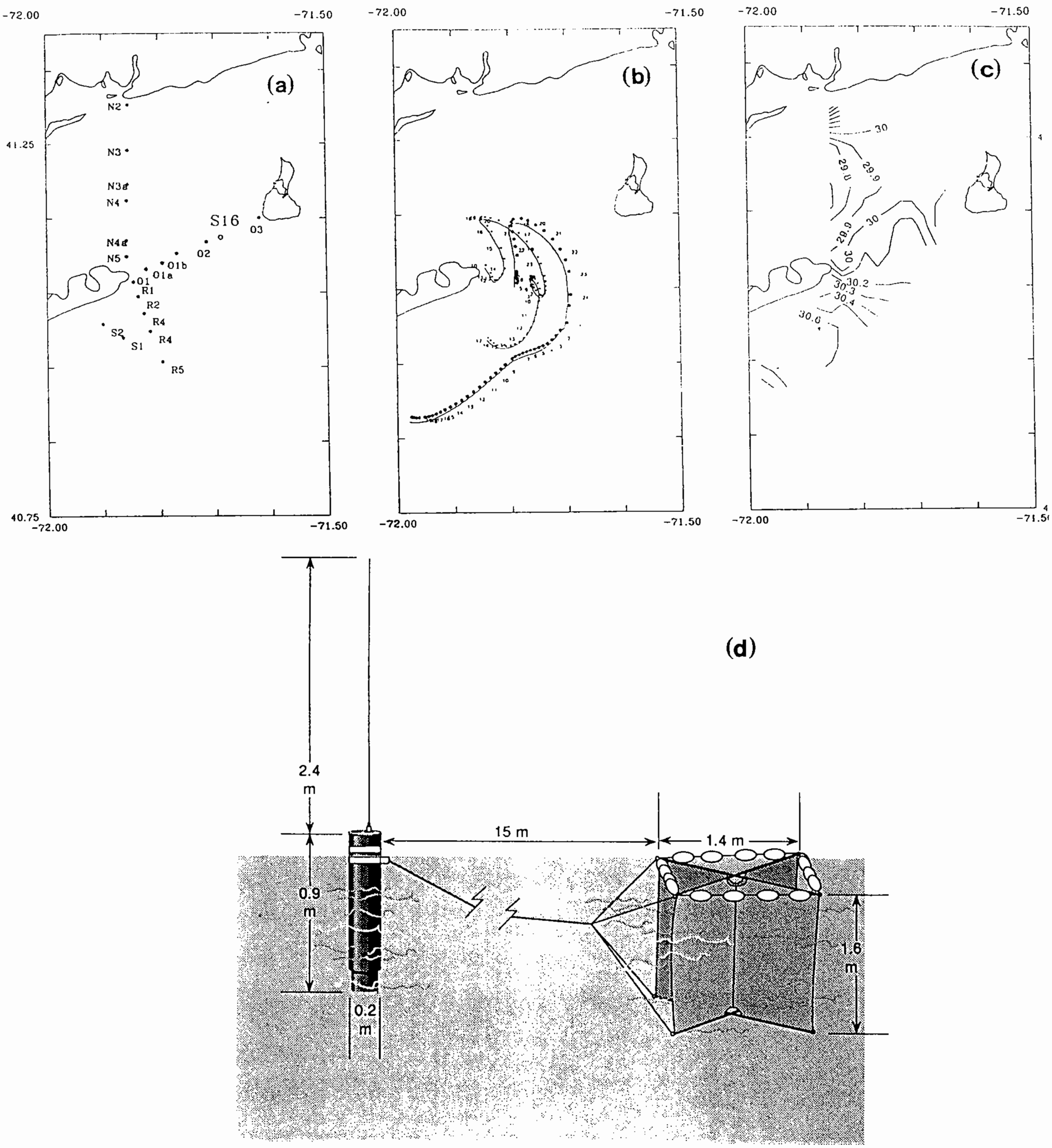

Figure 1: (a) A map of eastern Long Island Sound and Block Island Sound showing the station locations; (b) sequential positions of drifters at times (hours) indicated; (c) surface salinity distribution; and (d) a schematic of the LORAN tracked surface drifters.

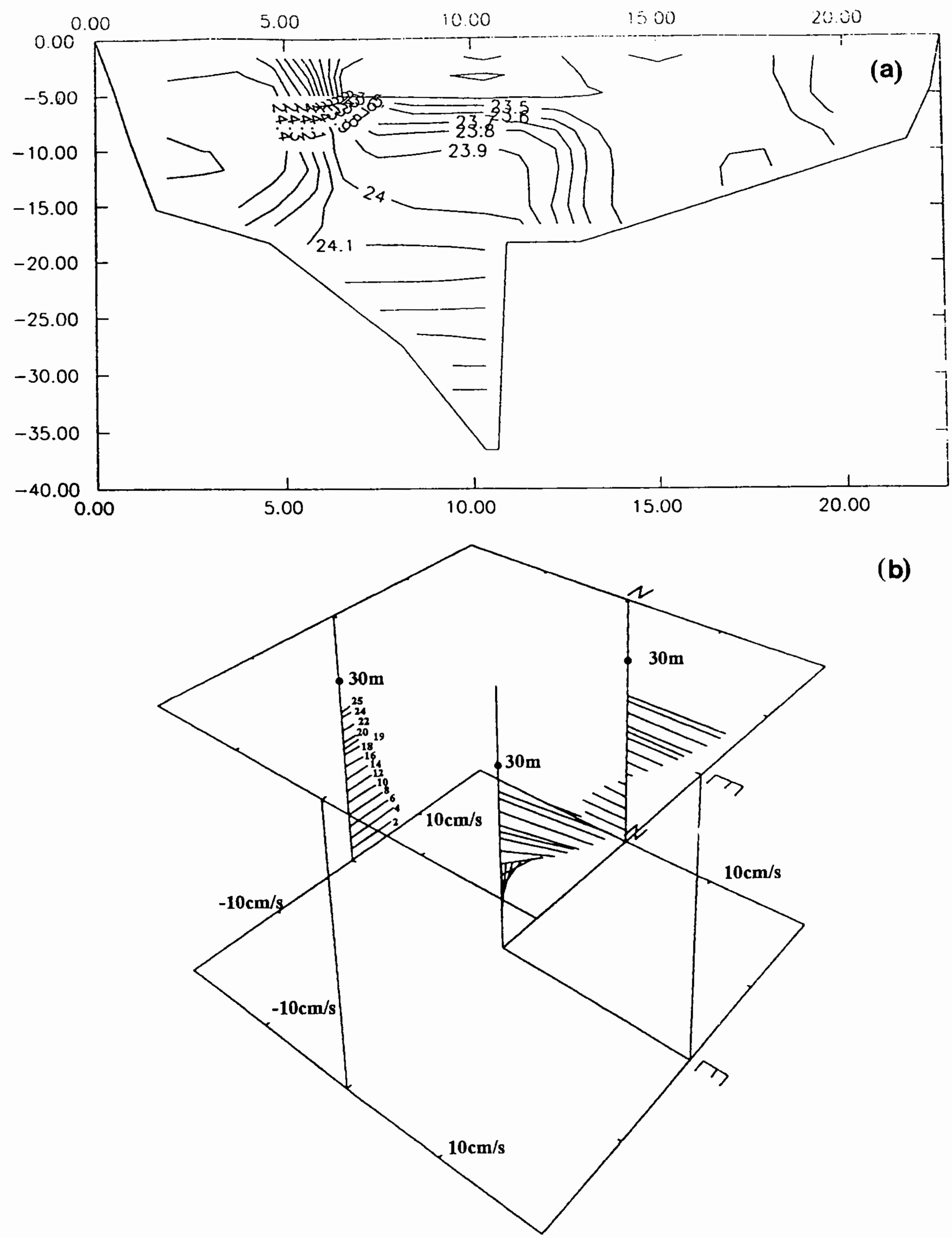

Figure 2: (a) Representative density (σ_t) distribution across section O; and (b) a three dimensional projection of the Eulerian mean currents observed at ADCP station S16. Note that the northward component of the velocity is projected on the left back face of the cube and the eastward component is shown on the back right face.

A second persistent feature of the hydrographic observations is the northward shoaling of isopycnals in section N and the eastward challenge of isopycnals in section 0. Applying a simple "thermal wind balance" argument to this regime, one would conclude that surface outflow from LIS flows through BIS and into the coastal ocean at Montauk and that the deeper water flows in the opposite direction. Quantitatively, the isopycnal slopes observed would suggest a geostrophic vertical shear of approximately 20cm/s. Of course, this estimate ignores the obviously important role of vertical friction and advective accelerations but, as will be shown, this estimate turns out to be in reasonable agreement with other direct current observations.

The salinity distributions along sections R and S on the continental shelf southeast of Montauk showed that the fresher water did indeed extend out onto the inner shelf though the offshore extent of the plume was not identified. This is clear in Figure lc which shows the spatial distribution of the near surface salinity on May 3rd, 1990.

Analysis of the trajectories of the two drifters that operated for more than a tidal cycle demonstrated that the motion of the surface water is out of Block Island Sound (southeastward) at approximately 25 cm/s and then westward along the south shore of Long Island at approximately 35 cm/s(see Figure lb). The order of magnitude of this residual exchange is consistent with the flow estimated by assuming the observed hydrography was characteristic of the mean, and the flow between Montauk and Block Island was in geostrophic balance.

To estimate the longer term mean exchange between BIS and the coastal ocean we calculated the record means of the acoustic Doppler current meter records obtained by NOAA at S16 (see Figure la). These Eulerian average currents are shown in Figure 2b. The near surface currents, approximately 5m below the surface, are directed out of the estuary almost eastward at lOcm/s with a small (2cm/s) northward component. This mean eastward flow extends with decreasing magnitude down to lOm above the bottom with the northward component increasing slightly. In the bottom lOm the flow turns westward with a maximum of 5cm/s approximately 5m from the bottom.

Summary and Conclusions

This paper summarizes the results of a preliminary observation campaign to describe the characteristics of the outflow from LIS and BIS. The hydrographic observations confirm that the density structure in BIS is characteristically homogeneous in the shallow areas near Watch Hill, Block Island and Montauk. Though this data set is lacking in extent and resolution, it provides fairly convincing evidence that the exchange is in several respects analogous to that observed at the mouth of the Delaware Bay: (l) the drifter observations show the existence of an outflow of buoyant water that appears to be associated with the buoyancy gradients, and which turns to the right of the mouth on entering the shelf; (2) the ADCP data show that there is a mean vertical shear at the mouth which is of the order of magnitude of that resulting from a flow in thermal wind balance with the density field; (3) since the vertical profile of the mean flow at S16 shows a net outflow, there must be other areas where there is net inflow, i.e. the structure of the flow in the mouth is two-dimensional.

Acknowledgments

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Estuarine Circulation and the Effects of Dredging in the Housatonic River Estuary

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The Housatonic River drains 4,971 km^2 in southwestern New England and is the second largest source of freshwater to Long Island Sound. The hydrochemical estuary is characterized by a relatively high tidal range (1.65 m) and a low freshwater discharge (median discharge 28 m^3/s) causing mixing to extend 22 km landward.

The natural estuary is a sand-dominated system with a narrow thalweg bordered by broad flanking shoals which are often exposed at low water. The modern estuary can be divided into three geomorphic reaches with distinct substrate characteristics. The mouth of the estuary, about 8km long, extends from Milford Point to just north of the I-95 bridge and is characterized by a narrow deep channel up to 7m deep. Grab samples and side-scan sonar records indicate that much of the channel is covered by oyster beds. Where bedforms are present they indicate sand transport into the estuary from Long Island Sound. The 6km long middle reach of the estuary which extends to just north of the Merritt Parkway bridge is narrow and shallow; at several cross-sections water depth is only 2m at low tide. The sand bed of this reach of the estuary is covered with ripples and sandwaves which indicate sand transport toward the mouth. The head of the estuary extends north to the confluence with the Naugatuck River. This 8km long reach has been dredged for sand and gravel aggregate to depths of up to 15m. Fathometer profiles and side scan sonar records reveal the irregular bottom morphology created by the dredging. In particular, the scoop marks made by the dredge are still visible years after the cessation of dredging. The sand bed of this reach of the estuary is now covered by a layer of black organic-rich mud that is draped over the bed topography created by dredging.

Estuarine circulation in the Housatonic River estuary exhibits large variability in salinity, current velocity, and dissolved oxygen caused by fluctuations in regulated freshwater discharge, semidiurnal and fortnightly tidal circulation, biological effects, and the unique geometry of the upper estuary, created by dredging activities. The shallow middle reach of the estuary functions as a broad sill that separates the estuary into two distinct circulation regimes. Under moderate to high river discharges saline or brackish water intrudes 10 to 12km into the estuary. Under these conditions the mouth of the estuary functions as a partially mixed estuary, while north of the sill the Housatonic system is a freshwater tidal river. Under conditions of low river discharge, brackish water intrudes north of the sill and the entire estuary approaches conditions typical of a sectionally homogeneous estuary. Salinity measurements made throughout the tidal cycle indicate that bottom water in the dredged reaches at the head of the estuary becomes stagnant during these low flow conditions. This stagnation, coupled with the biochemical oxygen demand of the substrate in the dredged reaches causes the bottom water to become hypoxic. In the upper estuary, strong vertical gradients in dissolved oxygen are created with hypoxic bottom waters caused by bacterial decomposition overlain by supersaturated surface waters produced by surface algal productivity. These conditions are not present in the lower estuary because the tidal volume is able to mix and aerate the entire water column.

Current velocity in the Housatonic estuary decreases with distance north of the mouth. The symmetry of duration of ebb and flood directed flow also decreases with distance north of the mouth, with ebb directed flows dominating at the head of the estuary. Thus, two layer tidal and net non-tidal flow only occur in the lower estuary and only under conditions of moderate to high river discharges. Comparison of a 1956 bathymetric survey with our surveys in 1991 indicate that the dredging activities have enlarged the estuary cross-section by as much as six times. We utilized the HEC-2 water surface profile model to estimate the average velocity of the dredged reaches before and after dredging. The model accurately predicts the current velocity measured at times of peak ebb flow in the field under the present conditions and indicates that the average velocity in the dredged cross-sections has decreased by as much as a factor of four. This decrease in current velocity is the primary reason for the mud deposition in the dredged reaches which directly contributes to the hypoxia in the upper estuary.

The modern Housatonic estuary is unusual in that both the mouth and the head of the estuary function as a sediment trap. The mouth of the estuary traps sand transported from both landward and Soundward directions. Today, the head of the estuary, drastically altered by dredging, is also a sediment trap. Here the low current velocities are unable to maintain sediment in suspension and organic detritus and fine-grained mud is accumulating in this reach. The lack of sand supply to the head of the estuary and the low current velocities associated with channel enlargement suggest that the dredged morphology will persist indefinitely. This condition will perpetuate the degradation of this estuary as organic-rich mud continues to accumulate in this reach.

Lateral Hydrographic Variability in Eastern Long Island Sound

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Abstract

This study examines hydrographic data collected monthly along three transects across eastern Long Island Sound between April and October 1988. Vertical stratification was greatest during the summer months. Lateral density differences were observed throughout the measurement period, although the strength and direction of the lateral density gradient changed seasonally. This lateral variability can be attributed to the combined effects of the Connecticut River discharge and exchanges with Block Island Sound. During spring and early summer the pycnocline sloped down to the north and on the surface the freshest water was located adjacent to the Connecticut shore. However from mid-summer through fall the pycnocline slope reversed, and the lowest salinity water was then located to the south, along the Long Island shore. This data shows that within the eastern section of Long Island Sound lateral density gradients are at least as large as the longitudinal gradients. Thus characterization of the residual circulation and transport in eastern Long Island Sound requires consideration of these lateral gradients.

Introduction

Hydrographic variability in estuaries is usually thought to occur primarily in the longitudinal direction, along the axis of the estuary. In many estuaries however the gradients in water properties across the estuary can be as great, if not greater than, the longitudinal gradients. Such lateral gradients may arise due to a modification of the tidal and residual flows by channel bends, bathymetric features, the Coriolis force or inflowing tributary rivers (Dyer,1977; Fischer *et al.* 1979; Boicourt, 1982; Huzzey, 1988).

Long Island Sound, lying between the Connecticut shore and Long Island, has a main axis oriented east-west. Although some lower salinity water enters at the western end of the Sound, most of the freshwater which enters Long Island Sound does so along the north side of the estuary via many small creeks and the Thames, Connecticut and Housatonic Rivers. In addition, the size of this estuary is sufficient for the residual flows to be influenced by Coriolis effects. Thus it would be expected that pronounced lateral, or cross-estuary, salinity and density gradients will occur across Long Island Sound. These gradients will play an important role in the direction of the density driven residual circulation.

Methods

Between April and December 1988, as part of the United States Environmental Protection Agency's Long Island Sound Study, thirty-three sites within the eastern half of Long Island Sound were sampled at least monthly for water quality and hydrographic parameters. These sites were arranged along north-south transects across Long Island Sound (LIS) and the adjacent Block Island Sound (Bohlen *et al.*, 1989). Although sampling of all sites took three days to complete each month, measurements along a given lateral transect were completed within two to three hours and thus were relatively synoptic. Along transects I, J and K (see Figure 1) vertical conductivity-temperature-depth (CTD) profiles were collected in April, May, July, August, September and October; data from June were lost due to instrument malfunction. This study utilizes these CTD data to examine seasonal

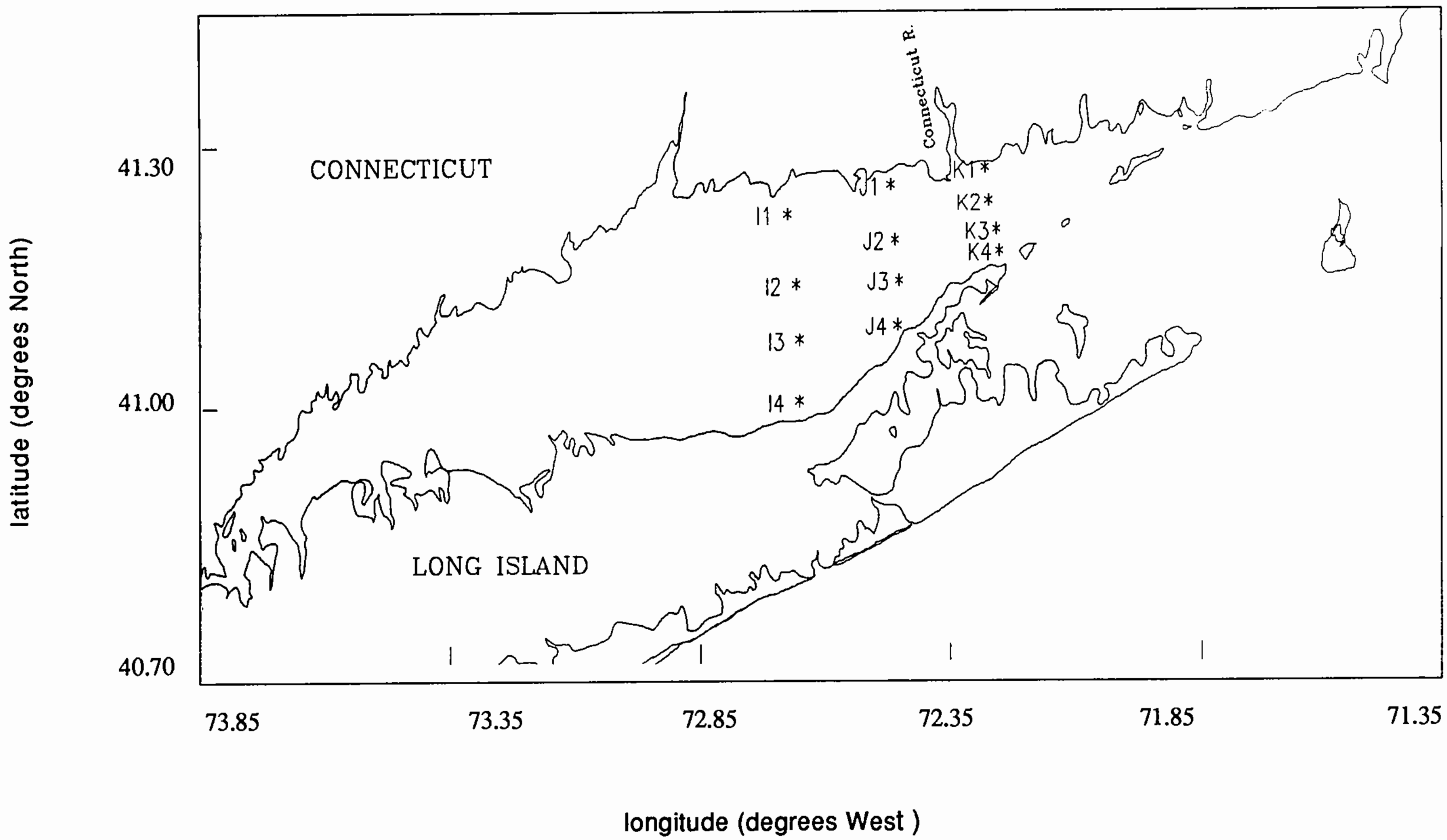

Figure 1: Hydrographic sampling station locations in eastern Long Island Sound during April to December 1988. Transect I = stations I1 to I4; Transect J = stations J1 to J4; Transect K = stations K1 to K4. All these stations were sampled monthly; station I2 was sampled fortnightly.

changes in the lateral density distribution across the eastern half of Long Island Sound.

The 1988 data were collected at different phases of the tide each month. In order to investigate the extent of tidally-induced changes in the lateral density distribution, on July 16, 1992 hydrographic measurements were made along transect J four times through a tidal cycle. Using the same station locations as were sampled in 1988, measurements were made at slack-before-ebb, maximum ebb, slack-before-flood and maximum flood.

Results

The vertical stratification within eastern LIS was greatest during mid-to-late summer. This can be seen in Figure 2, and was also evident in the vertical hydrographic data collected weekly at station I2. The pycnocline, when present, was located in the upper one-third of the water column and was due to vertical differences in both temperature and salinity. Across transects I and J (Figure 2) stratification broke down rapidly in early fall, and although data were not collected during the subsequent winter months it is expected that the well-mixed conditions would have continued. Transect K, which is close to the boundary between LIS and Block Island Sound, remained only weakly stratified throughout the year.

Across all three transects the pycnocline shows a distinct lateral slope (Figure 2). Transect I was vertically well mixed in April with slightly less dense water located to the north along the Connecticut shore. This lateral gradient became more pronounced in early May when the channel became weakly stratified and the pycnocline across the whole section sloped down to the north. However, by late May (data not shown) the pycnocline slope had reversed and the less dense water was found at the southern end of the section adjacent to the Long Island Shore. Similar lateral gradients persisted through June, July and August with a maximum density difference of 2 sigma-t over a distance of 25 km. This is very similar to the longitudinal density gradient along the channel between transect K and transect I during the same months. The lateral density distribution primarily reflects the salinity distribution. The surface waters along the Long Island shore had a lower salinity throughout the summer. In September the vertical stratification broke down, but a lateral density difference could still be seen with the less dense water to the south. Both lateral and vertical density differences had been erased by October.

A similar seasonal sequence was observed at transect J (Figure 2) although here the influence of the Connecticut River outflow can be seen more clearly. During April the water column was well mixed over the channel but distinctly stratified between Long Sand Shoal and the Connecticut shore, presumably due to outflow from the Connecticut River. A similar distribution was seen in May, but by July a moderate level of stratification had been established across the whole section and the lateral gradients had reversed such that the pycnocline sloped down toward the south. This distribution continued through August. In September the water column was once again well mixed although some lateral density gradient persisted with less dense water along the Long Island shore. In October increased river outflows generated a small lens of fresher water along the Connecticut shore.

In contrast to transects I and J, the pycnocline slope at transect K did not reverse between the spring and summer. There was no evidence of low density water due to outflow from the Connecticut River, even though some of the data were collected during the ebb tide. Throughout the measurement period the pycnocline was either approximately horizontal or tilted down to the south. The lateral gradients were not as strong as at transect I or J, but persisted into the early fall.

Measurements made across transect J on 7/16/92 showed that the direction of the pycnocline slope across the central and southern parts of the transect did not reverse through a tidal cycle. On this date transect J was weakly stratified with a pycnocline which sloped down to the south. This is

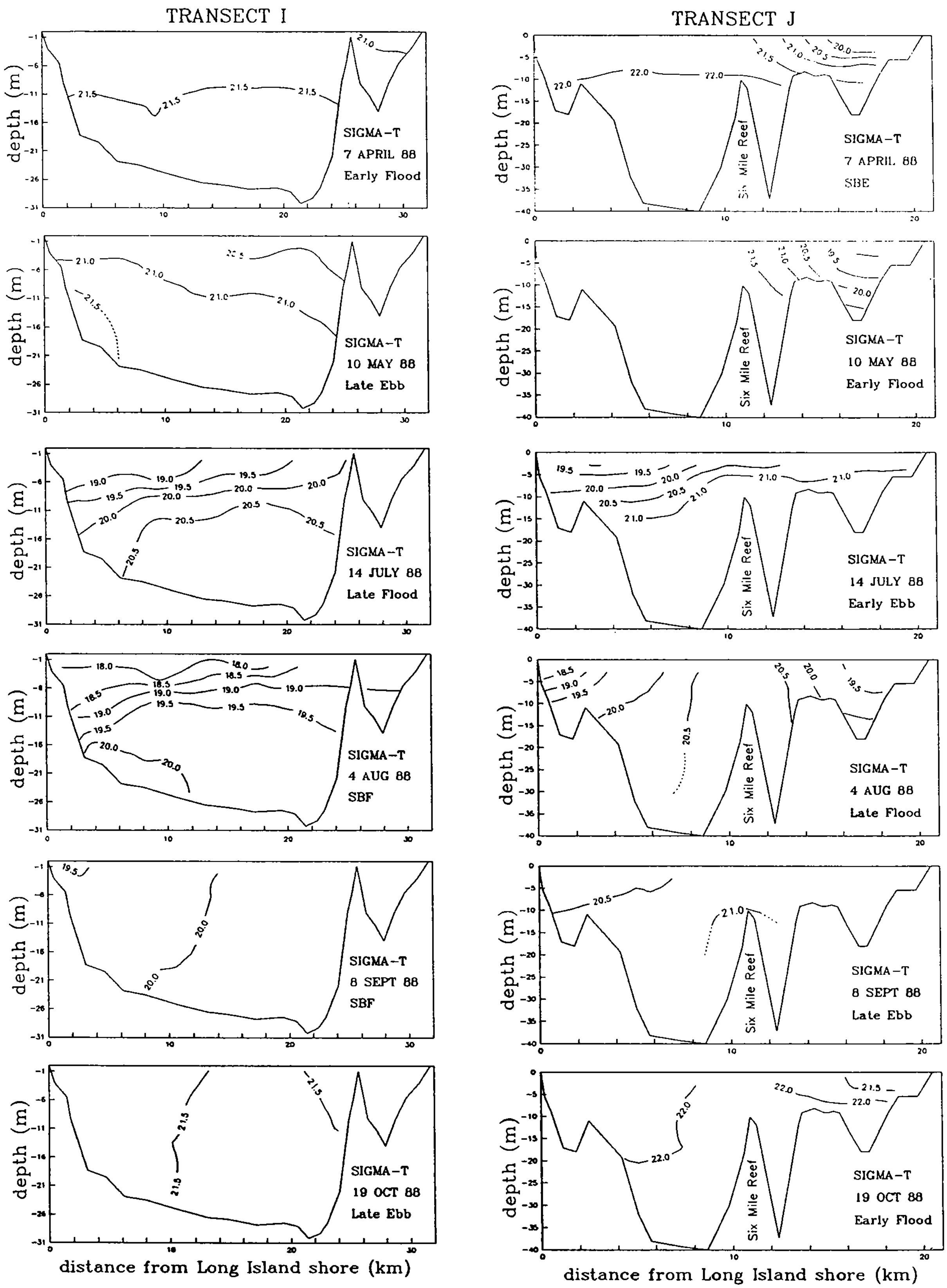

Figure 2: Isopycnals across eastern Long Island Sound for the months of April to December 1988. The sections are looking up-estuary (westward). For the locations of transects I and J see Fig. 1.

consistent with the measurements made in 1988. Adjacent to the Connecticut shore a localized reversal of the lateral gradient was seen at the end of the flood tide as lower salinity water from the Connecticut River plume was advected along the shore. From the 1992 results it can be inferred that the seasonal changes in lateral pycnocline slope observed across transects I and J are not an artifact of the data being collected at differing tidal phases.

Discussion

The lateral density distribution across eastern LIS is a reflection of the direction and strength of the residual circulation. This cannot be verified directly for the 1988 data because no current meters were deployed as part of the Long Island Sound Study in eastern LIS during the period April to December 1988. However, studies by Riley (1967), Gordon and Pilbeam (1975) and Wilson (1976) have shown that Long Island Sound exhibits a classical estuarine residual circulation pattern with up-estuary (westward) flow in the lower part of the water column, and down-estuary (eastward) flow near the surface. Within the eastern half of LIS the incoming residual currents are deflected by Coriolis and flow preferentially toward and along the northern shore, with the down estuary flow concentrated over the southern half of the Sound. This has been evident in the results of drifter studies (Gross and Bumpus, 1971; Hollman and Sandberg, 1972; Paskausky and Murphy, 1976) as well as current meter deployments (e.g. Gordon and Pilbeam, 1975).

The density distribution across the eastern part of LIS during 1988 supports this circulation pattern. The strongest vertical stratification occurred during mid-to-late summer. At this time it would be expected that the residual flow, and the influence of rotation on this flow, would be greatest. This was reflected in the pronounced lateral tilt of the pycnocline, with the more saline water positioned to the north throughout these months. Weaker residual circulation and less lateral separation of the flow would be expected in winter when the water column is only very weakly stratified.

The lateral density distribution observed during 1988 and 1992 may seem surprising knowing that a large volume of freshwater enters the LIS from the Connecticut River. Reduced salinities seen along the Connecticut shore in April and early May 1988, especially at transect J, and again along transect J at the end of the flood tide on 7/16/92, can be attributed to outflow from the Connecticut River which may be deflected westward by the flood tide (Garvine, 1974). It should be noted however the survey of 5/10/88 was done at the beginning of the flood tide, so clearly when the river outflow is large enough, the freshwater influence persists for more than a tidal cycle and may extend some distance along the Connecticut shore. At such times this freshwater may influence the lateral density distribution across eastern LIS such that the pycnocline slopes down toward the Connecticut shore. More usually though, turbulence and vertical mixing associated with the tidal and residual flow across Six Mile Reef and Long Sand Shoal contrive to mix this freshwater with the incoming seawater so that the salinity gradients are reduced. Gordon and Pilbeam (1975) have suggested that this region may act as a mixing zone, an idea which is supported by observations (by the authors) of longitudinal fronts along the Sound, just south of Six Mile Reef.

Conclusions

Within eastern LIS, hydrographic data suggests that lateral density gradients are a persistant feature through the spring and summer. Although the direction of the gradient changes in response to changes in the Connecticut River outflow, the magnitude of these gradients are at least as large as the longitudinal gradients. This density distribution will add a lateral component to the residual flow, directed to the south in the bottom waters. Although this flow will be smaller than the longitudinal flow, it may be significant when evaluating the dynamic balance and transport pathways in eastern Long Island Sound.

Acknowledgments

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Evidence of Helmholtz Resonance in Long Island Sound and its Response to a Rise in Sea Level

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Simulations are presented to support a contention that observed variations in tidal range and phase of the semidiurnal tide in Long Island Sound are more consistent with a Helmholtz response than quarter wave co-oscillation. The morphology of the basin should lead to a Helmholtz mode near 10 hours; the response would be characterized by a depression in range near the mouth, a rapid change in phase in the eastern Sound, and by a relatively uniform phase west of the Mattituck sill which lies near the entrance. Both of these features are observed. Preliminary results suggest that a rise in sea level will decrease the tidal amplification from mouth to head, as resonance theory predicts. However the tidal range at the mouth increases, resulting in a small increase in the tidal range throughout the region as sea level rises.

Marine Fisheries

Long Island Sound Fishery Resource Abundance in Relation to Dissolved Oxygen

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The Connecticut Department of Environmental Protection, Marine Fisheries, has monitored the status of fishery resources in Long Island Sound in a trawl survey program since 1984. The survey is based on a stratified-random sampling design and includes all trawlable areas of the Sound from about 5 m to more than 46 m on sand, mud and transitional sediments. In 1985, the Long Island Sound Study (LISS) identified hypoxia as the most pressing environmental problem of the Sound with the most severe hypoxia occurring in the westernmost areas. In response, the trawl survey was expanded between 1986 and 1990 to include four fixed stations north of Hempstead Harbor in the western narrows where severe hypoxia had been reported.

At each station a 14 m otter trawl with graduated mesh ranging from 102 mm at the mouth to 51 mm in the codend was towed for 30 minutes at 3.5 kts. Finfish, lobsters and squid were enumerated by species, and at the end of each tow, bottom temperature, salinity and dissolved oxygen (DO) were recorded using a YSI Model 33 salinometer and Model 58 dissolved oxygen meter. Length data were also collected from bluefish, scup, winter flounder and lobster. The four Hempstead stations and trawl survey sites as far east as Guilford, Connecticut were sampled then used to evaluate the effects of low dissolved oxygen on the relative abundance and size distribution of fishery resources in these areas.

We found significant reductions in frequency occurrence for 15 common species when DO declined below 2 mg/l. The occurrence of at least three of the most common species was also somewhat limited by DOs of 2-3 mg/l. The frequency occurrence of three other species - lobster, striped searobin and fourbeard rockling - did not decline significantly with DO, even below 2 mg/l. Species richness and ln transformed total counts per tow (all species combined) were also positively correlated with DO. Winter flounder showed a significant positive correlation between geometric mean length/tow and DO, whereas bluefish, scup, and lobster did not. We found little evidence that DOs greater than 3 mg/l were limiting to fishery resources.

A second three-year study was initiated in 1991 to complement the work done through 1990. Four principal factors were addressed in the design of the new study: first, the standard 30-minute tow often could not be completed because of obstructions to trawling, particularly in the western Sound and, additionally, the random selection of stations by area sometimes lead to too few hypoxia-prone shallow westernsites being sampled. The length of each tow (1.75 nmi) occasionally resulted in a tow being made through a gradient of bottom DO of 1.0 mg/l or more. It was often visually apparent that individuals of many species not measured (due to time constraints) were smaller in low DO areas, yet without a measure of biomass or extensive length sampling we could not demonstrate such effects, and there were concerns that many small individuals of several species were poorly retained in the larger mesh used in the previous study.

To address these limitations, a new stratified-random sampling design was developed. Sampling is conducted biweekly in July and August at 39 stations. Stations are stratified into five 10-12 nmi wide zones and two depth intervals (< 60 ft, > 60 ft) (Figure 1). Twenty stations are sampled with the trawl and 19 are sampled for water quality only. A 14 m net is used, but the mesh size has been reduced to 51 mm throughout the net with a 6.4 mm codend liner in order to retain smaller size fish and invertebrates. Tow duration and speed have also been reduced to 15 minutes and 2.5 kts resulting in an average distance trawled of 0.63 nmi. A CTD is used to record temperature, salinity and DO through the water column at the water quality stations and at the beginning and end of each trawl. Trawls with bottom (+1 m) DOs varying more than 1.0 mg/l between the start and end are eliminated from subsequent analyses. Winkler titrations from water samples collected at the surface (-2 m) and bottom (+2 m) at the beginning of each tow and at each water quality site are used to validate DOs from the CTD. And finally, biomass (kg) is now recorded for each species, including macroinvertebrates, and length frequency data are collected for 24 common species of finfish, lobster and squid.

The principal objectives of the study are to estimate the area and duration of hypoxia in 1.0 mg/l intervals throughout the 650 sq nmi sampling area and to identify dissolved oxygen thresholds for common species, species richness and total biomass. A preliminary evaluation of the revised sampling design was done based on 1991 sampling. The area and duration of hypoxia were estimated and possible DO impacts on resource abundance at 3.0 mg/l and above were evaluated.

In 1991, hypoxia persisted in the western narrows for approximately 42 days between July 17 and August 27, with DOs between 0.9 and 2.9 mg/l. Less severe hypoxia (2.0 -3.0 mg/l) persisted for at least 45 days and possibly as much as 52 days in the deeper (>60ft) areas of the western basin. Hypoxia was most widespread between late July and mid-August, prior to Hurricane Bob on August 19. During this period approximately 130 sq. mi. of the Sound was below 3 mg/l and another 135 sq. mi. was below 4.0 mg/l (Figure 2).

Trawl stations where DO was above 3 mg/l in 1991 were used to compare the response of ln transformed total counts/tow (all species combined), ln transformed total biomass/tow and species richness to dissolved oxygen concentration. We found no correlation between ln transformed counts/tow and DO above 3 mg/l, but significant positive correlations were found between both ln transformed biomass/tow ($P=0.28$, $R^2=0.11$) (Figure 3) and species richness ($P=0.04$, $R^2=0.09$) and DO. More detailed examination on an individual species basis will be conducted upon completion of sampling in 1993.

The shorter tow distance and stratification by area used in this study has increased access to sites between Norwalk and Bridgeport where DO may range from 1.0 to 5.0+ mg/l within a contiguous 50 sq. mi. area. In the previous study, most low DO (<3 mg/l) samples were taken at Hempstead and had to be compared to high DO (>3 mg/l) samples collected at locations 20 nmi or more to the east. Consequently, area and DO effects could not be distinguished. The smaller mesh clearly retains smaller fish, however, we have not yet determined whether the shorter tow duration and slower tow speed allows more of the largest fish such as adult bluefish to escape. Finally, biomass appears to be more responsive to dissolved oxygen concentration than counts/tow.

Table 1. 1991 areal hypoxia estimates
The area of Long Island Sound within 1 mg/l intervals was estimated for four sampling periods between July 11 and September 12, 1991.

	Sampling dates			
DO Interval (mg/l)	**Cruise 1 7/11 to 7/18 Area (sq.n.mi.)**	**Cruise 2 7/29 to 8/1 Area (sq.n.mi.)**	**Cruise 3 8/21 to 8/28 Area (sq.n.mi.)**	**Cruise 4 9/11 to 9/12 Area (sq.n.mi.)**
0.0–1.0	–	13.20	–	–
1.1–2.0	–	48.42	–	–
2.1–3.0	9.23	67.14	27.51	–
3.1–4.0	102.06	135.66	100.43	–
4.1–5.0	234.87	176.75	138.28	20.68*
5.1 and up	297.05	202.04	376.99	217.15*
Total area:	643.21	643.21	643.21	237.83*

*Only zones 1, 2 and 5 were sampled in September.

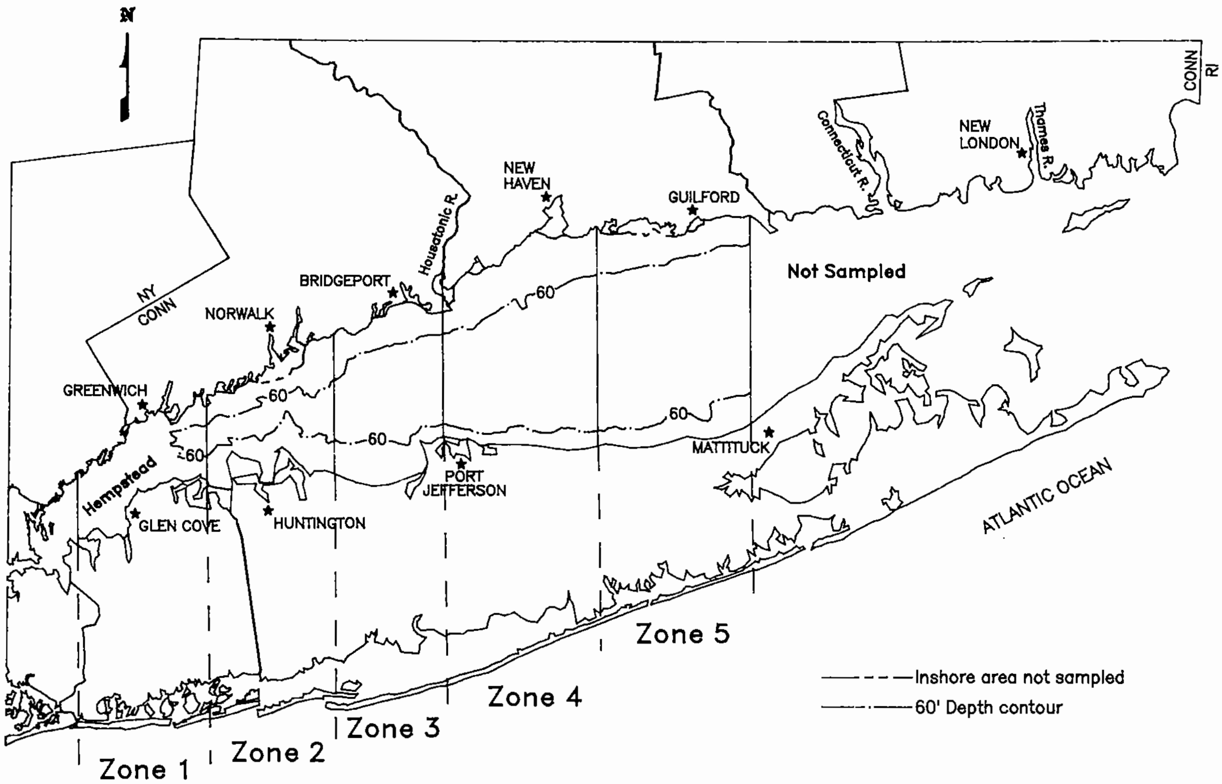

Figure 1. Summer survey map. Sampling is stratified by Zone (1-5) and Depth (<60 ft, >60 ft). The eastern Sound and inshore areas are not sampled.

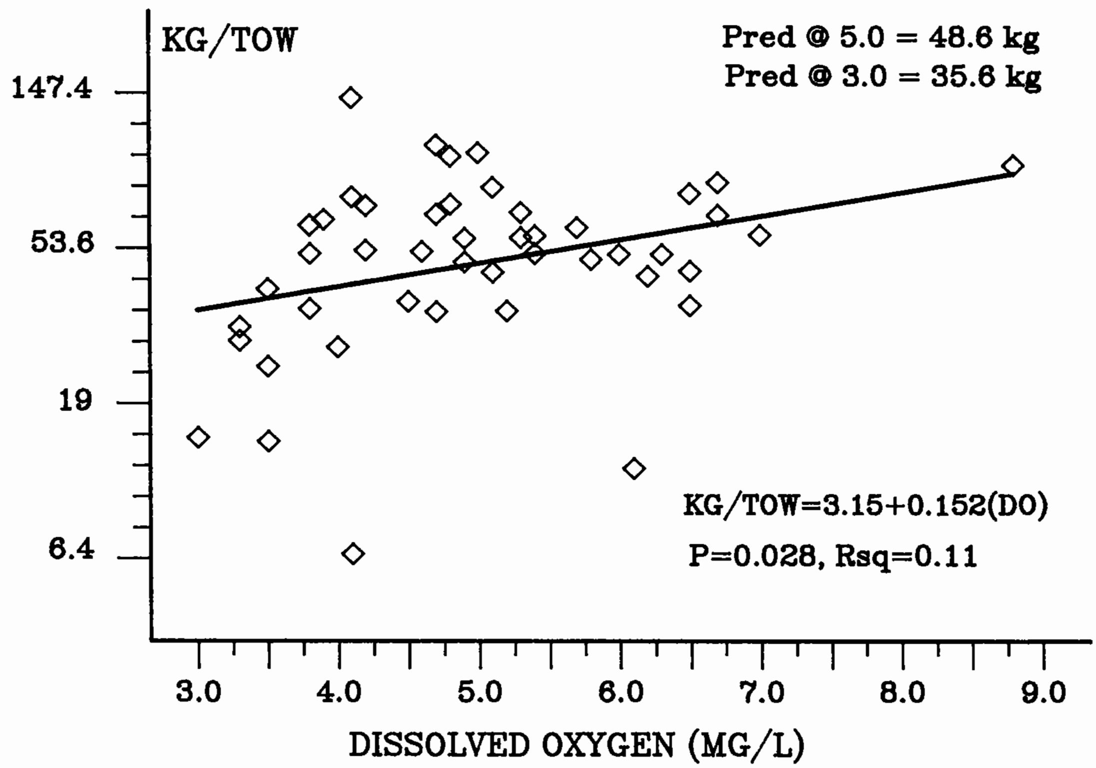

Figure 2. Linear regression of retransformed ln biomass (kg/tow) on dissolved oxygen (DO)(mg/l) from 45 sites in 1991 where DO was 3.0 mg/l or higher.

Biological Baselines of Plankton Populations in Long Island Sound: What We Know and Don't Know (Contribution No. XXX, Marine Sciences Research Center)

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Introduction

Basic knowledge on the trophic structure of the aquatic communities of Long Island Sound is central in understanding human impact on the system. Over the last 40 years, the plankton communities of the Sound have been surveyed at irregular intervals. Perhaps the best known and most thorough to date were those conducted in the early 1950s by Gordon Riley and associates at the Bingham Oceanographic Laboratory at Yale. Those surveys were the first and only Sound-wide studies of planktonic organisms. Since then, field studies have focused on smaller sampling regions or specific species, with various goals and objectives. The majority of academic research projects conducted in the Sound have been species-specific studies of copepods (e. g. Dam Guerrero, 1985; Johnson, 1987) and ichthyoplankton (Ausubel, 1983; Boampong, 1984; Monteleone, 1984). As a requirement for construction of power plants, e.g. the Millstone, Northport, Jamesport and Shoreham power plants (Figure 1), site-specific surveys of several taxonomic levels of organisms were contracted by utility companies. Also, short-term monitoring studies have been conducted for dredged material disposal sites (e.g. Eaton's Neck Disposal Site).

In an effort to characterize the lower trophic levels of plankton organisms in Long Island Sound, more than 50 data sets (Table l) were examined. We offer this summary report as an overview of the current state of knowledge of "what we know" about the abundance and distribution of phytoplankton, zooplankton and ichthyoplankton in the Sound. A more in-depth presentation of the data is provided in Monteleone *et al.* (1992). We conclude with a brief discussion of "what we don't know" and what is needed to better understand how perturbations of the Long Island Sound ecosystem (e. g. hypoxia) might affect plankton communities.

Phytoplankton

There are seasonal changes in concentration of phytoplankton in Long Island Sound (Conover, S. A. M., 1956; Riley, 1967; Riley and Conover, 1967; Capriulo and Carpenter, 1983; Peterson, 1986; EA, 1989a). A late winter, early spring phytoplankton bloom is triggered by the vernal increase in light intensity. The timing of this bloom, which can vary from year to year, most often occurs during February and early March. In the central and eastern Sound, chlorophyll *a* concentrations during the winter-spring bloom can exceed 15 $\mu g\ L^{-1}$ with corresponding cell densities of 35,000 m L^{-1} (more often 10-20,000 cells mL^{-1} (Conover, S. A. M., 1956; NUSCO, 1983, 1988; Normandeau, 1985; Peterson, 1986; Bellantoni, 1987; EA, 1988). Termination of this bloom is due to exhaustion of nitrogenous nutrients (Conover, S. A. M., 1956). A late summer, early fall bloom occurs in the Sound when the thermocline breaks down and allows nutrient-rich bottom water to be mixed upward (Riley and Conover, 1967). Phytoplankton concentrations during this summer-fall bloom can reach 10-15 μg chlorophyll L^{-1} and 5,000 cells mL^{-1} (Conover, S. A. M., 1956; NUSCO, 1983, 1988; Normandeau, 1985; Peterson, 1986; Bellantoni, 1987; EA, 1988).

The phytoplankton community in Long Island Sound is comprised of 40 major and 150 minor species constituents (Conover, S. A. M., 1956) with separate diatom and dinoflagellate blooms occurring at different times of the year. The diatoms *Skeletonema costatum*, and *Thalassiosira nordenskioldii*

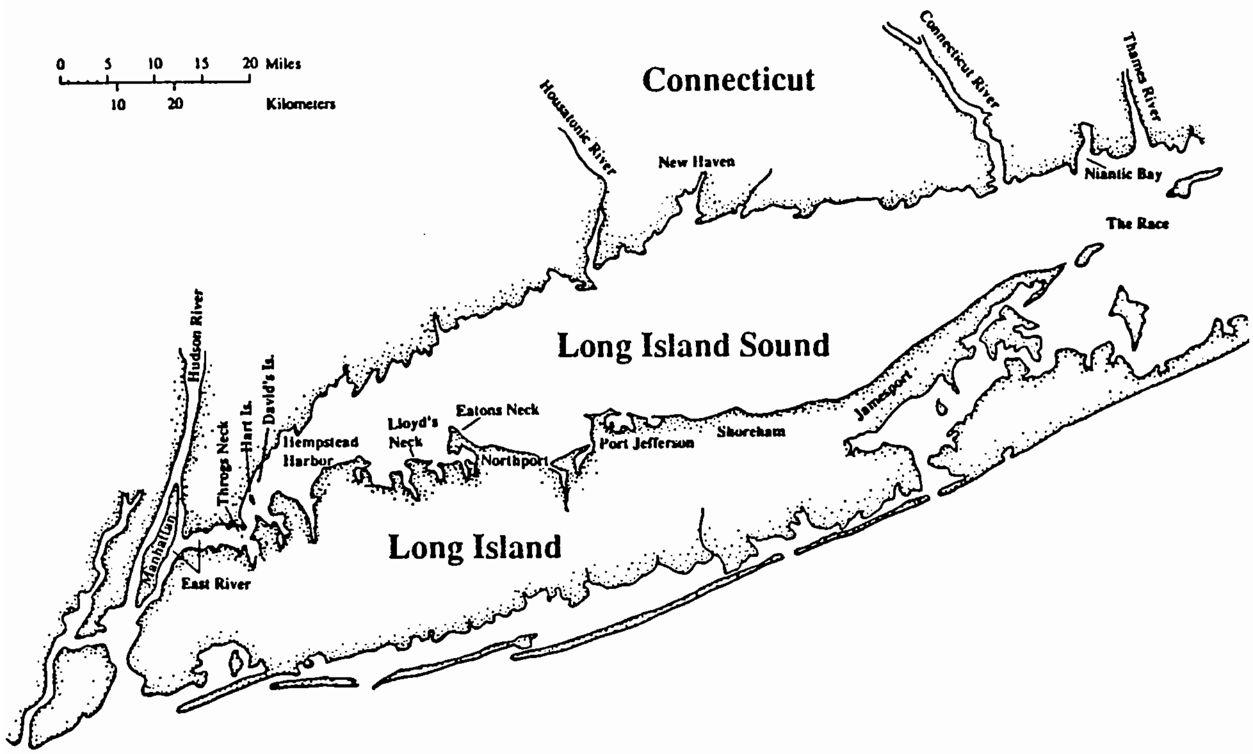

Figure 1. Map of Long Island Sound.

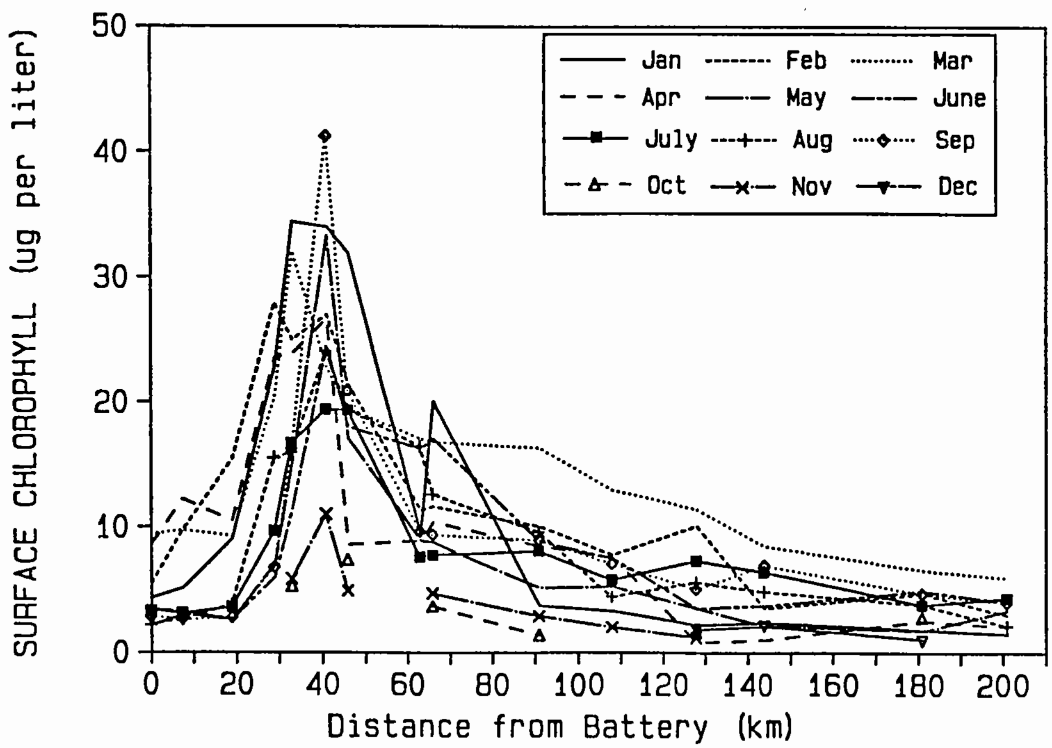

Figure 2. Surface chlorophyll a concentrations taken in Long Island Sound during 1989 (data from Cosper *et al.*, unpubl.).

Table 1. Sources of distribution and abundance data for P=Phytoplankton,Z=Zooplankton, I=Ichthyoplankton in Long Island Sound

Source	Region	Year	Data
Ausubel (1983)	Central Sound	1982-83	ZI
Bellantoni and Peterson (1987)	Central Sound	1985	PZ
Boampong (1984)	Central Sound	1982-83	I
Bowman *et al.* (1981)	Soundwide	1978	P
Caplan (1977)	Eaton's Neck, NY	1974-75	PZI
Capriulo and Carpenter (1980)	Port Jefferson, NY	1976-77	PZ
Capriulo and Carpenter (1983)	Port Jefferson, NY	1979-80	PZ
Conover, R. J. (1956)	Soundwide	1952-54	Z
Conover, S . A. M . (1956)	Soundwide	1952-54	P
Cosper et *al.* (unpub.)	Soundwide	1989	PZ
Dam Gurerro (1989)	Central Sound	1986	Z
Deevey (1956)	Soundwide	1952-54	Z
EA (1987)	Shoreham, NY	1983-86	PZI
EA (1989a,b,90)	Shoreham, NY	1987-89	I
Environ. Analysist (1975)	Hart Island, NY	1974	PZI
Hardy and Weyl (1970, 71)	Soundwide	1970	P
Johnson (1987)	Central Sound	1982	Z
J onasdottir (1992)	Central Sound	1989-90	PZ
Lekan and Wilson (1978)	Eastern Sound	1975	P
LILCO (1973)	Northport, NY	1972	PZI
LILCO (1974)	Shoreham, NY	1973-74	PZI
LILCO (1975)	Jamesport, NY	1974	PZI
LILCO (1977b)	Hempstead, NY	1976	IF
LILCO (197 7a)	Port Jefferson, NY	1976	IF
LILCO (1979,80,81,82,83)	Shoreham,NY	1977-82	PZI
McManus (1986)	Central Sound	1982-83	PZ
Monteleone (1984)	Central Sound	1982-83	PZI
Monteleone *et al.* (1987)	Central Sound	1951-83	PZI
NMFS (1972)	David's Island, NY	1971	PZI
Normandeau (1979, 81, 85)	New Haven, CT	1970-84	PZI
NUSCO (1983)	Waterford, CT	1968-81	PZI
NUSCO (1984)	Waterford, CT	1983	Z
Olson (1976)	Western Sound	1975	P
Pastalove (1973)	Western Sound	1971	Z
Perlmutter (1939)	Soundwide	1938	I
Peterson (1985, 86)	Central Sound	1982-83	PZ
Peterson and Bellantoni (1987)	Central Sound	1985	PZ
Richards (1959)	Soundwide	1954-56	I
Riley and Conover (1967)	Soundwide	1954-55	P
Schnitzer (1979)	Soundwide	1978	P
Wheatland (1956)	Soundwide	1952-54	I
Williams (1968)	Old Field Pt, NY	1964-66	I
Williams *et al.* (1971)	Northport, NY	1969	PZ

dominate during the winter-spring bloom. *Thalassionema nitzschoides*, several *Thalassiosira* species and *Rhizosolenia delicatulum* occur later in the spring and *S. costatum*, *T. nitzschoides*, *Ditylum brightwellii*, *Coscinodiscus sp.*, *Leptocylindricus danicus* and *Thalassiosira pseudonana* dominate in late summer (Olson, 1976; Conover, S. A. M, 1956). *S. costatum* has been the overwhelmingly dominant species present in at least trace quantities throughout the year in the Sound (Conover, S. A. M., 1956; Riley, 1967; LILCO, 1983; EA, 1988). The dinoflagellate genera *Prorocentrum*, *Peridinium*, *Gyrodinium* and *Exuviella* can be abundant when the water column is stratified from May through August (Peterson, 1986). It should be noted, however that the naked dinoflagellate communities were underestimated in many studies because samples were preserved in formalin which is not appropriate for these protists.

As part of an EPA Long Island Sound Study-funded project, chlorophyll *a* concentrations were measured in the surface waters (at a depth of 2 m) of the Sound during 1989 (Cosper *et al.*, unpub.) (Figure 2). In general, concentrations were relatively low in the East River and increased toward the western Sound. Chlorophyll concentrations tend to be greater in western Long Island Sound and decrease toward the east (Figure 2). The highest concentrations were consistently located in the region between the Throgs Neck Bridge and Lloyd's Neck; where, at times, the surface chlorophyll concentrations exceeded 30 $\mu g\ L^{-1}$. These concentrations were similar to those reported by Olson (1976) and Schnitzer (1979) who sampled this area 14 and 11 years earlier, respectively. In their studies, there was more than a 50 $\mu g\ L^{-1}$ increase in the surface chlorophyll values over an east-west transect about 25 km long (from about north of Smithtown Bay to north of Oyster Bay). When compared on a seasonal basis to other regions in Long Island Sound, chlorophyll concentrations are always substantially higher in the region of Throgs Neck to Lloyd's Neck.

When classified by size, spatial differences in phytoplankton abundance have been shown. Schnitzer (1979) determined that in September 1978 the percent nanoplankton chlorophyll (< 20 µm) in the surface waters of Long Island Sound were lowest in the west and along the Connecticut shore where nutrient levels were high, and increased toward the east and Long Island shore. Cosper *et al.* (unpub.) counted phytoplankton collected from stations along an east-west axis of the Sound in 1989. These data show that based on cell counts, an intense bloom of > 10 µm (diatom dominated) cells occurred in the western end of Long Island Sound in the spring. Another intense bloom of these larger cells occurred in the fall. The data collected from the Sound indicate that larger diameter phytoplankton tend to be more abundant at the eastern stations. However, more field studies are needed to confirm this phenomenon .

Zooplankton

Microzooplankton (defined as zooplankton <202 µm) are dominated by small flagellates and tintinnids. Heterotrophic flagellates are most abundant in spring and early summer when densities can reach 3,500,000 cell L^{-1} (McManus, 1986). Capriulo and Carpenter (1983) identified 24 species of tintinnids, ranging in abundance from 268-12,600 L^{-1} . Cosper *et al.* (unpub.) found similar densities in the 1989 Long Island Sound Study survey. Highest concentrations of tintinnids occur during the temperature maximum (Capriulo and Carpenter, 1983; Cosper *et al.*, unpub.) . At that time, *Tintinnopsis minuta* dominated and other ciliates occurred only occasionally.

Six major taxonomic groups contribute to more than 96% of the metazoan zooplankton collected in Long Island Sound. At the Millstone Power Station (northeastern Sound) in 1983, copepods accounted for 88.7%; cirripedians, 5.4%; gastropods, 3.2%; decapods, 1.2%; cladocerans, 0.7% and amphipods, 0.5%. Total numbers of zooplankton (excluding copepods) can reach densities of greater than 0.1 L^{-1} ($10^2\ m^{-3}$) (LILCO, 1979-83; EA, 1987-90) and represent a diverse species assemblage in the Sound. Both holoplankton (e.g., cladocerans and ctenophores) and meroplankton (e.g., early life stages of bivalves, gastropods, barnacles, polychaetes, shrimp, and crabs) are abundant.

In general, copepods are the principal mesozooplankters (by number and biomass) collected in the coastal waters of New York (Turner, 1982; LILCO, 1979-83; Gunn, 1987; Monteleone, 1988) and in Long Island Sound, there are two temporally segregated copepod assemblages (Figure 3) (LILCO, 1979-83; NUSCO, 1983; Peterson, 1986; Johnson, 1987). The winter-spring population is dominated by *Temora longicornis, Acartia hudsonica* (formerly *A. clausii)* and *Pseudocalanus sp.* During the summer and fall *Acartia tonsa, Paracalanus crassirostris* (formerly *Parvocalanus crassirostris)* and *Oithona similis* prevail. The temporal distribution of these species, noted by Peterson (1986) and Johnson (1987) from their 1982 survey in the central Sound, was consistent with a 1952-1953 survey by Deevey (1956) 30 years earlier. These patterns also were evident in all known surveys of Long Island Sound's zooplankton community including Pastalove (1973) in western Long Island Sound; Normandeau (1979, 1981, 1985) at New Haven Harbor, CT; NUSCO (1983) at Niantic Bay, CT; Caplan (1977) off Eaton's Neck, NY and LILCO (1979-83) off Shoreham, NY. There are a total of 18 species of copepods common to most of these studies.

The occurrence of various species of copepods depends on several factors. The abundance of cold-water species decreases when temperatures within the upper mixed layer exceed 19°C, when they are replaced by the warm water species which dominate until the water temperature falls to 15°C (Peterson, 1986). Copepod population increases usually are dependent on temperature and food concentrations (Peterson, 1986). Populations can be "restarted" by a few adults which may have persisted throughout the year (Smith and Lane, 1987), by the hatching of resting eggs (Marcus, 1982; Sullivan and McManus, 1986), and possibly by influxes of adults from Block Island Sound (W. T. Peterson, hypothesis). The early spring "restart" of the *Temora longicornis* population results from (l) a gradual increase in the abundance of adult females during the winter as the bottom water of Long Island Sound is replaced with Block Island Sound water, and (2) a burst in egg production in response to the annual spring phytoplankton bloom in February (Peterson, 1986). The "restart" of the *Acartia hudsonica* and *Pseudocalanus sp.* populations are not as well-understood, but in the case of *A. hudsonica* the hatching of resting eggs may be important (Sullivan and McManus, 1986).

The summer-fall assemblage of copepods is dominated by species with subtropical affinities. *Acartia tonsa, Paracalanus crassirostris* and *Oithona similis* begin to increase in abundance when the water temperature of the Sound exceeds 15°C in late spring/early summer. Although conditions (high phytoplankton concentration and elevated water temperatures) are suitable for rapid growth at that time , copepod populations do not achieve maximum abundances until September because of intense predation by the ctenophore, *Mnemiopsis leidyi* (Boampong, 1984; Johnson, 1987). There is a burst in copepod egg production in response to the fall phytoplankton bloom and lowered mortality rates resulting from declines in ctenophore abundances (Beckman and Peterson, 1986). The copepod population begins to decline again in early November because egg production rates become severely limited by cool temperatures and food availability.

Ichthyoplankton

In temperate waters fish are seasonal spawners (Herman, 1959; Ferraro, 1980; Monteleone, 1992), however some spawning seasons are more protracted than others (Table 2). The major spawners in the Sound appear to be ubiquitous (Table 2), although data are severely lacking for western Long Island Sound). The greatest number of species spawn from May through July and the least from September to November.

In general, the dominant fish eggs present in Long Island Sound are the bay anchovy (*Anchoa mitchilli*). The most abundant fish eggs by species (not in order) were Atlantic mackerel (*Scomber scombrus)*; two labrids, tautog (*Tautoga onitis*) and cunner (*Tautogolabrus adspersus*); fourbeard rockling (*Enchelyopus cimbrius*); windowpane flounder (*Scopthalmus aquosus*); summer flounder

Table 2. Occurrence (*=range; X=peak) of fish eggs and larvae in Long IslandSound (data from Wheatland, 1956; Richards, 1959; LILCO, 1979-83; Ausubel, 1983; Boampong, 1984; Monteleone, 1984)

EGGS SPECIES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Ammodytes americanus	****										XXXX	XXXX
Anchoa mitchilli					****	XXXX	XXXX	XXXX	****			
Brevoortia tyrannus			XXXX	XXXX	****	****	****	****				
Cynoscion regalis				****	****							
Enchelyopus cimbrius	****	****	****	XXXX	****	****						
Limanda ferruginea				****								
Menticirrhus saxatilis						****	****					
Peprilus triacanthus						XXXX	****	****	****			
Prionotus carolinus						****	XXXX	****				
Pleuronectes americanus			****	XXXX	****							
Scomber scombrus				****	XXXX	****						
Scopthalmus aquosus			****	****	XXXX	****	****	****	****	****		
Stenotomus chrysops					****	****	****					
Tautoga onitis					****	XXXX	XXXX	****	****	****		
Tautogolabrus adspersus					****	XXXX	XXXX	****	****			
Trinectes maculatus						****	XXXX	****				

LARVAE SPECIES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Ammodytes americanus	****	****	****	****	****	****						XXXX
Anchoa mitchilli						****	XXXX	****	****	****		
Anguilla rostrata	****											
Brevoortia tyrannus					****	****	XXXX	****	****	XXXX		
Clupea harengus			****									
Cynoscion regalis						****	XXXX					
Enchelyopus cimbrius					XXXX	****						
Limanda ferruginea				****	****	****						
Menidia menidia						****						
Mentricirrhus saxatilis								****				
Myoxocephalus octodemispinosus		XXXX	XXXX	****								
Paralychthys oblongus									****			
Peprilus triacanthus						****	****	****	****	**		
Prionotus carolinus								XXXX	****			
Pleuronectes americanus				*****	XXXX	****	***					
Scomber scombrus						****	****	****				
Scopthalmus aquosus						XXXX	****	****	*			
Sphaeroides maculatus							****					
Stenotomus chrysops						****	****					
Sygnanthus fuscus							****					
Tautoga onitis					XXXX	****						
Tautogolabrus adspersus						XXXX	****	****	****			

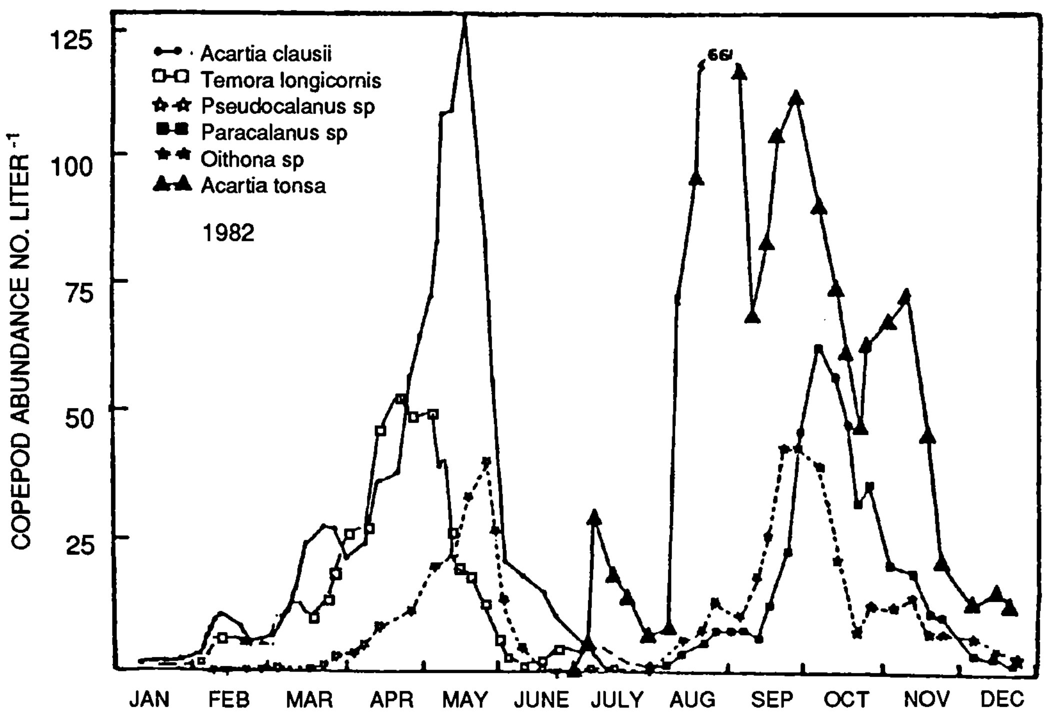

Figure 3. Densities of copepods populations in central Long Island Sound during 1982 (*clausii=hudsonica*). Data are integrated over the whole water column. Redrawn from Peterson (1986).

(*Paralychthys dentatus*); and yellowtail flounder (*Limanda ferruginea*). None of the plankton sampling programs attempted to collect demersal eggs (such as winter flounder, *Pleuronectes americanus* and American sand lance, *Ammodytes Americanus*). There were very few Atlantic mackerel eggs collected in the 1950s, but they were relatively abundant in the more recent surveys (Horvath, 1985).

American sand lance and bay anchovy were the two most abundant species collected as larvae in the Sound. American sand lance would undoubtedly outrank bay anchovy in the New Haven Harbor studies (Normandeau, 1919, 1981, 1985) if sampling had continued through December and January. Other dominant larval fish were tautog, winter flounder, pipefish (*Sygnanthus fuscus*), Atlantic mackerel, Atlantic menhaden, fourbeard rockling, weakfish (*Cynoscion regalis*), sculpin (*Myoxocephalus sp.*), butterfish (*Peprilus triacanthus*) and Atlantic silverside (*Menidia menidia*).

Discussion

Diversity, biomass, and reproduction of organisms may be altered by the degradation and destruction of habitat. Over 14 million people live within the drainage basin of Long Island Sound (LISS, 1989), which has led to perturbations of the ecosystem in many ways including hypoxia (Parker and O'Reilly, 1991), eutrophication, and toxic contamination (LISS, 1990). However, because of the lack of recent comprehensive data for the marine organisms, especially in the western Sound, the effects of hypoxia on the lower trophic levels in the plankton can not be adequately evaluated. In addition, it would be difficult to predict how improvements in dissolved oxygen concentrations in the Sound may affect planktonic organisms if basic information such as species abundance, seasonality, and vertical distribution patterns is not known.

The results of the 1989 sampling of phytoplankton in Long Island Sound clearly demonstrated regional differences. The western Long Island Sound is a region of extremely high chlorophyll concentrations, probably due to nutrient inputs. These concentrations do not exhibit the typical seasonal patterns found in the central and eastern portions of the Sound. Phytoplankton cell counts indicate that there is an abundance of cells greater than 10 µm in diameter in the western Sound. These cells tend to be diatoms, the group of phytoplankton commonly nutrient-limited in the summer months in other nearby coastal areas. However, because of eutrophication, nutrients are not limited; they may be dominant year-round in the western Sound. The implications of these changes on the trophic dynamics of the Sound may be substantial. For example, recent studies in the Sound suggest that, at times, diatoms may be of a lower food quality than flagellates in supporting copepod egg production (Jonasdottir, 1992).

The U. S. Environmental Protection Agency's Long Island Sound Study designated hypoxia as the primary concern of the Sound, yet the least amount of plankton research has been conducted in the western region where hypoxia (and eutrophication) is most severe. None of the studies discussed in the review were designed to determine the affects of hypoxia on living marine resources. We can only hypothesize how organisms may be affected. We know that the composition and abundance of phytoplankton varies spatially, but the last Sound-wide data set on zooplankton and ichthyoplankton is 40 years old. We cannot answer such basic questions as how the rate of primary productivity in the nutrient-enriched region compares to the rest of the Sound, or if the next trophic level has been affected by compositional changes in phytoplankton. We need to know if fish spawn in hypoxic regions and if the mortality rate of early life stages of fish varies among these regions.

To better understand the dynamics of the living marine resources, we must conduct more comprehensive studies throughout the Long Island Sound. Until then, we can only hypothesize about what effects perturbations such as eutrophication, hypoxia and toxicants have had on organisms.

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Using the Marine Recreational Fisheries Statistics Survey (MRFSS) to Calculate Catch Estimates for Long Island Sound

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The Marine Recreational Fisheries Statistics Survey (MRFSS) methodology calculates catch estimates at the state level but is not designed to give estimates for individual water bodies (i.e. bays, sounds, rivers). For management purposes it is often beneficial to have such detailed geographical catch data, especially if distinct sub-populations exist. This paper suggests a method to extrapolate what proportion of New York's MRFSS estimated landings are caught in Long Island Sound.

MRFSS landing estimates for New York were subdivided into Long Island Sound, other inland waters, and open ocean categories. Unexpanded intercept landings numbers were proportioned among these areas based on location of interview and where the angler said he/she had fished. Eleven years of MRFSS data (1979-89) were combined for this analysis.

Long Island Sound accounted for approximately one-half of the scup and tautog landed recreationally in New York from 1979-89. An estimated one-fourth of the bluefish and weakfish landings were caught in the Sound. Long Island Sound also accounted for 10-15% of New York's recreational landings for four other popular species (winter flounder, summer flounder, striped bass, and black seabass). Long Island Sound anglers indicated they were targeting bluefish (36%) most often, followed by winter flounder (16%), scup (11%), tautog (10%), and summer flounder (10%).

Ecologically Significant Organisms in LIS

Benthic Ecology of Long Island Sound: A Short History, a Tentative Model, and a Benthoscape Approach

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The ecology of benthic communities in Long Island Sound (LIS) has been studied since the mid-1950s. Most offshore studies have either concentrated on the central basin (primarily in relation to disposal sites), the Fishers Island Sound area, or have been Sound-wide surveys. From this work several general trends regarding benthic community structure in LIS have emerged. However, there is no comprehensive model of benthic community structure that can be applied to the entire Sound. Such a model is presented which extends a model proposed by McCall (1977) and Rhoads, *et al.* (1978) which characterizes offshore communities based on their successional stage. These successional stages are recognized as endpoints for a more diverse collection of successional pathways that may be found throughout the Sound.

Previous studies have concentrated on discerning Sound-wide trends based on the distribution of communities as determined by systematic sampling. Subsequently, relationships to physical and biological factors were determined. The advent of technologies (e.g. side scan sonar and video) which are used for detailed mapping of the seafloor allows researchers to establish the physical milieu and habitat characteristics which may determine soft-sediment community structure prior to sampling. In turn, this allows for more specific hypothesis testing to determine how habitat characteristics (size, shape, orientation to flow, etc.) influence benthic community structure. Examples of this approach are given for studies conducted in eastern LIS and using data previously collected by others.

Contaminants in Ducks Wintering on Long Island Sound

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Each year more than a dozen species of ducks migrate through or winter in large numbers on the waters of Long Island Sound. The most abundant of these ducks are the scaup ("broadbill"), opportunistic top-of-the-food-chain consumers of locally abundant benthic invertebrates such as small bivalves and snails. Scaup typically feed in shallow bays at depths up to 10m. Interestingly, the alga "sea lettuce" (*Ulva lactuca*) has become more prominant in scaup diets.

Several duck species, particularly the Greater Scaup (*Aythya marila*), have been undergoing prolonged population declines. Long Island Sound has been a major winter concentration area for the North American population of Greater Scaup for decades. Since many scaup prey species are filter feeders known to accumulate contaminants such as heavy metals, foods and feeding areas which may be contaminated could be contributing to the decline in Greater Scaup and other ducks.

An investigation of the potential link between Greater Scaup, their winter foods and habitats, and contaminants is underway. Results of tests to determine the levels of heavy metals (e.g. As, Cd, Cu, Cr, Ni, Pb, Se, Zn), persistent chlorinated hydrocarbons (pesticides) and certain PCBs (polychlorinated biphenyls) in tissues of Greater Scaup and Lesser Scaup, by species, sex, and age class, will be presented. These data will be compared to data for scaup obtained in 1980-81 (N=10) and 1987-89 (N=23) from Long Island Sound.

Population Genetics of Kelp Species from Long Island Sound to Newfoundland

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Long Island Sound marks the southern geographic limit for several kelp species (Order Laminariales) along our coast. Using starch gel isozyme electrophoresis procedures developed for this study, we have investigated the population genetics of six kelp species over a geographic range extending from Long Island Sound to Newfoundland. We have examined enzymes from 17 loci in each of the six species, including *Laminaria saccharina, L. longicruris, L. digitata, Chorad filum, Agarum cribosum* and *Alaria esculenta*. Overall we found a very low degree of polymorphism in each species both within and between subpopulations. Furthermore, the few loci (3-5) that were polymorphic showed extremely low levels of heterozygosity. These results are consistent with the few reported studies that have used molecular genetic techniques to look at intraspecific variability in laminarian algae. We suggest that at the species level, the Laminariales, and perhaps other groups of brown algae, are genetically extremely conservative relative to plants in other divisions.

Reproduction of the Macroalga *Laminaria longicruris* de la Pyl. in Long Island Sound.

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Laminaria longicruris de la Pyl. (Phaeophyta) is an economically and ecologically important kelp, near the southern limit of its geographical distribution in the Western Atlantic Ocean at Long Island Sound. *L. longicruris* is a benthic, subtidal alga characterized by very high productivity and large biomass, with typical sporophytes 2-4 meters long. The life cycle is typical of kelp, involving the alternation of a macroscopic, diploid sporophyte with a microscopic, haploid meiospore stage, followed by dioecious gametophytes. Although extensive work has been carried out on the growth rates and productivity of the sporophyte of this kelp (Egan and Yarish, 1990), little is known about the meiospore stage and reproduction of the species. In this study, allocation of resources to reproduction (reproductive effort) was quantified for *L. longicruris* at Black Ledge, at the mouth of the Thames River in eastern Long Island Sound, where it dominates the flora. This area contains what is probably the largest *L. longicruris* bed in LIS, with an area ~ 1 km^2. Since the sporophyte has basically a 2-dimensional structure, the allocation of blade surface to reproduction was expressed as the ratio of sorus (reproductive) area to total blade area, a technique used by Klinger (1985). Perimeters of both sporophytes and sori were traced on brown paper, then tracings were cut out and weighed to calculate the areas, using the areal density of the paper. Comparisons were made among the seasons for all LIS populations, and between LIS and populations at more northerly latitudes. Mean reproductive effort was highest in the late fall and winter, ranging from 1 to 37%, with an annual mean of 5% (Figure 1). The reproductive potential of this kelp was noted in one unusual individual with 99% of its blade covered with sori. (See Van Patten, 1992 and Van Patten & Yarish, 1993 for more detail.)

Reproductive effort was also plotted with monthly growth rates, clearly showing a strong inverse relationship between growth and reproduction. This suggests a possible trade-off of resources, although it is possible that both the initiation of sporogenesis and the cessation of growth are triggered by the same environmental signal, such as daylength. Sporangia density was quantified, yielding an estimate of 8.9×10^9 spores per adult sporophyte. This yields 5.25×10^{10} spores per m^2 of seafloor, using a density of 7 sporophytes per m^2, the lowest density found at the Long Island Sound study site by Egan and Yarish (1990). This estimate compares well to the work of Chapman (1984) in Nova Scotia, although the Black Ledge population has a greater density. While kelp are traditionally thought of in terms of contribution to detrital food webs and the grazing of sporophytes, this vast quantity of pigmented, motile meiospores may be an important addition to the meroplankton, occurring at a time when dinoflagellates and diatoms are in low abundance. It is also interesting to note that the peak spore release occurs just after the hurricane season, allowing settling spores to take advantage of newly exposed substrate.

Further investigation examined the Spring, 1992 reproductive effort for three populations along a temperature gradient, to examine the influence of water temperature on meiospore production. Three study sites were chosen along a temperature gradient of about 6° C. within a small latitudinal range, so that photoperiod and insolation were nearly equivalent at all sites. Mean reproductive effort for individual spring sporophytes was highest at the most northerly site, Halifax Harbor, Nova Scotia (44° N), lower in the Great Bay Estuary (43° N) and lowest in Long Island Sound (41° N). with means of 8.9%, 7%, and 5% respectively (Figure 2). Regressions of the reproductive effort with latitude show zero reproduction occurring at about 37.8° N, corresponding roughly with the observed southern boundary of the species. Regression of the reproductive effort with temperature show a maximum spring temperature of 12-13° C. This corresponds to a summer temperature of

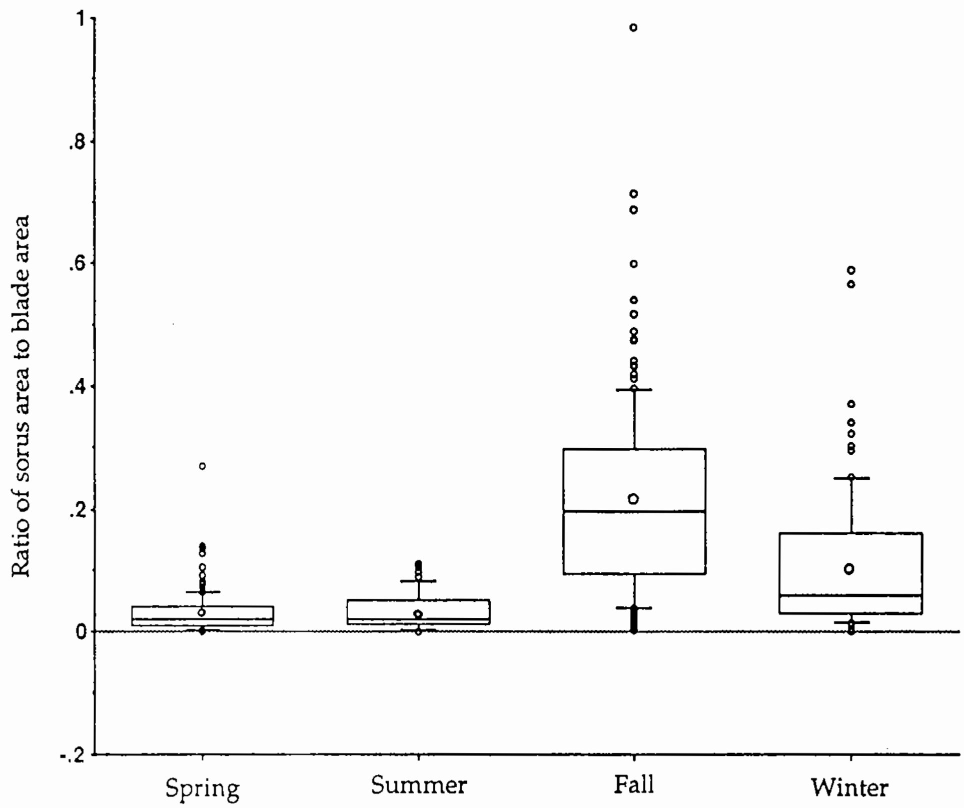

Figure 1. Reproductive effort (ratio of sorus area to total blade area) for kelp sporophytes in Long Island Sound.

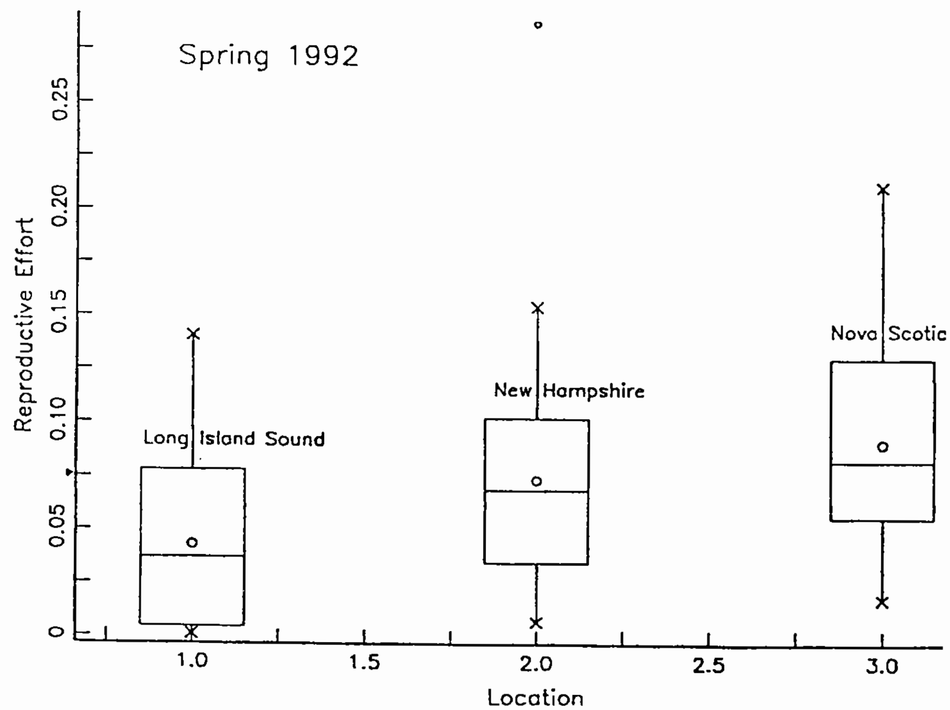

Figure 2. Comparison of reproductive effort (ratio of sorus area to total blade area) for kelp sporophytes along a temperature (latitudinal) gradient in the Northwestern Atlantic Ocean: a) Long Island Sound, b) Gulf of Maine, and c) Halifax Harbor, Nova Scotia.

23°C., known to be the lethal temperature for survival and growth of the sporophyte. These findings have grave implications for the future of *L. longicruris* in Long Island Sound. If the surface water temperature were to rise 1 or 2°C, the species would most likely be eliminated from the Long Island Sound estuary and markedly change the composition of its benthic communities.

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Habitat and Ecosystem Preservation and Restoration

Assessment and Management of Connecticut's Piping Plover and Least Tern Populations

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Background

The piping plover (*Charadrius melodus*) was listed as a federally threatened species in 1986. A threatened species is likely to become in danger of extinction within the foreseeable future throughout all or a significant portion of its range. It was listed in March, 1992 as a state threatened species in Connecticut. The piping plover was once considered a common summer resident on the beaches of the Atlantic coast. The U. S. Fish and Wildlife Service Piping Plover Recovery Plan estimated 553 pairs bred on the U.S. Atlantic Coast in 1986 (Dyer, 1986).

This small shorebird is the color of dry sand. During the breeding season, they have a characteristic single black neckband which may be incomplete and a black bar that sits above a white forehead. Piping plover males and females are similar in appearance and size. They mature and breed at one year of age.

Plovers arrive in Connecticut in late March. They prefer isolated sandy beaches that have sparse vegetation and access to mudflats for feeding on invertebrates. The first eggs are laid by late April in a shallow depression in the sand often lined with shells and placed near vegetation. The 3-4 eggs hatch in 27 days and young leave the nest within hours after hatching to feed. The young fledge in 28 days, but stay with the adults through migration. Birds that lose their nests or young will renest into early July.

Following the federal listing of the piping plover, the Connecticut Department of Environmental Protection's Wildlife Division initiated a project designed to conserve piping plover populations by increasing nesting success.

Concurrent with monitoring piping plover populations, the project surveyed populations of least terns (*Sterna antillarum*), a species which prefers the same breeding habitat as piping plovers. The California and the interior populations of least terns are listed as federally endangered. An endangered species is in danger of extinction throughout all or a significant portion of its range. The least tern was listed in March 1992 as state threatened in Connecticut.

The least tern is a gull-like bird about the size of a robin. It has a gray back, white belly, white forehead with a black cap and black wing tips. The female is smaller than the male. Terns first breed at two years of age.

Least terns arrive in Connecticut in early May, the time that piping plovers are laying eggs. Least terns prefer broad, sandy, vegetation-free beaches located close to an estuary with an abundant food supply of small fishes. In mid-May, the first eggs are laid in a shallow depression in the sand. Nests contain 1-3 eggs which hatch in 21 days. The downy young leave the nest by the second day. Twenty-one days later, the young are able to fly but continue to be fed by the parents until migration. Prior to the beginning of August, if a nest is destroyed or the young die at an early age, the parents can renest in 6-10 days.

Although Connecticut has 254.5 miles of coastline, open sandy beaches suitable for plover and tern nesting comprise only a small fraction (less than 80 miles) of the coast (Patton, 1992). This uncommon beach habitat is also a high-use recreation area. Shoreline development for recreation and residential use has limited the number of available nest sites for piping plovers and least terns. Beach stabilization projects have reduced the quality of the remaining sites, forcing birds to nest in areas with more vegetation and high human disturbance. Vegetation provides cover for predators like cats (*Felis domesticus*), rats (*Rattus* spp.), striped skunks (*Mephitis mephitis*), and raccoons (*Procyon lotor*). Natural avian predators such as crows (*Corvus* spp.), black-crowned night herons (*Nycticorax nycticorax*) and gulls (*Larus* spp.) are a consistent problem at many sites. Human disturbances, including unleashed dogs, affect productivity by keeping birds off nests, thus preventing them from attending eggs and young. Outright nest destruction is also a factor.

Since 1984, piping plovers have been known to breed at 13 sites in the state from Westport to Groton. During this time, least terns have been known to breed at 16 sites from Greenwich to Groton. The majority of both of these species nest between Bridgeport and West Haven and both favor sites with a history of use. Other sites that appear to be suitable are not utilized by either species. Inadequate food supplies, predation pressures, or habitat instability may be responsible.

Methods

Since 1986, the Division has annually employed two research assistants that have erected protective fencing, surveyed and monitored breeding sites to determine reproductive success, and provided public education. Almost every piping plover and least tern nesting location was cordoned off with string and posted with signs. Volunteers, recruited by the Nature Conservancy, were also utilized to assist in public education and monitoring efforts; since 1986, the Division has trained over 220 volunteers who have contributed over 1,400 hours to this project. Trapping and relocating mammalian predators before and during the breeding season was employed in 1989 and 1990. This effort proved to be time consuming and the benefits were short-lived as other predators rapidly invaded the vacant habitat. With the outbreak of raccoon rabies in 1991, the practice was discontinued.

Piping Plover

Nineteen ninety-two marked the sixth year that the Division used predator exclosures to protect piping plover nests. Piping plovers prefer to walk to their nest, and the exclosure construction allows this but keeps the mammalian predators out. Due to the tendency of least terns to nest in large colonies and to fly directly to their nests, fencing individual tern nests would be an obstacle. Also, for this reason, piping plover nests located within least tern colonies were not fenced. The shape of predator exclosures evolved from rectangular to triangular, in the experimental stage, and are now hexagonal for installation ease. Nests are surrounded by 65 feet of 4' high 2" X 4" woven wire utility fencing supported by metal stakes. As plover nests are found they are fenced. The bottom of the fence is buried 6 to 12 inches into the sand and rows of string are laced over the top to deter avian predators. The average fence installation time is 20 minutes. Nests are checked every one or two days as hatching dates approach. When the chicks hatch, the fencing is removed.

Least Tern

Least terns received no individual nest protection, but did benefit from string and stake fencing, weekend patrolling at select sites, and public education efforts. Division efforts toward this species have focused on determining number of pairs and number of chicks fledged.

Findings

Piping Plover

Connecticut's piping plover population has increased from 20 breeding pairs in 1986 to 40 breeding pairs in 1992, a 100% increase. Results from the 1991 International Piping Plover Census

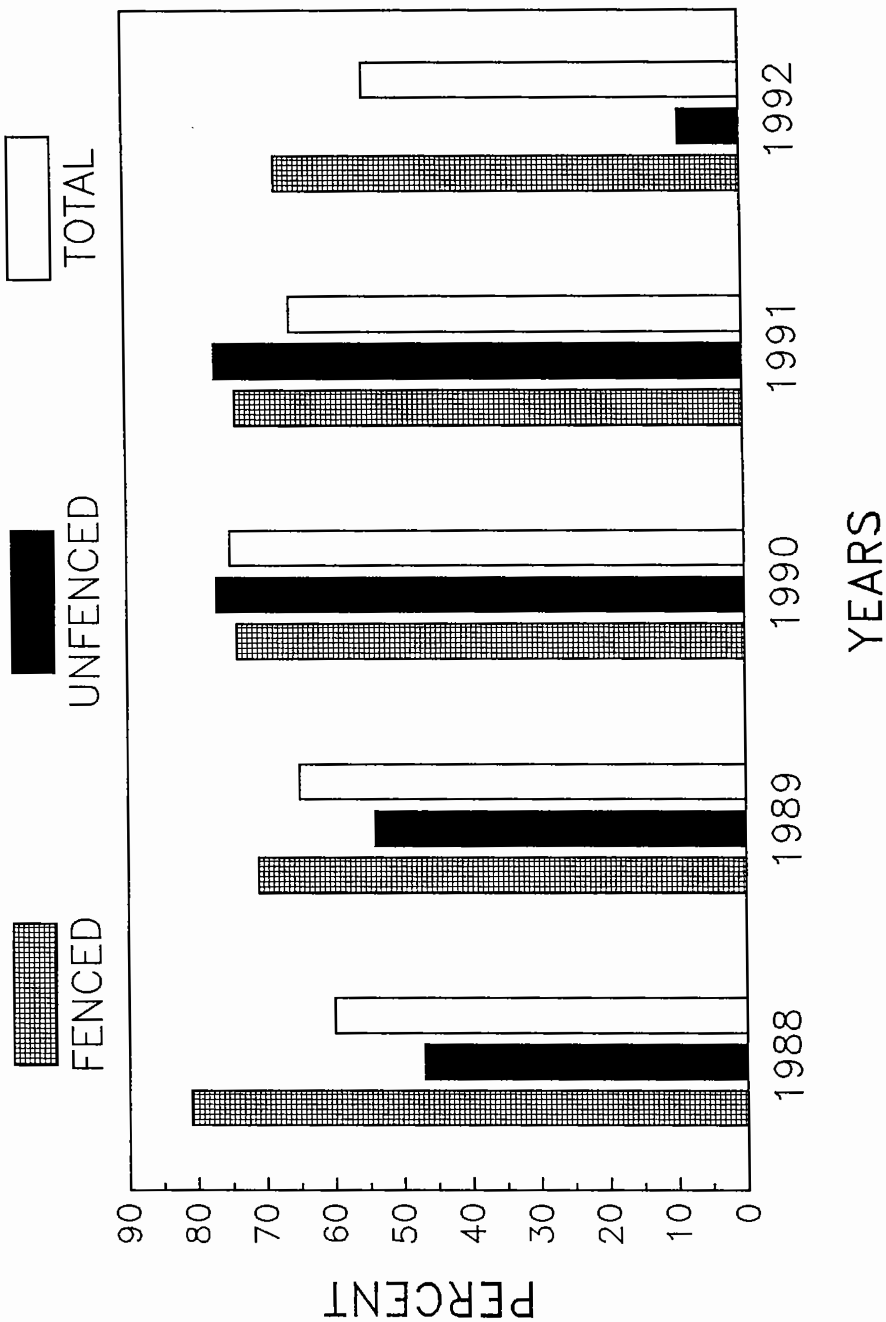

FIGURE 1. Connecticut piping plover hatching success rate all locations, 1988–1992.

indicate that there were 938 breeding pairs on the U.S. Atlantic Coast, a significant increase from the 1986 estimate of 553 breeding pairs. The Atlantic Coast population remains stable and there has been an unprecedented effort to protect plovers on the Atlantic Coast of the U.S. (Haig, 1992). Increased nesting and hatching success in Connecticut has been attributed to aggressive fencing, patrolling, and public education. Results compiled from the past five years indicate that for most years, the hatching success rate has improved with fencing (Figure 1). The overall hatching success rate (calculated as the number of eggs hatched per total number of eggs) has been 72% for fenced nests compared to 53% for unfenced nests. Better results have been reported for exclosures in Massachusetts on Cape Cod, 90% for fenced and 17% for unfenced, (Melvin, 1992) and at Crane's Beach, 92% for fenced and 25% for unfenced, (Rimmer, 1990). However, these studies were only conducted for one or two years. Nesting success rates (calculated as the number of nests in which at least one egg hatched per total number of nests) have been similar; 77% for fenced nests and 53% for unfenced nests. What is very encouraging about fencing is the consistencies of high nesting and hatching success from year to year. Hatching success with fencing has varied from a high of 81% in 1988 to 68% in 1992. Without fencing, success varied from a high of 77% in 1990 and 1991 to a low of 9% in 1992.

Fledging success (the number of juveniles fledged per eggs hatched) has ranged from 41% in 1987, with an average number of fledglings per pair of 1.29, to 67% in 1988 with 1.74 average fledglings per pair. A chick is considered fledged when it is seen flying. Since 1986, the overall fledgling success has been 53% and the average number fledged per pair has been 1. 60. This average is high compared to Atlantic Coast results where, from 1986-1991, the range was a low of 1.04 chicks fledged per nesting pair in 1987 to a high of 1.29 chicks fledged per nesting pair in 1989 (Hecht ,1992).

Least Tern

From 1986 to 1992, there was a noticeable decline in the reproductive success of least terns. Statewide surveys estimated that there were 527 fledged young per 859 pairs in 1985 compared to 101 fledged young per 655 pairs in 1992 (Figure 2). The tendency to renest when nesting is disrupted and the longevity of adult least terns are adaptations to unstable beach environments. A survival rate of 10 to 20% of least tern young is acceptable for maintaining a stable population, and one or two years of low productivity can be offset by subsequent years of high productivity. However, low productivity over a five-to-ten year period could pose a major threat to the population.

Terns respond to shifting beach conditions caused by sand deposition or increased vegetation by changing nest sites as the level of habitat quality and predation change. A study in New Jersey showed that small colonies suffered higher losses from human disturbance while larger colonies suffered significantly more predation (Burger 1984). Although causes of chick losses have varied by site and by year, the major problem in Connecticut for least terns has been predation. Consistently, black-crowned night herons (*Nycticorax nycticorax*) have been a problem and an effective means of controlling this predator has yet to be identified. Chick shelters of modified snow fencing in a cone shape placed over a center post and driven into the sand, have been used successfully in Massachusetts to provide protection and shade for least tern chicks prior to fledging (Jenks-Jay 1982). In 1988, a limited test was attemptedin Connecticut with chick shelters made of modified plastic cups . Although the number of chicks surviving to fledging stage appeared higher, the results were inconclusive (Brunton, 1988).

Conclusions and Recommendations

Competition between piping plovers, least terns and humans for sandy beaches will continue. This competition has forced Connecticut's management program to evolve into one of the more aggressive of its kind in the Northeast. The piping plover fencing program has realized some success in protecting nests, however, as with the least terns, there is still a major problem protecting young chicks after hatching.

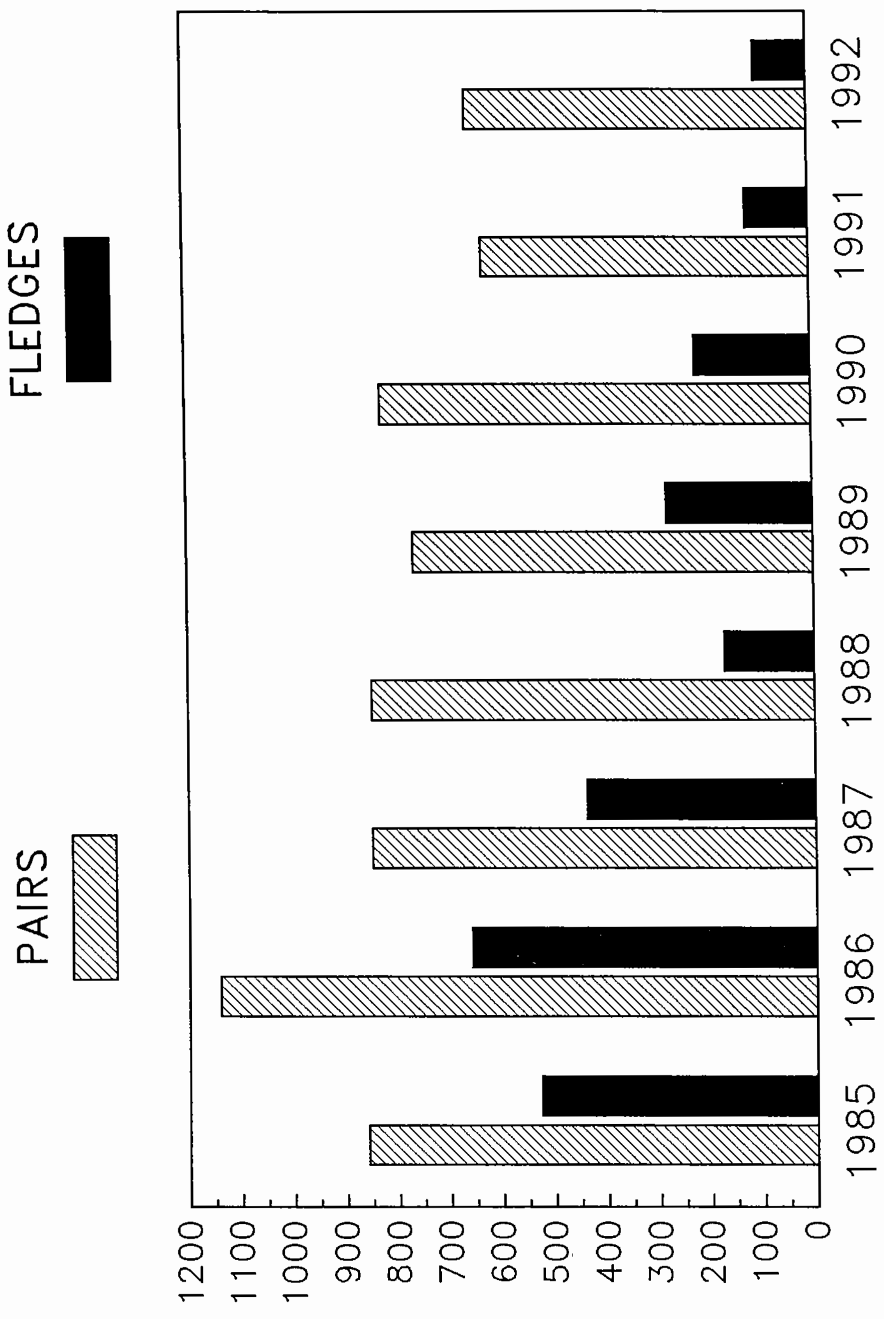

FIGURE 2. Connecticut least tern productivity 1985–1992.

Connecticut intends to pursue two major efforts to better manage piping plover and least tern populations. One is the development of a predator response plan with input from federal officials, describing the level of evidence needed to conclude that action is necessary and what steps are to be taken. The other is hiring a research assistant to concentrate on surveying least terns populations, to determine reproductive success and to experiment with shelters or other techniques to increase chick survival.

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Biotic Changes at the Barn Island Tidal Marshes (Stonington, CT): Sea-Level Rise and Restoration

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Introduction

Since the mid 1940s extensive areas of the 1.2 km^2 complex of tidal wetlands at Barn Island, Stonington, Connecticut, (Figure 1) have undergone significant vegetation change. The most dramatic changes have occurred in valley marshes that were diked and impounded for waterfowl management beginning in 1946. The impounded marshes, then dominated by saltmeadow hay (*Spartina patens*) and stunted saltwater cordgrass (*Spartina alterniflora*) were converted to cattail (*Typha angustafolia*) and reed grass (*Phragmites australis*) brackish and fresh water wetlands (Hebbard, 1976). Beginning in 1978 tidal exchange was reintroduced to the valley marsh that had been impounded for the longest time (IP in Figure 1). Over the past 14 years typical tidal salt marsh angiosperm species have recolonized *ca.* two thirds of the area (Sinecrope, *et al.* 1989, Barrett and Niering, 1993). This recovering or "restored" marsh can be compared to the eastern-most valley (DM in Figure 1) that has never been impounded.

In the late 1940s marsh vegetation below the impoundment dikes was dominated by nearly monospecific expanses of *S. patens*, limited scattered patches of stunted *S. alterniflora* and of mixed forbs, with a belt of black grass (*Juncus gerardi*) along the upland border and creek bank levees (Miller and Egler, 1950). Although this pattern still characterizes some areas today (WC and BP in Figure 1), large sections (HQ in Figure 1) have converted to a complex mosaic of stunted *S. alterniflora* and forbs, with *S. patens* and *J. gerardi* persisting only in limited, relic stands. For at least the last 50 years accretion on stable areas has kept pace with relative sea-level (RSL) rise; rates on changed portions are lower and surface elevations average 5 - 13 cm less than on the relatively stable sections (Warren and Niering, 1992).

Principal questions addressed in this study include: 1) What are the immediate environmental factors influencing plant species distribution, thus vegetation change? 2) How has total angiosperm primary productivity been altered between the 1940s and today as a result of vegetation changes on both the impounded, recovering valley marsh and the open, bayfront areas? 3) How have highmarsh macroinvertebrate populations, using *Melampus bidentatus* as a model, responded to vegetation changes? 4) How do the intertidal macroinvertebrates, the ribbed mussel (*Geukensia demissa*) and fiddler crabs (*Uca* spp.), as well as fish utilize the restored valley marsh *vs.* the unimpounded valley marsh and open, bayfront areas?

Methods

Vegetation of the WC, BP, HQ and DM sections was mapped in 1991 using air photos and ground truth. Pre-impoundment vegetation of IP was from Barrett and Niering (1993) and the 1988 vegetation was mapped by Sinecrope *et al.* (1990). HQ vegetation in 1948 was from Coleman (1978, see Warren and Niering 1992). Angiosperm primary productivity was estimated by community type using average peak live standing crop for 1990 and 1991. Total production of different areas at various times was calculated using community productivity and community cover determined from vegetation maps. Elevations, water table depths, soil salinities, and soil redox potential were followed over two growing seasons at 59 soil water wells established on all study areas and sampling all dominant plant communities.

Melampus was sampled on the high marsh by counting and measuring all animals in 0.25 m^2 quadrats located every 5 m along 13 bayfront or creekbank to upland transects distributed over all

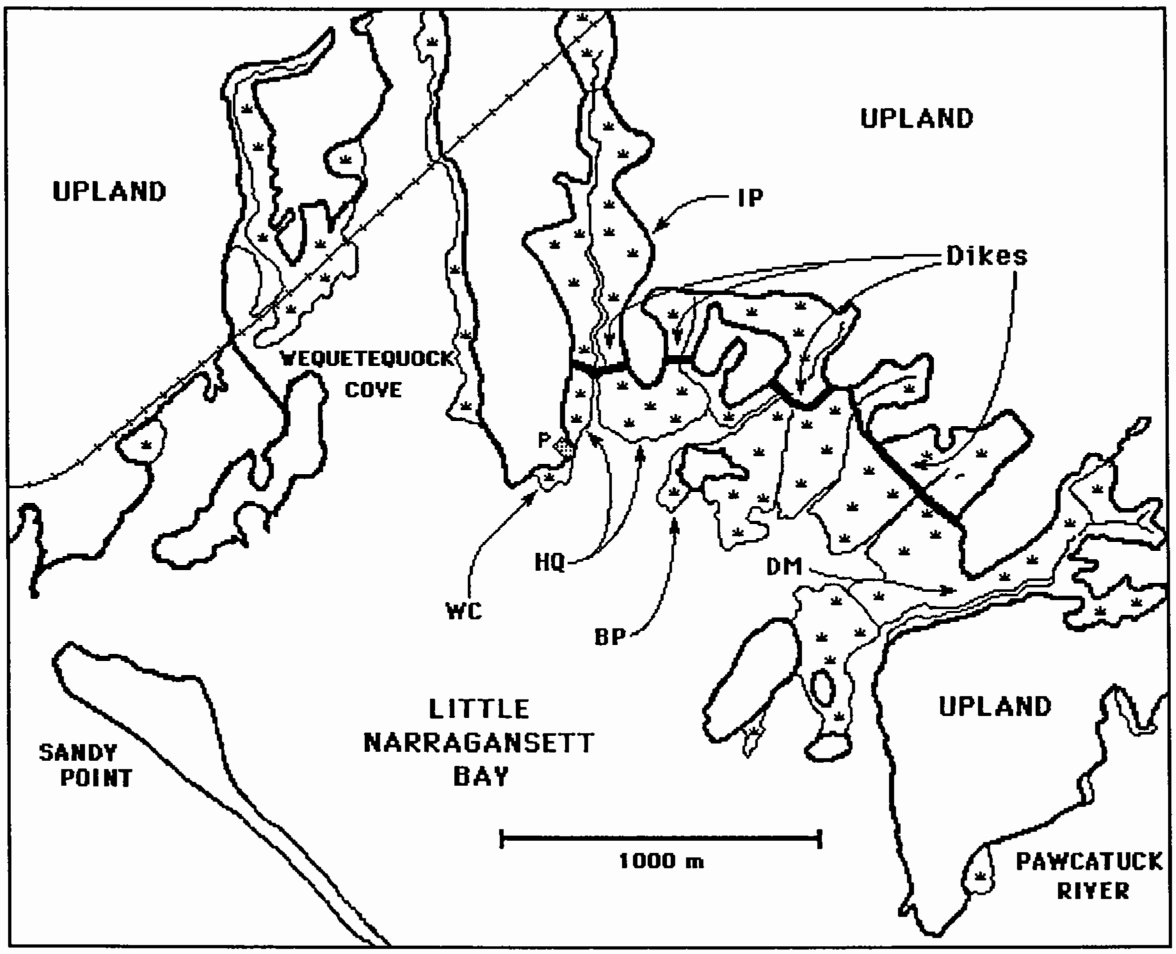

Fig. 1. Map of the Barn Island tidal salt marshes; areas studied include WC and BP - relatively stable bayfront sections, HQ - changed bayfront sections, DM - unimpounded valley marsh, and IP - impounded but "restored" valley marsh

study areas and sampling all dominant plant communities. A dry weight-size regression was used to estimate biomass. *Geukensia* and *Uca* were sampled in 0.25 m^2 quadrats situated every 3 m along banks of creeks and mosquito ditches. *Geukensia* were counted, measured, and biomass estimated from a shell length-wet weight regression; *Uca* populations were estimated by counting crabs extracted from burrows at low tide.

Fish were sampled from ditches in the IP, DM, and HQ sections. Guts of *Fundulus heteroclitus* trapped on flooding and ebbing spring tides were analyzed for total food and major components of gut contents.

Results and Discussion

The present day and historical vegetative composition of the various marsh sections, as per cent total cover by dominant community types, is seen in Figure 2. On the bayfront areas the similarity between WC in 1991 and HQ in 1948, and the dominance of *S. patens*, is striking and the changes in HQ are clear. Stunted *S. alterniflora*, forbs, and mixed communities, all of which indicate wetter site conditions, have largely replaced *S. patens* and *J. gerardi*. This is consistent with elevation, redox, soil water table depth, and salinity differences found on WC and BP *vs*. HQ (Table 1) and with the model that the principal factor driving this change is an imbalance between RSL rise and vertical growth of the marsh surface on HQ (Warren and Niering, 1992).

Table 1. Marsh Area Means for Soil Factors and Elevation Relative to Mean Sea Level

Marsh Area	Salinity (ppt)	Redox (mV)	Water Table Depth (cm)	Elevation (cm)
HQ (Significant Change)	30 ± 2.0	-124 ± 22	6.6 ± 1.19	44.9 ± 0.01
WC and BP (Relatively Stable)	23 ± 1.5	-29 ± 37	7.62 ± 0.8	49.9 ± 0.02

All means except water table depth are significantly different ($P \leq 0.05$).

On the two valley marshes, IP and DM, the vegetation on IP in 1946 was comparable to that on DM in 1991, with co-dominant *S. patens* and stunted *S. alterniflora* communities combining for over 80% of the total cover. Stunted *S. alterniflora* and forb communities now dominate IP; *S. patens* is just a minor component in today's vegetation and is largely localized at the southern end, near the dike. The reintroduction of tidal flooding, thus, has restored IP in the sense that this marsh now supports typical tidal salt marsh angiosperms and invertebrates (see below) and is again connected to the Little Narragansett Bay marsh-estuarine system. Restoration, however, has not yet resulted in a return to pre-impoundment conditions.

Vegetation differences, combined with variation in primary productivity among community types (Table 2) result in significant productivity differences among the marsh areas today, as well as within HQ and IP over time (Figure 3). The *S. patens-J.gerardi* dominated sections (WC in 1948 and 1991 and HQ in 1991) are similar and significantly greater than HQ and DM today and IP in 1946. The lowest productivity occurred on the restored IP section (IP 1991) and reflects the present dominance of stunted *S. alterniflora* and forbs.

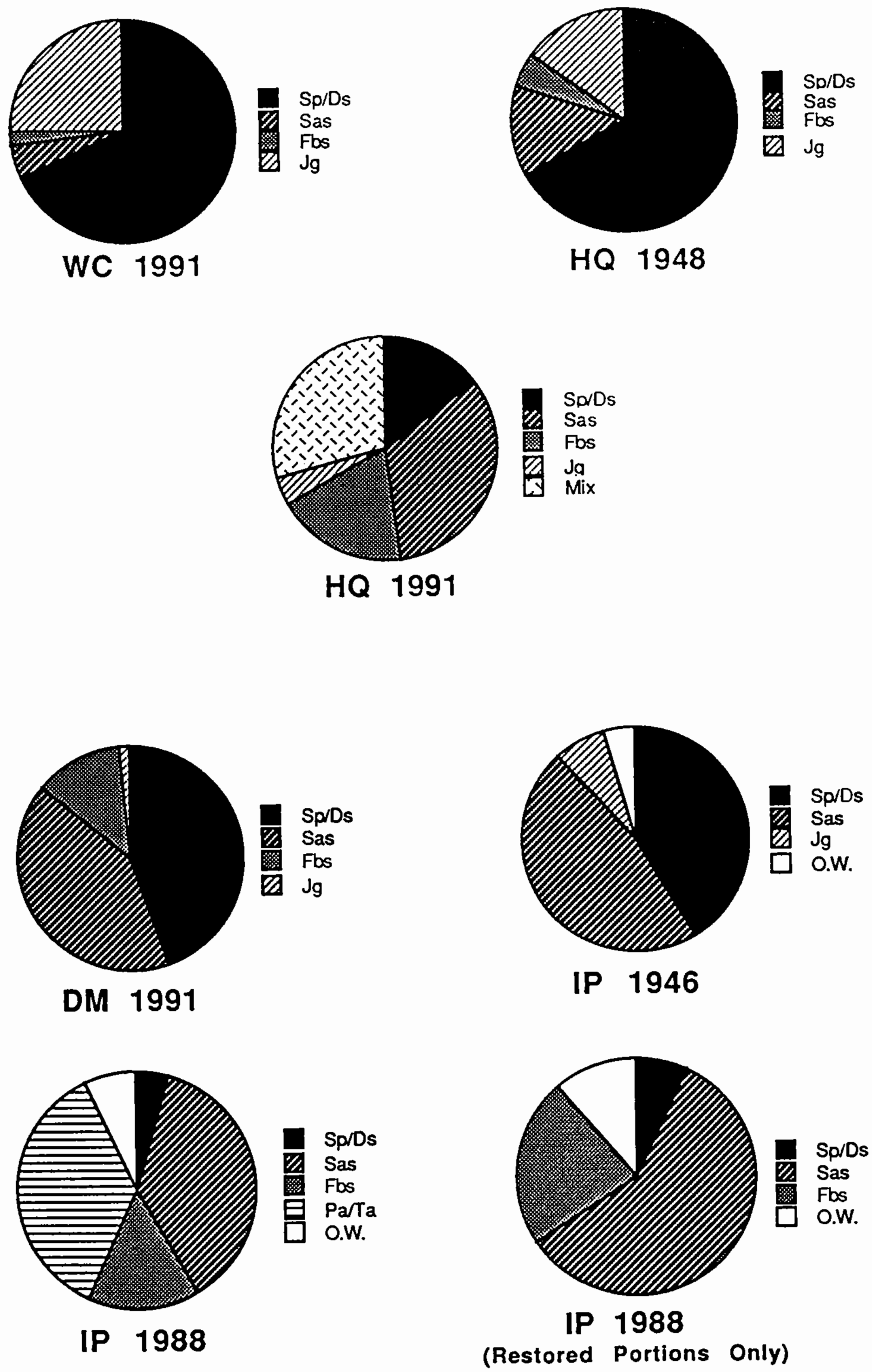

Fig. 2. Community composition by percent total area of the vegetation on the WC, HQ, DM, and IP sections as determined by recent vegetation mapping, and on HQ and IP from historic vegetation maps. (Sp/Ds - *Spartina patens* dominated community, often with significant *Distichlis spicata;* Sas - stunted *Spartina alterniflora* dominated; Fbs - mixed forb community; Jg - *J. gerardi* community; Mix - mixed community of *S. patens*, stunted *S. alterniflora*, and forbs; O.W. - open water; Pa/Ta - unrestored, *Phragmites australis* and *Typha angustafolia* dominated areas of IP.

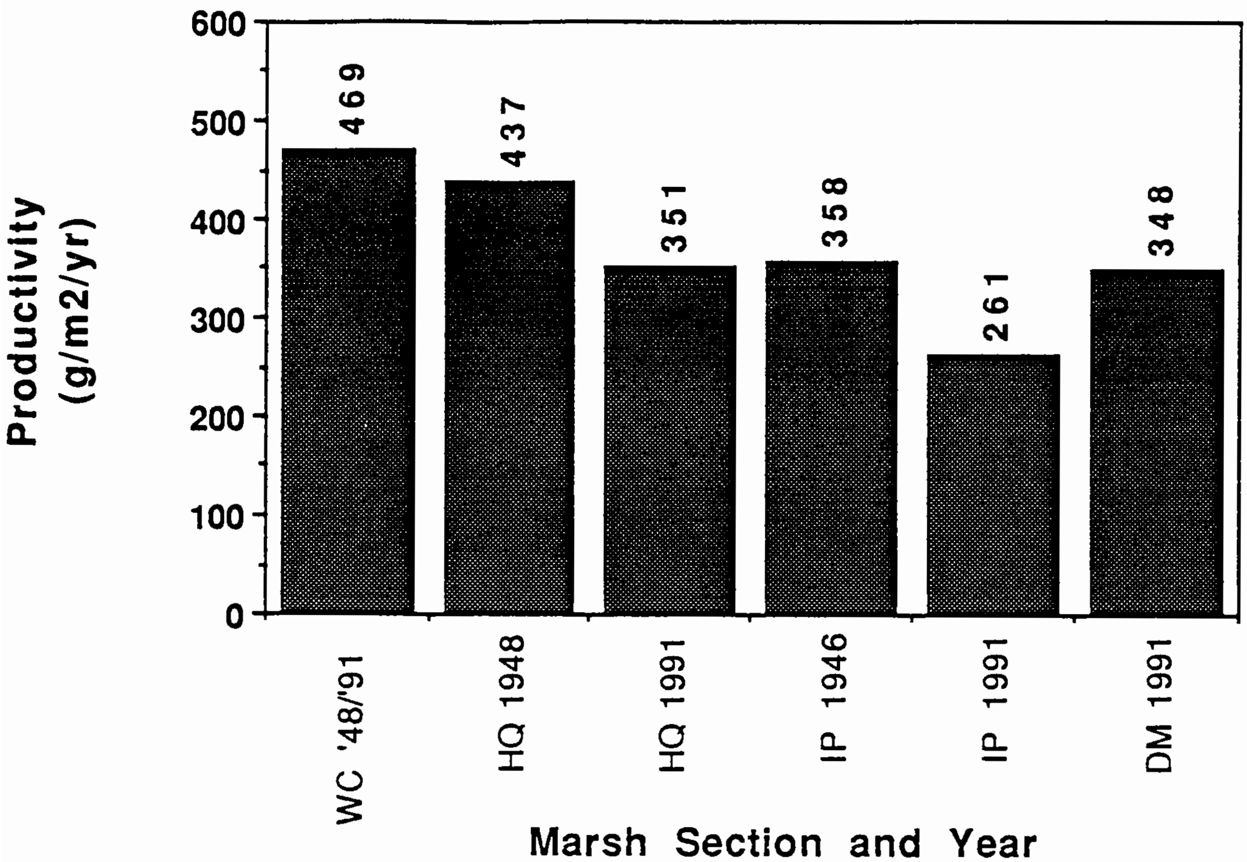

Fig. 3. Angiosperm productivity of the WC, HQ, DM and IP sections of the Barn Island marshes for 1991 with productivity estimates for WC and HQ in 1948 and IP in 1946. Productivity for sections was calculated from separate community productivity determinations and community data of Fig. 2.

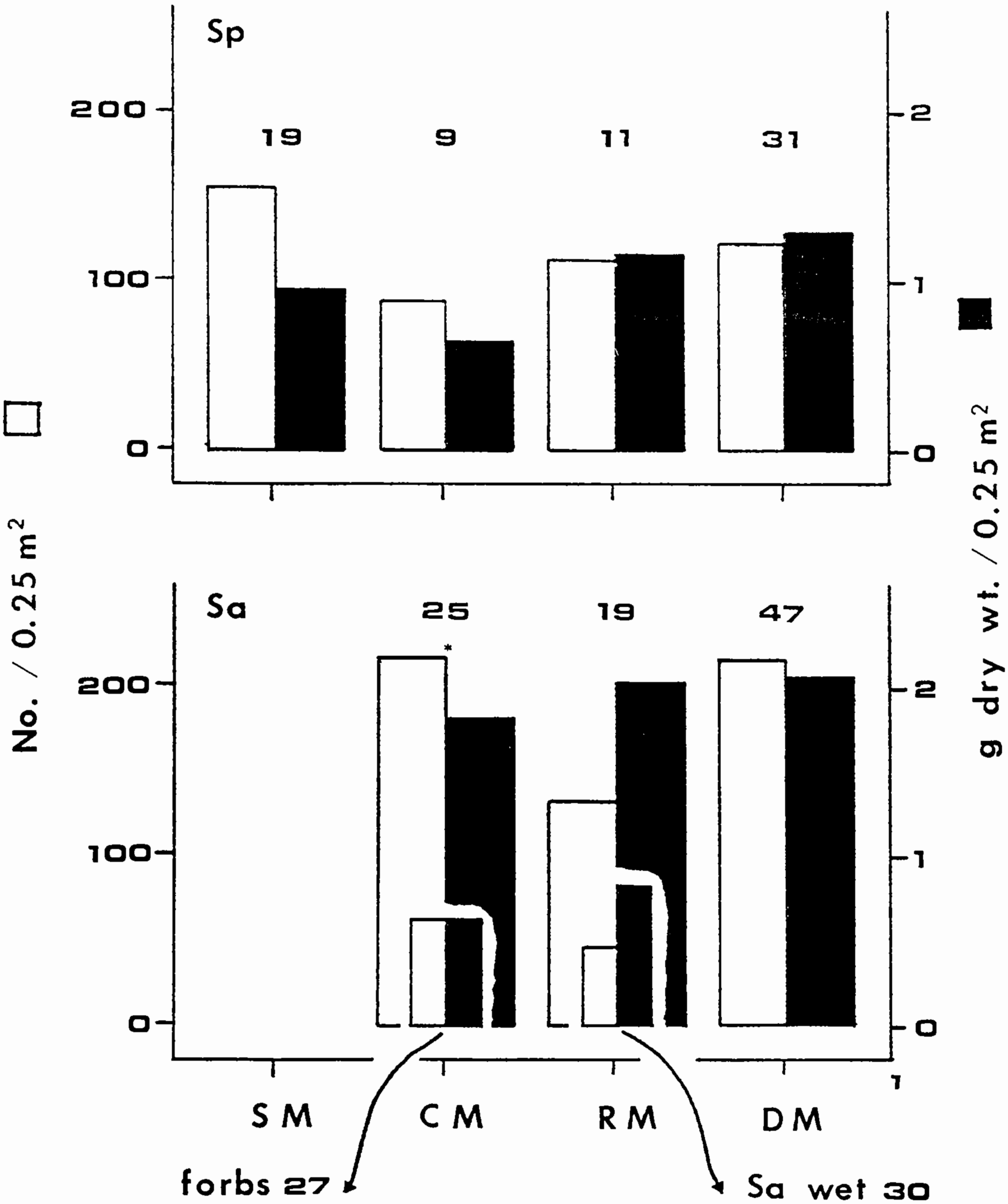

Fig. 4. Mean density (clear bars) and mean biomass (solid bars) of *Melampus bidentatus* in areas covered by *Spartina patens* (Sp) and short *Spartina alterniflora* (Sa) on different marsh sites at Barn Island. (SM = WC and BP: stable bayfront marshes; CM = HQ: changing bayfront marshes; RM = IP: restored impounded valley marsh; DM = unimpounded Davis marsh). The number of quadrats sampled on each marsh is indicated above the bars. Insets show the density and biomass of this snail in areas covered by forbs on the changing bayfront marsh and in areas of wet *S. alterniflora* on the restored marsh.

Table 2. Aboveground Productivity of Dominant High Marsh Communities Estimated by Peak Live Standing Crop

Community	Productivity (g $m^{-2} yr^{-1}$)
Juncus gerardi	706 a
Spartina patens	406 b
Distichlis spicata	333 b
Stunted *Spartina alterniflora*	273 b
Mixed Forbs	172 c

Values followed by the same letter are not significantly different ($P \leq 0.05$)

The marsh snail (*Melampus bidentatus*), the ribbed mussel (*Geukensia demissa*), fiddler crabs (*Uca* spp.), and other tidal marsh invertebrates have become re-established on the restored valley marsh above the opened impoundment dike (IP) and also occur on the other marsh areas considered in this study. Although no information is available concerning invertebrate populations on the impounded marsh prior to the reintroduction of tidal flooding, it is doubtful that typical tidal marsh species were present (Fell *et al.*, 1991). The occurrence of such animals and tidal marsh vegetation on the marsh in 1990 indicates that restoration of a more or less typical tidal marsh community has taken place on IP.

Although *Melampus* occurs at moderate population densities on IP, its mean density there [83± 9.9/0.25m^2, n=82] is somewhat lower than on the bayfront marshes below the impoundment dike [98± 15.7/0.25m^2, n=35 on the stable marshes and 117±11.6/0.25m^2, n=93 on the changing marshes] and less than half that on the unimpounded DM [178±14.0/0.25m^2, n=90]. On the upper part of IP where relic *Typha* persists, *Melampus* density tends to be low. In addition, the *Melampus* population is small in areas of wet *S. alterniflora* which before restoration efforts began were largely devoid of vegetation. More than a third of the quadrats sampled on IP were of this type. Similarly on the changing bayfront marshes, the extensive areas dominated by forbs support low densities of this snail (Figure 4).

On the other hand, *Melampus* tends to be substantially larger on IP compared to the populations on DM and on the bayfront marshes below the impoundment, WC, BP and HQ. Consequently the mean biomass of this snail on the restored marsh [1.24± 0.13 g dry wt./0.25 m^2] is more similar to that on unimpounded DM [1.74± 0.13 g dry wt./0.25 m^2] than is snail density and it is actually greater than on the changing marshes [1.01± 0.09 g dry wt./0.25 m^2] and stable marshes [0.63± 0.10 g dry wt./0.25 m^2] along the bayfront. In relatively dry regions covered by *S. alterniflora*, the biomasses of *Melampus* are similar on IP, the changing bayfront marshes (HQ) and the unimpounded valley, DM, even though snail densities are significantly greater on the latter two (Figure 4). Similarly, in regions of IP and DM covered by *S. patens*, both the densities and biomasses of *Melampus* are essentially the same.

Other high marsh invertebrates present on the restored marsh, as well as the other marshes surveyed in this study, include the amphipod *Orchestia grillus* and the isopod *Philoscia vittata*.

Geukensia was found along the banks of the main tidal creeks and mosquito ditches of both IP and DM. The mean densities and biomasses of this mussel are similar on the creek banks of both marshes [36 ± 4.4 and 7.4 ± 0.88 g dry wt./0.25 m^2;n=12 on IP and 39 ± 7.4 and 8.1± 1.28 g dry wt. / 0.25 m^2; n=12 on the DM]. Although the density of *Geukensia* in the mosquito ditches is much higher on IP [60± 10.4/0.25 m^2; n=12] than on the DM [20 ± 2.8/0.25 m^2; n=12], mussel biomasses are comparable [16.2 ± 2.45 and 13.6 ± 1.58 g dry wt./0.25 m^2; respectively] because mussels in ditches of the restored marsh tend to be small. Densities of *Uca pugnax* are also similar on these marshes.

Fish were trapped in one ditch each of IP, the HQ and the DM on a series of flooding and ebbing spring tides during late spring and summer. The fish assemblages on all three marshes were similar. *Fundulus heteroclitus* was always the dominant species. On HQ and at certain times on the other two marshes, *Fundulus* moving out of the ditches on the ebbing tide contained substantially more food in their guts than fish caught entering the ditches on the flooding tide, indicating that the ditches are important foraging areas (Table 3). Detritus and crustaceans were major gut components at all three sites.

Table 3. Gut Content Indices (wet weight of pooled gut contents expressed as a percentage of the combined wet weight of the fish) of Fish Caught in Ditches During Flooding (F) and Ebbing (E) Spring Tides. The Number of Fish in Each Sample is Indicated in Parentheses

Marsh Area	May 27 - 29		June 11 - 13		June 25 - 27		July 25 - 26	
	F	E	F	E	F	E	F	E
HQ	0.9 (48)	2.2 (45)	0.8 (45)	3.0 (40)	1.1 (42)	2.2 (43)	0.3 (45)	1.7 (40)
DM	1.5 (57)	1.5 (36)	2.0 (45)	2.2 (47)	1.1 (45)	2.5 (45)	0.1 (45)	2.1 (43)
IP	0.7 (48)	2.3 (54)	2.0 (42)	1.0 (35)	1.0 (38)	0.7 (39)	0.4 (48)	0.1 (23)

The June and July gut contents findings suggest that *Fundulus* is not using IP to the same extent, or in the same way, as DM and HQ. This appears to be another indication that the complete recovery of IP to pre-impoundment conditions has not yet been achieved.

Acknowledgments

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Watershed Protection - A Regional Approach
The Mianus River Watershed Project, A Project of The Westchester Land Trust

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The Mianus River Watershed Project, coordinated by The Westchester Land Trust, was designed to learn how the lifestyles of people living and working in the watershed affect the river, and to identify ways to protect and improve its water quality. One of the reasons that the Mianus was chosen for this study is that it is a small river system from fresh water source to salt water and is subject to the different influences from multiple towns, counties and state jurisdictions. In addition, there are no known points of pollution along its length and therefore, any pollution of the river comes from nonpoint sources.

During the course of the study, the Project developed:

1. A year-long chemical and biological testing program to profile the general health of the river and establish a baseline for future comparison;
2. The outline and initial layers of a regional landuse database with computer mapping capabilities;
3. A survey of the land use practices in 7,200 households; and
4. An ongoing education program for municipal governments, community organizations, schools, and residents of the watershed which includes a *Guide to Watershed Protection*, media presentations, regional conferences, teacher workshops, and public events.

The River's future effect on Long Island Sound and its own continued health and integrity depend on its care by those who live and work in the watershed. Two states, two counties, five municipalities, four school districts, and more than 50 Connecticut and New York organizations connected by the river have cooperated in the study to identify practical ways they can protect the water quality of the Mianus watershed through careful use and management of the land.

Watershed Characteristics

The Mianus and its watershed are valuable ecological and hydrological resources. They are home to a virgin hemlock forest and a variety of rare and protected plant species such as cardinal flower, maidenhair fern, lady slippers, trillium, butterfly weed and club mosses. As part of the Eastern Flyway, they lie on the migratory path for many birds of prey, songbirds and species of woodland birds. The River and its tributaries drain significant, but vanishing, wetlands before entering Long Island Sound. It is the primary source of drinking water for 130,000 people in parts of Greenwich, CT and Port Chester, Rye, and Rye Brook, NY. The watershed is hydrologically connected to the Mianus Aquifer.

The 37-mile-long Mianus River begins in Greenwich, CT and initially flows north through North Castle and Bedford, NY before it turns south through Pound Ridge, Stamford, CT and again into Greenwich entering the Long Island Sound estuary at the Cos Cob Harbor. Its watershed, site of 7,200 households, comprises 35 square miles of mixed land use. The headwaters flow through predominantly low density residential areas, undeveloped land and passive open space.

While there are no major agricultural areas within the watershed, there are significant open fields, forested areas, wetlands, and a 600-acre wildlife sanctuary in the first 18 miles of the River. These sections of the upper Mianus are susceptible to sedimentation and related nonpoint source pollution because of their low gradient and relatively low flow. These characteristics combine to create a silty stream bottom and poor flushing capability throughout the River's headwaters. In addition, the glaciation that created the northerly flow pattern of the Mianus also carved steep slopes of erodible soils that comprise much of the area through the watershed. The lower portion of the Mianus flows through a high density residential area (4,700 households in 17.1 square miles) before emptying into the Long Island Sound. Although this lower portion of the River appears to have greater flushing capabilities due to the larger gradient drop, it is also threatened by nonpoint source pollution.

The New York State Department of Environmental Conservation (NYSDEC) has given the Mianus its highest water quality classification, "AA Special": a surface source of drinking water into which no sewage disposal discharges are allowed. The same classification is made by the Connecticut Department of Environmental Protection (CT DEP) for that portion of the river upstream of the Mianus Filtration Plant in Greenwich, CT. Below the Filtration Plant, the river is classified as "B: suitable for bathing, other recreational purposes, agricultural uses, certain industrial processes; excellent fish and wildlife habitat, good aesthetic value.

River Testing Program

The river testing program was designed to gain an understanding of the current quality of the river water, to compare that quality with historical data to discern trends where possible, and to establish a baseline against which future test results could be compared. It was not designed to identify the effects of specific land use on water quality.

Test Parameters

The selection of test program parameters and testing sites was based on previous town studies and consultations with the SUNY Purchase Department Environmental Science Program (SUNY), the NYSDEC and the Connecticut American Water Company (CAWCo.). Base flow samples (nitrogen/ammonia, nitrogen/nitrates, total phosphorus, chlorides, turbidity, biochemical oxygen demand, and total and fecal coliform) were collected, and field observations (pH, dissolved oxygen, velocity, water and water and air temperature) were taken at ten sites along the river and its tributaries every five weeks for one year (April 1991-April 1992) by trained volunteers. In addition, samples of benthic (bottom-dwelling) macroinvertebrates were taken using the standard kick-net procedure at four of the test sites in July, September and April of the test year. The sampling and analytical procedures used by the Yorktown Medical Laboratory Environmental Services (YMLES) were based on the *APHA Standard Methods for the Examination of Water and Wastewater*. 17th edition, (1989) and followed accepted scientific practices. Storm event monitoring was not a part of this study (sampling in August 1991 occurred within days of Hurricane Bob and a second, un-named but severe rainstorm).

Test Results

The results of the chemical tests performed indicated that the sampled river water was well within the anticipated range for a river classified as "AA Special". Macroinvertebrate sampling conducted by the NYSDEC showed the river to be slightly impacted at the four sites studied and subsequent sampling by the Land Trust confirmed those findings.

The biological test results did, however, indicate levels of coliform bacteria in the river which were above Environmental Protection Agency (EPA), NYSDEC and CT DEP standards. Of the 93 test samples analyzed throughout the year, 88% exceeded either the NYS DEC limits for total and fecal coliform bacteria and/or the CT DEP fecal coliform bacteria limits (CT DEP standards consider only fecal coliform).

This source of contamination is cause for concern because fecal coliform bacteria exist under the same conditions as certain disease-causing organisms such as *Streptococcus* and *Salmonella.*

Although our testing program was not designed to determine the specific type or source of the contamination, the role of coliform bacteria as indicators of concern about public health and sanitary water quality raises serious questions about the water quality in the Mianus. It questions the advisability of using the river for recreation (swimming, camping) that includes contact or ingestion of its untreated waters.

According to the EPA annual "Water Quality Inventory," one third of the United States surface waters fail to meet Federal and State Water Quality Standards. Regrettably, the Mianus falls into this category with regard to total and fecal coliform bacteria.

Watershed Planning Database

The Westchester Land Trust, as part of the Mianus Project, developed a regional planning tool, the Mianus Watershed Geographic Information System (GIS). The advantage of using GIS over traditional planning tools such as paper maps and books is that information can be combined in one place, one medium and one format. By superimposing different layers of data, relationships become readily apparent that might not have been evident from separate paper maps.

Thanks to a computer system provided by IBM and ARC/INFO software provided by ESRI, we were able to synthesize a database from information supplied by the following:

- Westchester County Department of Planning, Geographic Information Systems (GIS) Services;
- Connecticut Department of Environmental Protection, Natural Resource Center, Geographic Information Services
- Town of Bedford
- Town of Greenwich
- Town of North Castle
- Town of Pound Ridge
- City of Stamford
- Connecticut American Water Co.

The database includes 1988 Westchester County designated land use, existing town zoning maps, tax lots, a watershed maximum buildout map based on existing zoning and tax lots, hydrography, Westchester County drainage basins, public water supplies, sewer service areas, municipal boundaries, 1982 New York State Department of Transportation roads, New York soils, the watershed boundary, and 1991/92 river sampling sites. It also includes Connecticut roads, CT DEP-designated land use/land cover, drainage basins, public water supply service areas and sewer service areas.

Regional Watershed Planning

Current environmental thinking holds that certain types of land, notably wetlands, impervious soils, steep slopes, and wildlife habitat are valuable environmental resources which are not necessarily appropriate for development. With GIS, planners can use the synthesized data for this entire watershed to superimpose water monitoring data, existing zoning maps, master plans and regulations on maps indicating sensitive environmental areas and to identify those areas where rezoning should be considered to take into account their environmental sensitivity.

Public Outreach and Education

The Project's river testing results and land use database offer the foundation for a regional watershed protection education program based on scientific data and common understanding. As part of its education program, the Project has:

- Published the results of the two year study in the *Mianus River Watershed Report* distributed to municipalities, county and state agencies;
- Developed a *Guide to Watershed Protection For Those Living and Working in the Mianus River Watershed* for the 7,200 watershed households. This booklet offers practical suggestions for ways to better protect and preserve water quality and supply.
- Hosted teacher workshops in the four watershed school districts, and is currently developing a three workshop series in conjunction with SUNY Purchase;
- Held two Mianus Festivals;
- Produced two cable TV shows, and
- Hosted a regional conference, "Watershed Protection - A Bioregional Approach", attended by representatives from 65 Connecticut and New York organizations.

Future Recommendations

This project has been based on the willingness of the parts to participate for the good of the whole. Therefore, the Project recommends that the five towns of Bedford, Greenwich, North Castle, Pound Ridge and Stamford, and those state and county government agencies with jurisdiction in the watershed:

1. Adopt an intermunicipal resolution that recognizes the Mianus River and its watershed as a regional natural resource.
2. Form an Intergovernmental Watershed Advisory Committee that will:
   - Define and recognize the watershed boundary;
   - Identify the major issues affecting water quality in the Mianus River. These include, but may not be limited to: - inconsistent development standards; - environmentally sensitive zones; - the impact of development on water quality throughout the bioregion.
   - Designate a regional environmental corridor along the river and its tributaries;
   - Establish planning goals and implementation strategies to insure water quality protection in the river and its watershed. These would include: consistent standards for future development setbacks; wetland protection; consistent standards for sewage disposal design and placement; consistent standards for storm drain design, placement and maintenance.
   - Develop a river protection management plan as a framework for watershed protection efforts and as a guide for assessing the potential impacts of proposed new land uses on water quality in the River;
   - Test the water quality of the river periodically and investigate the elevated levels of coliform bacteria and metals found in the testing program to determine the extent and source of this contamination.
   - Provide the best technical data on out-of-district off-site impacts during the planning process in land use and subdivision proposals.
3. Use and augment the Mianus Watershed Geographic Information System database and mapping capabilities located at The Westchester Land Trust.
4. Encourage innovative methods for protecting sensitive lands in future development proposals.

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Geographic Information System (GIS) is a computer system capable of holding and using data that describe places on the earth's surface by linking text and database information to graphic maps.

Three Years of Marsh Restoration in Mumford Cove, Groton, Connecticut

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Thirty five acres of salt marsh have been restored on a 45-acre dredged spoil marsh in Mumford Cove, Groton, Connecticut with the co-operation of the Groton Health Department, the Department of Environmental Protection Office of Long Island Sound Programs (DEP), the United States Fish & Wildlife Service (USFW), the Mosquito & Vector Control Section (MVCS) and the Site Review Committee (SRC) for Open Marsh Water Management (OMWM) for the State of Connecticut. All work was done under DEP and Army Corps of Engineers permits. Dredge materials along with *Phragmites australis* grasses have been removed using low ground pressure equipment from the Mosquito & Vector Control Section and the United States Fish & Wildlife Service. After three years, several restored areas have shown signs of colonization by salt marsh plants and animals that inhabit other salt marshes in the area.

Restoration

In 1988, the MVCS started a project to eliminate mosquito breeding in a large *Phragmites* marsh known as Mumford Cove in Groton. Several complaints were coming from the Mumford Cove Association and Landing Bite Counts were very high when the complaints were investigated by the Mosquito Control Supervisor in the area. During the fall of 1988, the MVCS pushed down the *Phragmites* grasses in an effort to locate mosquito breeding depressions in this area. The dredged area had salt water coming into it and very few ditches leaving it through the northwestern weir board structure. The MVCS sprayed the area in the early spring of 1989, but the continuous growth of the *Phragmites* grasses stopped the Section from spraying by mid- June. Ditching might have solved the mosquito problem, but the ditching would be continually choked by the *Phragmites* grasses. The Site Review Committee suggested that the MVCS could use some Open Marsh Water Management/ marsh restoration techniques in the area.

With the help of the local health department of Groton, the MVCS began to survey the area outside the dredge site for elevations in the fall of 1989. All natural salt marsh areas were shot and elevations were brought into the site from several different angles from known N.V.D.G. in the Mumford Cove Association roads. Data was collected during the summer of 1989 and there was no salinity in the dredge site ponds and low areas but plenty of mosquito breeding. Aerial photos dating back to 1932 show the area to have been a salt marsh with two main creeks entering the marsh system, one in the northwest and one in the south, with several ponds. Aerial photos taken in the 1950s show the marsh covered with dredge spoils. On shooting the elevations into the site, it was determined that dredge spoils on the original marsh surface were at least 30 to 100 cm deep. The project was broken into several phases which would take the MVCS several years to complete. Phase 1, located in the northwestern part of the marsh near the railroad tracks, was started by the MVCS in the late fall of 1989. The work consisted of reestablishing the main creek with two low marsh areas and several ponds and grading off to the upland with high marsh areas.

During Phase 1, the USFW got involved with the project as part of their marsh restoration program in the northeast. Any restoration done by a private or state agency could be funded by the USFW Service or the USFW could make equipment to do the necessary work available. After several discussions, the USFW decided to get involved with the Mumford Cove project by providing equipment and personnel under the direction of the MVCS. When work was started on Phase 1, moving spoils off site would be a problem. If the spoils were over 100 meters away from the upland edge, then a spoil island would have to be created. Elevations were marked into the site with stakes which told the low-ground-pressure-equipment crews where low marsh, high marsh, and ponds were to be created. With the help of USFW the MVCS could do a lot of work in a very short period of time.

Phase 2 consisted of one month of work during March 1990. The MVCS worked with the USFW and started on a site south of Phase 1 which included a one-acre pond, the southern main creek with side channels, low marsh, high marsh, and two spoil islands. At any one time there were at least five pieces of equipment on the site; three bulldozers and two excavators. The spoils from the pond were put on the upland area to the south and west of the pond. The pond had two sill or connector ditches leading into it, one ditch from the Phase 1 in the northwest and one ditch from the south main creek. The ditches were dug to depths which would hold water in the pond at low tides but would also allow daily tidal flows. The pond was graded with a long sloping side to allow for mud flats when the tide was low. The southern main creek was at least 4 meters wide and had sloping sides to the upland to allow salt water to flood a wide area at high tides during the full and new moon.

No work was done between the beginning of April and the end of August because of a pair of ospreys nesting on the site. Phase 3 was started in September 1990. It consisted of creating a large, low marsh area with three spoil islands north of the southern main creek, a graded marsh to the southeast of the main creek where spoils were placed in a horseshoe shaped berm, and two rectangular brackish ponds connected by a ditch near the northeast part of the marsh near the railroad track and upland areas.

OMWM techniques were used to establish tidal ditches, connector ditches, reservoir ditches, and ponds. Some areas were ideal for ponds and pannes. Highest tides were staked out during a July 1991 flooding and after winter northeastern storms. The restoration site receives daily tidal flow and flushing. During 1991 and 1992, photos were taken at several stations and salinity and other data are still being collected. There are still some *Phragmites* areas left as control areas. Rebecca Waters and Dr. R. Scott Warren of the Botany Department of Connecticut College have been doing a baseline study of the Mumford Cove tidal marsh restoration during 1991 and 1992.

Vegetation

The marsh restoration has continued on the site now for three years. No grasses were planted except for moving twelve plugs of *Spartina alterniflora* into a low marsh area in Phase 1. The plugs were taken from a marsh outside of the dredge area which was blocking the northeastern main creek. Phase 2 was completed in March of 1990 and Phase 3 was completed in September of 1990. Salt marsh vegetation has started taking over some spots in the low marsh areas, main creeks, and in the ponds.

In Phase 1 in lower wet areas, *Salicornia europaea* and *S. alterniflora* began to dominate (Waters 1991). In some of the higher areas *Juncus gerardi* started growing. In the fall of 1990, some of the *Phragmites* was sprayed with a herbicide which stunted or killed several dense stands. Phase 2 and Phase 3 vegetation consisted of *Panicum dichotomiflorum*, *Scripus validus* and *Typha angustifolia*. *Phragmites* still dominates the drier areas but in low areas an algal mat has taken over. Near the two northeastern brackish water ponds, *Typha latifolia* had surrounds the ponds.

Vegetation varies on the spoil islands but *Phragmites* has dominated. Other vegetation includes panicum, pokeweed, ragweed and goldenrod. Marsh elder and other upper border marsh plants surround the islands.

Salinity

With the increase of tidal flow, salinity has increased as well. Salinity readings were at least 25 to 30 ppt in the low marsh areas and in the ponds that were connected by sill ditches which is similar to the Mumford Cove readings. The high marsh areas also receive tidal flows at the full or new moon which tends to bring salinity into these areas. The brackish ponds in the northeast receive some salt water but have remained at 2 to 4 ppt.

Wildlife

In 1988, very little wildlife used the area. The *Phragmites* was very tall, at least 3 to 4 meters high, and was very dense. Nothing was living in it and no deer trails were seen. After work was started, the wildlife consisted of the animals that would be seen in a typical salt marsh area. Birds, fish, snails and crabs were noted on several occasions. Wading birds, including Snowy Egrets (*Leucophoyx thula*), Lesser Yellow Legs (*Totanus flavipes*), Willets (*Catoptrophorus semipalmata*) and Sandpipers (*Erolia minutilla* and *Ereunetes pusillus*) were observed using several ponds in the area. Ponds were also visited by Mallards (*Anas platyrhynchos*), Black Ducks (*Anas rubripes*) and Green Herons (*Butorides virescens*). In the main channels, there were many Mud Snails (*Nassarius obsoletus*), Crabs (*Sesarma reticulatum* and *Uca spp*) and schools of Common Mummichogs (*Fundulus hetroclitus*). Other wildlife included deer, muskrats and many overflying birds.

Summary

Originally this was to be a simple mosquito control project to eliminate mosquito breeding areas by ditching. But because of the *Phragmites* grasses it turned into one of the best examples of the Mosquito & Vector Control Section's Open Marsh Water Management/Marsh Restoration project. Instead of going into the site every few years to clean out any ditching done with just the rotary ditcher, we now have a restored salt marsh which can be managed to control mosquitoes but also to bring back salt marsh vegetation and wildlife. This project also showed the cooperation of several private, local, state and federal agencies and what the necessary low-ground-pressure could do for many areas of the state's degraded wetlands. The MVCS and DEP are now looking at several other marsh restoration projects using what we learned in Mumford Cove. Under the MVCS permits we have identified several areas suitable for OMWM/Marsh Restoration and have completed ten projects by the spring of 1992 which were partially funded by United States Fish & Wildlife Service. With budget cuts, three of five men were eliminated by the Department of Health Services for the Mosquito & Vector Control Section on July 1, 1992. The three men and most of the program were picked up by the legislators who changed the Long Island Sound Cleanup Bonding Account and included marsh restoration into that package. The MVCS then signed an agreement with DEP to receive funds to support our program and to purchase equipment necessary to perform marsh restoration activities. Our mosquito program did suffer because 50% of the larviciding program was eliminated. The crew carried on by identifying OMWM/Marsh Restoration sites and adulticiding for adult mosquitoes when complaints were received. The MVCS is not in any budget options for 1993 and after the legislative session has started in January, we will be looking for funding sources to continue our mosquito control/marsh restoration efforts.

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The Application of Geographical Information Systems (GIS) to the Management of Long Island Sound and its Coast: How Do We Organize and Optimize?

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GIS activity in relation to Long Island Sound (LIS) is growing at federal, state, regional, and local levels, as well as at academic institutions and private environmental firms. We pose the question, "Will there be an effort to unify all the information generated so that the overall goals of understanding and managing the Sound are achieved?" GIS is in many ways a buzzword. Although it provides powerful technology to organize, display, and analyze environmental data, it does not necessarily guarantee progress toward the stated goals. Without some unifying framework we will generate interesting and fruitful parallel efforts which address specific problems using GIS, but may lose the chance to tap the full potential of this information. We suggest that a data library be created/ supported, taking information from a variety of formats and putting it into a common data base. This information would then be available to those using GIS to manage and assess LIS. Indeed, those not employing GIS should also add to and use the library and have their information converted and stored. The end result may be the opportunity for planners, managers, researchers, etc., to have available to them a richer context for their work which in turn will hopefully produce more powerful analyses and management plans. In pointing out the need to organize and optimize GIS activity centering on LIS, we hope to stimulate discussion as to what may be the best course to take, and what might be the best modes for a data library. There are several possibilities available now that will be suggested.

Effects of Nutrient Enrichment on Kelp (*Laminaria longicruris*) from Long Island Sound

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The kelp, *Laminaria longicruris* de la Pyl., reaches the southern limit of its distribution along the northern shore of eastern Long Island Sound. In eastern Long Island Sound, *L. longicruris* can form productive, dense, subtidal beds.

The effects of enhanced nutrient (as ammonium) concentrations on juvenile sporophytes (i.e, blades) and microscopic gametophytes were measured under several temperatures (i.e., 5°, 10°, 15°, and 20° C) and irradiance regimes (i.e., 10, 35, and 75 $\mu E/m^2s$). Responses to 0, 10, 20, 50 and 100 µM ammonium were measured as male and female gametogenesis and sporophyte production.

Sporophyte production was more sensitive (i.e., inhibited) to enhanced concentrations of ammonium than male and female gametogenesis. In addition, sporophyte production was more sensitive to increasing light and temperature than male and female gametogenesis. Greater inhibition of all responses (i.e., male and female gametogenesis and sporophyte production) occurred at 20° C and low light; and at 5° C and higher irradiance.

Water Quality

Twenty-five Years of Dredged Material Disposal Site Monitoring in Long Island Sound: A Long-term Perspective

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Introduction

The long-term history of dredged material disposal in Long Island Sound, and throughout New England, has shown that dredged material disposal can be managed so that impacts are minimal. This perspective has developed from experiences gained over more than twenty-five years of practical management of disposal sites and from investigative and monitoring studies that were specifically designed to identify the magnitude and extent of negative impacts. These studies have included a relatively long history of impact investigations in the Sound (resulting in more than 200 technical publications) which have used many different physical, chemical, and biological approaches conducted by numerous independent investigators.

A common conclusion of this body of work is that the only discernible adverse impacts are near-field and short-term. Substantial far-field, long-term impacts do not seem likely given what we have learned. This conclusion is based on the magnitude of disposal activity relative to natural (e.g., storms) and other anthropogenic impacts (e.g., outfalls) (Science Applications International Corporation In prep a; US Army Corps of Engineers, 1991) and the low level of disposal-related impacts that have been documented. Further, the ability to minimize impacts through pre-dredging testing and a disposal site monitoring program linked with management decisions has demonstrated that open-water disposal can successfully and safely serve as one of the multiple uses of our offshore waters. The basis for this perspective is provided in the following sections which summarize the key points of the history of disposal and monitoring in the Sound.

Disposal history

The waters of Long Island Sound have been the primary alternative used for the disposal of sediments dredged from harbors and channels of this waterbody for more than fifty years. Existing records, although somewhat incomplete, show a continuous use since 1941 though undoubtedly this practice began long before then. Reliable data are available since 1954 (Figure 1). Total disposal volumes between the years 1954 and 1991 exceed 38 million cubic meters (50 million cubic yards) of sediment. The preference for use of the Sound for disposal can be attributed to the substantially greater costs of alternatives such as upland disposal, as well as the difficulty of siting and acquiring nearshore or upland real estate for disposal (US Army Corps of Engineers, 1980). In fact, during the 1970s, due to increasing awareness of the environmental damages caused by disposal on wetlands or valuable nearshore resources, the actual trend was to shift a greater proportion of disposal to open-water sites in the Sound. If, however, upland disposal had been the alternative of choice over this time, the area needed to accommodate the historical volume would exceed 1,240 hectares (3,100 acres) if the sediment were mounded three meters (ten feet) high. This would be equivalent to a land area equal to almost 25 % of the City of New Haven.

The choice of locations and the management of open-water dredged material disposal sites have undergone considerable change to reduce the potential for environmental impacts. In the early part of the century, the location at which disposal took place varied each time a harbor was dredged. By the 1950s most harbors had a distinct area that was identified for disposal. Records show that 19 disposal sites could be identified throughout the Sound (Figure 2.) (Dames and Moore, 1980). By the

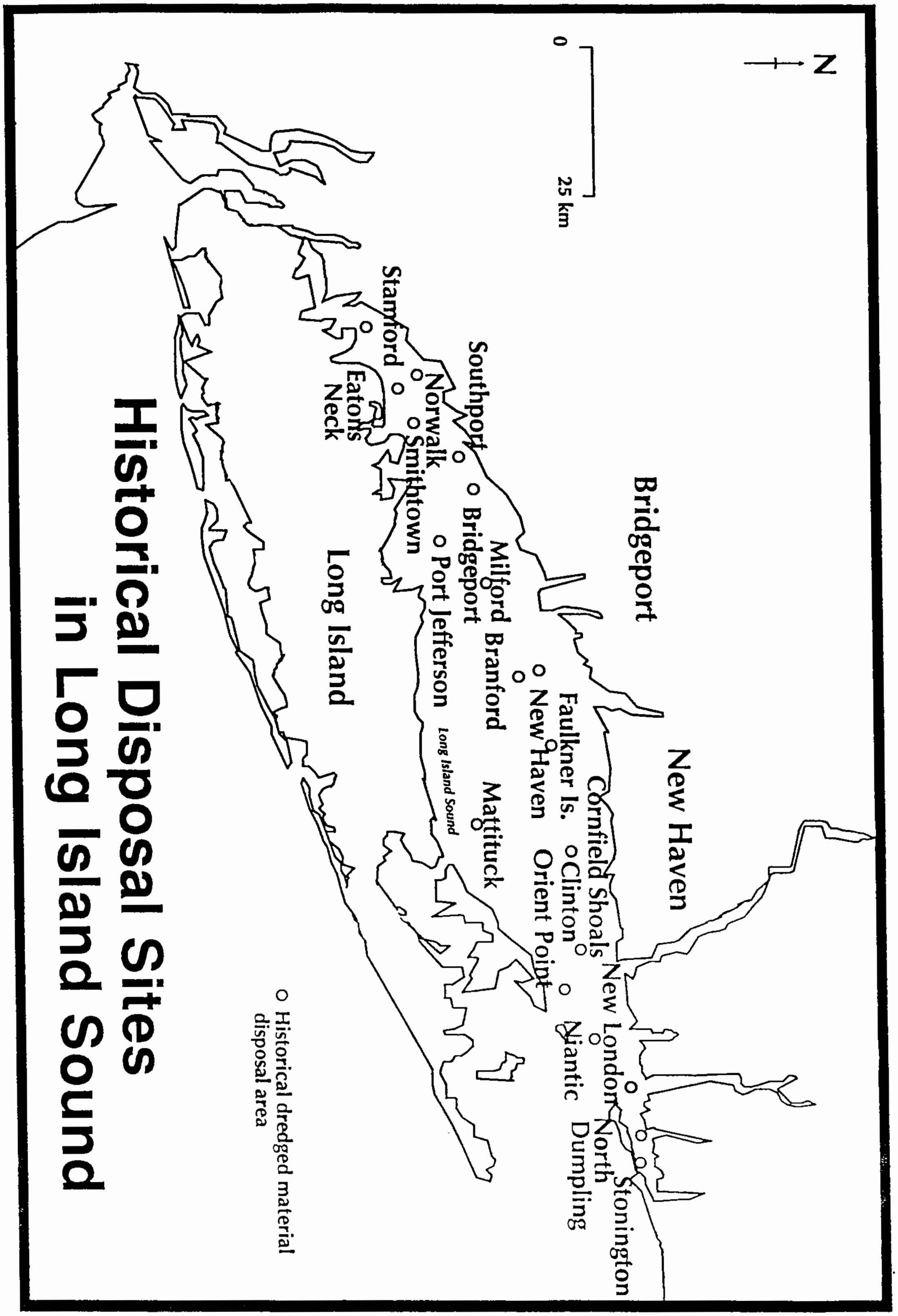

Figure 1. Historical dredged material disposal sites in Long Island Sound (modified from Dames & Moore 1980).

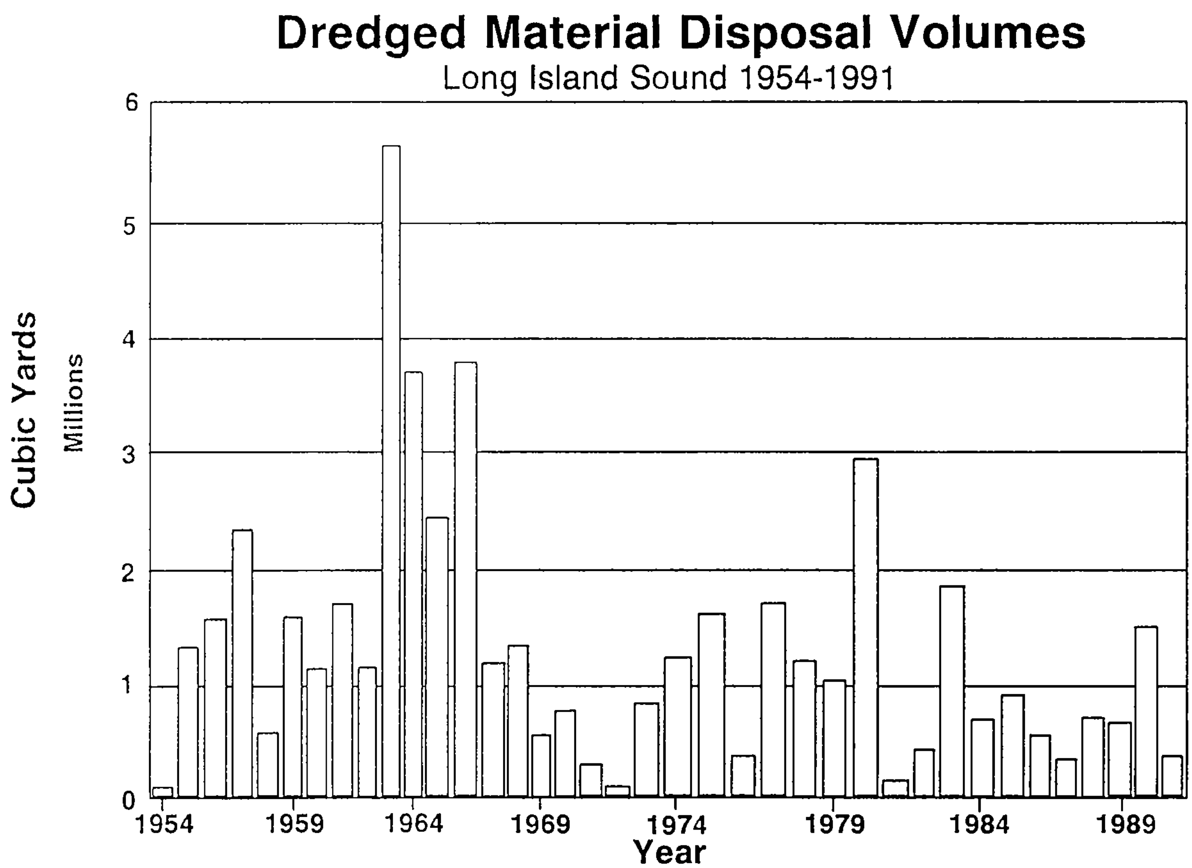

Figure 2. Disposal volumes at Long Island Sound open-water dredged material disposal sites, 1954-1991.

early 1970s, to reduce the amount of seafloor that was being impacted, the majority of the 19 sites were closed, and four regional sites were established to serve the open-water disposal needs of most projects. These four sites were the New London, Cornfield Shoals (Cornfield Point), Central Long Island Sound (New Haven), and Eaton's Neck disposal sites. Today, four sites continue to serve the sediment disposal needs of private and federal navigation projects, though the Eaton's Neck site was closed and replaced by the Western Long Island Sound disposal site, which was established in 1982.

Parallel to the reduction in the number of sites, testing and evaluation of sediments to be dredged has become more structured and detailed in order to better evaluate the potential environmental impacts from sediment associated contaminants. Today, testing follows a tiered approach: the lowest tier relying on existing data and/or physical testing, the second tier involving project-specific characterization of a wide suite of organic contaminants (including PCBs, pesticides, and PAHs) and priority pollutant heavy metals, and the highest tiers involving bioassay and bioaccumulation tests. Testing on each project proceeds through the tiers only as far as needed to make an evaluation of the sediment. In contrast, testing in the early 1970s was generally limited to several heavy metals and oil and grease measurements. Prior to that, sediments were dredged and disposed without much regard to the contaminants that were associated with them.

Monitoring history

SR Series

The environmental concerns for potential impact that led to a decrease in the number of sites also brought about an evolution and increase of monitoring activities. The US Army Corps of Engineers, New England Division (NED) first sponsored investigations into the behavior and impact of disposed sediment with a series of studies conducted by the University of Rhode Island (e.g., Saila *et al.*, 1969, 1971) and Yale University (e.g., Gordon *et al.*, 1972) dating back to 1967 (Andreliunas and Hard, 1972). The reports from these studies were published as Scientific Report (SR) documents [for which an index was created in 1990 (Science Applications International Corporation, 1990)]. These early studies focused on near-field impacts to the benthic community (e.g., Rhoads and Yingst, 1976) and short-term chemical and physical processes. Biological studies showed that impacts to the community could be detected only within a few hundred meters of the disposal point. In areas further from the disposal point, where only thin (<50cm) layers of sediment were deposited, benthic organisms were capable of burrowing through the overburden. On the mounds themselves, recolonization of the benthic community proceeded rapidly. Although the community structure changed after disposal, these differences could be attributed to physical changes such as grain size.

Physical studies conducted as part of the SR series focused on the oceanographic conditions at the disposal sites (Bohlen and Tramontano, 1974a, 1974b; Nalwalk *et al.*, 1974), within the Sound (Paskausky *et al.*, 1974a, 1974b) and the dynamic processes of disposal (Gordon, 1973). Many of these still represent the key studies on their respective topics. These studies found that disposed sediments were quickly transported to the bottom and that the short-term losses of sediment to dispersion ranged from 1-5%. These studies also found that the tidal current regimes at the sites were insufficient to significantly erode the deposited sediments. Even at sites where limited erosion did occur, it was observed that the finer sediments would be winnowed out of the surface sediments, but a lag deposit of coarser grained sediments would develop to armor the remaining sediments from erosion.

DAMOS

In 1977, NED formally established the Disposal Area Monitoring System (DAMOS): a program designed to take a unified approach to investigations, monitoring, and management of all of the New England disposal sites. It was at this time of transition that management of sediments through the first carefully planned capping operation was conducted (Morton, 1980; Naval Underwater Systems Center, 1979a-f; Science Applications, Inc., 1980a, 1980b). This capping operation involved extensive studies to determine whether highly contaminated sediments could be disposed and covered (capped) by relatively uncontaminated sediments, thus isolating the contaminants from the environment. The project involved disposal of 52,750 cubic meters (69,000 cubic yards) of sediment from Stamford Harbor at two separate disposal points within the Central Long Island Sound disposal site. Following the completion of contaminated sediment disposal, the south mound was successfully capped using fine grained sediments (silts and clays) from inner New Haven harbor, and the north mound was similarly capped with silty sand from outer New Haven harbor.

The success of this initial capping project and the lessons learned from subsequent capping projects over the last 14 years have led to the development of several capping management procedures. These procedures include (1) the use of taut-wire buoys to confine contaminated material disposal to a limited area, (2) bathymetric and sediment profile camera surveys to determine sediment distribution and to design cap placement, and (3) follow-up monitoring to assure capping success and benthic community recovery.

Other DAMOS studies through the 1980s expanded on the earlier SR investigations with continued emphasis placed on capping, along with studies of mussel bioaccumulation response during and following disposal (Feng, 1982, 1983, 1984; Science Applications International Corporation, 1987) and benthic recolonization (Naval Underwater Systems Center, 1983; Science Applications, Inc., 1983). Feng's work demonstrated that mussels located within a few hundred meters of disposal activities had significant bioaccumulation of contaminants, but those located further away showed no significant accumulation. In addition, once disposal ceased, contaminant levels of the affected mussels returned to those observed at reference locations. Similarly, the benthic recolonization work strengthened the conclusions of the SR reports that the benthic community was only temporarily disturbed.

Reflecting on the experience gained over these years of study, the DAMOS program has now developed a tiered approach to guide monitoring decisions (Fredette *et al.*, 1986; Fredette *et al.*, 1987; Science Applications International Corporation In press). The tiered approach outlines monitoring techniques to be used and provides clearly-defined decision points based on the data collected. The approach is designed so that monitoring efforts and costs are minimized in the lower tiers to provide rapid data return to guide management decisions. The decision points require a comparison of the data collected (e.g., recolonization status) to the expected condition (reference and model predictions). Expected results confirm predictions and invoke another assurance check at a later time, while unexpected results cause a search for an explanation along with initiation of monitoring at the next tier (e.g., more intensive or a different type of monitoring).

Current DAMOS investigations are not limited to tiered monitoring but also address questions such as cumulative impacts, bioaccumulation by benthic infauna, and the long-term effectiveness of capping. Recent work has developed a pilot technique to extract spionid and capetellid polychaetes (early colonizers of disposal mounds) from sediments as a possible means to better evaluate sediment-food web contaminant transfers (Science Applications International Corporation, In prep b). DAMOS has also begun to look at some of the historically used disposal sites to assess whether there are any persistent negative impacts from materials that were disposed before chemical and biological testing were introduced (Science Applications International Corporation In prep c). If impacts are found, these sites may be recommended for remedial action such as capping or other methods as appropriate.

In 1990, a coring study was conducted on the capped mounds created in 1978 (the mounds created back at the start of the DAMOS program) to evaluate the effectiveness of contaminant isolation. Results from these cores supported the hypothesis that contaminants would remain isolated below the caps (Sumeri *et al.*, 1991; Fredette*et al.*, in press).

Related Investigations

In addition to NED investigations of disposal effects in the Sound, work has been conducted under the Dredged Material Research Program (DMRP) and the Field Verification Program (FVP). The FVP, conducted from 1982 to 1986, was a joint US Army Corps of Engineers-United States Environmental Protection Agency study that (1) examined the predictive capabilities of dredged sediment evaluation tests and (2) field-verified the predicted impacts at upland, marsh, and open-water disposal sites. The testing approaches currently in regulatory use represent those that demonstrated the greatest reliability in this program. The FVP also clearly demonstrated that the saturated, anoxic condition that contaminated sediments retain through offshore disposal has a relatively low risk for release of those contaminants to the environment. The DMRP, a six-year, $30 million nationwide program, conducted studies in the Sound which focused extensively on the Eaton's Neck disposal site (e.g., Bokuniewicz *et al.*, 1977; Cobb *et al.*, 1978) and field verification of a numerical disposal model (Bokuniewicz *et al.*, 1978).

Conclusion

Our experience in New England has convinced us that dredged material can be managed in a way that is compatible with environmental stewardship. Today this management includes (1) contaminant characterization of harbors through directed sediment testing and the creation and use of a historical sediment database, (2) chemical characterization of sediments, (3) biological evaluation of sediments, (4) permit conditions requiring management (e.g., sequencing or capping), (5) environmental monitoring, and (6) active management of the disposal sites (e.g., cap maintenance, mound height control, etc.).

Offshore disposal will likely continue to play a major role in Long Island Sound, as a relatively inexpensive dredged material disposal solution that has been successfully accomplished with minimal environmental risk. At current rates of usage, the sites in Long Island Sound have sufficient capacity to meet the need well into the first quarter of the next century. Open-water disposal, perhaps disproportionately to the facts, remains extremely controversial (particularly among the general public). Scientists and regulators knowledgeable about the long-term research and monitoring results in Long Island Sound need to expand efforts to disseminate that information to a wider audience. Other disposal alternatives (upland, nearshore, island creation) are always evaluated for each project, but upon close inspection they are often found to have their own environmental disadvantages (such as nearshore or upland habitat loss or contaminant release). In comparison, the evidence provided by years of studies and monitoring indicates that well-managed offshore disposal has few disadvantages. Instead, the advantages open-water disposal offers leads to the conclusion that it is the best environmental and cost alternative for many projects.

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Results from Three Years of Sampling Activities for EPA's Environmental Monitoring and Assessment Program in Long Island Sound

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In 1990, EPA's Office of Research and Development initiated the Environmental Monitoring and Assessment Program (E MAP), in conjunction with NOAA's National Ocean Service, in estuaries of the mid-Atlantic region, which included sampling in Long Island Sound. These activities have continued since then. Focus of the program has been on regional-scale, statistically-designed sampling surveys which emphasize biological responses (direct measures of living resources), but data have also been collected on environmental exposures and habitats, which affect living resources (e.g., dissolved oxygen and contaminant concentrations, and salinity). Indices have been developed and tested which aggregate numerous individual biological measures. As an example, benthic index for 1990 data indicates that about 20 percent of total estuarine area in the mid-Atlantic region (8,400 km^2 out of 21,400 km^2) has degraded benthic resources compared to regional reference sites. Over seventy percent of this degraded area was associated with areas that also exhibited low dissolved oxygen conditions (<5 ppm). Results for Long Island Sound will be presented across the multiple sampling years within the regional context that E MAP was designed to provide.

Pelagic Microbial Processes Influencing Hypoxia in Western Long Island Sound

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This ongoing project was initiated to improve knowledge of the role of planktonic microbial communities in affecting seasonal hypoxia in the Western Sound. We report here the preliminary results of the first year's analysis of community activity during the onset, height, and recovery of seasonal hypoxia.

Weekly cruises were undertaken from July 7 through September 21, 1992 in the Western Narrows of Long Island Sound. Based upon physical structure determined by initial casts of an AMS CTD combined with a YSI DO meter, plankton community measurements were performed at several heights in the water column.

Community respiration and oxygen production were measured by a 12 hour light and dark bottle technique after Strickland and Parson's (1972). All incubations were performed in an on-deck incubation bath of continuously pumped ambient seawater. Data on the vertical distribution of oxygen and nutrients were also acquired.

Bacterial production and mortality were measured by the method of Taylor and Haberstroh (in preparation) employing fluorescently labeled bacteria (FLB) as a non-dividing tracer of grazing on the bacterial community. Production and grazing were then calculated from epifluorescent microscopy counts of two differentially stained growing and non-growing populations by the following equation:

$$\frac{dS_3}{dt} = (k-g)S_2 - gS_1$$

where: S_1 = FLB population (non-growing) g = rate of grazing
S_2 = Dapi stained (growing) population k= specific rate of increase
S_3 = Total population

Phytoplankton production and mortality rates were measured by the technique of Landry and Hassett (1982). Incubations were carried out on serial dilutions of the plankton community which decrease the encounter rate of phytoplankton and their grazers using 0.2μm filtered seawater obtained at the site and time of collection. The constants k and g used in the following equation were derived from the y-intercept and slope of the regression between net rate of increase and dilution:

$$P_t = P_0 e^{(k-g)t}$$

where: P_t = Phytoplankton population at the end of the incubation
P_0 = Phytoplankton population at t=0

Due to text limitations only the more novel results are presented in the following account of this season's results.

The summer of 1992 was characterized by unusually cool temperatures yielding peak surface water temperatures in Western Long Island Sound one to two Celsius degrees cooler than average (Figure 1). Nonetheless, oxygen measurements in subpycnal waters dropped, although somewhat more irregularly than observed in previous years, to hypoxic (<3mg/l) levels by early August (1.6 mg/l on August 11, Julian day 216) (Figure 1). Our August 17 cruise (Julian day 230) encountered a well mixed and well oxygenated water column. The four days preceding this cruise were characterized by strong Northeast winds and wave heights of several feet. Stratification was quickly reestablished and oxygen began to drop in subpycnal waters such that hypoxia was reestablished for short durations several times in September (see Figure 1).A peak in phytoplankton abundance, measured as chlorophyll *a* concentration at 3 m depth, occurred immediately preceding the early August hypoxia.

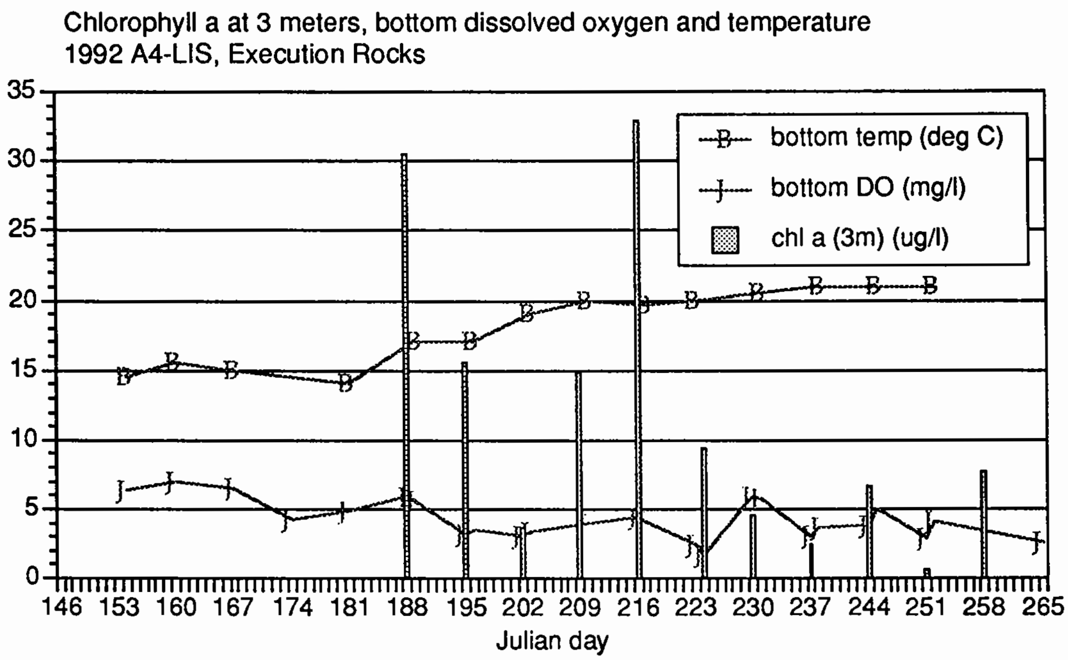

Figure 1.

After experiencing a drop in mid July, community respiration at the 3 meter depth increased to 2.5 mg O_2 l^{-1} day^{-1} by August 11. By August 17, Julian day 230, respiration had dropped to 0.5 mg O_2 l^{-1} day^{-1} and remained less than 1 mg O_2 l^{-1} day^{-1} throughout the remainder of the field season. Similar trends were found in the pycnocline and deep waters although at lower magnitudes (data not presented).

Julian day 230 was also a turning point for phytoplankton production (see Figure 2). Subsequent to this date, phytoplankton biomass remained low but production consistently outpaced apparent grazing during the days sampled. Following late summer turnover, phytoplankton production experienced several peaks and exceeded grazing throughout the remainder of the monitoring period. Apparent grazing may exceed production for one of two reasons: (i) insufficient temporal resolution aliasing lag between production and consumption or (ii) advective transport of senescent phytoplankton into the sample site which are grazed by herbivores not subject to the same transport parameters (e.g. vertical migrators).

Bacterial production more than doubled (see Figure 3) following mid-August overturn. Grazing on the bacterial community kept pace with production throughout the period thereby maintaining bacterial populations throughout the study season at approximately 10^6 cells/ml. Further study is needed to evaluate the production and grazing of the filamentous subset of the bacterial community as this large celled and presumably rapidly growing fraction exhibits widely fluctuating abundances.

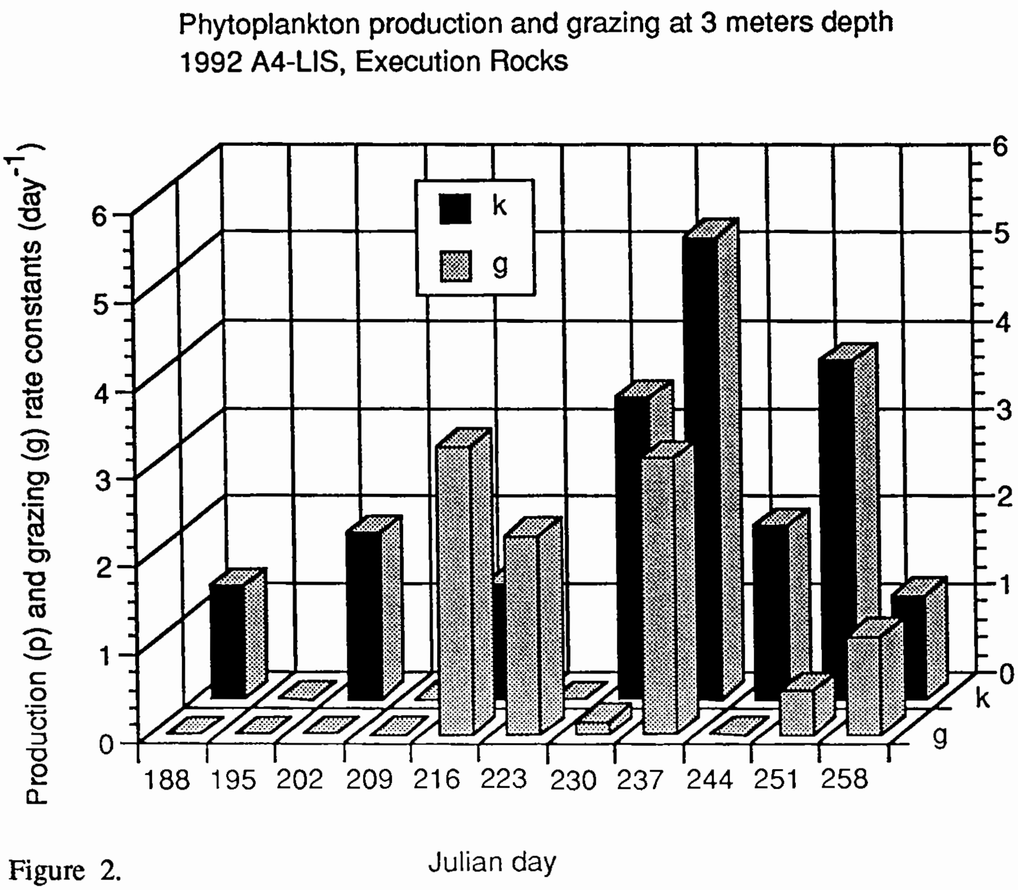

Figure 2.

The generalized view of events occurring over the sampling period was consistent with a scenario of nutrient depleted surface waters in a stratified water column unable to support rapid phytoplankton growth until overturn occurs and resupplies surface waters with remineralized nutrients from deep waters. Poor linkage of bacterial production with the early August peak in phytoplankton density suggests that the bacterial community may be more controlled by allochthonous input of detrital carbon. Correlation analyses between all measurements and material balances of carbon and oxygen will be derived over the coming months.

Ultimately, this study will be used to evaluate the fate of oxygen, carbon, and nutrients in this oceanographically unique estuary. Previous efforts to evaluate the role of the water column in controlling oxygen concentration have stopped short of partitioning the respiration between the bacterial and phytoplankton communities (Welsh and Eller, 1991). By statistically apportioning the respiration to the production of each community by the method of Jensen (1990) individual bacterial and phytoplankton respiration rates will be calculated.

In the 1993 season, we intend to expand this study along several lines. Two adjacent sites will be included periodically for geographical comparison. The techniques of ^{3}H-leucine and ^{3}H-adenine incorporation as indices of microbial production will be employed to compare with measurements made in other estuaries such as Delaware Bay and Chesapeake Bay (Kemp and Boynton, 1981; Ducklow, 1982; Jensen, 1983; Coffin and Sharp, 1987; Kirchman and Hoch, 1988).

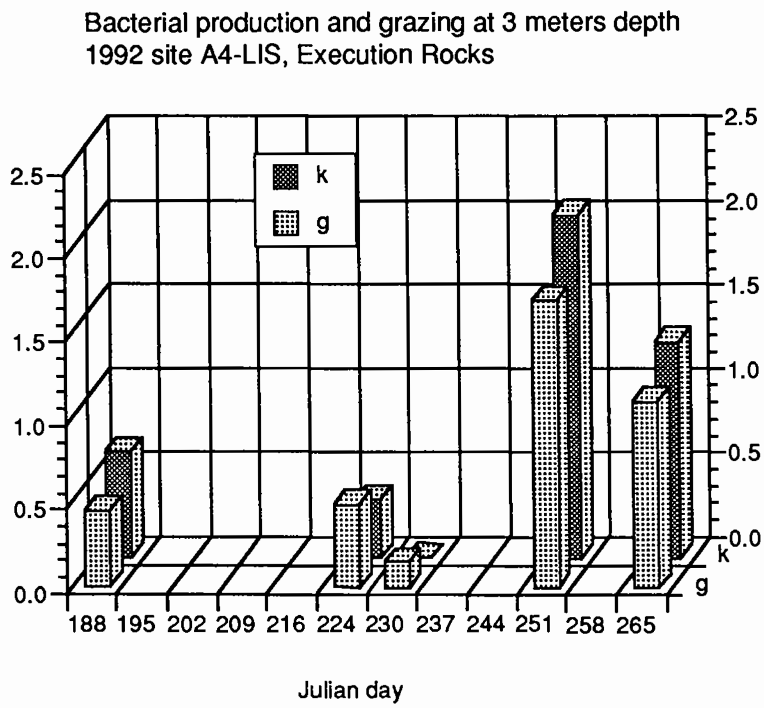

Figure 3.

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Spatial and Temporal Trends of Dissolved Oxygen in the East River and Western Long Island Sound

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Introduction

Significant improvements in dissolved oxygen (DO) concentrations over the past 20 years in most areas of the Hudson-Raritan estuarine system have been extensively documented (O'Connor, 1990; Parker and Riley, 1992; Wagner, 1992). These improvements are associated with the area-wide construction and upgrading of water pollution control plants to secondary treatment, which removes 85 percent of the biochemical oxygen demand (BOD) and total suspended solids (TSS) from raw sewage.

However, despite the elimination of raw sewage discharges, and the dramatic decrease in BOD and TSS point source loads from all communities tributary and adjacent to the Sound, DO concentrations in the Western Long Island Sound (WLIS) have not improved, and appear to have become significantly worse (NYCDEP, 1991; Swanson *et al.*, 1991). Since 1986, the Long Island Sound Study (LISS) has documented hypoxia (DO < 3.0 mg/l) in bottom waters of WLIS, extending from 65 to 180 km^2, and lasting for 2 to 6 weeks (Stacey, 1990).

The purpose of this paper is to highlight what is and is not known regarding spatial and temporal changes in DO in the East River and Western Long Island Sound.

Factors Affecting Water Quality in the East River and WLIS

The East River tidal strait conveys estuarine water between Upper New York Bay and LIS. It is 16 miles long running southwest to northeast from the Battery in NYC to Throgs Neck in the Bronx. Shipping channels are maintained at 35 feet in the northern end and 40 feet in the southern end, with maximum depths of over 100 feet at Throgs Neck and Hell Gate (NYC DEP, 1983). The residence time for the Lower and Upper East River combined is 1.25 days (Jay and Bowman, 1975). Daily tidal excursions range from 9.9 - 13 miles and average 70 percent of the East River's length. Tidal currents are driven by head differences at the two ends of the strait, with velocities exceeding five knots on the ebb tide at Hell Gate. Surface waters at Throgs Neck have a net flow towards LIS, while bottom waters flow towards the Harbor, resulting in a net average flow to NY Harbor (St. John, 1992). The magnitude of these flows is being estimated by the LISS. The effect of these flows is to transport salt water from LIS to the Harbor, and fresh water from the Hudson River to LIS.

The East River exhibits minimal stratification, and has very low plankton levels (chlorophyll 'a' < 5 µg/L). Despite significant improvements, it continues to exhibit chronically low bottom summer DO, with a typical summer mean of 3 - 5 mg/l, and summer minima of 2-3 mg/l (NYC DEP, 1991). Moving up the East River into WLIS, nitrogen concentrations decrease, while plankton levels, surface-to-bottom DO differences, and daily and annual DO variability increase, as algae bloom and crash in response to local ambient conditions. The severity of hypoxia also increases as one moves towards WLIS, where it typically starts earlier in the summer, lasts longer, and exhibits lower minima than typically observed in the East River (NYC DEP, 1991).

WLIS has a natural predisposition for hypoxia. Moving from eastern to western LIS, the surface area and wind fetch decrease, resulting in diminishing wind-driven vertical mixing and atmospheric DO exchange (Bowman, 1991). Tidal currents and estuarine circulation also decrease from east to west, especially in summer when runoff from the Hudson River is at a minimum. Higher summer temperatures and diminished winds allow a weak stratification to persist until disrupted by storms (Parker and O'Reilly, 1991; Welsh and Eller, 1991). High respiration rates in the water column may fortify this weak pycnocline by further restricting the vertical distribution of DO (Welsh and Eller, 1991). Stagnation of bottom waters is enhanced further by the Hempstead Sill, which acts as an impediment to intrusion of deep water to WLIS (Wilson, 1991).

Historical Changes to the East River

Prior to 1680, the original shoreline was irregular with coves, wetlands, mudflats, and small streams (NYC DEP, 1983). Oysters were the dominant shellfish. From 1680 to 1850 wetlands and stream mouths were altered and/or filled. Over-harvesting eliminated oysters from the Lower East River (LER) by the late 1600s, and from Newtown Creek by 1800s (NYCDEP, 1983). From 1850 to 1920 major 'channel improvements' occurred, including removal of rocks and reefs through dredging to 30 - 40 feet below mean low water. Continued landfilling destroyed littoral zones and shorelines became rigid and even. Overharvesting, physical changes and pollution closed a limited lobster fishery at Hell Gate and NY Bay in 1880, and the great Harlem River oyster beds by 1911 (NYCDEP, 1983). Dissolved oxygen declined from 60 percent saturation in 1909 to 10 - 20 percent saturation from the 1920s through the 1950s (Brosnan et *al.*, 1987).

Of NYC's 14 water pollution control plants (WPCPs), six have been constructed on the East River since the mid-1930s. The following changes to loadings into the East River are estimated to have occurred over the past 30 years (modified from Swanson, 1991):

	1960	1990	Percent Change
Raw Sewage (mgd)	400	<1	-100
Treated Sewage (mgd)	477	1021	114
Total (Raw + Treated) Sewage (mgd)	877	1021	16
TSS Loads (mt/d)	225 (Peak = 276 in 1974)	71	-68
BOD Loads (mt/d)	218 (Peak = 263 in 1974)	75	-66
Total Nitrogen Loads (mt/d)	63 (Peak = 72 in 1973)	60	-5

From July 1991 through June 1992, New York City's 14 WPCPs processed 1.593 billion gallons per day (bgd). Thirty-eight percent of this total was discharged through four WPCPs on the Upper East River. An additional 21 percent was discharged through two WPCPs on the Lower East River. Five of the six East River WPCPs provide full secondary treatment. Of these five, Tallman Island is the NYC WPCP closest to LIS, and has been experimenting with biological nutrient removal (BNR) on a portion of its flow since 1990; plans exist to extend this process to the entire flow in the future. The sixth WPCP, Newtown Creek, discharges into the Lower East River, and currently achieves removals of 64 % and 77 % for BOD and TSS respectively. Newtown Creek will be upgraded to full secondary treatment in the future. In addition to receiving flows from six WPCPs, the East River receives the discharge of combined urban runoff and sewage from 239 combined sewer overflow (CSO) discharge points during precipitation events. A 10 year, $1.5 billion CSO Abatement Program is currently assessing and planning remediation for CSOs throughout NY Harbor (Gaffoglio, 1990).

Methods

NYC has been monitoring DO in various stations in NY Harbor, including the East River and WLIS, since 1909. The frequency of summer (June-September) sampling has increased overall from five times or less from 1909-1930, to five for 1931-1950, six to nine for 1951-1970, twelve for 1970-1984, eight to ten for 1985-1987; and 12 for 1988 through 1992. From 1909 to 1984, dissolved oxygen (DO) was determined onboard the sampling vessel using the azide modification of the Winkler method (APHA, 1985). From 1985 through 1987, YSI DO meters were often used. These DO meters were calibrated and rechecked two or three times each sampling day using the Winkler method. Since 1988, the Winkler method has been used almost exclusively. Duplicates were analyzed at one random station per day.

Water samples were collected from surface depths (1.5 m below the water surface) and bottom depths (1.5 m above the sediment surface) using 3.2 liter Kemmerer samplers. Other measurements collected along with the DO data include, salinity, temperature, Secchi transparency, nutrients (total phosphorus, and the dissolved fractions of orthophosphate, ammonia, and nitrate-nitrite), chlorophyll *a*, plankton, TSS, BOD, pH, and coliform bacteria (NYCDEP, 1991).

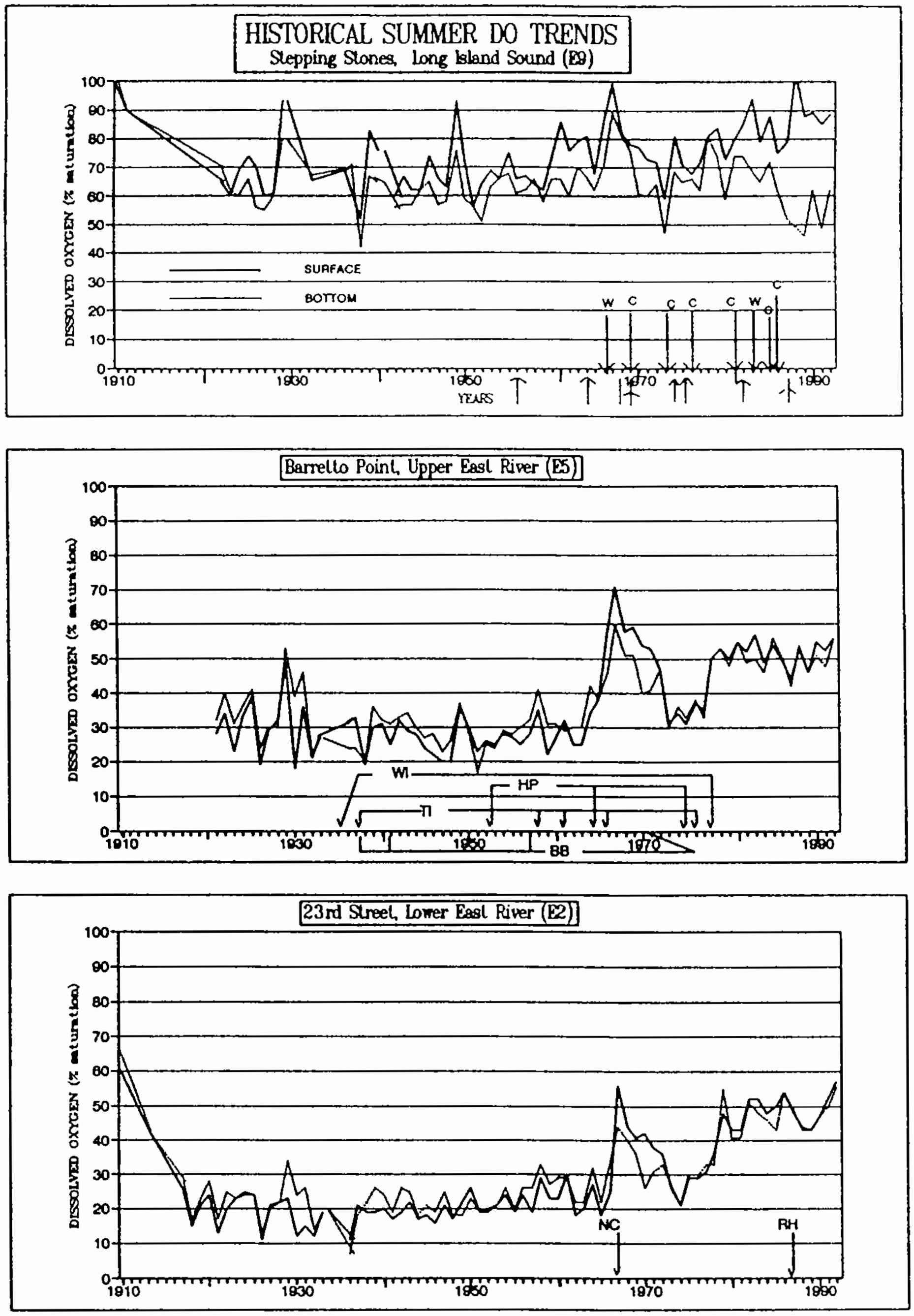
Results and Discussion

Following a steep decline from 1909 to the 1920s, average summer DO percent saturation in the Lower East River fluctuated between 10-30 percent through the 1930s (Figure 1, bottom). In response to the construction and upgrading of WPCPs, conditions gradually improved in the East River from less than 30% saturation in the 1930s, to 40% in the 1970s, to 50% in the 1980s, with present levels approaching 1909 conditions, or 60% (Figure 1, bottom). These improvements were observed in virtually every waterway contiguous to NY Harbor, and coincided with sharp declines in municipal point source TSS and BOD loadings, and decreases of ambient sewage-indicator coliform bacteria, BOD, and total organic carbon (NYCDEP, 1991). Ambient data also suggests that nitrogen concentrations have declined harborwide since the mid-1970s, and have remained unchanged since 1977.

Curiously, DO levels in WLIS appear independent of these improvements, with bottom concentrations displaying no improvements from 1920-1980, and a sharp decline during the summers of 1986-1989 (Figure 1, top). This is in contrast to continued decreases of coliforms in both WLIS and NY Harbor.

Historical trends of the minimum concentration of summer DO observed in WLIS indicate that although borderline hypoxia was observed intermittently in the late 1920s, late 1930s, early 1960s, and especially in the late 1940s and early 1950s, its recurrence and magnitude seem to have increased in the 1970s and 1980s. This has culminated in some of the lowest-ever concentrations observed from 1986-1991 (NYCDEP, 1991). Minimum DOs measured at Stepping Stones Lighthouse in WLIS were 1.6 mg/L or less for 1987 through 1991. In 1992, the minimum DO increased to 3.4 mg/L, presumably in response to a cool, wet summer. These years were also marked by increasing DO stratification with supersaturated surface waters overlying hypoxic bottom waters, a condition often associated with eutrophication (Figure 1, top).

The recent decline and rebound in mean and minimum bottom DO values observed in WLIS were also observed elsewhere in the Harbor, particularly in areas exhibiting algae blooms and density stratification, including Bergen Basin in Jamaica Bay, Raritan Bay and the southern Arthur Kill, and the Hudson River (NYCDEP, 1991). This widespread covariance of DO minima suggests a broad scale meteorological or oceanographic effect. Some of the warmest temperatures on record were recorded in the late 1980s, with 1990 being the warmest ever recorded in NYC (Swanson, 1990). Notorious floatable wash-ups on New Jersey shores in 1987 and the south shore of Long Island in 1988



Average summer D.O. percent saturation for the East River Transect, from 1910 through 1992. Construction of, and significant upgrades to NYC WPCP's on the East River are also depicted: WI=Wards Island, BB=Bowery Bay, TI=Tallman Island, HP=Hunts Point, NC=Newtown Creek, and RH=Red Hook. For top graph, Westchester (W) and Connecticut (C) WPCP's west of the Housatonic River & > 10 mgd are depicted above years. Arrows below years represent WPCP's (including Nassau) < 10 mgd.

BB HARBOR1.WQ1 10/23/92

coincided with harborwide low DOs, fishkills in LIS in 1987, and dolphin die-offs along several coastal states in 1988 (NYCDEP, 1991).

Bottom DO has not improved in WLIS and may be getting worse, despite massive reductions in point source oxygen-demanding organic loads from WPCPs in NYC, Westchester, Nassau, and Suffolk counties, and coastal Connecticut. There is, however, a perception that the problem is getting worse due to recent increases in nitrogen loadings. If this is true, the source of the increases is not clear. As noted in the table above, NYC WPCP nitrogen loads have declined by 12 metric tons per day, or 17 %, from peak loads in the 1970s - again without any improvement in WLIS. The trend in nonpoint loads from changes in landuse throughout the LIS watershed is less clear, although continued suburbanization has presumably increased nonpoint and point source loads.

Some have hypothesized that hypoxia in LIS may be occurring not in spite of, but due to, the recent construction and upgrading of regional WPCPs (Parker and O'Reilly, 1991). If secondary treatment is somehow linked to these DO declines in WLIS, either through changes in particulate to dissolved nitrogen ratios, reduced turbidity, reduced toxicity, changes in ambient water or sediment denitrification, etc., it is certainly an unforeseen side-effect. This has potentially significant implications for future planned CSO abatement facilities, upgrading of WPCPs, continued reductions of toxics (especially the phyto-toxin copper) and potential tertiary treatment (NYCDEP, 1991).

This scenario of reducing pollutant loads and declining water quality is counterintuitive. This was unpredicted by scientists and regulators using state-of-the-art mathematical water quality models in the mid-1970s, when most of the recent upgrades to secondary treatment were carried out (Figure 1). These same WPCPs are now being targeted for nitrogen removal on the basis of mathematical modeling performed for the Long Island Sound Study (LISS). Preliminary modeling estimates that seventy percent of the DO depression in the WLIS hotspot is attributable to nitrogen, with the remainder due to oxidizable carbon (St John, 1991). Historical observations of the lack of improvements in WLIS after 50 years of constructing and upgrading WPCPs raises questions regarding the present assumption that removal of East River WPCP nitrogen loads will result in significant improvements in WLIS.

Nevertheless, despite these uncertainties, in an attempt to prevent the problem from getting worse NYC is cooperating with a LISS decision to freeze the discharge of nitrogenous compounds from its six East River WPCPs to 1990 levels. As noted above, NYC is also conducting a pilot program for biological nutrient removal (BNR) at Tallman Island. Feasibility studies to evaluate ways for NYC's six East River WPCPs to perform full nitrogen removal have estimated construction costs alone at over $7 billion (Wagner, 1992).

In summary, hypoxia in WLIS appears to be getting worse, although there is no consensus as to why. Elevated nitrogen concentrations have been observed for decades, but severe sustained hypoxia appears to be a recent phenomenon. WLIS has not responded as predicted to point source pollution abatement in the past, and this reduces confidence in planned future point source reductions. A quantitative assessment of how WLIS came to its present condition is critical to understanding the past and present relationship between pollutant loadings and DO levels, as well as for predicting what future management scenarios might produce. Understanding how much of the problem is due to point source anthropogenic nutrients, and how much is due to non-point sources and unstudied physical factors is crucial to attempts to manage these problems.

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A Comparison of the Norwalk and Saugatuck Estuaries With Respect to Dissolved Oxygen Levels and Benthic Juvenile Fish

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A study of two neighboring estuaries, the Norwalk and Saugatuck harbor was undertaken to determine the seasonal availability of dissolved oxygen in the water column and its relationship to populations of juvenile benthic fish. Both estuaries are beginning to show the long term effects of anthropogenic nitrogen enrichment which ultimately results in a buildup of organic material ("black mayonnaise") and the formation of *Ulva* beds on the harbor floors . The Norwalk estuary now exhibits large areas that are impacted in this manner.

Results indicate that the Saugatuck estuary (Figure 1a, harbor map) is well-mixed and maintains good flushing characteristics; whereas, the Norwalk estuary with its extensively altered shoreline is highly stratified with respect to oxygen levels and exhibits poor flushing characteristics. In the Saugatuck estuary benthic oxygen levels during the summer seldom drop below 4 ppm, and there is little variability between levels at the surface and the bottomat Station 3S (Figure 2a) . In addition, salinity varies only slightly. At the uppermost station (6S) (Figure 2b) salinity levels of 15 ppt are routinely found at the surface and 17 ppt levels at the bottom. Stratification with respect to oxygen and salinity levels are minimal .

The natural physical configuration of the Saugatuck estuary appears to assist its flushing. In addition to input from the flow of the upper river and Stony Brook Creek, the northern zone of the estuary contains two large basins, one just below the Route 1 bridge and the second one just below the Metro North railroad bridge (Figure 1) . Water inputs from these sources act to boost the flushing efficiency during the ebb tide. The Saugatuck estuary is too shallow for large vessels and its shoreline is mostly developed by large residential properties. There are only several medium sized marinas within its boundaries.

In spite of good flushing characteristics and relatively healthy oxygen levels, it is very probable that anthropogenic nitrogen levels in the Saugatuck estuary are high . Large plankton blooms, extensive beds of *Ulva* in the mid and outer harbor and deteriorated bottom conditions characterized by a heavy buildup of organic matter in the northern end, all suggest that nitrogen enrichment is a problem. The sewage effluent from the Westport Wastewater Treatment Plant is low (1 m.gal./day). Fixed nitrogen levels in the Saugatuck River, however, range from 1 to 4 ppm/day. This concentration is dependent on weather conditions, run-off from residential properties, faulty septic systems and the input of lawn wastes that are deposited into the river.

In contrast, the Norwalk estuary is almost fully developed along commercial lines with industrial enterprises and extensive marinas. The upper harbor (Figure 1b) is basically a large man-made ditch with no tidal wetlands (except for a few strip marshes). The estuary is also characterized by massive bridge abutments which severely impede tidal flow and several large land fills situated along its shoreline. In addition, the estuary receives effluent input from a 15 m.gal./day wastewater treatment plant situated in the upper harbor .

Water quality is severely degraded in the upper estuary in Norwalk Harbor . During the late summer, this area regularly experiences the effects of hypoxia. The last documented hypoxic event occurred in mid-September 1991, when oxygen levels in the estuary dropped so low that large schools of bunker and benthic fish species died. During the same time the Saugatuck estuary did not experience any hypoxia. Station 6N (see Figure 2c) clearly shows extended oxygen deprivation at the bottom throughout the summer, even though the incoming fresh water input from the Norwalk River

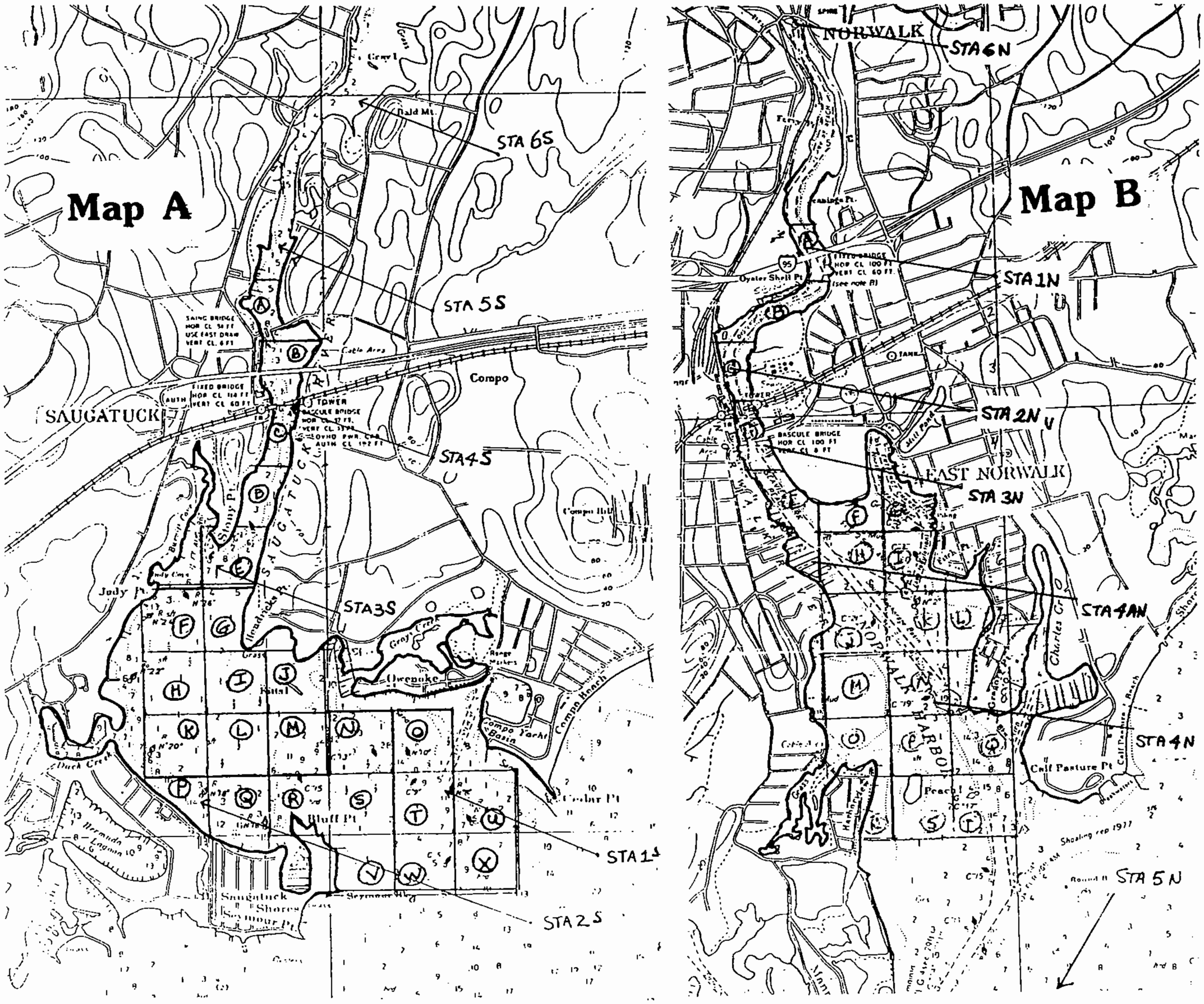

Figure 1. Map A, the Saugatuck Harbor; Map B, The Norwalk Harbor.

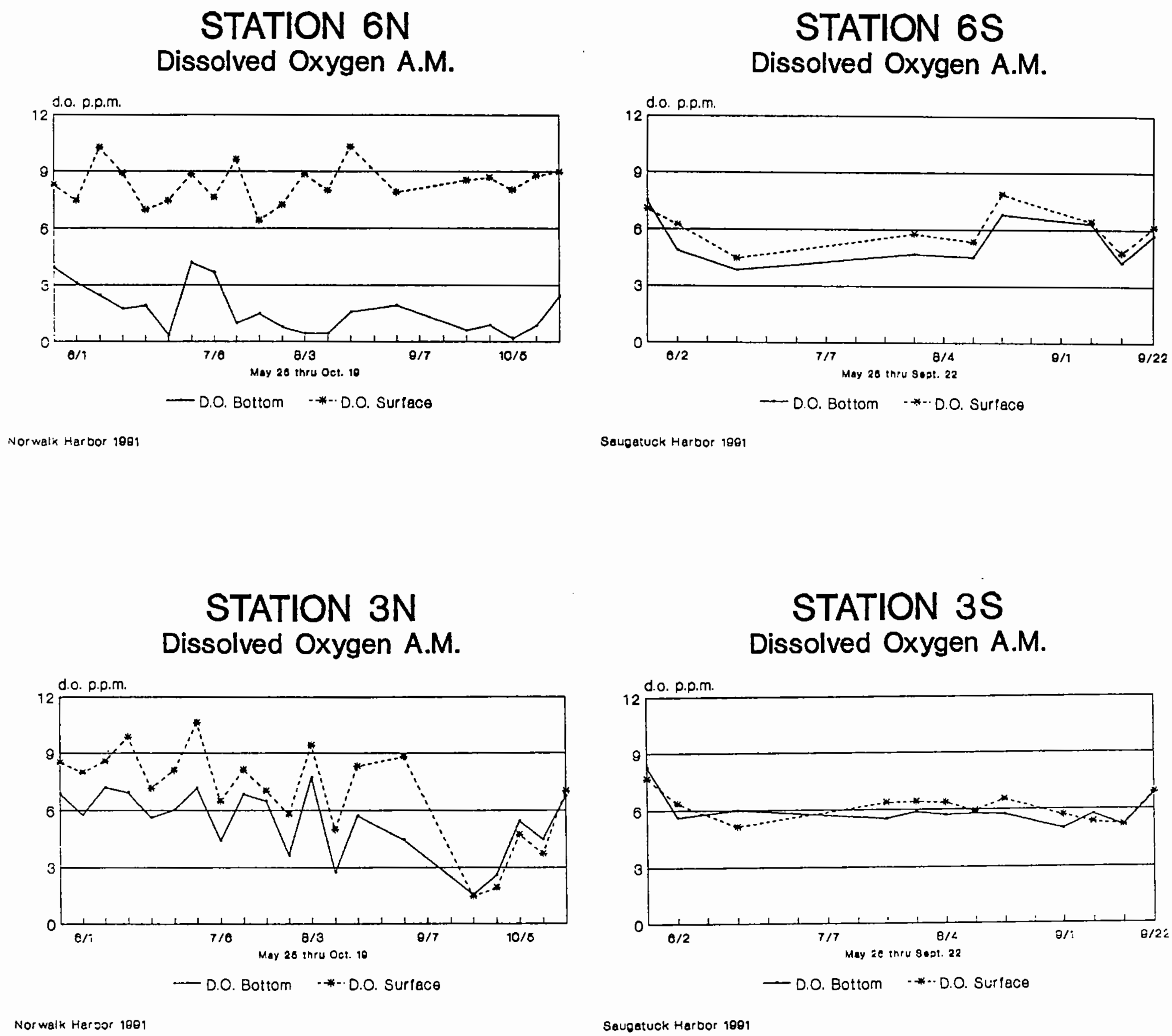

Figure 2. Dissolved oxygen profiles (a.m.) of the Norwalk Harbor Stations (6N & 3N) and the Saugatuck Harbor Stations (6S & 3S) for the upper and mid-harbor areas from late May through September, 1991.

ranges from near zero to 22 ppt. The upper estuary is highly stratified with respect to salinity which retards mixing. The mid-harbor station (3N, Figure l) shows the rapid decline in water quality which occurred immediately following a hurricane (Bob) in mid-August 1991.

The review of both estuaries indicates the following:

1. The Norwalk Harbor with its extensive shoreline alterations, constrained tidal flushing, heavy input of pollution and stratified condition, has a narrow margin of safety for the survival of benthic organisms, both fish and invertebrates. Weather conditions, i.e. hot weather and storms, can stress the estuary and quickly push it to an hypoxic condition. When these events occur it is harmful to all fish, not just bunker.

2. The Saugatuck Harbor, which is moderately developed, maintains a strong flushing cycle, and receives considerably less pollutants, and is more resilient to summertime stresses. Fish have a better chance of survival because the estuary maintains good levels of oxygen throughout the summer. Hypoxia has not been observed at any sampling station in the Saugatuck.

3. The Saugatuck Harbor has a greater speciation of benthic fish in comparison to Norwalk Harbor, which suggests that some of the more fragile species can no longer tolerate conditions in that estuary.

4. It is not known if either estuary is in a steady state or in a continual decline. Observations suggest that the loss of good bottom in both estuaries is increasing and remedial efforts particularly aimed at the reduction of excessive nutrients are needed.

Sediment Toxicity in Long Island Sound Embayments

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Abstract

As part of NOAA's National Status and Trends (NS&T) Program, surface sediment samples were collected from 20 embayments in Long Island Sound and from a central Long Island Sound reference site in an effort to document the severity and geographic extent of toxicity. Three toxicity tests were used: the 10-day solid phase bioassay (*Ampelisca abdita*), the 48-hour sediment elutriate bioassay (*Mulinia lateralis*), and the Microtox bioassay on organic extracts. Sediments were analyzed for inorganic and organic elements, for Acid Volatile Sulfides (AVS) and Simultaneously Extracted Metals (SEM), and for grainsize and carbon (TOC) content.

There is general agreement between results of *Ampelisca* and Microtox; *Mulinia* results show fewer responses. Toxic response was generally correlated with sediment contaminant concentrations, mostly from bays in the western end of the Sound. A large number of samples exhibited significant toxicity relative to controls with the greater toxicities observed in embayments from the west end of the Sound. Metal toxicity is unlikely since the molar ratios of SEM:AVS were less than 1.0 for all but three samples. Results suggest that the toxicity is likely caused by organic contaminants and not by metals.

Introduction

In 1985 the Long Island Sound Study (LISS) was initiated by the U.S. Environmental Protection Agency (EPA) in order to examine the extent of pollution and related problems within the Sound with the intent of using the information for planning future management activities. Numerous studies of sediment chemical contaminant concentrations and some few toxicity and bioeffects surveys have been performed by the National Oceanic and Atmospheric Administration (NOAA) in conjunction with and in support of the LISS activities (summarized in Wolfe et al., 1992 and Long *et al.*, 1992). Results of these studies in addition to those of other research and monitoring programs have shown that there is a gradient from high concentrations in the western Sound to lower concentrations in the eastern Sound, and that in general, effects and contaminants were greatest in areas of highest population (Turgeon and O'Connor, 1991; Robertson *et al.*, 1991; Stiles *et al.*, 1991; Gronlund *et al.*, 1991; Greig *et al.*, 1977). With a few exceptions, most of these previous studies and longer-term monitoring programs (NOAA's National Status and Trends Program [NS&T]; EPA's Environmental Monitoring and Assessment Program [EMAP]) have focused on samples taken from the main stem of the Sound. This resulted in a lack of information regarding toxic contaminant levels and associated biological effects in potential hotspot areas believed to have the greatest contamination and toxicity within Long Island Sound. Thus, a thorough assessment could not be made of the most highly contaminated areas that might require management action.

The objectives of the study were to document the severity of toxicity of surficial sediments within harbors and embayments of Long Island Sound, to identify geographic patterns and the extent of toxicity, and to assess the potential cause/effect relationships between expressed toxicity and contaminant levels in sediment samples. Within each harbor or embayment stations were chosen to represent a gradient in conditions and thus are not expected to be representative or integrative of the area. This research was funded by a special NOAA appropriation for the study of Long Island Sound in cooperation with and in support of EPA's LISS and was performed as part of the National Status and Trends Program.

Study Area

Long Island Sound is an elongate embayment with a predominantly east-west axis that is bounded to the north by the state of Connecticut and to the south by Long Island, New York. The Sound is divided into 3 basins by two sills, the Stratford Shoal and Mattituck Sill (Figure 1) which influence the circulation of the Sound by restricting seawater inflow at the eastern boundary. The Connecticut River accounts for 70% of the total freshwater input to the Sound and enters to the east of the Eastern sill. The East River enters at the western end connecting the Sound to New York Harbor. The Housatonic and Thames River discharges, and surface runoff from New York and Connecticut account for the balance of freshwater inflow. The watershed area is 4.2×10^4 km^2, 25% of which is urban and built up, 14% agricultural, 60% forest and wetlands, and 1% barren (SAB, 1987). The water surface area is 3200 km^2, with a mean depth of 20 m, and a mean residence time of 166 days (SAB, 1990).

Besides upstream sources, the major source of contaminants including cadmium, copper, mercury, zinc, and chlorinated hydrocarbon pesticides is industrial and municipal wastewater discharges. There are 313 industrial and municipal point sources (SAB, 1990) that discharge approximately 1500×10^6 m^3 sewage per year into the Sound (Farrow *et al.*, 1986). Of the total sewage discharge, about 85% is discharged to the western basin, 11% and 4 % to the central and eastern basins, respectively. The distribution of point sources reflects the distribution of population within coastal counties. Approximately 70% of the total 8.75 million residents in 1988 were living in counties bordering the eastern basin, 24% and 6% in counties bordering the central and eastern basins, respectively (Wolfe *et al.*, 1991). Urban runoff is also an important source of some pollutants, particularly lead, as is atmospheric deposition.

Methods

FIELD SAMPLING:

A total of 63 samples were collected from 21 sites within bays and harbors of Long Island Sound and from a reference site in Central Long Island Sound. At each site, 3 samples were collected for toxicity tests, organic and inorganic chemical analyses, Acid Volatile Sulfide and Simultaneously Extracted Metals (AVS/SEM) analyses, and Total Organic Carbon (TOC) and grainsize analyses. A Smith MacIntyre grab and a modified Van Veen grab were used on the NOAA ship FERREL and its 23 foot workboat, the SEA OX, respectively. The grab samplers and sampling scoops were cleaned by successive rinses with dichloromethane, acetone, and de-ionized water prior to each sample collection. Only fine grained sediments (<75% sand) were intended to be accepted, although at some stations, sediments of >75% sand were accepted when finer grained sediments could not be found (SAIC, 1992).

ANALYTICAL METHODS

Toxicity tests: Toxicity tests were conducted on each sample using three different test organisms and four endpoints. Sediments were kept at 4°C (not frozen) prior to testing.

The 10-day solid phase test followed the basic procedures of the ASTM (1991) for testing of sediments with estuarine and marine amphipods. The tests were performed in quintuplicate with 10-day static exposure to solid phase sediments and overlying seawater. The endpoint reported was percent survival of the amphipod *Ampelisca abdita* relative to controls.

The 48-hour elutriate test was performed using larvae of *Mulinia lateralis* which were exposed to a seawater derived elutriate of the sediment. The elutriates were filtered to recover the

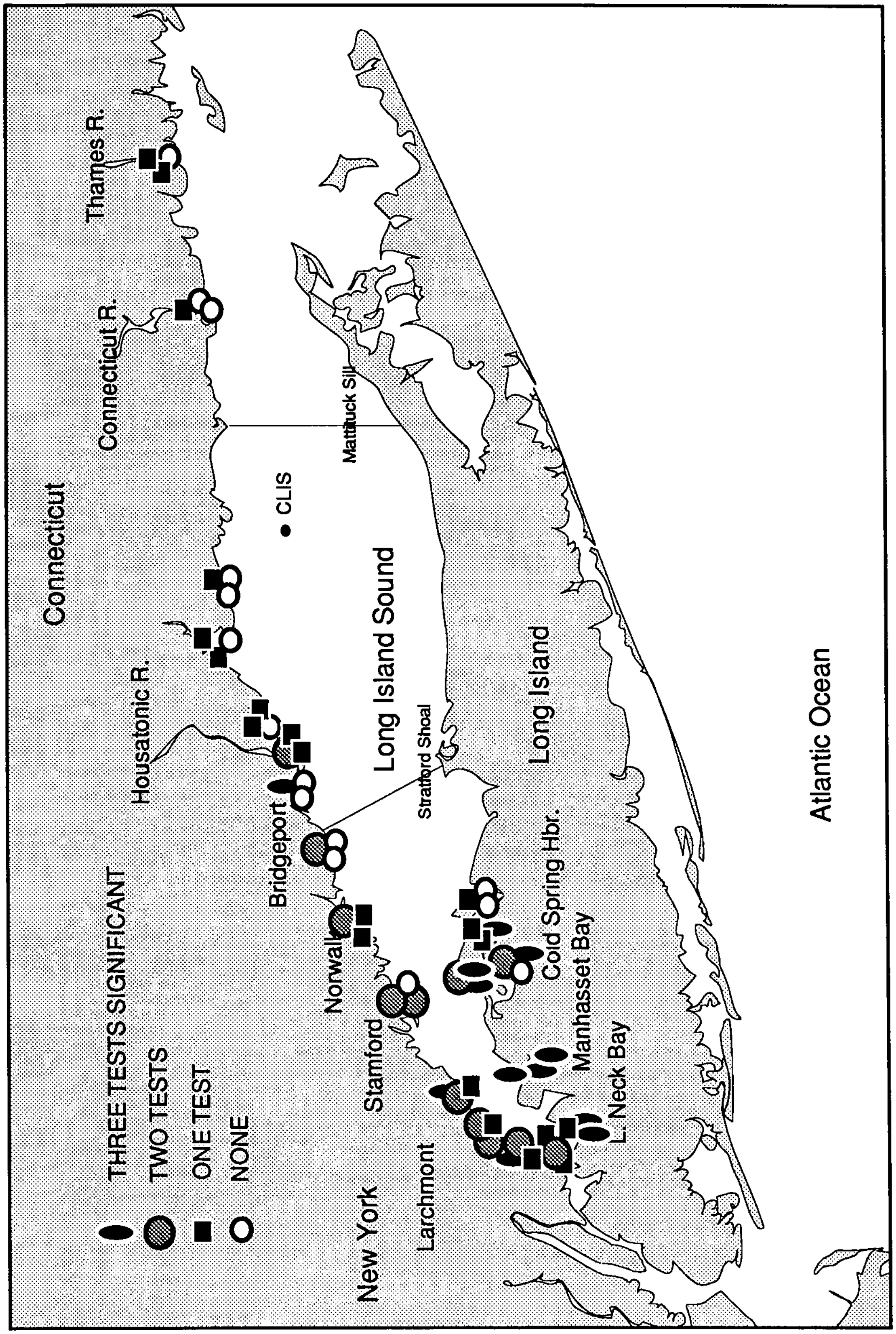

Figure 1: Sampling locations in Long Island Sound where sediments were significantly toxic in three, two, one, or no tests. "Significant" includes statistically significant (p = .05) reduction from and <80% of control survival for Ampelisca and Mulinia or <70% of control for Microtox. CLIS is the reference station. The approximate locations of the Stratford Shoal and Mattituck Sill that divide the Sound are shown also.

liquid phase for testing. This test followed the basic procedures outlined by the USEPA/USACOE (1978) and PSEP (1990). Two end-points were reported, percent mortality and percent abnormal development after 48-hours relative to controls. These tests also were performed in quintuplicate on each sample.

The Microtox sediment toxicity test was performed with a dichloromethane extract of the sediment and followed the basic procedures of the EPA Puget Sound Protocols (PSEP, 1990; Chapman and Becker, 1986; Shiewe *et al.*, 1985). Following a range-finding step, four serial dilutions were tested and the results reported as EC50s, the Effective Concentrations at which light production by the bacteria *Photobacterium phosphoreum* is reduced by 50%.

Chemical Analyses and Ancillary Measurements: The suite of organic and inorganic chemicals to be measured are those routinely measured by the NS&T Program, including DDT and its metabolites, Polycyclic Aromatic Hydrocarbons (PAHs), chlorinated pesticides other than DDT, polychlorinated biphenyls (PCBs), and 16 trace and heavy metals. Procedures for analysis of organic chemicals are outlined in MacLeod *et al.* (1985) and Battelle Ocean Sciences (1991). Briefly, PAHs, PCBs and chlorinated pesticides were analyzed by mass selective or electron capture detection gas chromatography. Methods for inorganic chemical analyses are those used for the NOAA's NS&T's Mussel Watch Project and can be found in Battelle Ocean Sciences (1991). In short, metal concentrations were determined by cold vapor atomic absorption, hydride generation atomic absorption, graphite furnace atomic absorption, or inductively coupled plasma/mass spectrometry. The analysis for AVS used selective generation of hydrogen sulfide, cryogenic trapping, gas chromatographic separation, and photoionization detection (Cutter and Oates, 1987; Allen *et al.*, 1991). Following AVS analysis and digestate filtration, SEM analyses were performed on the HCL sediment digestate for cadmium, copper, lead, mercury, nickel, and zinc. Total organic carbon content was determined using a LECO carbon analyzer after first removing inorganic carbon with 6N HCl. Grainsize was determined using the standard sieve and pipette method (Battelle Ocean Sciences, 1991).

Results and Discussion

Toxicity test results showed that a large number of the samples exhibited significant toxicities relative to control sediments from central Long Island Sound and that the greater toxicity was observed in harbors and embayments in the western end of the Sound (Figure 1) A total of 50 of the 60 stations showed toxic response estimated by the % survival of *Ampelisca*, 58% by Microtox, and 35% estimated by % survival of *Mulinia*. The % abnormal development of *Mulinia* was not as sensitive a test showing toxic response at only 8% of the stations and will not be discussed further. Unfortunately, there are few previous toxicity surveys that can be used for comparison to these results; however, the E to W gradient in toxicity among all embayments matches previous reports of sediment contaminant gradients within the Sound. This distribution reflects population demographics and known pollutant input sources.

Correlation analyses (Spearman ranks; Siegel, 1956) were performed on the total population of results (63 stations including the CLIS reference site) to determine whether there was a significant relationship between sediment contamination and/or sediment characteristics and toxicity. Toxicities estimated by Microtox were significantly correlated to % fines (silt and clay), % TOC in the sediment and to the inorganic (Zn, Pb, Hg, Cu, Cr, Cd) and organic (PCBs, DDTs, PAHs, pesticides) contaminants measured in the sediments (Table 1). The %fines, %TOC were significantly correlated to each other and to contaminants. The results of the Microtox test were not significantly correlated with either the % survival of *Ampelisca* or of *Mulinia*. Toxicities measured by the % survival endpoints were not correlated with % fines but were correlated with %TOC and to each other. Although the toxicity results of both tests were significantly related to various sediment contaminant concentrations, the correlations were not as strong as for the Microtox response (Table 1). However, in a general sense, these analyses gave the expected result, that the greatest toxicities are observed for sediments that have the greatest contaminant concentrations, and for the most part these were embayments located in the western end of the Sound. Toxicities were highest in Bridgeport Harbor, Connecticut and in Little Neck Inlet, Manhasset Bay, Larchmont Harbor, Cold Spring Harbor, Oyster Bay, and Pelham Bay, in New York.

For 17 of the 20 sites, the three stations were arranged in a transect so that an analysis could be made of the spatial distribution of contaminants and toxicities within each embayment or harbor. Using the sum of ranks in Friedman's Two-Way Analysis of Variance Test (Siegel, 1956) a significant decreasing trend was found from upper to lower embayment stations for inorganic and organic contaminants, %TOC, grainsize, and AVS, though for some the trend was stronger than for others (Figure 2). As expected, this corresponds to the location of the pollutant sources upstream. This same analysis for the toxicity test results showed conflicting results. Toxicities estimated by the Microtox test show an identical pattern, with the greatest toxic response shown in the upper stations. However, the toxicities measured by *Mulinia* and *Ampelisca* % survival show the reverse trend, with the greatest toxic response elicited by sediments located near the mouth of the harbors and embayments, where contaminant concentrations are lower (Figure 2).

This does not seem to make sense until it is noted that the 48-hour elutriate test and the 10-day solid phase tests are performed with seawater extracts or seawater plus sediment, which presumably does not alter the contaminant-organic carbon bond. The Microtox test by contrast, uses an organic extract of the sediment, and therefore does not reflect a natural bioaccumulation situation. The toxic responses indicated by the whole organism % survival endpoints are observed at lower bay stations with lower %TOC in the sediment. The %TOC in the upper bay stations may act as a modulator of toxicity, rendering contaminants unavailable for biologic uptake.

The remaining question is the cause/effect relationships between contaminants and toxicities, since both organic and inorganic contaminants are greater in the upper embayment stations. The SEM:AVS ratios suggest that the metals are not causing toxicity since, for all but three stations, the values are less than one indicating that the metals are effectively removed from the biologically available pool as sulfide phases. In addition, the toxicities at the three stations where the values are equal to or greater than 1, are low to moderate where they might have been expected to be severe if metals were the causative factor. These results implicate organic contaminants as those causing toxic response. Additionally, the Microtox results are based on an organic extract, and thus presumably is testing only the organic contaminants, suggest that the organics are toxic. Taken together, these results suggest that the sediment organic carbon modulates the effect of the organic contaminants, which are probably the causative factor in the observed toxicities. This is consistent with the Sediment Partitioning Coefficient Concept as it is being applied by the EPA for development of sediment quality criteria (EPA, 1991; Di Toro *et al.*, 1991).

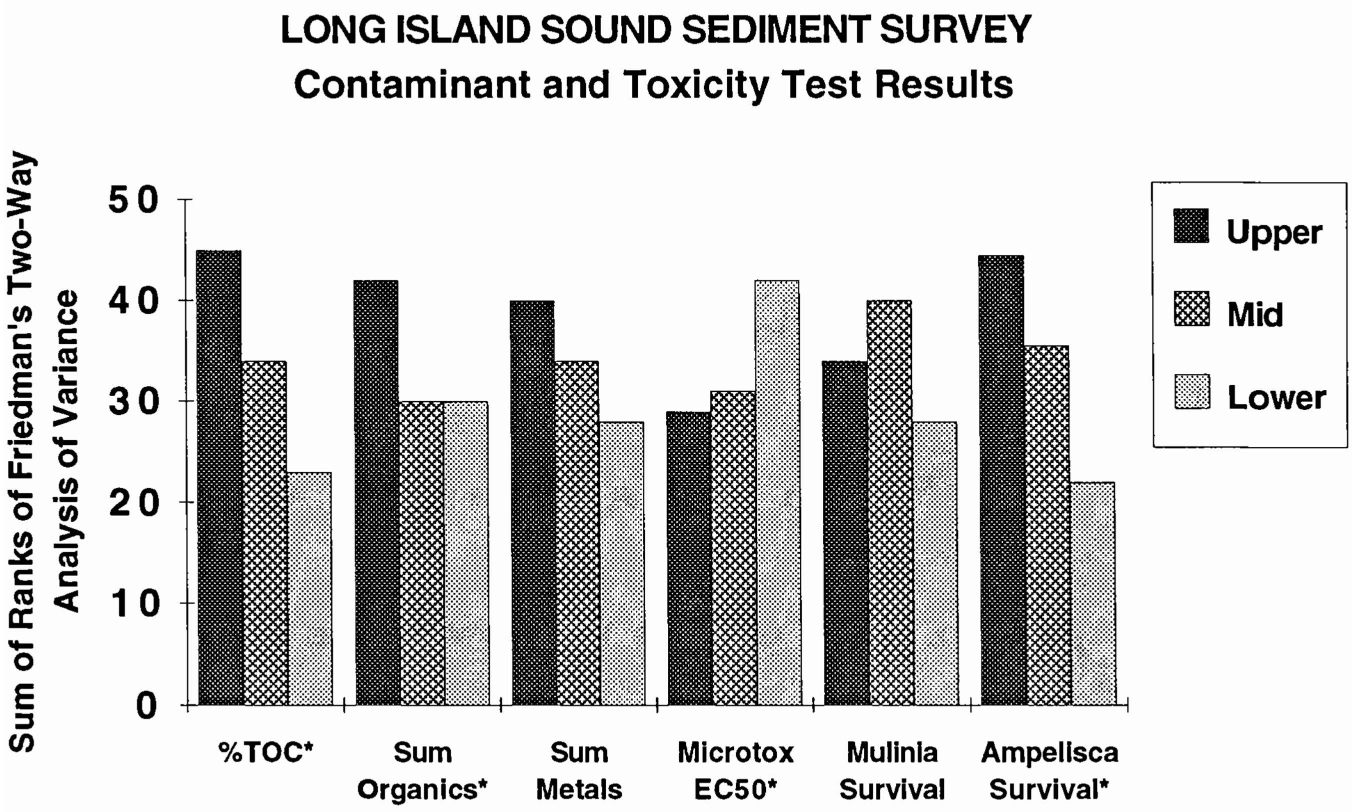

Figure 2: Results of Friedman's Two-Way Analysis of Variance Test to determine whether trends in spatial distribution of contaminants and toxicities within embayments are significant. An asterisk indicates that there is a significant difference between upper and lower stations within embayments at the 95% confidence level. Note that the Microtox results show greatest toxic response (lowest EC50) in the upper stations where %TOC and contaminants are highest, while the greatest response shown by % survival endpoints is observed in the lower bay stations.

TABLE 1: LONG ISLAND SOUND SEDIMENT SURVEY SIGNIFICANT RELATIONSHIPS: SPEARMAN RANK TEST*

	Microtox EC50	Ampelisca % Survival	Mulinia % Survival
%Fines	-0.411	NS	NS
%TOC	-0.757	-0.258	-0.346
Zn	-0.686	-0.335	-0.329
Pb	-0.687	-0.299	-0.354
Hg	-0.712	NS	-0.310
Cu	-0.535	-0.320	-0.281
Cr	-0.525	-0.292	NS
Cd	-0.671	-0.360	-0.270
PCBs	-0.486	-0.328	NS
DDTs	-0.447	-0.259	NS
PAHs	-0.495	-0.267	NS
Pesticides	-0.552	NS	-0.431
Microtox EC50	NS	NS	NS
Ampelisca % Survival	NS	NS	0.333
Mulinia % Survival	NS	0.333	NS

*These correlations were performed on the total population of 63 samples, 3 stations per site plus the three stations at CLIS. These relationships are significant at the 95% confidence level. NS indicates that there was not a significant correlation.

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Relationships between Bacterial Abundance and Selected Hydrographic and Seston Measures at Three Long Island Sound Sites, 1987-1988.

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There is a widely-recognized ecological gradient in Long Island Sound, ranging from estuarine and impacted by human population in the western basin to more oceanic and less affected by pollution in the east. Less clear are the biotic effects of this gradient, which may include both biological enhancements and inhibitions such as: 1) increases in phytoplankton productivity arising from nutrient over-enrichment in the west and nutrient limitation of primary productivity in the east, 2) toxic pollutant stress in the west and lower levels of toxics in the east, and 3) higher metabolic rates in the west resulting from slightly higher water temperatures.

In 1987 and 1988, multi-disciplinary studies of factors influencing population biology of the hard clam, *Mercenaria mercenaria*, were conducted by Milford Laboratory staff at three sites along the Connecticut coast: Greenwich, Milford, and Stonington. These sites were selected to represent a wide environmental gradient. As essentially immobile benthic suspension-feeders, hard clams are likely to respond to the types of hydrographic productivity, and pollutant differences that characterize the Sound. The general design of our study was to plant young (ca. 12 mm length) laboratory-reared clams in predator-exclusion cages at the sites and to measure, over the growing season (April - November) at 2-4 week intervals, clam shell length (growth) and an extensive suite of hydrographic, seston, and microbiological variables. Primary data and interpretations of hydrographic regimes, phytoplankton assemblages, and clam growth and recruitment observations have been (or will be) reported elsewhere (Blogoslawski *et al.*, 1988; Goldberg and Wikfors, 1992; Wikfors, 1992, in prep.; Goldberg and Widman, in prep.; Wikfors and Goldberg, in prep.). The purpose of the present study is to investigate how hydrographic, seston, and site characteristics may be related to the presence of *Vibrio* bacteria in water, sediment, and clam samples; some strains of *Vibrio* are potential clam pathogens. Relationships in data sets, collected concurrently by three collaborating research teams, were explored using correlation analysis.

Detailed methods of data collection and some analyses are given in the reports cited above. Briefly, temperature was measured *in situ*, and standard methods were employed for determinations of seston dry weight (gravimetric, following rinses with isotonic ammonium formate to remove salts) and chlorophyll *a* (Strickland and Parsons, 1968). Bacterial counts were by the spread-plate method, using appropriate dilutions of water, sediment, and planted clam samples (Buck and Cleverdon, 1960). OZR agar plates were counted for total heterotrophic bacteria, and TCBS plates — a growth medium selective for *Vibrio* — provided counts for this bacterial genus (Tettelbach *et al.*, 1984). The following ten variables (designations in Table 1, in parentheses) were included in a matrix subjected to Spearman rank correlation analysis: station number, temperature [°C], chlorophyll *a* (CHL *a* WATER) [μg/l], seston dry weight (DRY WT SESTON) [mg/l], and bacterial counts (CFU/ml = count-forming units) for total heterotrophs from water (BACT WATER), sediment (BACT SEDIMENT), and clams (BACT CLAM), as well as for *Vibrio* bacteria from the same samples (VIBRIO CLAM, VIBRIO SEDIMENT, and VIBRIO WATER, respectively).

1987 data were not included in statistical analysis because we believe 1987 was an anomalous year. In the western half of Long Island Sound (including both Greenwich and Milford sites), an exceptionally widespread and persistent bloom of the dinoflagellate *Prorocentrum* occurred during mid-summer; this bloom interfered with normal feeding and growth of hard clams, as evidenced by declines in clam growth rates coincident with the bloom (Goldberg and Widman, in prep.; Wikfors, in prep.). Follow-up laboratory experiments demonstrated no growth of hard clams when fed cultured *P. minimum*; these experiments provided evidence that detrimental effects of this dinoflagellate upon bay scallops, *Argopecten irradians,* were caused by a molluscan enterotoxin in *P. minimum* (Wikfors and Smolowitz, in press).

Spearman rank correlation analysis of 1988 data revealed significant (p<.01 and p<.05) relationships between a number of variables (Table 1). A cautionary note about correlation analysis should be stressed, however. A significant correlation does not indicate cause-and-effect, but rather, suggests that there may be a relationship. Subsequent cause-and-effect hypotheses must rely upon the application of logic and knowledge of mechanisms that may be involved. Another technical point to consider in extrapolating these results to disease processes in clams is that there was no evidence of disease outbreak in the planted clams analyzed. Several bacterial isolates obtained from the post-set clams were, however, shown in laboratory exposure studies to be pathogenic to larval clams (Blogoslawski *et al.*, 1988). It appears that some *Vibrio* strains pathogenic to larval *M. mercenaria* do not cause disease condition in post-set animals. We suggest that elevated *Vibrio* counts in post-set clams indicate likelihood of exposure of larval clams, assuming that larvae and post-set will be exposed to the same conditions, filter the same water, etc. We also note that *Vibrio* counts in clams were highest during mid-summer when the larvae of clams are pelagic (see below). With these cautions in mind, a discussion of observed correlations and a hypothesized scenario for events that may contribute to larval hard clam disease outbreaks follows.

Considering significant correlations with the variable "VIBRIO CLAM," i.e., *Vibrio* counts from clam samples, in order of their appearance in Table 1, a relationship with station number is first apparent. As Greenwich was designated "Station 3," Milford "2," and Stonington "1," the correlation with station number indicates that *Vibrio* counts were generally higher in the west. Looking next at cross-correlations with station number, both chlorophyll *a* and *Vibrio* counts in sediment samples were higher in the west than in the east as well. Temperature is correlated positively with *Vibrio* counts in the clams, suggesting a seasonal (summer) as well as geographic component associated with elevated *Vibrio* counts in clams. Cross correlations with temperature indicate that chlorophyll a levels, and *Vibrio* counts in sediment and water samples are also generally higher in mid-summer. These data agree with the findings of Brown *et al.* (1988), who observed increasing bacterial counts — especially *Vibrio* — as the water temperature of Long Island Sound rose during the summer of 1980. Kaneko and Colwell (1973) noted that *V. parahaemolyticus* was released from the sediments of Chesapeake Bay during the late spring and associated itself with the zooplankton.

Chlorophyll *a* levels, also coincident with elevated *Vibrio* counts in clams, tend to be higher at mid-summer in Greenwich and also are correlated with higher seston dry weights and *Vibrio* counts in the sediment. Seston dry weight, in these data, is mostly a function of how much bottom sediment was mixed into the water column; the percentage of seston dry weight composed of the biological components protein, carbohydrate, and lipid was in the range of 10-20% (Wikfors, in prep.). Suspended seston dry weight was correlated with elevated *Vibrio* in the clam, and a cross correlation with *Vibrio* in the sediment indicates that bottom sediment was most often mixed into the water column at times when *Vibrio* counts in the sediment were high. Finally, *Vibrio* in the sediment was correlated strongly with *Vibrio* in the clam, and cross-correlated with most of the variables mentioned above: station number, temperature, chlorophyll *a*, and suspended sediment, along with total heterotrophic bacteria in the sediment.

It is very interesting to note several associations that may have been hypothesized, but are not borne out by the statistics in this correlation matrix. Most notably, *Vibrio* counts from whole water samples (VIBRIO WATER) do not correlate with *Vibrio* counts from clam samples. This may, at first, seem a contradiction; however, the primary data show several instances of *Vibrio* counts being relatively high in clams when counts from water samples were low — and instances of high counts in the water with low counts in the clam. There are several possible explanations for this. Among them, free-living *Vibrio* bacteria, i.e., those not attached to seston particles, may be too small to be removed from suspension by filtering clams; filtration efficiency of particles <2μm is poor for *M. mercenaria* (Malouf and Bricelj, 1989). The efficiency of clam larvae in filtering sub-micron particles

Table 1. Spearman rank correlation coefficients for 1988 Long Island Sound data (n = 20, explanation of variable designations in text).

	VIBRIO CLAM	STATION NUMBER	TEMP °C	CHL a WATER	DRY WT SESTON	VIBRIO SEDIMENT	VIBRIO WATER	BACT SEDIMENT	BACT WATER
STATION NUMBER	**								
TEMP °C	*	○							
CHL a WATER	*	**	*						
DRY WT SESTON	*	○	○	*					
VIBRIO SEDIMENT	**	**	*	*	**				
VIBRIO WATER	○	○	**	○	○	○			
BACT SEDIMENT	○	○	○	○	○	*	○		
BACT WATER	○	○	○	○	○	○	○	○	
BACT CLAM	○	○	○	○	○	○	○	○	○

** P < .01   * P < .05   ○ P > .05

is not known. An alternative interpretation is that *Vibrio* bacteria isolated from clam samples may have been filtered some time previously and retained within the clam; this bacterium can reproduce in both seawater and clam tissues. Whatever the reason, our 1988 data suggest that monitoring whole water samples for potential *Vibrio* pathogens may underestimate the risk of exposure.

The scenario in which filter-feeding clams (larvae or adults) would be exposed to *Vibrio* bacteria, as suggested by the above correlations, would involve the following factors:

1) Geographic — exposure is more likely in the western Sound than at other locations; this agrees with our assumptions about environmental quality.

2) Seasonal — exposure is more likely in mid-summer than during colder seasons; this makes sense from a metabolic standpoint, for both bacteria and clams. In addition, clams only reproduce in warm summer months, thus the most sensitive stage in the life cycle is at risk of exposure.

3) Meteorological or disturbance — wind-driven, or dredged, mixing of sediment into the water column may make *Vibrio*-rich sediment available to suspension feeders.

4) Effective particle size of infective agent — *Vibrio* bacteria attached to sediment particles may be more likely to be filtered and retained by clams.

The scenario described above suggests a possible role of meteorological or disturbance events in the epidemiology of shellfish diseases. If, indeed, larval stages are more susceptible to pathogenic bacteria, and if exposure is influenced by mixing of benthic sediment into the water column, then wind-driven mixing of the water, or sediment suspension caused by dredging, during the short (10-15 day) pelagic larval stage of the hard clam may determine to a large extent the importance of disease in larval survival, settlement, and subsequent recruitment into the commercial fishery. Increases in *Vibrio* counts coincident with harbor dredging were reported previously by Brown *et al*, (1988). *Vibrio* isolates from post-set clams in the present study did cause mortality of larval clams in laboratory exposures (Blogoslawski *et al.*, 1988); therefore, these pathogens are present in nature. Although disease mortality can be devastating to laboratory and hatchery rearing efforts (Brown and Tettelbach, 1988), very little is known about the importance of diseases in the population biology of bivalve mollusks in the field. The present report offers a few clues about the poorly-understood phenomenon of shellfish disease in the natural environment.

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Poster Sessions

Ultra-Clean Method Analysis of Trace Metals in a Long Island Sound Sub-Estuary

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Measurement of trace metals in both fresh and salt waters requires ultra-clean methods including use of laminar-flow clean benches, acid-washing of all containers, use of ultra-pure reagents, checks against certified water standards, special methods of storage, preservation, and transport of samples, and improved collection techniques. Blanks and yields must be determined for every step of sample collection, treatment, and analysis. Ordinary precautions and normal "good laboratory practices" are not adequate to prevent sample contamination and erroneously high results. For example, conventional acid cleaning is not sufficient to prevent artifacts. All surfaces that will contact samples must be acid-cleaned in a positive pressure clean room or laminar-flow clean bench. Then the apparatus must be stored and transported to and from the field in double plastic bags (inner bag acid-cleaned). Sample digestion and preconcentration must also be performed in a filtered-air environment; conventional laboratory fume hoods are entirely inadequate for such procedures.

Water samples were collected from the Quinnipiac River-New Haven Harbor estuarine system and measured for Pb, Cu, and Zn using these methods. Results indicate simple, consistent patterns relative to ancillary geochemical parameters like salinity, suspended particulate matter, dissolved organic carbon, and nutrients.

Time Series Observations of the Variability of the Suspended Material Field in Long Island Sound

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Data provided by long-term deployments of bottom-mounted instrument arrays indicate significant spatial and temporal variability in Long Island Sound's suspended material field. In the western Sound suspended concentrations average 3-5mg/l and display regular diurnal variability. Tidal currents and concentrations are inversely correlated with maximum near-bottom concentrations occurring during periods of minimum velocity. The response is representative of a system dominated by alternate resuspension and settling of a "fluff" layer rather that erosion/resuspension of the underlying sediment column. In the central Sound average concentrations approach 8mg/l. Instantaneous values generally vary simply in response to near-bottom currents indicative of progressive erosion/resuspension of the sediment -water interface and/or portions of the deeper sediment column. This classic response is also observed in the eastern Sound where although concentrations fall to less than 2mg/l values continue to display evident diurnal change in phase with local tidal currents. This east to west spatial variability appears dominated by variations in the tidal regime and associated transport energies with particulate composition as a secondary factor.

Average ambient conditions can be significantly perturbed by high energy storm events. Array data show the response to be highly non-linear affecting both the timing and magnitude of the concentration variations. Observations during several storm events, including a hurricane, show resuspension dominated by wave-current interactions.

The variety of observations provided by the arrays point out the difficulty of adequately sampling the estuarine suspended material field using shipboard methods and argue for the increased use of *in-situ* systems and long-term deployments.

Habitat Suitability, Low Dissolved Oxygen and Genetic Strain Performance of Oysters in Long Island Sound

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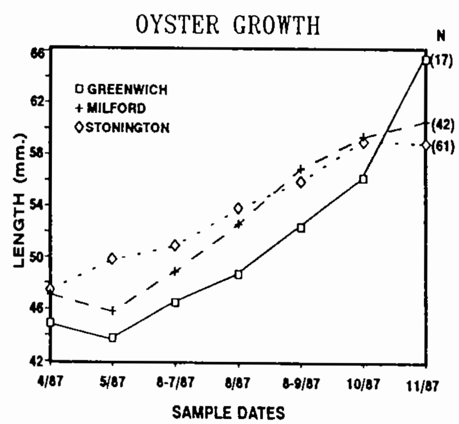
To assess site suitability for growth and survival and to test their field performance, genetically related (sib-inbred) oysters were deployed at three sites. Stocking density was 100 oysters per 0.36 square meter. Initial growth rates were similar at western, central and eastern sites in Long Island Sound. At 7 months, however, oysters held at the western end of the Sound were significantly larger. Their cage density was also less due to greater mortality at the western location beginning mid-summer of 1987. This mortality occurred almost simultaneously with fish kills in some Sound harbors, coincidental with low levels of dissolved oxygen, especially at the western end of the Sound.

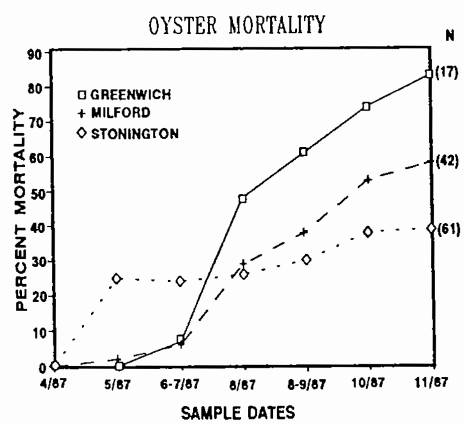
Several of the hottest summers on record which contributed to hypoxic conditions in Long Island Sound occurred in the 1980s, including 1987 (Backer, 1991). As late as October of 1991, there was an unexpected fish kill from low dissolved oxygen levels in the western end of the Sound (Backer, 1991; Harris, 1992).

Genetically more homozygous organisms as these oysters should provide a more sensitive measure of environmental conditions than more heterogeneous populations (Stiles, 1978). In addition, tests of habitat suitability should entail sufficiently long periods of time for full assessment of varying environmental conditions.

Conclusions

- There were significant differences in growth and survival of the genetic strain of oysters at the 3 separate sites after 7 months.
- Differences, especially in survival, could be attributed to low levels of dissolved oxygen.
- Survival/mortality seemed selective, despite the use of more inbred oysters.
- Growth may have been density dependent.





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Effects of Pesticides on Organic Anion Transport in Primary Cultures of Winter Flounder Renal Proximal Tubules

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Primary cultures of winter flounder renal proximal tubules provide a tool to assess the capacity of the kidney to excrete xenobiotics. We tested pesticides as substrates for organic anion secretion, as indicated by inhibition of secretion of p-aminohippuric acid (PAH), a model compound. Herbicides tested were the known inhibitor 2,4-dichlorophenoxyacetic acid (2,4-D), 2-methyl-4-chlorophenoxyacetic acid (MCPA), 2-(2,4-dichlorophenoxy) propionic acid (dichlorprop or 2,4-DP), and 2-(2-methyl-4-chlorophenoxy) propionic acid (mecoprop or MCPP). 2,4-D inhibited PAH secretion 80 % at 1.0 mM and 28 % at 0.1 mM. MCPA had no effect at 0.1 mM and was not tested further. Dichlorprop inhibited secretion 76 % at 1.0 mM, 28 % at 0.1 mM, and 20 % at 0.01 mM. Mecoprop inhibited PAH secretion 83 % at 1.0 mM and 17 % at 0.1 mM. At mecoprop concentrations of 0.1 and 1.0 μM, PAH secretion increased gradually, reaching 139 % and 132 % of control, respectively, within 2 hours. Mecoprop may stimulate by increasing an anion exchange step at the peritubular membrane. We tested the anticholinesterase insecticide chlorpyrifos (phosphorothioic acid O,O-diethyl O-(3,5,6-trichloro-2-pyridinal ester) and its more potent metabolite chlorpyrifosoxon at 0.1 mM. The oxon inhibited PAH secretion by 28 %. Within 2 hours, chlorpyrifos stimulated PAH secretion by 15 %. Supported by NIEHS and CT DEP.

A Novel Fish-Based Biomonitoring System That Uses Their Own Cellular Stress Response Profiles as Damage Indicators

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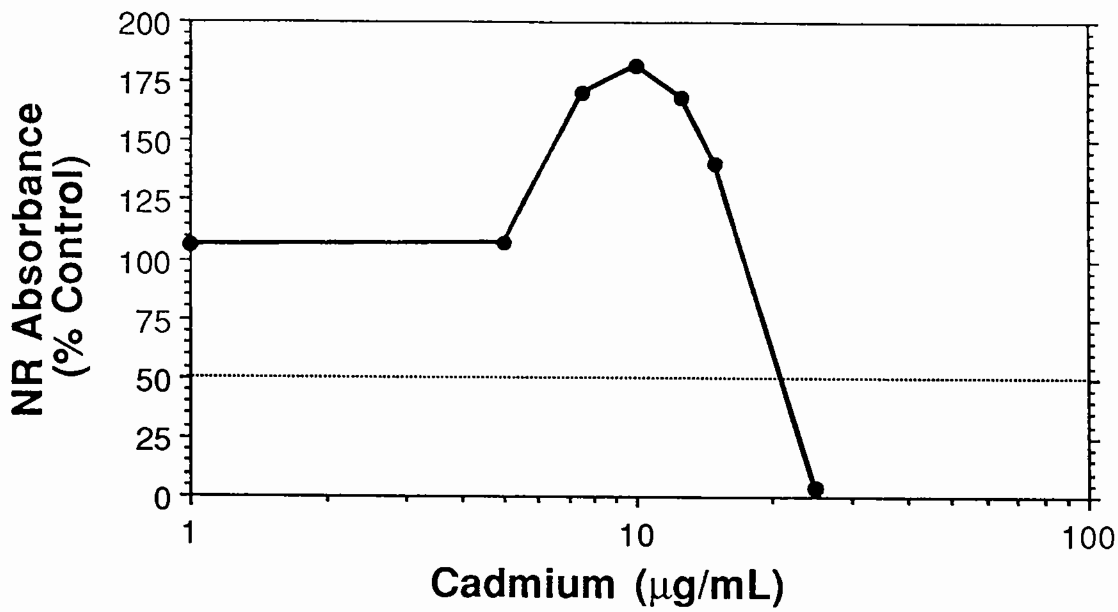
The utility and effectiveness of methods currently used to monitor the exposure of natural populations to potentially toxic xenobiotics have become increasingly important not only to government but also to industry. We are currently developing a biomonitoring system that uses the cellular induction of specific stress indicator proteins in both fish cell cultures and environmental tissue samples to measure and characterize their response to a variety of toxic xenobiotics.

All organisms, from bacteria and yeast to humans, respond to physical and chemical stressors by increasing the synthesis of a small group of "cellular stress response proteins". The most abundant of these stress proteins, the hsp70 family, were originally identified as heat shock proteins, but have since been shown to be induced in response to a wide variety of agents and conditions that result in widespread protein damage, including anoxia, heavy metals and oxidizing agents, in addition to heat. Other stress proteins, such as heme oxygenase, may be induced in response to agents whose primary insults are more target specific resulting in very limited but still serious cellular damage. By using one dimensional polyacrylamide gel electrophoresis (SDS-PAGE) in conjunction with an *in vitro* neutral red uptake toxicity assay we have developed a method that allows us to rapidly screen pollutants for their cytotoxicity and at the same time characterize their cellular stress response profiles. Once identified and characterized, these specific proteins markers will then be used to develop assays for screening environmental samples.

There are two fish-derived cell cultures currently used in these assays. The first, PLHC-1, is derived from a hepatocellular carcinoma from the desert topminnow *(Poeciliopsis lucida)*, and has now been in culture for over 200 generations. One of the most important characteristics of these cells is their ability to metabolize and process metabolism-mediated cytotoxicants such as 7, 12-dimethylbenz(a)anthracene; they have been shown to possess cytochrome P450 activity inducible by 3,3',4,4'-tetrachlorobiphenyl (M. E. Hahn *et al.*, 1990) or Arochlor 1254 (H. Babich *et al.*, 1991) making them very useful for studying both the mechanisms of induction and for use in *in vitro* cytotoxicity assays. PLHC-l cells also exhibit a very strong cellular stress response, producing 3 major classes of stress proteins that together account for almost 50% of the total protein synthetic capacity of heat shocked cells. The second culture system uses early passage mixed (consisting of epithelial, macrophages and fibroblast cells) cell cultures derived from winter flounder *(Pleuronectes americanus)* kidney (Dickman and Renfro, 1986).

The neutral red assay we are currently using to screen environmental toxins is a modification of an assay developed for *in vitro* cytotoxicity testing (Borenfreund and Puerner, 1985) for measuring the survival of cells exposed to varied concentrations of test agents by quantitating changes in the lysosomal uptake and accumulation of neutral red stain, a supravital cationic dye. Additionally, since the cells are fixed using formalin during the assay, they can also be stained using standard histochemical methods for morphological evaluation. Thus both morphological and physiological data can be compared within the same assay. Once a neutral red uptake dose response profile is obtained for a test agent, the NR_{50} (an endpoint where the neutral red uptake is 50% of the control; equivalent to an LC_{50}) can be determined. The top graph (see top panel of Figure l) is a typical neutral red uptake dose response to a heavy metal. The area of the graph, showing increased neutral red uptake (5-15μg/mL Cd), may represent increased lysosomal activity as the cell attempts to process cadmium-induced protein damage. Cells can recover from exposure to these sublethal levels of cadmium if given a medium change at the end of the exposure period.



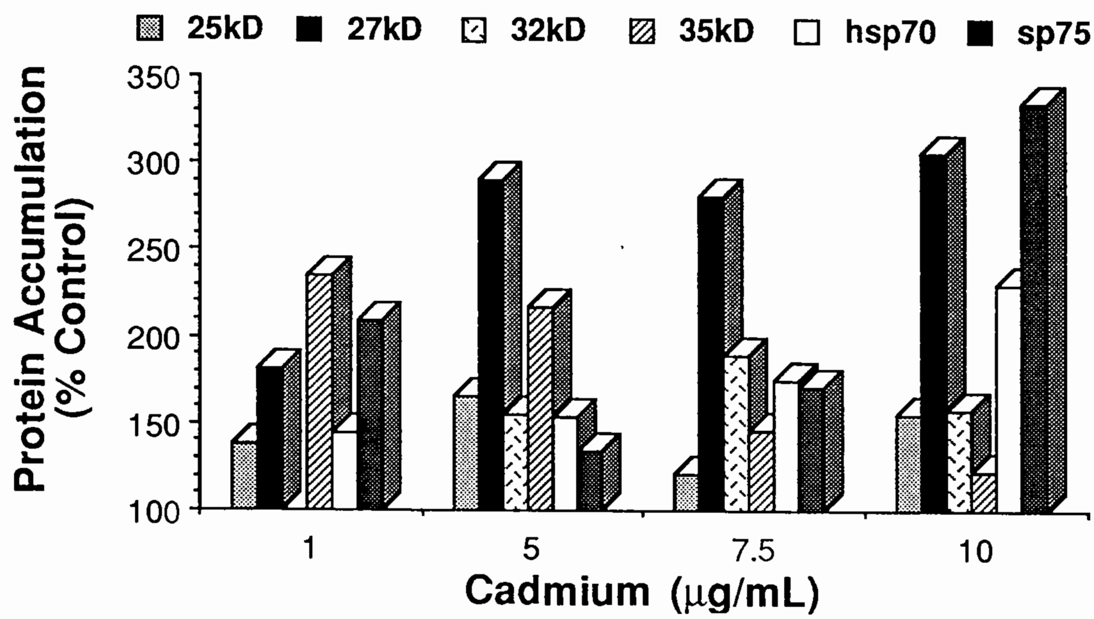


Figure 1. Correlation of neutral red uptake and stress protein accumulation in PLHC- 1 cells as a result of exposure to cadmium. The top graph shows a typical dose response curve; note the increased uptake (above control levels) of neutral red from 5 to 10μg/mL cadmium. The bottom graph shows increased accumulation of specific proteins over this same range indicating that these proteins may be good markers for stress.

By using SDS-PAGE we are able to characterize the cellular stress response and begin the process of identifying potential biomarkers. The bar graph (see bottom panel of Figure l) shows the dose-dependent increased accumulation of 6 proteins from exposure to the same levels of cadmium that increased neutral red uptake in the top graph. Our goal is to develop similar profiles for a wide variety of xenobiotic compounds and identify proteins that will be useful as Tier I biomarkers, indicating exposure to sublethal stressors, as well as Tier II markers, indicating exposure to specific contaminants. Once identified these proteins will be purified and antibodies developed from them for probing either Western blots or histological sections. This will then allow us to test the suitability of these proteins by screening xenobiotic compounds *in vivo* using whole fish rather than cell cultures.

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West River Salt Marsh Restoration

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The primary objective of this study is to assess the feasibility of a salt marsh restoration in New Haven, Connecticut. The marsh has been degraded by restriction of tidal exchange and filling. During the study period, tidal and fresh water flow volumes, water levels, and salt concentrations were measured in the West River for three conditions. In addition, marsh and channel elevations were surveyed.

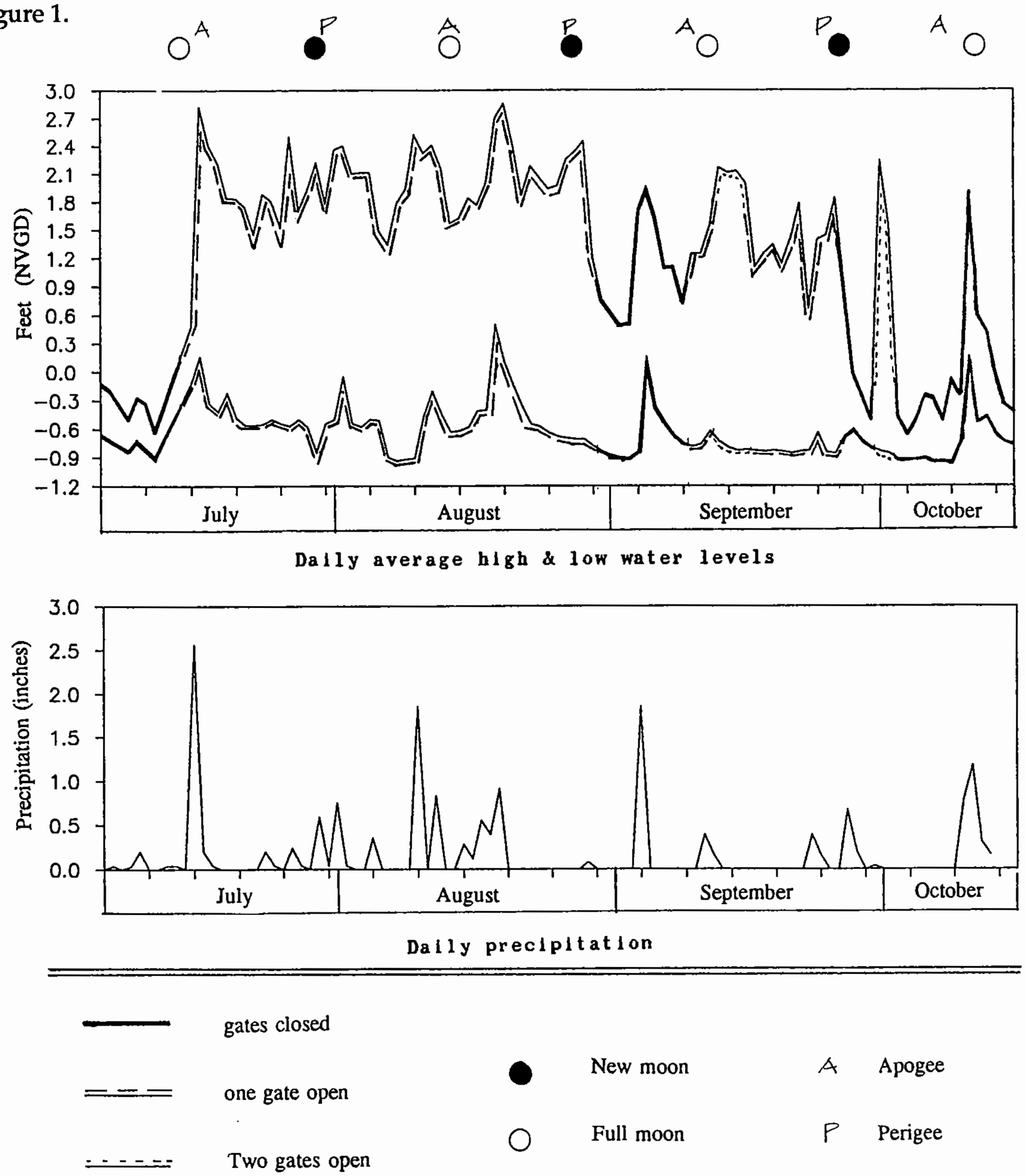
The seventy acre marsh lies within the bounds of the West River Memorial Park. The West River has a 37 square mile watershed and a length of 16.7 miles. The last three miles of the river were tidally influenced. In 1919, twelve 40 ft^2 tidal gates were installed 1.1 miles upstream from the original terminus of the river. At low tide the gates swing open and allow the river water to flow to Long Island Sound. At high tide, the gates are forced shut by the incoming tide; virtually no tidal inflow occurs beyond this point. Common reed grass, *Phragmites australis*, has colonized large areas upstream of the tidal gates. It is an aggressive herbaceous perennial that flourishes in poorly drained soils and commonly reaches a height of twelve feet. Once established, it reproduces vegetatively and displaces most other plants. The dense *Phragmites* stands exclude most native wildlife while providing prime habitat for mosquitoes. This large mass of *Phragmites* is a troublesome fuel source for brush fires.

Common reed grass was not a deliberate choice for the park's vegetative cover. The tidal gates were originally installed to convert the salt marsh to a traditional urban park. In the 1920s, Olmsted Associates, the prominent landscape architectural firm of Central Park fame, were retained to design the West River Memorial Park. Although their park design was never fully implemented, significant evidence of it remains in the form of a mile-long channel dredged through the marsh. Throughout the country many parks designed by Olmsted Associates have been restored because of their historical significance.

The vegetation of most salt marshes can be divided into two sub-communities. The lower marsh exists at about mean high tide. The upper marsh extends from mean high tide to the spring high tide (Niering and Warren, 1980). While higher salt concentrations are typically found in the lower marsh, both communities grow fairly well within a 15 to 30 grams/liter salt concentration range (Niering and Warren, 1980). It is our objective to determine if these conditions can be restored to this degraded salt marsh.

During June through September 1992, hydrologic parameters were studied under three conditions: (1) the existing condition - all gates closed, (2) one tidal gate open, and (3) two tidal gates open. The resulting tidal flows, water levels, and salt concentrations were measured (Figure 1). The maximum rate of tidal inflows increased from a negligible quantity with all gates closed, to 300 ft^3/second with one gate open, and nearly 600 ft^3/second with two gates open. The West River baseflow averaged 30 ft^3/second during the study period. When baseflow and treatment conditions coincided, tidal inflow was the dominant force determining high tide water levels. High tide water levels throughout the marsh increased by 1.5 to 2.0 feet with one gate open and an additional 0.5 to 1.0 feet with two gates open. Water column salinity increased throughout the marsh over the study period. The highest levels were measured with two gates open. One hundred feet upstream of the gates, salinity levels ranged from 9 grams/liter at the water surface to 20 grams/liter at a depth of 5 feet. At a sampling site 1.3 miles upstream from the gates, levels ranged from 0 at the water surface to 3 grams/liter at a depth of 4 feet. Final analyses will couple hydrologic and topographic data to determine water level-discharge relationships and salinity gradients. Detailed topographical data is currently being reviewed and synthesized. A computer model based on these functions will be used to estimate water levels resulting from the opening of additional gates.

Figure 1.



The restoration of the salt marsh in the West River Memorial Park, along with the completion of the Olmsted park design concepts, could have many benefits. The primary ecological benefit to the marsh and Long Island Sound would be an increase in biological productivity. This would lead to a marked increase in the diversity and abundance of wildlife and marine organisms. The additional benefits would include improved public awareness of salt marsh ecosystems. Valuable urban open space will be made more accessible and desirable to thousands of area residents. Schools could use the park and marsh for environmental education. All of this could happen within just a one mile from downtown New Haven.

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Development of Dissolved Oxygen Criterial for Long Island Sound: the Acute Effects Database

D. C. Miller[1], S. L. Poucher[2] and L. L. Coiro[2]; [1]*U.S. EPA*, [2]*SAIC, Narragansett, RI*

Time standardized (96H) laboratory tests were conducted to quantify the acute effects of low dissolved oxygen (D.O.) for nine species of Long Island Sound summer fauna. Acute values for five additional species are available from the literature. LC50s for juvenile and/or adult stages of these species range from 1.5 to <0.5 mgL^{-1}. The more sensitive species, with LC50s of 1.5 to 1.4 mg DO L^{-1}, are sand shrimp (*Crangon septemspinosa*), striped bass (*Morone saxatilis*) and winter flounder (*Pleuronectes americanus*). The less sensitive organisms have LC50s of ≤ 1.0 mgL^{-1} and include three fishes, two bivalves, and five crustaceans. Larval American lobsters (*Homarus americanus*) and grass shrimp (*Palaemonetes vulgaris*) are more sensitive than the juvenile and adult stages by at least a factor of two. These early life stages are pelagic and occur chiefly above the pycnocline, while the later stages of these species are benthic. The greater sensitivity of these larvae suggests the need to establish separate D.O. criteria for water above the pycnocline.

Additional studies are being conducted with acutely sensitive species to determine the LC10 as the acute effect threshold. Preliminary results suggest the LC10 may be estimated from the LC50 using a multiplier of 1.4. Time to death studies conducted with larval grass shrimp indicate a decline in the exposure time required for acute effects (i.e. the LT50) from four days when exposed to the LC50 concentration, to - 3 hours when the D.O. concentration declines to 30% below the LC50. The implications of these findings for LIS D.O. criteria will be discussed.

Development of Dissolved Oxygen Criteria for Long Island Sound: Subacute Effect

S. L. Poucher[1], L. L. Coiro[1], and D. C. Miller[2]; [1]*SAIC*, [2]*U.S. EPA, Narragansett, RI*

Laboratory tests have been developed to demonstrate the sublethal effects of reduced dissolved oxygen on hatching in fishes, and growth and molting in a crustacean. Delayed hatch was observed in response to reduced oxygen with two estuarine fishes tested to date: *Menidia beryllina*, and *Cyprinidon variagatus*. The delay increased with decreasing oxygen concentrations ranging from 4.5 to 1.5 mg/L.

American lobster, *Homarus americanus*, responded to reduced oxygen with retarded growth and delayed molting. Although the pelagic larval stages were most sensitive, concentrations affecting growth and molt time were near the levels of incipient mortality (LC10s). Post-larvae and juveniles, while less sensitive than younger stages, exhibited reduced growth at oxygen concentrations at least 1 mg/L higher than those affecting survival. Molt rate was intermediate in sensitivity to reduced oxygen between growth and survival.

Sublethal effects of reduced oxygen on fish hatching, and on growth and molting of lobster larvae, were observed in tests conducted over four to seven days. Longer tests were required with post-larval and juvenile lobsters due to their longer molt cycles. The ecological implications of these tests will be discussed in the context of Long Island Sound summer dissolved oxygen conditions.

Reproductive Success of Winter Flounder (*Pleuronectes Americanus*) in Long Island Sound with Special Reference to the Effects of Dredging

D. A. Nelson, J. C. Widman, J. J. Pereira, and J. E. Miller; *National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Fisheries Science Center, Milford Laboratory, 212 Rogers Ave., Milford, CT 06460*

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Please contact authors for information.

Investigating Shellfish Nutrition

B. C. Smith, G. H. Wikfors, and G. E. Ferris; *NOAA, National Marine Fisheries Service, Northeast Fisheries Science Center, 212 Rogers Ave. Milford, CT 06460-6499*

Laboratory investigations into the dietary requirements of marine filter feeding mollusks have a long history at the Milford Laboratory. Knowing which microalgae possess the necessary nutrients in the required amounts for shellfish growth is important to Long Island Sound research as well as to the aquaculture and shellfishing industries.

A collection of over 150 axenic microalgal strains is housed at the Milford Laboratory. These strains are used to inoculate 15-liter axenic cultures. Cell densities of over 30×10^6 cells ml^{-1} are possible using a high nutrient algal growth medium and stringently controlled physical conditions.

Protein, lipid, and carbohydrate analyses are applied to the algal strains. Discrete rations of algae are also fed to oysters, clams, and scallops housed in specialized rearing chambers. The growth of these mollusks is measured to determine the nutritional value of different algal species and effects of dissolved nutrients and pollutants.

Phytoplankton samples from the field can be subjected to the same biochemical analyses and the data compared to the results of our controlled laboratory experiments. This information enables us to assess the nutritional well-being of commercially valuable shellfish in Long Island Sound.

Genotoxicity of Petroleum and PCB Compounds to Eggs and Embryos of Oysters From Long Island Sound

S. Stiles, *National Marine Fisheries Service, Northeast Fisheries Science Center, Milford Laboratory, Milford, CT, 06460*

Petroleum aromatic hydrocarbons and polychlorinated biphenyls (PCBs) are ubiquitous compounds, some of which can be persistent in the global aquatic environment, including in Long Island Sound (Chytalo, 1979; Fox, 1992; Stacy, 1987; Stiles *et al.*, 1991; Turgeon and O'Connor, 1991).

Genotoxicity of the petrochemicals, benzene and naphthalene, and of the polychlorinated biphenyl (PCB) Aroclor 1254, was determined to assess effects on early reproductive stages of the commercial American oyster, *Crassostrea virginica*, from Long Island Sound. Compounds were tested individually and in combination at concentrations of 0.1, 10 and 100 mg/l at different temperatures and salinities using cytogenetic, cytological and developmental measures (Figure 1). Dose-dependent responses were observed. Major cytogenetic aberrations in embryos consisted of spindle-related abnormalities such as anaphase bridges, laggard chromosomes, multipolar spindles, polyploidy, aneuploidy and mosaicism. Micronuclei and clumped, pycnotic and deteriorating nuclei were observed in moribund larvae (Figure 2). Progression in number and severity of abnormalities by the later stage suggested a cumulative effect. At the highest concentration, mortality was 100% in some instances. Naphthalene and aroclor were more toxic than benzene. Furthermore, benzene was antagonistic in interactions with naphthalene and with aroclor. High temperature was synergistic with naphthalene and with aroclor, probably by increasing solubility and uptake. Benzene and naphthalene together in high temperature-high salinity water were more toxic than in low temperature-low salinity water.

Genotoxicity and viability data, with additional information on temperature, salinity and prevailing levels of other environmental contaminants, could be used in models which estimate pollution-related mortality of early stages of shellfish.

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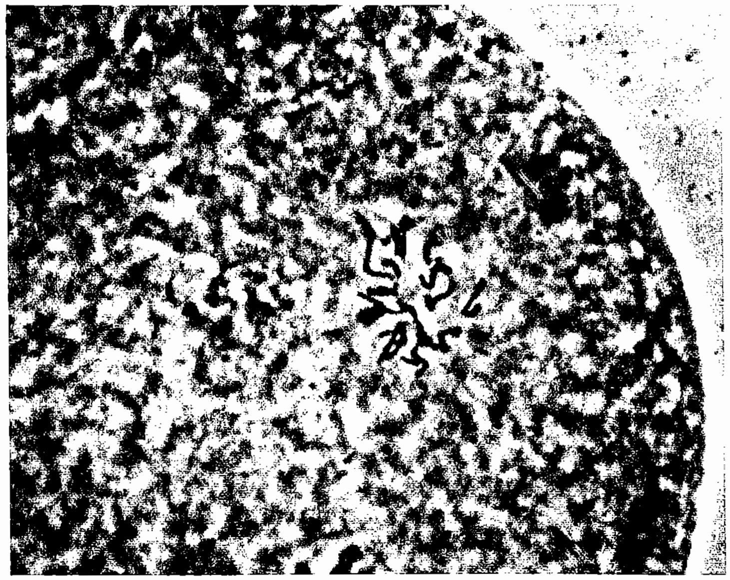

Figure 1. Normal mitotic metaphase chromosomes in an early oyster embryo.

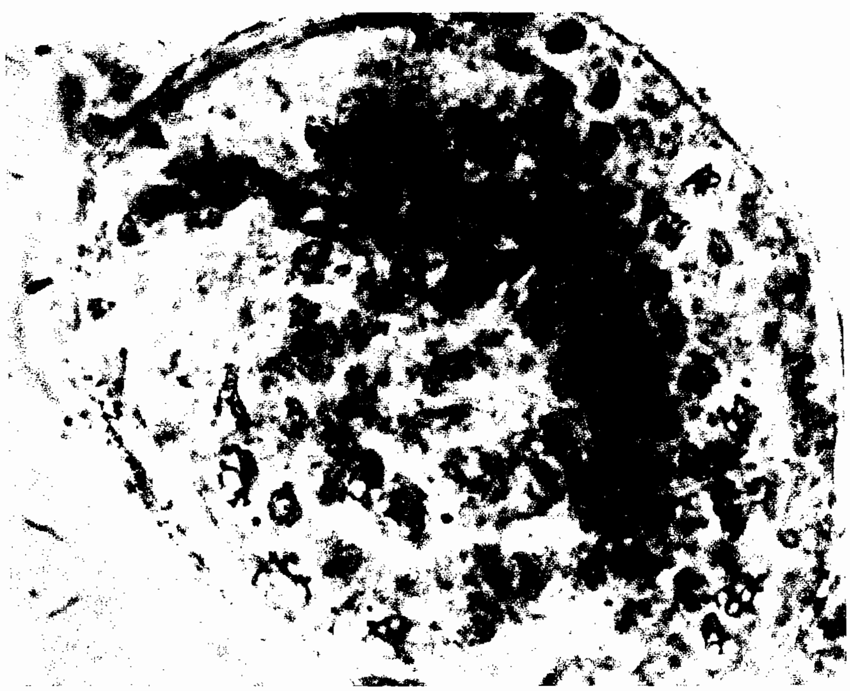

Figure 2. Abnormal, sticky nuclei and micronuclei in an early oyster larva following containment exposure during development.

The Response of Infaunal Communities to Dredging in a Small Connecticut Estuary

R. N. Zajac[1] and R. B. Whitlatch[2]; [1]*Dept. of Biology and Environmental Sciences, University of New Haven, West Haven, CT 06516*, [2]*Dept of Marine Sciences, University of Connecticut, Avery Point Campus, Groton, CT 06340*

In 1988, the lower channel of Alewife Cove, located between New London and Waterford, Connecticut, was dredged as part of a habitat restoration project. A three year study determined short and long term changes in infaunal community structure both proximal and distal to the dredge area. Communities in the channel underwent selective short-term changes, primarily in relation to direct dredging operations. There were temporary declines of several species and increases of opportunistic oligochaetes. Communities near the channel exhibited changes over the first year primarily associated with changes in tidal regime and sediment composition. Over the long-term, communities in and near the channel stabilized and had a greater component of species typical of sandy intertidal and subtidal habitats than that present prior to dredging.

In the upper portions of the cove, which were not directly dredged, infaunal communities were dominated by a small group of polychaete and amphipod species known to be associated with organic enrichment. This was the case prior to dredging, and as such little change occurred over the three years following dredging. However, there was an influx of several species (e.g. *Ampilesca abdita*) more typical of habitats outside the cove.

In summary, infaunal communities exhibited moderate changes due to dredging. These changes comprise shifts in relative abundance on the most part. We attribute this overall response to the "shallow" dredging that was conducted in the lower sections of the cove and the large mass of organic sediments that have accumulated in the upper section of the cove over past decades.

The Application of Ultrasonic Tracking Strategies for Monitoring Movement of the American Lobster (*Homarus americanus*)

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Introduction

Habitat utilization, migratory behavior, and foraging activity of lobsters (*Homarus americanus*) have intrigued scientists for many years (Bumpus, 1898; Conan, 1984; Duggan, 1991; Karnofsky, 1989; Wahle, 1990). Movement brings lobsters in contact with a wide variety of environmental factors which may influence their behavior and potentially their survival. Historically, it has been extremely difficult to monitor lobster behavior. Observations were limited to the length of time that a SCUBA diver could stay on site and to calm, good weather conditions (Munro, 1983; Ennis, 1984).

The purpose of this project is to apply ultrasonic tracking techniques to monitor habitat utilization, foraging and migratory behavior of the American lobster (*Homarus americanus*) in waters surrounding the University's research facility on Outer Island in Branford, Connecticut. Specific attention has been given to: 1) applying newly developed techniques for attaching ultrasonic tags to lobsters, 2) analyzing the impact of ultrasonic tags on lobster behavior, 3) improving strategies for monitoring lobster movement, and 4) assessing the feasibility of utilizing ultrasonic tags for monitoring lobster movement intermittently or continuously.

Materials and Methods

Ultrasonic tags designed by Sonotronics were used in this research project. The tags have a frequency of 75 kHz and a life expectancy of approximately six months. The tags are 16 mm in diameter and 65 mm in length; they weigh 21.2 grams in air and 10.1 grams in water. Each of the tags is identifiable by frequency and pulse rate. These variations allow lobsters to be tracked independently and identified accurately.

Two lobsters captured in the vicinity of Outer Island were fitted with ultrasonic tags. The tagged lobsters were released directly into Long Island Sound (LIS) from the beach on the north shore of the Outer Island Center for Research and Instruction. As the lobsters moved into LIS, their movements were monitored twenty-four hours a day for a period of two days. Intermittent monitoring was continued for a period of six months for the first lobster and four months for the second lobster.

Tracking teams documented lobster movement using omnidirectional and directional hydrophones mounted on the R/V CHARTER OAK. Location data was recorded on tracking grids. Locations were documented using visual cues in addition to LORAN and GPS information. Data concerning tag frequency, pulse rate, time of day, environmental conditions, and bottom types were recorded. Location information was verified by underwater telescope and SCUBA teams using diver-operated hydrophone units.

Data obtained by the tracking teams was recorded on a series of tracking maps. Analysis of the data points permitted the research team to develop a track of lobster movement during the observation period. From data collected during the project, it will be possible to analyze migratory and foraging activity in conjunction with tide changes and photoperiod. Data gathered by SCUBA teams and recording sonar have provided information on lobster habitat.

Results

The lobsters under observation started to move from their burrows at dusk. Movement continued throughout the night and the lobsters returned to their burrows shortly after dawn. During the period of movement, the lobsters moved a maximum distance of 60 meters from their burrows. Their movement was constrained by a depth change along a contour line that marked an abrupt transition from 13 to 20 feet at mean low tide. Intermittent monitoring during daylight hours found the lobsters in their burrows. Night time observations found them foraging in areas of boulders and cobble within a radius of 60 meters from their burrows. During the entire study, neither lobster ventured beyond the 13-foot contour line.

Discussion

The lobster is an organism of interest to scientists and it is also a major economic resource. American lobsters account for 31% of all fisheries landings in New England, making it the area's most important commercial species. From an earlier study conducted by Haakonsen, *et al* (1981) under National Science Foundation sponsorship, it was determined that 91-93% of all legal-sized lobsters are taken annually from Long Island Sound waters. The organism is being fished at its maximum sustainable yield level. The organism merits careful monitoring as new management regulations go into effect. This project has demonstrated that ultrasonic tracking strategies can play an important role in monitoring migratory behavior of *Homarus americanus*. In the future, the foraging and migratory behavior of the lobsters can be monitored to determine if lobsters move into areas that are hypoxic or anoxic. In addition, this tracking technique may prove to be useful in monitoring the movement of lobsters in areas where gaffkemia is a serious problem.

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Mycorrhizae in Plants of Impacted Wetlands in the Lower Quinnipiac River Estuary.

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The maintenance and restoration of vegetation in tidal wetlands is directly related to the functions of habitat and the presence of soil microorganisms. As part of an ongoing research program to understand and develop methods for dealing with problems of vegetative restoration in coastal and inland wetlands, we conducted a survey for mycorrhizal fungi in the plant roots of tidal wetlands in the lower Quinnipiac River estuary. Mycorrhizal fungi develop an obligate symbiotic association with the storage tissue (cortex) of plant feeder roots. The growth of hyphae (fungal threads) into the soil from the infected roots has been shown to increase the uptake of nutrients and to make these nutrients available to the host plant (Bolan, 1991; Harley and Smith, 1983).

The lower region of the Quinnipiac River marsh area represents part of what was originally the largest salt marsh wetland in the state of Connecticut (Bell 1985). The water quality of the Quinnipiac River and its tidal wetlands have been environmentally impacted as a result of the activities associated with urban and industrial development. In the wetlands below the Rte. 40 overpass, disturbances have included major filling on the eastern side of the river for railroad yards, filling on the northern and western sides for industrial sites, and excavation of clay on the western side. Discharge of organic chemicals and heavy metals from the industrial sites and landfills has occurred (Wheeler *et al.*, 1992; Metzler and Rosza, 1988). Because of these environmental perturbations, the tidal wetlands associated with the lower region of the river represent an ideal test site to determine the presence of mycorrhizae in an area heavily influenced by human activity. The functional significance of mycorrhizae is poorly understood in such areas.

Our objectives in this study were to determine the distribution of mycorrhizae in specific species of plants at selected sites in the lower Quinnipiac River estuary and to document the percentage and intensity of feeder root infection for each plant species collected within each site. The results were compared with data collected form other tidal wetlands sampled in Southeastern Connecticut.

Sampling Sites

Transects were sampled at nine locations from north of the Rte. 40 overpass to Hemingway Creek, southeast of I-91. Emphasis was on four major plant communities: (1) transects I & II, typical high salt marsh vegetation on the eastern shore near the confluence of Hemingway Creek, (2) transects III, IV, V, and VI, brackish marsh areas dominated by *Phragmites australis* (Cav.) Trin. ex Steud. south of Sackett Pt. Dr., (3) transects VII & VIII, fresh water region on the west shore of the river north of Sackett Pt. Dr. dominated by *Lythrum salicaria* L. and (4) transect IX, fresh water region, west of the river, immediately above the Rte. 40 bridge. This latter site had mixed vegetation including *Impatiens capensis* Meerb., *Typha angustifolia* L., *Rudbeckia laciniata* L. and *L. salicaria*.

Methods

Roots of plants were collected at intervals along transects from the river's edge into the wetlands for variable distances depending upon the vegetation. The roots were brought back to the lab and washed. About two grams wet weight of roots from each collection were preserved in killing-fixing solution until processed. This involved clearing the roots in 10% KOH and staining them with

Tripan blue following procedures used previously (Cooke & Lefor 1990). The stained fungal structures were dark blue and the host plant tissue a pale light blue. Feeder roots were used to determine percent and intensity of infection using a Wilde M-20 research microscope (Giovannetti and Mosse, 1980; Kormanik and McGraw, 1982).

Results (See TABLE I)

Transects I & II: infection was found in the following species: *Distichlis spicata* (L.) Greene, *Iva frutescens* L., P. *australis*, *Plantago maritima*, and *Spartina patens* (Ait.) Muhl. No infection was found in *Atriplex petula* L. or *S. alterniflora* Loisel.

Transects III, IV, and VI: no infection was found in any of the plants of these three transects. In each, *P. australis* was the dominant species. Transect IV had *S. alterniflora* and *Eleocharis rostellatta* Torr. at 14 meters from the river's edge. Transect VI had *Peltandra virginica* (L.) Schott & Endl. at the river's edge and *I. capensis* 12 meters from the river.

Transect V: located on the west side of the river and parallel with the river at 11 meters from the river's edge. Plants from this transect included *T. angustifolia*, *Eleocharis parvula* (R. & S.) Link and *Phalaris arundinacea* L. No infection was found in the six *Typha* plants sampled. Infection was found in both *Eleocharis* and *Phalaris*.

Transects VII & VIII: *L. salicaria* was the dominant plant of these transects. Seventeen of the 18 plants sampled from this site showed root infection. The single sample lacking mycorrhizal fungi was from the river's edge of transect VII. One sample of *Impatiens capensis* taken in transect VIII at 13 m also lacked mycorrhizal infection.

Transect IX: the four species of plants sampled were infected with mycorrhizal fungi.

Discussion

No specimens of *S. alterniflora* have been found infected with vesicular arbuscular mycorrhizae in any of several salt marshes sampled in eastern Connecticut. While *P. australis* is abundant in the brackish marsh regions (south of Sackett Pt. Dr. and north of I-91), no infection was found in any plants sampled from these areas. However, infection was found in this species from the high salt marsh area of transect I as well as from samples from similar areas of the Indian River in Clinton, Connecticut and the Mystic River estuary in Mystic, Connecticut. Vesicular arbuscular mycorrhizal fungi do occur in the brackish marsh region of the Quinnipiac River as shown by the infection of two of the species collected in transect V. *T. angustifolia* was not infected in the present study although it has been shown to become infected in other wetlands. In general, when *Typha* is infected, the percent and intensity of infection is low.

The roots of plant species from the Quinnipiac River sites when compared with the roots of the same species sampled from other non-disturbed wetland sites generally showed a lower percent and intensity of infection. These sites included areas on the Connecticut River, non-disturbed salt water marshes of the Indian River and several other salt water marshes along the southeastern coast of Connecticut.

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TABLE I

HOST PLANT	TRANSECTS I	II	III	IV	V	VI	VII	VIII	IX
Atriplex patula	0%								
Eleocharis parvula					14-51% A C V				
Impatiens capensis						0%		0%	21-28% A C V
Iva frutescens	12-46% A C V								
Lythrum salicaria							0-71% A C V	0-66% A C V	3.7% A C V
Peltandra virginica						0%			
Phalaris arundinacea					16-71% A C V				
Phragmites australis	0.2-7% A C V		0%	0%		0%			
Plantago maritima		57% A C V							
Rudbeckia laciniata									68% A C V
Spartina alterniflora	0%	0%							
Typha angustifolia					0%				0.7% V
SA-Eleocharis rostellata				0%					
SP - DS - IF mix		50% A C V							
SP - DS - PA mix	0.2-6% A C V	4.3-10.% A C V							
SP - DS mix	14-49% A C V	0.1-18% A C V							

SA = Spartina alterniflora
SP = Spartina patens
IF = Iva frutescens

DS = Distichlis spicata
PA = Phragmites australis

A = arbuscules present
C = coils present
V = vesicles present

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