The Marine Resources of the Parker River-Plum Island Sound Estuary: An Update after 30 Years

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funded by the Massachusetts Office of Coastal Zone Management

Based on the 1968 monograph by the Massachusetts Division of Marine Fisheries:

A Study of the Marine Resources of the Parker River-Plum Island Sound Estuary
by
William Jerome, Arthur Chesmore, and Charles O. Anderson, Jr.

and on the

Plum Island Sound Minibay Project Report
by
Robert Buchsbaum, Andrea Cooper, and Joan LeBlanc

TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

CHAPTER 1. INTRODUCTION

From 1963 through the mid 1970s, the Massachusetts Division of Marine Fisheries (DMF) produced monographs on seventeen estuaries along the Massachusetts coast. These studies were undertaken as a result of recommendations of the 1960 Massachusetts Marine Fisheries Advisory Commission to the Governor of the Commonwealth. Each monograph was based on one year of field study that focused on the physical characteristics, water quality, and fish and shellfish resources of the estuary. The reports also contained important historical information on the fisheries supported by each estuary, sometimes dating back to colonial times. Since these monographs are recognized as a valuable source of baseline data, a number of agencies and researchers, including DMF, have suggested that the studies be repeated periodically so that changes over time could be examined (DMF 1985, EOEA 1991, Leigh Bridges DMF, pers. comm).

The opportunity to reexamine and update the 1968 Parker River-Plum Island Sound monograph came in 1997 as a result of funding from the Massachusetts Office of Coastal Zone Management. The Massachusetts Audubon Society's North Shore Conservation Advocacy Office (MAS:NS) received a contract to carry out the work and subcontracted out part of the effort to the Parker River Clean Water Association (PRCWA). Both organizations are familiar with the region and have carried out recent projects about the marine resources of the Plum Island Sound region, as described below.

In 1991, MAS:NS was funded by the Massachusetts Bays Program to carry out the Plum Island Sound Minibay Project. This project included a reexamination of the fisheries resources that had been described in DMF's 1968 monograph on the Parker River-Plum Island Sound estuary. It also included studies of fecal coliform contamination of the Sound and its tributary rivers, an assessment of current and anticipated future land uses, an examination of the flushing characteristics of the Sound, an examination of historical and current data on bird use of Plum Island and environs, and a management plan for the region.

The Parker River Clean Water Association is a citizens-based watershed association that was formed in 1995 to address water resource issues on the Parker River. Its focus has been on water quality in the Parker River and its tributaries, the impact of tidal restrictions on salt marsh habitats, and the condition of the anadromous fishways of the Parker River.

1.1. PERSONNEL AND ACKNOWLEDGEMENTS

The original study of the marine resources of the Parker River-Plum Island Sound estuary was conducted and the report written by Marine Fisheries Biologist William C. Jerome, Jr., Assistant Marine Fisheries Biologists, Arthur P. Chesmore and Charles O. Anderson, Jr., and Daniel G. Lyons, Skilled Conservation Helper. Student assistants,

Warren S. Collings, Stuart Wyman and Robert Nersasian supplemented team personnel during the summer of 1965. Frank Grice, Chief of Research, and Frederick C. Wilbour, Jr., Director of the Division of Marine Fisheries, provided over-all supervision of the estuarine programs. Commercial fishermen, sportsmen, and personnel from the Massachusetts Department of Public Health, Parker River National Wildlife Refuge, U. S. Coast Guard, U. S. Geological Survey, U. S. Bureau of Commercial Fisheries, and University of New Hampshire (Botany Department) also contributed valuable data.

Much of the update of the 1968 monograph is based on the Plum Island Sound Minibay Project, a collaborative effort between a number of organizations coordinated by MAS:NS. Some of the project participants are indicated in the chapter headings. Massachusetts Audubon collaboratively with Dr. Linda Deegan, Robert Garritt and colleagues at the Woods Hole Ecosystems Center carried out the fisheries component of the project. Applied Sciences Associates, Inc. of Narragansett, Rhode Island performed the flushing studies under the direction of Dr. Henry Rines and Christopher Turner. Horsley-Witten, Inc. carried out the stormwater modeling. Andrea Cooper contributed to sections dealing with land use and management issues and Joan LeBlanc wrote various sections of the Minibay project report that were incorporated into this report. Many MAS and PRCWA volunteers aided in data collection and members of the PRCWA also helped with some of the writing.

Many volunteers assisted with the field collections and the sorting and counting of fish. We particularly acknowledge the assistance of volunteers Mary Kingsley and Richard and Pinckney Johnson. Past and present DMF personnel provided valuable guidance to the Minibay project and to this document. William Jerome, who directed the 1968 monograph team, served as an advisor to the Minibay project. Additional insights into the comparability of the two efforts were gained through conversations with H. Russell Iwanowicz. Jeff Kennedy and Wayne Castonguay of DMF provided advice on the bacterial studies of the Sound and shellfish bed locations.

In addition to DMF personnel, Jack Grundstrom, David Mountain, Steve Barrett, Philip Kent, Mark Baker, Verne Noyes and Joan Beskinis contributed to a number of sections of this document. Ricky Holt contributed to the section on habitat issues and Amy Prime and the Parker River National Wildlife Refuge to the section on birds. We also acknowledge the help of George Thompson whose clamming maps provided a basis for the shellfish maps. The shellfish maps were done in conjunction with Jerrard Whitten of the Merrimack Valley Planning Commission through technical assistance kindly allocated by the Towns of Ipswich, Rowley and Newbury. Rebecca Haney, coastal geologist for Massachusetts Office of Coastal Zone Management, reviewed the chapter on geology and morphology.

Direct funding for this project came from the Massachusetts Office of Coastal Zone Management. The Massachusetts Bays Program and the Land Margin Ecosystems Research program of the National Science Foundation funded the research that contributed to updating the old monograph.

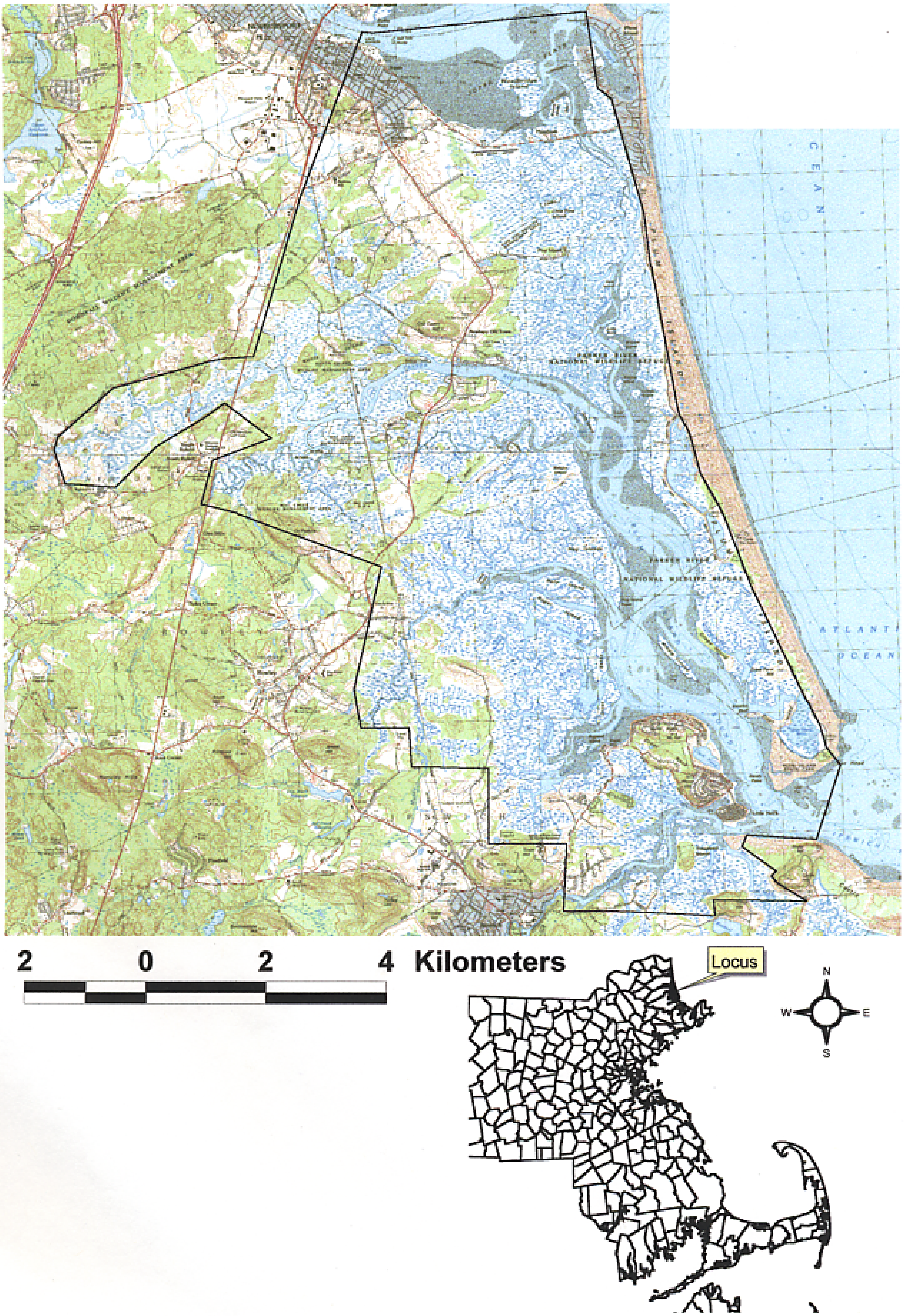
1.2. OBJECTIVES

The basic objective of the original DMF study of the marine resources of Parker River-Plum Island Sound was to determine the type, status and value of commercially valuable resources and to obtain data concerning the physical and chemical characteristics which affect those resources. An investigation of the species of finfish, shellfish, and crustaceans present, their abundance and the degree of exploitation of certain species by sport and commercial fishermen, was conducted to provide statistical evidence of the economic value of the fisheries in the area during the study period. The objective of this update is to examine the status of the marine resources and water quality in Plum Island Sound with particular emphasis on finfish and bacterial contamination. The existence of two data sets collected in a similar manner provides a unique opportunity to compare long term changes in an estuarine ecosystem and to identify trends. The more recent data can also be placed within the historical context of the fisheries, since the 1968 monograph examined historical records on fisheries over several centuries.

1.3. Study Area

Both the original DMF estuarine monograph and the Plum Island Sound Minibay Project established the upper boundaries of the study area near the head of tidewater in the Parker River, and in the Plum Island River near the mouth of Pine Island Creek (Fig. 1.1). The Plum Island River south of this location is under the tidal influence of the Parker River-Plum Island Sound estuary and north of this point, under the tidal influence of the Merrimack River. The lower or seaward boundary was established as a line from the southern tip of Plum Island to Castle Neck, Ipswich, where the estuary flows into Ipswich Bay. Sampling for the 1968 study was limited to the estuarine portions of the Sound, the Parker River, the Ipswich River, and other smaller tributaries. Water quality sampling in the Minibay project included some of the freshwater sections of the rivers leading in to the Sound. Fish sampling in the DMF study included a station in Ipswich Bay.

Fig. 1.1. Study Area



CHAPTER 2. GEOLOGY AND MORPHOMETRY OF THE PARKER RIVER-PLUM ISLAND SOUND ESTUARY

2.1. Overview

The original DMF monograph reported data on the morphometry and geology of the Plum Island Sound region. Some of this has been updated by the Massachusetts Geographic Information Systems (MassGIS) unit and by more recent soil surveys of Essex County. New information on postglacial movements of the barrier beach is based on the work of Duncan Fitzgerald and his students at Boston University and information on intertidal bedforms is based on the work of Joan Daboll from her work at the University of Massachusetts.

2.2. Methods

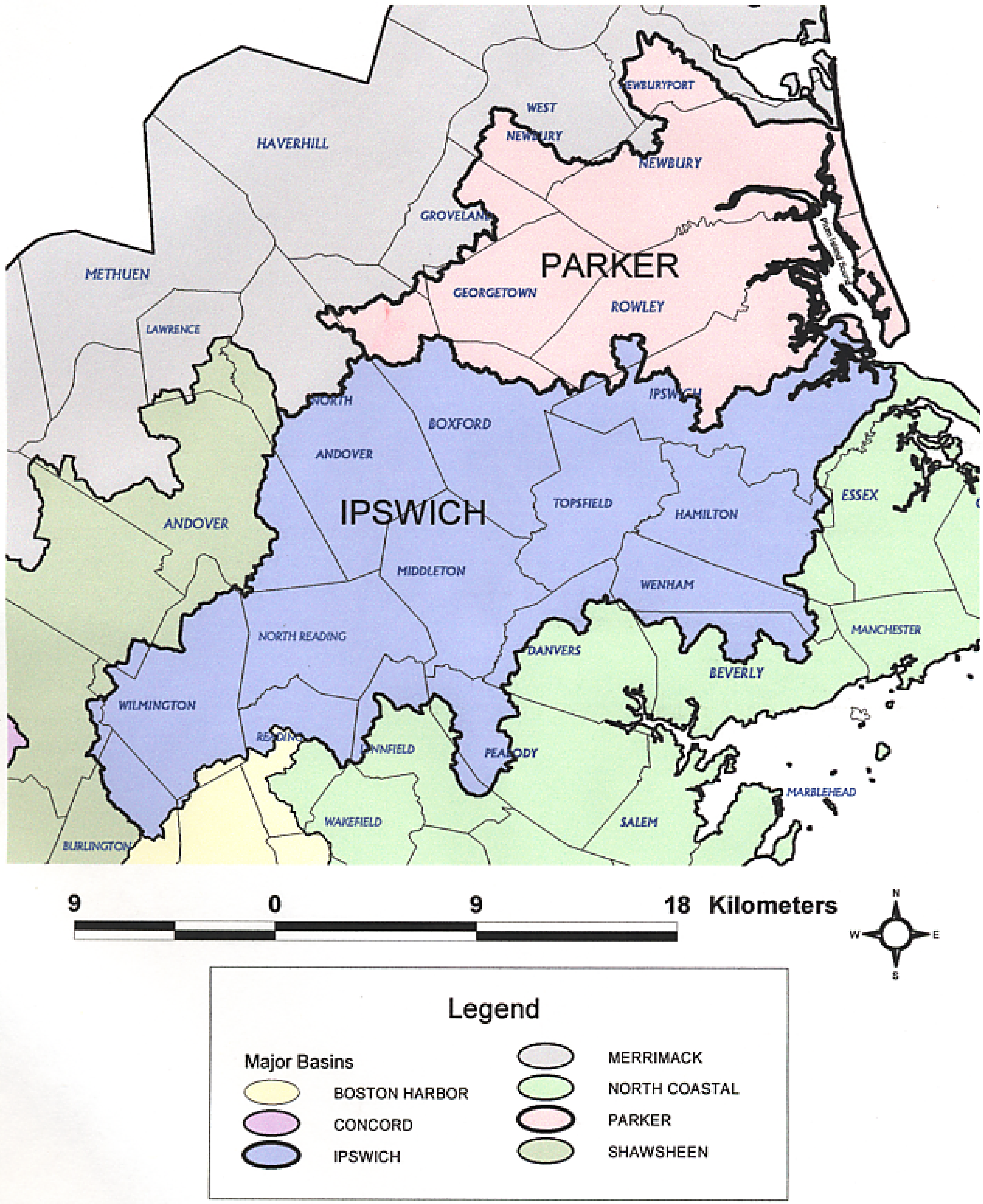
Coast and Geodetic Survey Chart #213 with a scale of 1:20,000 was used for all morphometric measurements in Jerome et al. (1968). Linear measurements were obtained with the use of a graduated straight-edge and a map rotometer. All area measurements were computed with a dot grid overlay. Updated measurements were taken from the watershed, subbasin, and 1:5000 data layers available from MassGIS.

2.3. Geography and Morphometry

The Parker River/ Plum Island Sound estuary is located in the towns of Newbury, Rowley and Ipswich. This estuary is formed primarily by the Plum Island Sound, the Parker, Plum Island, Rowley, Eagle Hill, and Ipswich rivers and (Fig. 2.1). Major tributaries to the Parker River include Mill and Little Rivers, Newbury. The Parker and Rowley Rivers drain a watershed of about 212 km^2 (Fig. 2.1). The Ipswich River watershed covers 401 km^2, and is by far the largest watershed draining into the Sound. The Ipswich River enters the Sound close to its mouth between Little Neck and Steep Hill.

The estuary contains a vast network of tidal creeks, large and small, which meander through approximately 3500 hectares of salt marsh. These vastly increase the amount of shoreline. The maximum length of the study area is 13.2 km (actual stream length, approximately 22.5 km), but the length of shoreline within the estuary is 262 km. The total surface area of the estuary is 1810 hectares (MHW) or approximately one-half the acreage of the surrounding salt marsh.

Fig. 2.1. Watersheds of the Parker River/ Plum Island Sound estuary, including the Ipswich River.



Plum Island Sound is a relatively shallow estuary as indicated by its depth contours (Table 2.1). The average depth within the study area varies from 3 m (MHW) to 1.6 m (MLW) depending on the tide. The percentage change in water volume between high and low tide is 68.6 percent.

Table 2.1. Area of Submerged Contours for the Parker River-Plum Island Sound Estuary, 1965.

Mean Low Water

Depth (feet)	1965 Area	1965 Percentage of Total
0-6	2,106	78.2
6-12	336	12.5
Over 12	250	9.3

Mean High Water (feet)

Depth (feet)	1965 Area	1965 Percentage of Total
Intertidal Area	1,778	39.8
0-6	2,106	47.1
6-12	336	7.5
Over 12	250	5.6

Table 2.2. A summary of the significant morphometric measurements of the area (modified from Jerome et al. 1968; MassGIS):

Maximum Length:	13.18 km
Maximum Effective Length:	8.50 km (mean high water, MHW)
	3.31 km (mean low water, MLW)
Maximum Width:	3.00 km (MHW)
	1.80 km (MLW)
Maximum Effective Width:	3.00 km (MHW)
	1.11 km (MLW)
Mean Width:	1.37 km (MHW)
	0.84 km (MLW)
Maximum Depth:	15.24 m (MHW)
	12.50 m (MLW)
Mean Depth:	3.0 m (MHW)
	1.6 m (MLW)
Mean Depth-Maximum Depth Relation:	0.20 (MHW)
	0.13 (MLW)
Maximum Depth-Surface Area Relation:	0.004 (MHW)
	0.004 (MLW)
Total Surface Area:	1,810 hectares (MHW)
	1,090 hectares (MLW)
Length of Shoreline:	261.6 km (MHW)
	219.5 km (MLW)
Shore Development:	17.32 (MHW)
	18.72 (MLW)
Volume:	54,782,973.7 cu. meters (MHW)
	17178852.3 cu. meters (MLW)
Salt Marsh Area:	3,405 hectares (33.9 sq. km)
Mean Tidal Amplitude:	2.6 m (Ipswich River Entrance)

2.4. Geological Background

Bedrock in the drainage basins that surround Plum Island Sound, “is primarily metamorphosed sedimentary, igneous, and volcanic rock, and unaltered igneous rocks. Most of the bedrock is overlain by unconsolidated materials that were deposited during and after the last advance of the glaciers…” (Jerome et al., 1968 and references cited within).

2.41. Bedrock

"There are two types of bedrock in the Parker River estuary (Clapp, 1921 as cited in Jerome et al., 1968). Above the Route I-A bridge the estuary is underlain by the Lynn Volcanic Complex, which is chiefly metamorphosed volcanic rocks containing abundant quartz and light-colored feldspar. The area downstream from the bridge is underlain by the Dedham Granodiorite, which is a coarse-grained, metamorphosed igneous rock containing abundant quartz and white and pink feldspar. It commonly has white feldspar crystals up to 5 centimeters long.

"The Rowley River estuary is underlain by Salem Gabbro-Diorite. This medium-grained, metamorphosed igneous rock contains white to light-gray feldspar and abundant dark ferromagnesium minerals.”

2.42. Surficial deposits

2.421. Glacial and postglacial history

The last glacial episode ended about 10,000 years ago in the region and left a strong impact on the landscape of the region. Glacial till overlies bedrock throughout much of the area. Thick deposits of till on top of bedrock occur on North Ridge and Plover Hill in Great Neck. Drumlins, low “hogback” hills of glacial debris with one steep side and the remainder sloping gradually, are prominent features. Examples include Castle Hill, Old Town Hill, and Sandy Point.

During the time of the last glaciation, the sea level in the region was about 400 feet lower than at present. The sea level rose as melting glaciers released vast amounts of water. Silt and clay were deposited in lowlands newly inundated by the rising sea. “As the glaciers disappeared, removal of their weight on the earth's crust caused rebound (or uplift) of the land which raised some of the marine silts and clays above present day sea level. The fine-grained deposits of the lowlands bordering the Parker and Rowley Rivers were formed in this manner, and were later covered, in places, by tidal marsh deposits (Jerome et al., 1968). The tidal marshes started to develop approximately 6000 years ago in conjunction with the formation of the Plum Island barrier Beach (McIntire and Morgan, 1962).

"Sea level stopped rising about 3000 years ago (McIntire and Morgan, 1962; Kaye and Barghoorn, 1964 cited in Jerome et al. 1968). Uplift of the land near this coastal section of Massachusetts ceased between about 7500 and 6000 years ago (McIntire and Morgan, 1962; Kaye and Barghoorn, 1964). From that time a slight downward warping of the crust of the earth caused the land to subside again." At present, sea level is rising in relation to the land.

2.422. Soil Types

A variety of soil types occur within the Plum Island /Parker River Estuary (Table 2.3 and USDA, 1981). The soil types in a given locale have a direct bearing on where septic systems should be located. Soils that are well to moderately well drained with a year round low water table are best suited for a traditional septic tank with a leaching field.

2.423. Intertidal bedforms

In general, large bedforms are abundant in the easterly sandy areas and their morphology is a result of current patterns at the mouth of the estuary. The orientation of these bedforms change depending upon the channel depths; in the main channels they tend to be ebb-oriented, whereas in the smaller creeks they are flood oriented. The shape and pattern of the internal bedforms vary with type of sediments present. The distribution of shellfish and other biota are dictated by the grain size of sediments. In sandy regions the medium grain sands tend to shift more often than the fine grain sands due to varying current velocities, with low velocity conditions most apt to move smaller sediments, therefore larger populations of shellfish are often found in the fine grain sand conditions. Grain size tends to decrease further up the estuary. Within the main channels the coarsest sediment is found on the highest elevations, but this tendency is reversed in the smaller tributaries (DaBoll, 1969).

The consequences of the erosion and deposition of sediments in the sound have a direct bearing on shellfish harvesting. The development of the highly productive Roaring Bull clam flat in Ipswich is a testament to the shifting sediments in the mouth of the estuary. Boothroyd and Hubbard (1975) determined that bedform type is dictated by the maximum flood and ebb tide velocities, the difference of maximum flood and ebb tide velocities, and the time span above a given velocity.

Table 2.3. Soil Types in the Plum Island Sound Estuary. Unpublished data from the Parker River Watershed Team, Massachusetts Executive Office of Environmental Affairs (EOEA, 1996).

Location	USDA Abbreviation	Type	Properties
Lower Section of the Parker River	IW	Ipswich and Westbrook Mucky Peats	Poorly Drained, Inundated Daily
Lower Section of the Parker River	AgA	Agawam Fine, Sandy Loam	Well Drained, Moderate to Rapid Permeability
Lower Section of the Parker River	BxC	Buxton, Rock Outcrop	Well Drained, Bedrock Exposures
Lower Section of the Parker River	RoD	Rock Outcrop, Charlton-Hollis Complex	Found on Slopes of 15 to 35 % slope, Shallow
Lower Section of the Parker River	MA	Maybid Silt Loam	Deep, Poorly Drained, Slow Permeability
Lower Section of the Parker River	CcC	Canton, Extremely Fine Sandy Loam	Moderately Rapid Permeability
Lower Section of the Little River	IW	Ipswich and Westbrook Mucky Peats	Poorly Drained, Inundated Daily
Lower Section of the Little River	RnC	Rock Outcrop, Buxton	Exposed Bedrock with moderately well drained soils, Moderately slow permeability
Lower Section of the Little River	RnD	Buxton	Soils that occur on 15-25 % slopes, exposed bedrock, moderately well drained soils, soil permeability, seasonal high water table
Lower Section of the Little River	BuB	Buxton Silt Loam	Soils that occur on 3-8 % slopes, moderately well drained, high water table
Lower Section of the Mill River	IW	Ipswich and Westbrook Mucky Peats	Poorly Drained, Inundated Daily

2.43. Hydrology

The complex flood-tidal delta system that makes up the Plum Island Sound Estuary is comprised of a main river, the Parker, and a series of many tributaries of the Parker, the largest include: the Mill River, the Little River, and the Rowley River. The large amount of salt marshes and fresh water wetlands present throughout the watershed acts to minimize the impacts of coastal flooding.

Hydrographic data show the estuary to be predominantly horizontally and vertically mixed (Daboll, 1969). Salinity stratification is slightly horizontal, especially during the ebb period in the upper estuary. The maximum salinity level difference was

4%. Daboll also noted that ebb currents were stronger than flood currents in the main channel, but flood currents were stronger in the smaller tidal creeks and mudflats.

Precipitation in the Parker River Basin according to the rain gage located in Newburyport averages 108 cm per year from 1913 to 1995. On average rainfall is 10.3 cm in the wettest month, November, and 2.8 cm in the driest month, August. Evapotranspiration is about 44% of the rainfall with the rest draining into the ocean as runoff (EOEA, 1996).

Approximately one-third of the runoff from the Parker River Basin is measured at the stream gauge in Byfield. The flow duration curve for the Parker River at the gauging station indicates that there is a moderate amount of natural storage in the upper regions of the watershed. Data from the stream gauge indicate that flows averaging at least 10 cfs occurred 70% of the days of record (EOEA, 1996).

2.44. Origin of Plum Island

"Plum Island began as a mainland beach about 6000-7000 years ago. As the land subsided and sea level rose, the shoreline should have migrated rapidly westward. However, an abundant supply of sand from the Merrimack River and sand plains to the north resulted in enlargement of the beach. Vertical growth of the beach kept pace with sea level rise and land subsidence, and the beach became an offshore bar. A salt-water marsh between the offshore bar and the mainland developed contemporaneously with the bar. Onshore winds blew beach sand above the storm high tide line and formed dunes which migrated landward covering some of the adjacent marsh deposits. Wind and wave action resulted in a gradual shifting of the shoreline to the west. Longshore currents carrying sand southward along the coast and depositing this sand along Plum Island shore extended the island southward until it was connected to the small hill of glacial till at the southern tip of the island" (McIntire and Morgan, 1962).

CHAPTER 3: THE WATER QUALITY AND FLUSHING CHARACTERISTICS OF THE PARKER RIVER-PLUM ISLAND SOUND ESTUARY

3.1 Overview

The original DMF monograph presented data on water quality and the type and degree of pollution which affect the marine environment within the study area. In the years subsequent to this report, there have been a number of water quality studies of the Sound. These include the Plum Island Sound Minibay Project, which analyzed the flushing characteristics and fecal coliform contamination while also obtaining some baseline measurements of nutrients. The Massachusetts Department of Environmental Protection (DEP) carried out several general water quality surveys through the Watershed Initiative.

3.2. Methods and Materials

3.21. 1968 Monograph

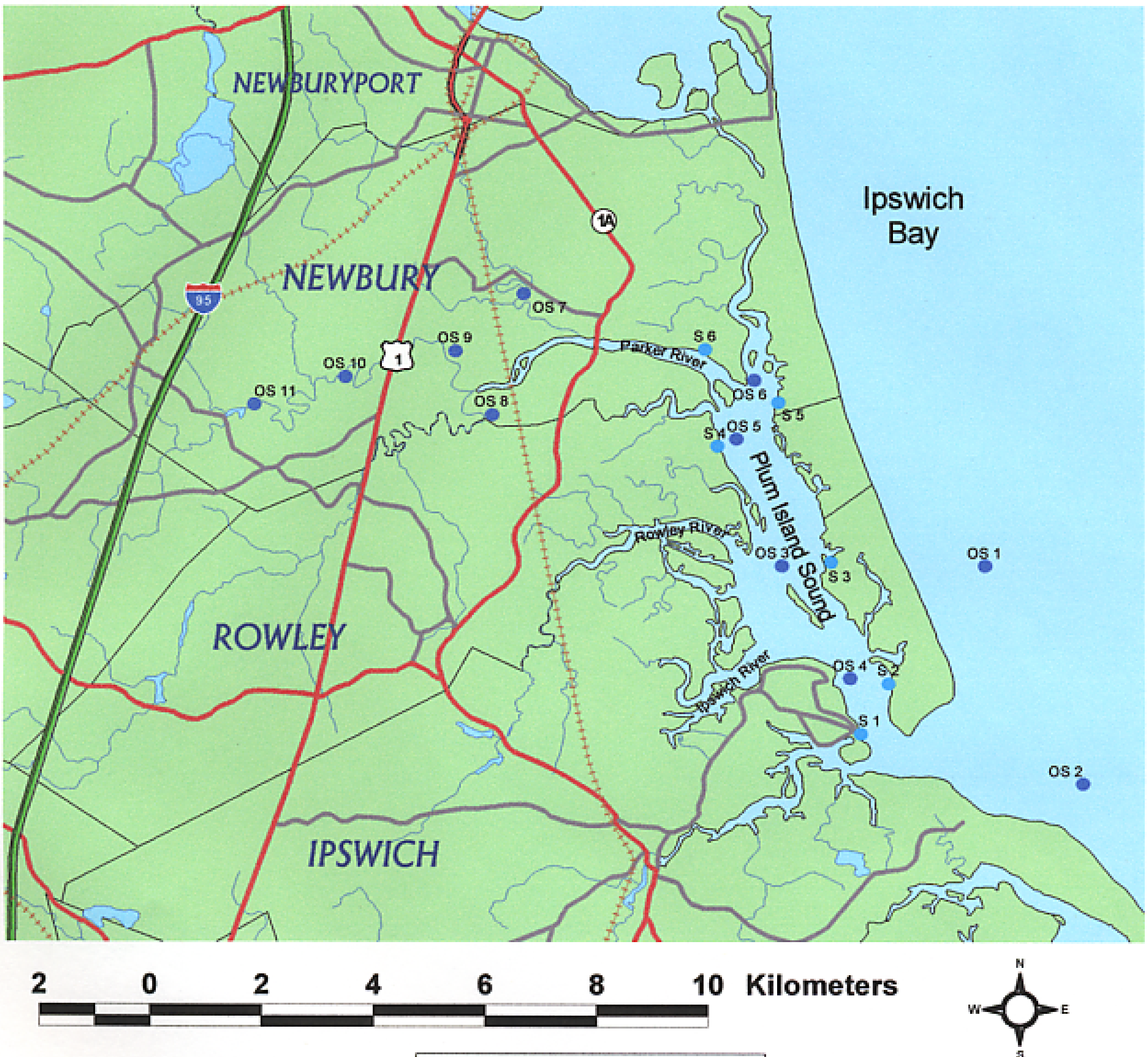
Six shore sampling stations were established at various locations along the shores of the study area, over a distance of six miles (Fig. 3.1a). These stations included Little Neck, S_1; Bluffs, S_2; Knobs, S_3; Nelson's Island, S_4; SubHeadquarters, S_5; and Newbury Town Landing, S_6. Sampling was conducted monthly from January through December 1965. More detailed descriptions of these sampling stations are in the chapter on fisheries resources.

Air and surface water temperatures and surface salinities were also recorded at three offshore stations set up primarily for monthly finfish sampling by the contract dragger *Peggybell* in the deep water portions of the estuary and adjacent areas. These stations were all within Ipswich: Camp Sea Haven, OS_1; Castle Neck, OS_2; and Middle Ground OS_3.

Supplementary surface water temperatures and salinity measurements were obtained during periodic offshore finfish sampling utilizing the shrimp trawl. Eight stations were sampled throughout the estuary from the lower portion of Plum Island Sound (Great Neck) to the head of the tidal portion of Parker River (Woolen Mill). These stations included Great Neck, OS_4; Nelson's Island, OS_5; Cape Merrill, OS_6; White's Bridge, OS_7; Mill River, OS_8; South Shore, OS_9; Thurlow's Bridge, OS_{10}; and the Woolen Mill, OS_{11} (Fig. 3.1a).

Colorimetric water chemistry kits were utilized in the field for water sampling. Hach Kit #CA-2 was used for dissolved oxygen, carbon dioxide and hydrogen ion (pH) determinations. Hach Kit #ABS-2 was used for determining detergent concentrations. Wide range salinity hydrometers, calibrated from 0-45 ppt, were used for surface salinity measurements. Pocket thermometers, calibrated in 2^{o} Fahrenheit (F) graduations, were used for taking air and surface

Fig. 3.1a. DMF Water Quality Stations

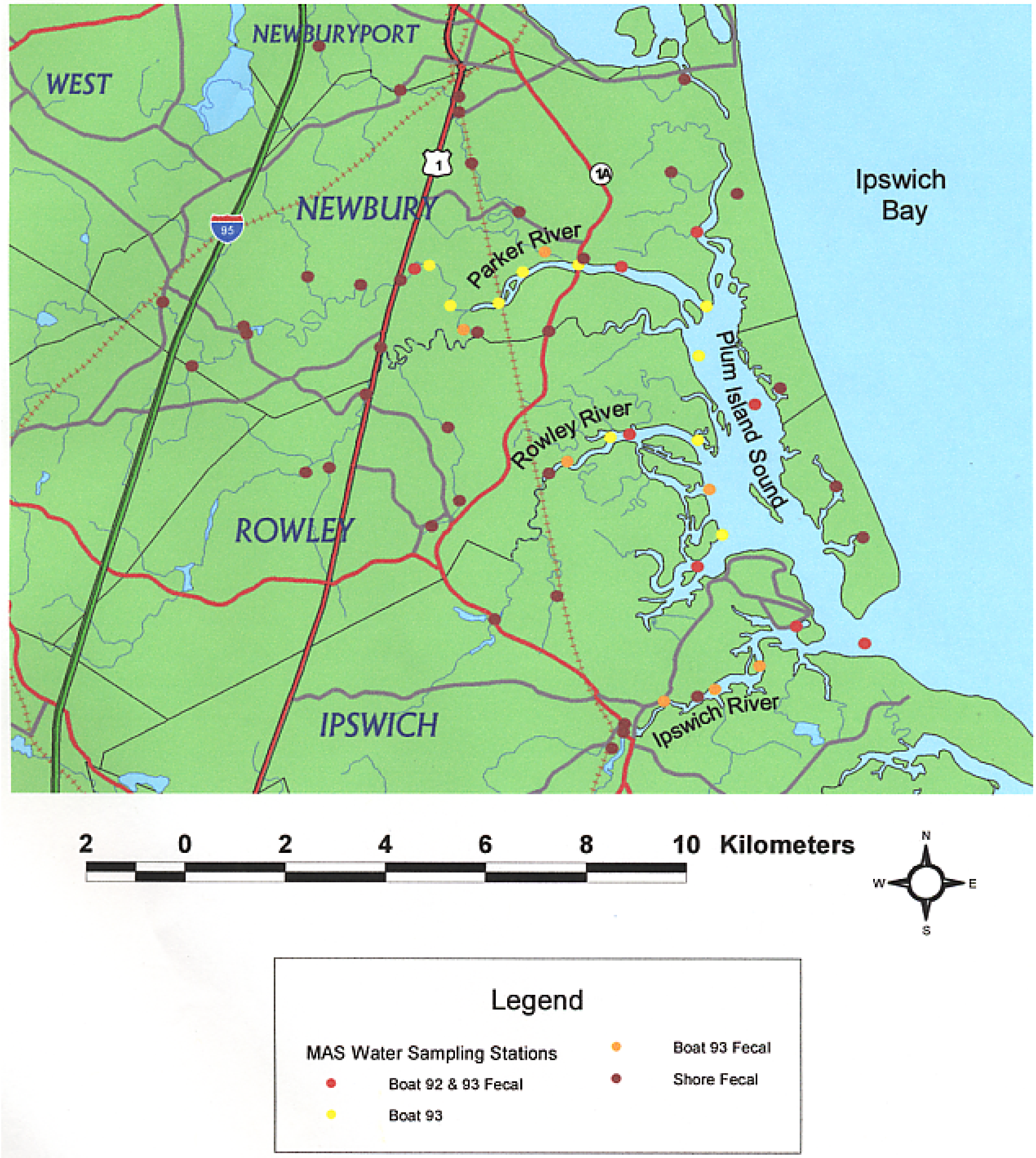


Legend

DMF Water Sampling Stations

- Off Shore
- Shoreline

Fig. 3.1b. MAS Water Quality Stations



water temperatures. A Secchi disc was used to determine water transparencies. Supplementary temperatures and salinities were recorded at eight additional offshore finfish sampling stations checked periodically in the shallower portions of the estuary.

3.22. Minibay Project

3.221 Salinity, Temperature, Dissolved Oxygen and Nutrients

Field sampling for these parameters in 1992 consisted of surveys of eight stations sampled both at low and at high tide (Fig. 3.1b). They are labeled in the text as MAS1, MAS2, etc. Data were collected for salinity, temperature, dissolved oxygen, nutrients, fecal coliforms and Secchi depth. A Sea Bird SBE-19 profiler was used to measure temperature, conductivity, depth and dissolved oxygen. Refer to the Minibay Project report for more details.

Water samples for nutrient analyses were collected at the same eight stations using a WILDCO horizontal sampler. At the shallower stations, a single sample was collected from 1 m depth, or at mid-depth if very shallow. At the two deeper stations, station 1 at the mouth of the Sound and station 12 in the middle of the Sound, two samples were taken, one at 1 m depth and one at 1 m above bottom. During each survey, two samples were collected at each of two stations as replicates.

Fifty milliliters of each sample was filtered through a glass fiber filter (Gelman A/E) into a bottle containing a premeasured volume of phenol solution to fix the sample for ammonium analysis. The filter was then folded, wrapped in labeled aluminum foil and placed in a desiccator for chlorophyll α analysis. The remaining sample was placed in a sterile 250 ml wide mouth bottle for fecal coliform analysis and two pre-cleaned 500 ml polyethylene bottles for analysis of other nutrients. The parameters measured and the methods used are indicated in Tables 3.1a and 3.1b.

Table 3.1a. Sampling conditions for the analytes measured during the water quality surveys.

Parameter	Matrix	Sampling Points*	Sampling Method	Holding Time h=hours d=days	Container Type**
ammonia	Filtered water	1992, 1993	Discrete sample	12 h	AG
nitrate + nitrite	whole water	1992, 1993	Discrete sample	12 h	P
total particulate nitrogen	whole water	1992, 1993	Discrete sample	12 h	P
total nitrogen	whole water	1992, 1993	Discrete sample	12 h	P
phosphate	whole water	1992, 1993	Discrete sample	48 h	P
total phosphorus	whole water	1992, 1993	Discrete sample	48 h	P
silicate	whole water	1992, 1993	Discrete sample	28 d	P
total particulate carbon	whole water	1992, 1993	Discrete sample	7d	P
chlorophyll *a*	filtered particles	1992, 1993	Discrete sample	30 d	F
fecal coliforms	whole water	1992, 1993	Discrete sample	6 h	P
salinity	whole water	vertical profile at each station	1992: Seacat 1993: STD-12	N/A	N/A
temperature	whole water	vertical profile at each station	1992: Seacat 1993: STD-12	N/A	N/A
dissolved oxygen	whole water	1992 only, vertical profile at each station	Seacat profiler	N/A	N/A

* 1992: Low and high tide, 1 per station, 2 depths at stations 1 and 12, replicates at 2 stations.
1993: Low tide only; nutrients at stations 1, 3, 12, 15; fecal coliforms at 15 stations.

** AG = Amber Glass; P = Polyethylene; F = Filter

Table 3.1b. Analytical conditions for the analytes measured during the water quality surveys.

Parameter	Method	Reference	Accuracy (µM)	Detection Limit (µM)
ammonia	phenol/hypochlorite (autoanalyzer)	Lambert and Oviatt, 1986	0.02 *	0.06**
nitrate + nitrite	Cd-Cu reduction / sulfanilamide / N-ED HCl_2	Lambert and Oviatt, 1986	0.01*	0.03**
total particulate nitrogen	elemental analyzer	Lambert and Oviatt, 1986	0.05	0.56
total nitrogen	persulfate oxidation / NO_3 analysis	Lambert and Oviatt, 1986	0.1-0.3*	0.3 - 0.9**
phosphate	molybdate/ascorbic acid	Lambert and Oviatt, 1986	0.01 *	0.03**
total phosphorus	persulfate oxidation / PO_4 analysis	Lambert and Oviatt, 1986	0.04*	0.12**
silicate	molybdate/ascorbic acid	Lambert and Oviatt, 1986	0.02*	0.06**
total particulate carbon	elemental analyzer	Lambert and Oviatt, 1986	0.5	0.6
chlorophyll *a*	acetone extraction/ fluorescence	Lambert and Oviatt, 1986	0.01 µg/L	0.01 µg/L
fecal coliforms	membrane filtration	APHA 1989	( )	( )
Conductivity	internal field electrode	Sea Bird Instruments (manual)	0.001 s/m	0 to 6.5 s/m (range)
temperature	thermistor	Sea Bird Instruments (manual)	0.01° C	-5 to 35° C (range)
dissolved oxygen	polarigraphic electrode	Sea Bird Instruments (manual)	0.15 mg/L	0 to 15 mg/L (range)

* Accuracy is equivalent to the standard deviation of the estimate for each analysis as reported in Lambert and Oviatt

** Detection threshold is defined as three times the standard deviation.

The sampling program was altered in 1993 to allow a more intensive sampling of salinity distribution to better evaluate the flushing characteristics of the Plum Island Sound system. This involved several changes: (1) a different salinity profiling instrument (2) more salinity profiling stations, and (3) fewer water chemistry stations. There were 21 standard stations in the 1993 program covering most of the same areas as in 1992, except for Plum Island River, with a greater density of sampling stations as well as extending sampling further up the Ipswich and Rowley Rivers (Figure 3.2b). Stations 1 through 21 are the standard sampling stations for these surveys. Stations 22 through 25 are additional stations that were sampled at low tide on most surveys for salinity and fecal coliforms. Hydrographic measurements were taken at each station at low and high tide. An Applied Microsystems Model STD-12 was used to sample the salinity and temperature profiles. Sampling intervals were set at 0.1 m for all surveys.

Water sampling for nutrient analyses was considerably reduced in 1993. The 1992 data provided a good basis for evaluating nutrient levels in the Sound/rivers system, but a few stations were sampled in 1993 to provide a basis for evaluating differences between years. Only four stations were sampled, at the surface, and only at low tide. These were stations 1, 3, 12 and 15. Sample handling and analysis were the same as for 1992.

To prevent this document from becoming too lengthy, our data presentation includes only those stations from the Minibay project that are near or at DMF stations. For information on the additional stations, the reader should examine the report from that project.

3.222 Flushing Characteristics

Streamflow data - For carrying out flushing time analyses, freshwater input rates are required. The primary sources of freshwater to the Plum Island Sound system are the Ipswich and Parker Rivers, both of which are gauged by the U.S. Geological Survey (USGS). Streamflow data were provided by USGS for 1992 and 1993 (through November) for the Ipswich River gauge near Ipswich (Station 01102000) and the Parker River gauge at Byfield (station 01101000). The locations of these gauges are shown in Figure 3.3. These stations only measure flows resulting from 80% of the drainage area to the Ipswich River and 36% of the area draining to the Parker River, and it does not account for other areas such as those draining to the Rowley River, the Eagle Hill River and directly to the Sound. In 1992, these additional areas were to be accounted for by scaling areas from USGS gauge readings.

The Ipswich and Parker River USGS stream gauges were used for calculating total streamflow to each subarea of Plum Island Sound. These represented the greatest area of drainage by far, and a more stable basis for calculating fresh water sources than measurements of flow from the smaller drainage subbasins. Values have been standardized by drainage basin area to calculate a volume flow rate per area.

Estimation of Flushing Times - Flushing time calculations were carried out using an estuarine box model called BayModel developed at Applied Science Associates, Inc. A separate set of such values were produced for each survey day.

A box model previously developed for Narragansett Bay (Swanson and Jayko, 1988) was used to calculate flushing times in Plum Island Sound. The model is based on the box model approach presented by Officer (1980). In a box model, the region under consideration is segmented into a number of boxes in which the physical characteristics are approximately uniform. Each box can have either one or two layers in the vertical. Mean, tidally-averaged values are used for all input parameters and the exchange coefficients and concentrations calculated by the model are, likewise, time-invariant solutions.

Officer's (1980) box model methodology was developed for estuarine application. The primary forcing mechanisms for mean estuarine circulation are river flow and horizontal and vertical salinity gradients. The box model of Swanson and Jayko (1988) extends the

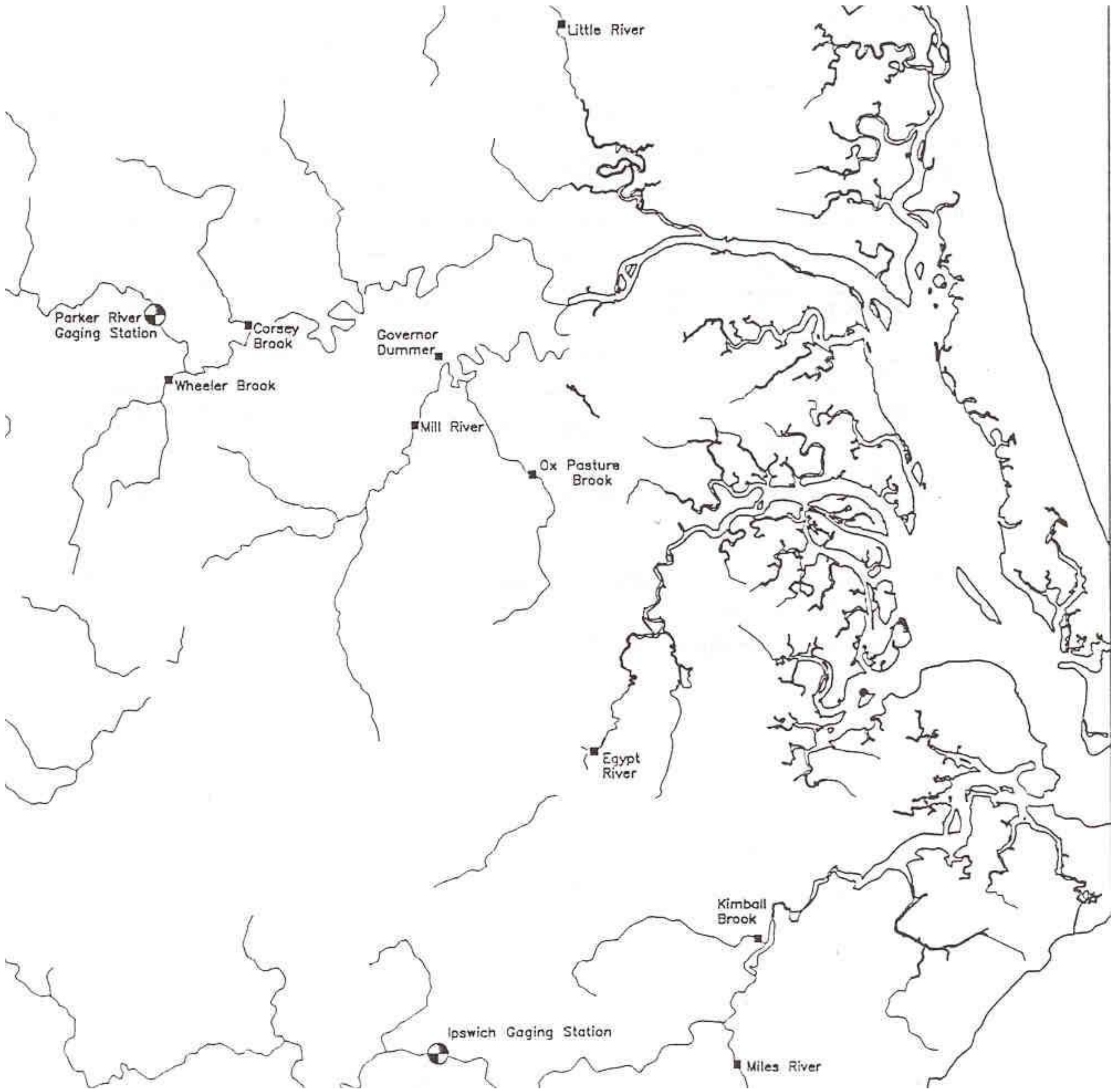


Figure 3.2. Location of USGS stream flow gauging stations on the Ipswich and Parker Rivers.

methodology presented by Officer to represent three dimensions by allowing each box to have four vertical faces through which flow may enter or leave, in addition to two layers in the vertical.

Observed values of salinity and river flow are used to determine the hydrodynamic exchange coefficients. All exchanges occur at the boundaries of the boxes. The vertical boundaries should enclose regions of similar properties. The horizontal boundary between upper and lower layers, where used, is placed at the halocline.

The model can also be used to calculate constituent (e.g., total nutrient) concentrations in each box. The conservation of constituent mass equation, with allowances for flux input and/or output (decay and settling of the constituent) is solved for each box. The calculated concentrations represent a steady state condition determined by the river (freshwater) flow, salinity, and constituent (e.g., nutrient) loading.

The flushing time of each box is determined using the fraction of freshwater method (Mills et al., 1984). With the estuary divided into boxes, the flushing time may be calculated:

$$t = \sum \frac{f_i V_i}{R_i}$$

This equation says that the flushing time for the system is the sum of the flushing times for each box, expressed as the volume of freshwater in the box, $f_i V_i$, divided by the river flow through the box R_i. The fraction of freshwater, f_i, is given by

$$f_i = \frac{S_o - S_i}{S_o}$$

in which S_o is the local ocean salinity. The flushing time of a dissolved constituent discharged at any point into the estuary can be computed by summing the flushing times of each of the boxes seaward of the discharge.

3.223. Fecal Coliforms Studies

In the Minibay Project water samples for fecal coliform analysis were collected in 1992 and 1993 from stations sampled by boat throughout Plum Island Sound and the estuarine reaches of the Parker River, the Rowley River and the Ipswich River (Fig. 3.1b). This two year sampling effort was done in conjunction with the flushing and nutrient studies described above. Because the results from the two years of sampling by boat indicated that the major sources of fecal coliform to the Sound were upstream, a program of shoreline sampling was initiated throughout the tributary rivers of the Sound in late 1992 and continued through 1995. The bacterial concentrations found at these stations, combined with flow measurements estimated from the size of the drainage basin, were used to estimate loadings of bacteria to the Sound from different sources.

Water samples were collected in pre-sterilized, pre-labeled 250 ml polyethylene bottles from both boat and shoreline sites. Samples were taken according to EPA standard procedures for collecting, handling, and analyzing water for microbes. Water samples were analyzed using the mTEC method (Dufour et al. 1981, US EPA 1985). All laboratory analyses were carried out at Massachusetts Audubon's Norman's Woe Marine Laboratory. See Buchsbaum et al. (1996) for further details.

Sampling for the Minibay Project was designed with two goals. The first was to identify particular "hot spots", i.e., areas with particularly high concentrations of fecal coliforms. This was carried out by repeatedly sampling a variety of marine and freshwater stations throughout the Plum Island Sound watershed. The second goal was to calculate the relative loads of fecal coliforms from different subwatersheds. We selected one station from each subwatershed for intensive sampling and combined the information from fecal coliform tests and with estimates of flow volume (from basin area and streamflow measurements - see ASA Report, Section A) to calculate loadings.

The Minibay project intercalibrated their bacterial sampling with those from the shellfish sanitation program of DMF. Some samples were split roughly in half and analyzed both by MAS and DMF. This gave us an estimate of the comparability of the mTEC method with the most probable number (MPN) procedures used by DMF.

Sampling events were divided into those occurring during dry and wet weather, since precipitation typically has a profound influence on fecal coliform concentrations in coastal waters. Rainfall was measured at the Ipswich Wastewater Treatment Facility and provided to the Massachusetts Audubon by Timothy Henry. The categorization of sampling events as either rain or dry is somewhat arbitrary, since the amount, timing, and longevity of any bacterial pulse from a storm event will be affected by the size, gradient, and other physical characteristics of the drainage basin. A sampling day was considered as a rain event if it had rained greater than 0.5 inches within the previous 36 hours or greater than 1.0 inch within the previous 84 hours. This definition of a wet weather event is less conservative than that used by DMF's shellfish sanitation program for Plum Island Sound. DMF closes shellfish beds for 5 days after a rainfall of greater than 0.5 inches and for 8 days after a rainfall of over 1 inch. The Massachusetts Water Resources Authority's Harbor Studies Program defines a rainfall event in Boston Harbor as greater than 0.3 inches of rain the previous two days (A. Rex, pers. comm.).

3.3. Results and Discussion of Water Quality Analysis

3.31. Dissolved Oxygen and Transparency

The DMF study indicated that Plum Island Sound did not have a low dissolved oxygen (DO) problem in 1965 (see Tables 3.2-3.7 and 3.12). Of the six shoreline stations sampled by DMF in 1965, four never had DO lower than 10.0 mg/L even in midsummer when DO concentrations are often somewhat depressed in coastal waters. The lowest DO recorded by DMF, 7.0 mg/L at Nelson's Island in July, was still above the Massachusetts water quality standard of 6.0 for marine waters. Depressed dissolved oxygen concentrations are not unusual for an organically-rich salt marsh area in mid summer. The measurements of DO in the Minibay project in 1992 were slightly lower than that of DMF (Tables 3.13-3.18), but in most cases were still above the state standard and therefore not indicative of low DO problems. Several samples from the Town Landing and Route 1 stations on the Parker River, however, were below the state standard of 6.0 (Tables 3.13-3.18). Although water quality could have declined between 1965 and 1992 due to increased nutrient loading, the difference between the two studies could also be attributed to differences in analytical methods (Winkler titrations on a grab sample versus a continuous measurement with the Seabird Seacat Profiler) or to normal variations. The samples collected by the Minibay Project were an integration of DO concentrations at all depths by the Seabird profiler, whereas those collected by DMF were from a discrete surface sample. Normal variability cannot be ruled out either, since marsh creeks are naturally high in organic matter in the summer. As is described in the fisheries section, the 1965 survey was carried out during a time of relative drought when less land-based organic matter and nutrients would have been washed into the upper portions of the Sound, hence higher DO concentrations were likely under oceanic influence in those years.

The Massachusetts Department of Environmental Protection carried out a water quality survey in 1989 of Ipswich and Essex Bays. Their sampling stations included some in the lower part of Plum Island Sound and in the Ipswich River estuary (Tables 3.19-3.21). Their results support the idea that dissolved oxygen levels in the Sound itself are generally high and close to saturation even during the summer months. Like the Minibay Project, however, dissolved oxygen levels in some of their "upstream" stations were occasionally below the state standard (data not shown, refer to Mass DEP 1989). There may be an issue with organic matter or nutrient loading at these sites.

The more open areas of the southern part of the Sound had the highest transparency, generally in excess of 5 m even in midsummer. Water transparency depths varied from greater than 5 m to less than 2 m. According to the DMF data, two stations relatively upstream from the mouth of the Sound, the Nelson's Island station and the station on the Parker River at the Newbury town landing, were more turbid than those closer to the mouth.

3.32. Temperature and Salinity

Surface water temperatures recorded at the six shore stations from January through December 1965 varied from a low of -1^{o}C to a high of 26^{o}C (Tables 3.2-3.8). Recorded surface water temperatures seldom exceeded 21^{o}C at the shore stations during 1965. The highest surface water temperatures recorded at Little Neck and the Bluffs, located in the lower portion of the estuary were 16^{o}C and 18^{o}C, respectively. The range of values for the three offshore stations sampled throughout the year, which were also in the lower part of the estuary, was 2-19^{o}C (Tables 3.9-3.11).

Surface water temperatures taken at the eight shrimp trawl stations sampled during the period from May 13 to September 24, 1965 ranged from 12^{o} to 22^{o}C and surface salinities from 0 to 31.0 ppt (Table 3.12). Five of the eight offshore shrimp trawl stations had recorded surface water temperatures of 22^{o}C in September.

Minimum and maximum surface salinity measurements recorded at the six shore stations ranged from 21.0 to 33.5 ppt in 1965 (Table 3.8). The maximum salinity fluctuation recorded at any one station occurred at Newbury Town Landing (21.0 to 31.0 ppt), located approximately 8 miles from the mouth of Plum Island Sound.

Jerome et al. (1968) reported that the freshwater discharge from the Parker River-Plum Island Sound watershed had relatively little dilution effect on the ocean waters within the estuary compared to other Massachusetts estuaries. This resulted in a more uniform, relatively high salinity environment in Plum Island Sound and in much of the tidal portion of Parker River.

The Minibay Project also found a considerable range of freshwater dilution of seawater upstream over the course of the 1992 and 1993 seasons particularly at the more upstream stations (Tables 3.13-3.18). In April 1992, the Parker River was almost totally fresh at low tide. In August and September on the other hand, there was relatively little dilution of the seawater until well up the Parker River at station MAS21. Results for June and December lay between these extremes.

Salinities were generally higher at comparable sampling stations during the DMF study compared to the Minibay project. Salinity data from the two studies suggest that the period of the DMF study was one of lower freshwater inputs and lower rainfall. Salinity differences were also apparent between the two years of the Minibay project. Salinities tended to be higher in 1993 than in 1992 (Tables 3.13-3.18) suggesting that 1993 was a drier year. In the September survey 1993, salinity remained above 26 ppt at low tide. During the 1992 surveys, the upstream stations showed lower salinities than this even at high tide.

Table 3.2. Water Analysis Data Collected at the Little Neck Shore Station (S1), 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)	pH	Dissolved Oxygen (ppm)	Carbon Dioxide (pprn)	Deter-gent (ppm)	Trans-parency (feet)
Jan 6	Low +2 1/2 (hrs)	34	46	30.0	8.0	>10.0	10.0	0.1	>15
Feb 11	High +4	31	41	32.5	8.0	>10.0	5.0	0.1	>15
March 9	Low +3 1/2	38	*40*	23.0	8.0	10.0	10.0	0.1	>15
May 18	Low +2	56	54	26.0	8.0	10.0	*5.0*	0.1	15
June 1	High +1	56	74	31.0	8.0	10.0	*5.0*	0.0	>15
July 12	High	56	78	30.0	8.0	>10.0	*5.0*	0.1	>15
Aug 26	High +1	58	62	30.0	8.0	>10.0	*5.0*	0.1	>15
Sept 22	High +2 1/2	61	93	31.0	8.0	>10.0	*5.0*	0.1	>15
Oct 14	Low +4	54	57	32.0	8.0	>10.0	*5.0*	0.1	>15
Nov 15	Low +1	44	39	33.5	8.0	>10.0	*5.0*	0.1	>15
Dec 15	Low +2	40	34	31.0	8.0	>10.0	*5.0*	0.1	>15

Table 3.3. Water Analysis Data Collected at the Bluffs Shore Station (S2), 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)	Dissolved Oxygen pH	Carbon Dioxide (ppm)	Deter-gent (ppm)	Trans-parency (feet)
March 15	High +1 (hr)	36	44	31.0	8.0	5.0	0.1	-
April 28	High + 1 1/2	44	57	26.0	8.5	5.0	0.1	15+
May 18	Low +5	52	57	25.0	8.0	5.0	0.1	15
June 1	High +11/2	56	68	30.5	8.0	0.0	0.1	15+
July 15	High +1	56	81	29.0	8.5	0.0	0.1	15+
Aug 25	High +1	58	87	31.5	8.0	0.0	0.0	-
Sept 23	High + 1/2 64	74	32.0	8.0	5.0	0.2	15+	
Oct 15	Low +2	56	63	28.0	8.0	5.0	0.1	15+
Nov 16	Low +3	48	51	32.0	8.0	5.0	0.2	15+
Dec 16	Low +3	40	42	31.0	8.0	5.0	0.3	-

Table 3.4. Water Analysis Data Collected at the Knobs Shore Station (S3), 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)	pH	Dissolved Oxygen (ppm)	Carbon Dioxide (ppm)	Deter-gent (ppm)	Trans-parency (feet)
March 16	High +4 1/2 (hrs)	40	42	29.5	8.5	>10.0	5.0	0.1	-
April 28	High +21/2	47	58	27.0	8.5	>10.0	5.0	0.1	>15
May 21	Low +3	59	59	29.0	8.0	>10.0	10.0	0.1	>15
June 14	High	54	52	30.0	8.0	10.0	5.0	0.0	>15
July 13	High +2	64	80	30.0	8.5	>10.0	0.0	0.1	>15
Aug 25	High	60	80	31.0	8.0	>10.0	0.0	0.1	-
Sept 22	High	72	88	28.5	8.0	10.0	5.0	0.1	>15
Oct 15	Low +1	53	63	31.5	8.0	>10.0	5.0	0.1	>15
Nov 16	Low +31/2	46	51	31.0	8.0	>10.0	5.0	0.2	>15
Dec 15	Low +5	37	36	30.5	8.0	>10.0	5.0	0.2	>15

Table 3.5. Water Analysis Data Collected at the Nelson's Island Shore Station, 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)	pH	Dissolved Oxygen (ppm)	Carbon Dioxide (ppm)	Deter-gent (ppm)	Trans-parency (feet)
Jan 6	Low +4 (hrs)	30	40	28.0	8.0	>10.0	10.0	0.1	6
March 15	High +5	40	37	32.5	8.0	>10.0	5.0	0.1	3
April 27	Low +3	48	45	24.5	7.5	>10.0	5.0	0.1	>15
May 18	Low +4	57	55	25.0	7.5	9.0	5.0	0.1	-
June 14	Low +31/262	58	23.0	8.0	9.0	10.0	0.1	5	
July 13	Low +31/273	74	26.5	8.0	7.0	5.0	0.1	8	
Aug 27	High + 1	66	76	30.0	8.0	9.0	10.0	0.0	5
Sept 22	High +31/2	68	92	31.0	8.0	>10.0	5.0	0.1	7
Oct 14	Low +3	54	59	32.5	7.0	>10.0	10.0	0.1	>15
Nov 15	Low +21/244	41	32.0	8.0	>10.0	10.0	0.1	>15	
Dec 15	Low +3	34	36	29.0	8.0	>10.0	5.0	0.1	10

Table 3.6. Water Analysis Data Collected* at *the Sub-Headquarters Shore Station (S5), 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)	pH	Dissolved Oxygen (ppm)	Carbon Dioxide (ppm)	Deter-gent (ppm)	Trans-parency (f-t)
Jan 26	High +4 (hrs)	30	34	31.5	8.0	10.0	10.0	0.2	-
Feb 9	Low +31/230	35	28.0	8.0	>10.0	10.0	0.2	-	
March 25	Low	40	58	24.0	8.0	10.0	10.0	0.1	>15
April 28	High +5	52	58	25.0	8.0	>10.0	5.0	0.1	>15
May 21	Low +4	66	64	24.0	8.0	10.0	10.0	0.1	>15
June 14	High +1	62	52	29.0	8.0	>10.0	10.0	0.1	10
July 12	High +3	69	72	31.0	8.0	>10.0	5.0	0.1	>15
Aug 25	High	66	78	30.0	8.0	>10.0	10.0	0.1	-
Sept 24	Low +4	70	74	28.0	7.5	10.0	5.0	0.1	-
Oct 15	Low +3112,	56	63	30.0	8.0	>10.0	5.0	0.1	10
Nov 16	Low +4	46	50	31.0	8.0	>10.0	5.0	0.2	>15
Dec 16	Low +4	38	40	29.0	8.0	>10.0	5.0	0.2	-

Table 3.7. Water Analysis Data Collected at the Town Landing Shore Station (S6), 1965.

Date	Time of Day	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)	pH	Dissolved Oxygen (ppm)	Carbon Dioxide (ppm)	Deter-gent (PP-)	Trans-parency (feet)
Jan 6	1:30 P.M.	High	30	42	27.5	8.0	>10.0	10.0	0.1	8
Feb 9	11:00 A.M.	Low	30	37	21.0	7.0	>10.0	10.0	0.1	-
March 15	11:30 A.M.	High +21/2 (Hrs)	36	41	27.0	8.0	>10.0	5.0	0.1	7
April 27	10:45 A.M.	High +346	47	21.0	8.0	>10.0	5.0	0.2	7	
May 17	11:40 A.M.	Low +5	58	60	26.5	8.0	8.0	5.0	0.1	6
June 1	12:10 P.M.	High	62	70	27.0	8.0	8.0	5.0	0.1	5
July 13	10:00 A.M.	Low +5	72	84	26.0	8.0	10.0	5.0	0.1	>15
Augt 26	1:15 P.M.	High +3	66	64	30.0	8.0	8.0	10.0	0.1	-
Sept 22	8:45 A.M.	High +1/2	60	76	29.0	8.0	9.0	10.0	0.1	>15
Octr 14	10:25 A.M.	Low +2	58	58	28.0	7.5	>10.0	10.0	0.1	8
Nover 15	1:45 P.M.	Low +4	44	41	31.0	8.0	>10.0	10.0	0.1	>15
Decer 15	1 1:00 A.M.	Low +1	36	34	29.0	8.0	10.0+	10.0	0.1	5

Table 3.8. Ranges for Temperature and Water Analysis Measurements for the shoreline stations in the Parker River-Plum Island Sound Estuary, 1965.

Sampling	Temperature (F) Water		Air		Salinity (ppt)			pH			Diss. Oxygen (mg/L)			Carbon Dioxide (ppm)			Detergent (ppm)		
Station	Min	Max	Min	Max	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave
Little Neck	31	61	34	93	23.0	33.5	28.2	8.0	8.5	8.0	10.0	10.0	10.0	5.0	10.0	5.8	0.0	0.2	0.1
Bluffs	36	64	42	87	25.0	32.0	29.6	8.0	8.5	8.1	10.0	10.0	10.0	0.0	5.0	3.9	0.0	0.3	0.1
Knobs	37	72	36	88	27.0	31.5	29.8	8.0	8.5	8.2	10.0	10.0	10.0	0.0	10.0	4.5	0.0	0.2	0.1
Nelson's Island	30	73	36	92	23.0	32.5	28.5	7.5	8.0	7.9	7.0	10.0	9.5	5.0	10.0	7.2	0.0	0.1	0.1
Sub-Headquarters	30	70	34	78	24.0	31.5	28.4	7.5	8.0	8.0	10.0	10.0	10.0	5.0	10.0	7.5	0.1	0.2	0.1
Town Landing	30	72	34	84	21.0	31.0	26.8	7.0	8.0	7.9	8.0	10.0	9.4	5.0	10.0	7.9	0.1	0.2	0.1

Table 3.9. Water Analysis Data Collected at the Camp Sea Haven Offshore Station (OS1), 1965.

Date	Tidal Stage	Temp (ºF) Water	Air	Salinity (ppt)
Jan 6	Low +3 (hrs)	36	37	32.5
March 3	High	36	42	29.0
April 21	Low +3	42	48	28.0
May 26	High +4	-	-	30.0
June 28	High +2	56	78	30.0
Aug 25	High +2	59	68	-
Sept 28	Low +2	54	50	32.0
Oct 13	Low *+5*	50	56	-
Nov 26	Low *+5*	44	48	33.0
Dec 8	High +21/2	38	35	31.5

Table 3.10. Water Analysis Data Collected at the Castle Neck Offshore Station (OS2), 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)
January 6	Low +5 (hrs)	37	40	32.5
March 3	High + 1	36	52	30.5
April 21	Low +4	44	56	29.0
May 26	High +3	-	-	29.0
June 28	Low +4 1/2	54	72	31.0
Aug 25	High + 1	60	66	-
Sept 28	Low +5	54	56	31.0
Oct 13	High +1 1/2	50	56	-
Nov 26	High + I/2	44	46	32.5
Dec 8	High + 1 1/2,	40	33	32.0

Table 3.11. Water Analysis Data Collected at the Middle Ground Offshore Station (OS3), 1965.

Date	Tidal Stage	Temperature (F) Water	Air	Salinity (ppt)
January 6	High +1 (hr)	36	40	32.5
April 21	High	42	*50*	-
May 26	High +2	-	-	28.5
June 28	High + 1/2	54	74	30.5
August 25	High + ½	66	70	-
September 28	High + 1/2	54	57	31.0
October 13High + 1/2	*50*	52	-	
November 26	High +1	44	48	32.0
December 8	High	40	28	32.5

Table 3.12. Water Analysis Data Collected at the Eight Shrimp Trawl Stations (OS4-OS11), 1965.

Station	Date	Tidal Stage	Water Temperature (F)	Salinity (ppt)
Great Neck	June 29	High + 1 (hr)	54	30.0
	September 23	High +3 1/2	63	31.0
Nelson's Island	June 29	High +2	66	30.0
	September 23	High +4 1/2	72	29.0
Cape Merrill	May 28	High +3	66	26.0
	June 28	High +3 1/2	-	30.0
	September 23	High +5	72	28.5
White's Bridge	May 14	High +2 1/2	60	24.0
	May 28	High +2 1/2	67	20.0
Mill River	May 14	High + 1/2	60	20.0
	June 30	Low +51/272	20.0	
South Shore	May 14	High	60	22.0
	June 30	High + ½	62	21.0
Thurlow's Bridge	May 13	High +21/2	64	10.0
	June 30	High + 1/2	66	20.0
	September 24	High +2 1/2	72	-
Woolen Mill	May 13	High + 1 1/2	66	0.0
	September 24	High + 1 1/2	72	-

Table 3.13. Salinity, temperature, and dissolved oxygen (DO) data at the mouth of the Sound off Steep Hill (MAS1), 1992 and 1993. DO was not measured in 1993. This station is between DMF's S1 (Little Neck Shore Station) and OS 2 (Castle Neck Offshore Station). Data from Plum Island Sound Minibay Project.

Survey	Date	Instrument	Tide	Depth (m)	Temperature ©-	Salinity (ppt)	Oxygen (mg/L)
1992-1	04/28/92	SEACAT	High	9.5	6.15	28.63	9.55
1992-1	04/28/92	SEACAT	Low	6.2	8.12	25.08	11.05
1992-2	06/11/92	SEACAT	High	9.6	13.17	28.82	8.18
1992-2	06/11/92	SEACAT	Low	7.8	15.10	27.25	8.87
1992-3	08/26/92	SEACAT	High	12.3	16.43	30.50	7.13
1992-4	09/25/92	SEACAT	High	13.0	11.88	30.67	8.22
1992-4	09/25/92	SEACAT	Low	1.3	14.73	30.57	7.19
1992-5	12/16/92	SEACAT	High	6.8	5.01	31.58	9.50
1992-5	12/16/92	SEACAT	Low	6.9	2.84	28.38	9.36
1993-1	06/03/93	STD-12	High	6.9	8.97	30.29	
1993-1	06/03/93	STD-12	Low	3.6	11.84	29.72	
1993-2	07/07/93	STD-12	High	6.2	14.54	30.78	
1993-2	07/09/93	STD-12	Low	4.6	18.82	30.78	
1993-3	08/04/93	STD-12	High	8.4	15.12	30.95	
1993-3	08/04/93	STD-12	Low	3.9	19.73	30.36	
1993-4	09/08/93	STD-12	High	6.4	15.18	30.53	
1993-4	09/08/93	STD-12	Low	3.8	17.29	30.95	
1993-5	11/19/93	STD-12	Low	2.6	7.71	29.05	
1993-5	12/02/93	STD-12	High	3.8	6.31	30.61	

Table 3.14. Salinity, temperature, and dissolved oxygen (DO) data at the Ipswich River station at Little Neck (MAS2), 1992 and 1993. DO was not measured in 1993. No equivalent DMF station. Data from Plum Island Sound Minibay Project.

Survey	Date	Instrument	Tide	Depth (m)	Temperature ©-	Salinity (ppt)	Oxygen (mg/L)
1992-1	04/28/92	SEACAT	High	3.9	6.16	28.71	9.04
1992-1	04/28/92	SEACAT	Low	2.3	10.81	13.42	8.99
1992-2	06/11/92	SEACAT	High	4.6	13.77	27.46	7.22
1992-2	06/11/92	SEACAT	Low	2.7	18.12	18.63	8.15
1992-3	08/26/92	SEACAT	High	3.7	16.96	30.12	6.76
1992-4	09/25/92	SEACAT	High	3.9	11.86	30.58	8.37
1992-4	09/25/92	SEACAT	Low	6.9	12.69	27.28	8.86
1992-5	12/16/92	SEACAT	High	2.2	4.88	31.38	9.47
1992-5	12/16/92	SEACAT	Low	0.8	1.33	13.15	11.09
1993-1	06/03/93	STD-12	High	2.6	9.90	29.97	
1993-1	06/03/93	STD-12	Low	2.0	14.54	24.24	
1993-2	07/07/93	STD-12	High	2.0	15.55	30.71	
1993-2	07/09/93	STD-12	Low	1.3	21.03	29.40	
1993-3	08/04/93	STD-12	High	3.1	16.38	30.87	
1993-3	08/04/93	STD-12	Low	1.1	19.82	28.82	
1993-4	09/08/93	STD-12	High	1.8	15.75	30.57	
1993-4	09/08/93	STD-12	Low	1.4	18.51	29.96	
1993-5	11/19/93	STD-12	Low	1.7	7.12	19.27	
1993-5	12/02/93	STD-12	High	2.7	5.85	30.00	

Table 3.15. Salinity, temperature, and dissolved oxygen (DO) data in the center of Plum Island Sound near Can 23 (MAS12), 1992 and 1993. DO was not measured in 1993. MAS12 is between DMF's OS3 and OS5 (Middle Ground and Nelson's Island Offshore Stations). Data from Plum Island Sound Minibay Project.

Survey	Date	Instrument	Tide	Depth (m)	Temperature ©	Salinity (ppt)	Oxygen (mg/L)
1992-1	04/28/92	SEACAT	High	5.6	7.60	24.44	9.48
1992-1	04/28/92	SEACAT	Low	2.9	10.64	16.87	9.84
1992-2	06/11/92	SEACAT	High	4.3	14.38	27.46	7.78
1992-2	06/11/92	SEACAT	Low	4.1	19.14	22.17	7.01
1992-3	08/26/92	SEACAT	High	5.4	16.78	30.45	7.03
1992-4	09/25/92	SEACAT	High	3.5	11.83	30.40	8.23
1992-4	09/25/92	SEACAT	Low	1.0	14.81	29.50	7.39
1992-5	12/16/92	SEACAT	High	2.0	4.78	31.26	9.43
1993-1	06/03/93	STD-12	High	4.7	13.01	28.35	
1993-1	06/03/93	STD-12	Low	3.9	14.78	26.15	
1993-2	07/07/93	STD-12	High	5.3	17.08	30.81	
1993-2	07/09/93	STD-12	Low	3.4	24.70	30.24	
1993-3	08/04/93	STD-12	High	6.5	16.63	30.87	
1993-3	08/04/93	STD-12	Low	3.7	23.25	30.64	
1993-4	09/08/93	STD-12	High	6.1	16.77	30.77	
1993-4	09/08/93	STD-12	Low	4.0	20.42	30.61	
1993-5	11/19/93	STD-12	Low	2.4	7.76	27.20	
1993-5	12/02/93	STD-12	High	4.5	6.05	30.43	

Table 3.16. Salinity, temperature, and dissolved oxygen (DO) data in the Parker River near the Newbury Town Landing (MAS15), 1992 and 1993. DO not measured in 1993. This station is equivalent to DMF's S6 (Newbury Town Landing). Data from Plum Island Sound Minibay Project.

Survey	Date	Instrument	Tide	Depth (m)	Temperature ©	Salinity (ppt)	Oxygen (mg/L)
1992-1	04/28/92	SEACAT	High	3.9	9.25	19.00	9.43
1992-1	04/28/92	SEACAT	Low	1.0	11.44	0.22	8.95
1992-2	06/11/92	SEACAT	Low	1.9	20.50	10.12	5.49
1992-3	08/26/92	SEACAT	High	2.9	22.09	27.51	5.71
1992-4	09/25/92	SEACAT	High	2.6	13.55	30.35	7.98
1992-4	09/25/92	SEACAT	Low	1.4	15.75	25.33	6.52
1992-5	12/16/92	SEACAT	High	0.9	2.04	26.35	10.15
1993-1	06/03/93	STD-12	High	1.3	14.28	25.91	
1993-2	07/07/93	STD-12	High	4.4	22.63	30.44	
1993-2	07/09/93	STD-12	Low	1.9	25.74	27.67	
1993-3	08/04/93	STD-12	High	4.5	22.64	30.80	
1993-3	08/04/93	STD-12	Low	2.1	24.14	29.18	
1993-4	09/08/93	STD-12	High	4.1	19.72	30.62	
1993-4	09/08/93	STD-12	Low	2.2	21.98	29.88	
1993-5	11/19/93	STD-12	Low	0.4	8.02	22.27	
1993-5	12/02/93	STD-12	High	3.0	4.03	26.94	

Table 3.17. Salinity, temperature, and dissolved oxygen (DO) data in the Parker River at Route 1 (MAS21), 1992 and 1993. DO not measured in 1993. This station is near DMF's OS9 (South Shore). Data from Plum Island Sound Minibay Project.

Survey	Date	Instrument	Tide	Depth (m)	Temperature ©	Salinity (ppt)	Oxygen (mg/L)
1992-1	04/28/92	SEACAT	High	5.1	10.18	2.96	8.64
1992-1	04/28/92	SEACAT	Low	0.7	11.47	0.13	8.32
1992-2	06/11/92	SEACAT	Low	5.5	20.81	4.29	5.87
1992-3	08/26/92	SEACAT	High	4.7	23.47	15.83	4.31
1992-4	09/25/92	SEACAT	High	4.0	16.02	23.93	5.77
1992-4	09/25/92	SEACAT	Low	1.8	16.38	10.95	7.00
1992-5	12/16/92	SEACAT	High	2.3	0.17	12.09	11.37
1992-5	12/16/92	SEACAT	Low	1.3		0.98	12.73
1993-1	06/03/93	STD-12	High	4.0	15.43	12.73	
1993-2	07/07/93	STD-12	High	5.5	24.60	26.39	
1993-2	07/09/93	STD-12	Low	3.2	26.11	14.15	
1993-3	08/04/93	STD-12	High	5.8	24.85	28.74	
1993-3	08/04/93	STD-12	Low	3.5	24.76	21.53	
1993-4	09/08/93	STD-12	High	5.5	22.24	29.14	
1993-4	09/08/93	STD-12	Low	3.7	22.64	25.93	
1993-5	11/19/93	STD-12	Low	3.1	7.40	7.19	
1993-5	12/02/93	STD-12	High	5.1	3.54	14.79	

Table 3.18. Ranges for temperature, salinity, and dissolved oxygen (DO) for the Parker River-Plum Island Sound Estuary, 1992-3. Compare with Table 3.12. Data from Plum Island Sound Minibay Project.

	Temp		Salinity (ppt)			Dissolved Oxygen (mg/L)		
Station	min	max	min	max	ave	min	max	ave
Steep Hill	2.84	19.73	25.08	31.58	29.76	7.13	11.05	8.78
Little Neck	1.33	21.03	13.15	31.38	26.55	6.76	11.09	8.66
Mid Sound	4.78	24.70	16.87	31.16	28.26	7.01	9.84	8.27
Town Landing	2.04	25.74	0.22	30.80	24.54	5.49	10.15	7.75
Parker at Rte 1	0.17	26.11	0.13	29.14	14.11	4.31	12.73	8.00

Table 3.19. Temperature, salinity, and dissolved oxygen concentrations from the mouth of Plum Island Sound in 1989 from a Massachusetts Department of Environmental Protection survey (station IP10). This station is at DMF's OS2 (Castle Neck Offshore Station and near MAS1 (Steep Hill). Samples were taken at an ebbing tide at 1 m depths intervals. Since there were only minor differences between different depths, only the results of samples collected at the depth closest to the surface (0.5 or 1 m) are shown. All measurements were made in situ with a Hydrolab Surveyor II (model SVR2) except 8/01 which was with a model 33 YSI SCT meter.

Date	Temperature (^{o}C)	Salinity (ppt)	Dissolved Oxygen (mg/L)
5/30/89	11.0	28.2	10.2
5/31/89	10.4	29.2	10.0
7/31/89	18.6	30.2	8.2
8/01/89	19.5	25.0	8.4
8/28/89	16.9	30.2	8.9
8/29/89	15.8	30.4	8.4

Table 3.20. Temperature, salinity, and dissolved oxygen (DO) from the Ipswich River at Little Neck in 1989 (DEP's IP07 station). This station is near MAS2. See Table 3.20 for details.

Date	Temperature (^{o}C)	Salinity (ppt)	Dissolved Oxygen (mg/L)
5/30/89	11.3	28.6	9.7
5/31/89	11.2	28.9	9.8
7/31/89	19.2	30.0	8.2
8/01/89	20.0	2405	8.4
8/28/89	17.2	30.2	8.4
8/29/89	18.4	29.6	7.5

Table 3.21. Temperature, salinity, and dissolved oxygen from Plum Island Sound off Great Neck in 1989 (DEP's IP09 station). This station is at DMF's Great Neck Offshore Station (DMF OS4). See Table 3.20 for details.

Date	Temperature (^{o}C)	Salinity (ppt)	Dissolved Oxygen (mg/L)
5/30/89	11.4	28.3	10.1
5/31/89	10.3	29.3	10.1
7/31/89	19.7	30.0	7.9
8/01/89	20.0	25.0	8.5
8/28/89	16.9	30.2	8.2
8/29/89	16.1	30.6	8.7

3.33 Nutrients

Results of the nutrient analyses for water samples collected during the 1992 and 1993 surveys conducted by the Minibay Project indicate a substantial range of values varying over the season and among different sample stations (Tables 3.22-3.29). Phosphate, for instance, appears to have a pattern of increasing upstream concentrations in June and August, but less obviously so or not at all during the other three surveys. Silicate routinely shows increasing upstream concentrations, most obviously for the Parker River. Nitrate plus nitrite, and to a lesser degree ammonia, show similar patterns to silicate, but are less consistent.

Total nitrogen and total phosphorus show similar increases in concentration with distance from the mouth of the Sound on all but the December survey. The ratio between the two varies somewhat from one survey to the next. Particulate carbon and particulate nitrogen also show comparable patterns of distribution over all surveys and retain a relatively uniform ratio of one to the other. The patterns from one survey to the next may vary, such that during some surveys (e.g., April) there are no conspicuous sources of particulates and during others, one or another of the rivers may be high (e.g., the Parker in June and September; the Ipswich in December).

Chlorophyll α distribution patterns resembled those of particulates more than any other constituent. Concentrations ranged over several orders of magnitude and varied more among different sample days than among individual stations on the same date. On June 11, 1992, chlorophyll α concentrations were between 9 and 32 ug/L whereas on December 16, 1992, all stations were less than 0.1 ug/L. Chlorophyll α levels in 1993 were similar to those in 1992, except that there were no very high or very low days. As a basis for comparison, chlorophyll α range from about 2-3 ug/L in the open waters of Massachusetts Bay (MWRA Contingency Plan, February 1997). According to NOAA, "normal [algal] blooms become problematic when chlorophyll α values reach 20 ug/L" (MWRA, 1997). Thus the chlorophyll α values in parts of Plum Island Sound occasionally exceeded a level that might stimulate eutrophication, at least in 1992.

Generally, replicate measurements of the same samples were very good (see report of the Minibay project). Poor replication appears to result from either of two conditions: (1) measurement of low concentration near the detection limit of the analysis, or (2) measurement of particle-related parameters. Ammonia is an analyte that was frequently found at low concentrations relative to its detection level. Thus, small variations between replicates appear as large relative changes. Ammonia is also very sensitive to contamination. Chlorophyll α and particulate carbon and nitrogen, are all particle related. Variation between replicates for such parameters is most likely largely driven by the natural variation in particle concentration in seawater ("patchiness") and is not so much due to sampling or analytical error.

As with chlorophyll, none of the nutrients measured in 1993 indicates any departure from the patterns seen in 1992. Given the ranges of values seen in 1992 and the relatively small sample number in 1993, only a large consistent shift in any variable would be evident as a change in conditions.

Table 3.22. Nutrient concentrations from the Steep Hill sampling station (MAS1), 1992 and 1993.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (uM)	NO2+ NO3 (uM)	TOTAL N (uM)	TOTAL P (uM)	DIP (uM)	PART. C (uM)	PART. N (uM)	SILICA (uM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	0.50	1.03	1.63	27.35	0.65	0.44	36.05	4.53	14.97	0.43	0.063
04/28/92	High	6	1.46	1.81	1.89	25.69	0.52	0.36	27.79	2.78	14.50	0.33	0.039
04/28/92	Low	1	2.33	1.09	0.72	29.75	0.78	0.23	35.92	4.68	31.31	0.43	0.066
04/28/92	Low	6	2.03	1.21	1.27	31.86	0.78	0.20	36.89	4.59	14.52	0.44	0.064
06/11/92	High	1	11.96	0.23	0.87	10.51	0.56	0.33	24.45	1.81	5.53	0.29	0.025
06/11/92	High	5	11.49	0.17	0.60	9.90	0.43	0.14	21.43	1.87	4.14	0.26	0.026
06/11/92	Low	1	18.76	0.31	0.22	10.87	0.51	0.09	13.05	1.71	6.81	0.16	0.024
06/11/92	Low	4	10.32	0.56	0.31	12.90	0.85	0.01	15.68	1.84	7.21	0.19	0.026
08/26/92	High	1	2.12	0.07	0.11	8.36	0.69	0.07	12.64	1.41	3.60	0.15	0.020
08/26/92	High	5	0.89	0.07	0.14	8.88	0.89	0.10	16.34	2.47	4.37	0.20	0.035
09/25/92	High	1	2.54	0.01	0.22	9.47	0.41	0.31	22.94	3.95	5.97	0.28	0.055
09/25/92	High	4	2.67	0.66	0.11	9.94	0.41	0.18	17.87	3.19	6.01	0.21	0.045
09/25/92	Low	1	1.30	3.49	1.71	22.27	0.70	0.68	36.71	4.07	25.83	0.44	0.057
09/25/92	Low	4	1.58	0.72	0.22	14.02	0.56	0.41	39.06	5.37	5.97	0.47	0.075
12/16/92	High	1	0.02	0.68	7.65	22.07	2.44	0.80	127.29	15.01	11.31	1.53	0.210
12/16/92	High	5	0.04	0.68	7.42	17.95	1.53	0.63	111.31	12.44	12.94	1.34	0.174
12/16/92	Low	1	0.02	1.00	7.55	19.23	1.24	0.52	44.68	3.10	20.41	0.54	0.043
12/16/92	Low	4	0.02	1.03	7.63	19.82	1.21	0.50	50.72	6.45	21.94	0.61	0.090
06/03/93	Low	1	3.08	0.50	0.10	22.10	0.40	0.02	9.25	1.14	3.50	0.11	0.016
07/07/93	Low	1	2.50	0.20	0.10	20.00	0.80	0.02	18.17	2.64	43.30	0.22	0.037
08/04/93	Low	1	3.33	0.20	0.30	30.60	0.40	0.18	26.67	3.71	17.90	0.32	0.052
09/08/93	Low	1	2.75	0.60	0.50	16.20	0.80	0.39	30.33	3.57	5.60	0.36	0.050
11/19/93	Low	1	2.42	1.60	1.20	22.80	0.40	0.02	25.75	3.14	24.10	0.31	0.044

Table 3.23. Nutrient concentrations at the Ipswich River station (MAS2 in 1992, MAS3 in 1993), 1992-1993.

DATE	TIDE	DEPTH (m)	CHL_A (µg/L)	NH4 (µM)	NO2 + NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	0.88	0.38	1.02	26.66	1.20	0.46	38.93	3.51	12.27	0.47	0.049
04/28/92	Low	1	2.10	2.96	3.11	39.78	0.91	0.49	24.67	3.35	35.48	0.30	0.047
06/11/92	High	1	9.26	0.54	1.07	11.70	0.65	0.16	20.80	1.46	7.62	0.25	0.020
06/11/92	Low	1	9.85	1.91	1.60	24.22	0.77	0.22	21.09	2.25	34.74	0.25	0.032
08/26/92	High	1	1.44	0.22	0.22	8.75	1.23	0.13	14.03	2.05	5.61	0.17	0.029
09/25/92	High	1	3.08	0.81	0.46	10.81	0.41	0.33	27.81	4.27	7.02	0.33	0.060
09/25/92	Low	1	1.99	2.14	0.75	28.63	0.73	0.78	55.53	7.29	17.97	0.67	0.102
12/16/92	High	1	0.02	0.83	7.78	36.29	4.24	0.66	155.72	11.29	12.76	1.87	0.158
12/16/92	Low	1	0.02	2.22	13.19	40.11	2.47	0.84	110.05	9.77	81.91	1.32	0.137
06/03/93	Low	0.5	2.75	2.20	8.40	32.20	0.40	0.18	13.00	0.93	40.20	0.16	0.013
07/07/93	Low	0.5	3.00	1.80	0.20	39.30	0.40	0.02	19.92	2.86	8.20	0.24	0.040
08/04/93	Low	0.5	2.08	1.10	1.70	19.70	1.70	1.05	22.17	2.14	11.60	0.27	0.030
09/08/93	Low	0.5	3.00	4.30	1.20	29.70	1.20	0.90	28.75	3.79	15.10	0.35	0.053
11/19/93	Low	1	1.83	2.90	1.60	26.20	1.80	1.48	26.92	2.00	136.80	0.32	0.028

Table 3.24. Nutrient concentrations at Rowley River sampling station (MAS9), 1992-1993.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (µM)	NO2+ NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	2.10	0.30	1.20	31.40	1.56	0.36	40.74	5.85	14.27	0.49	0.082
04/28/92	Low	0.5	2.36	2.90	3.23	44.51	0.71	0.28	34.84	4.49	41.14	0.42	0.063
06/11/92	High	1	14.30	0.62	1.06	17.83	0.82	0.17	15.73	2.15	12.33	0.19	0.030
06/11/92	Low	0.5	28.84	2.45	1.80	28.78	1.10	0.13	23.84	2.40	23.75	0.29	0.034
08/26/92	High	1	1.85	0.34	0.20	10.59	1.15	0.16	21.71	4.31	6.33	0.26	0.060
09/25/92	High	1	3.01	0.29	0.30	10.36	0.40	0.36	28.57	5.67	5.86	0.34	0.079
09/25/92	Low	0.5	2.12	1.78	0.57	21.64	0.91	0.39	53.34	7.37	8.20	0.64	0.103
12/16/92	High	1	0.03	1.15	7.49	20.87	1.45	0.83	30.57	4.93	17.73	0.37	0.069
12/16/92	Low	0.5	0.02	1.38	6.35	23.59	0.97	0.22	22.55	3.88	39.64	0.27	0.054

Table 3.25. Nutrient concentrations in the middle of Plum Island Sound near Can 23 (MAS12), 1992-1993.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (µM)	NO2+ NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	2.60	0.42	1.46	29.19	0.88	0.41	33.73	4.36	14.10	0.40	0.061
04/28/92	High	5	1.48	0.06	1.41	30.18	0.91	0.41	37.00	4.74	14.06	0.44	0.066
04/28/92	Low	1	3.59	2.60	3.01	38.56	0.39	0.33	39.81	5.43	22.35	0.48	0.076
04/28/92	Low	4	1.55	2.78	3.03	36.13	0.52	0.28	40.16	5.47	41.48	0.48	0.077
06/11/92	High	1	12.66	0.51	0.76	13.94	0.90	0.38	15.93	1.80	8.11	0.19	0.025
06/11/92	High	4	14.77	0.45	0.58	11.65	0.43	0.12	9.86	1.22	6.53	0.12	0.017
06/11/92	Low	1	28.14	1.58	1.48	22.27	1.41	0.27	18.49	2.72	18.87	0.22	0.038
06/11/92	Low	4	24.15	1.18	1.42	21.44	0.88	0.38	18.17	2.32	18.00	0.22	0.033
08/26/92	High	1	0.89	0.01	0.14	8.49	0.89	0.07	13.78	1.99	3.73	0.17	0.028
08/26/92	High	4	1.30	0.16	0.12	8.15	0.53	0.05	11.32	1.07	4.24	0.14	0.015
09/25/92	High	1	3.08	0.25	0.54	10.58	0.46	0.31	26.71	4.95	6.05	0.32	0.069
09/25/92	High	4	4.04	0.16	0.39	10.69	0.48	0.36	31.69	5.48	5.97	0.38	0.077
09/25/92	Low	1	2.67	1.29	1.96	25.33	1.55	0.61	41.22	5.40	12.82	0.49	0.076
09/25/92	Low	4	1.71	1.66	0.61	21.11	1.01	0.49	36.53	4.73	8.71	0.44	0.066
12/16/92	High	1	0.04	0.77	7.67	20.05	1.91	0.69	37.33	6.79	12.51	0.45	0.095
12/16/92	High	4	0.04	0.77	7.74	20.27	1.75	0.66	14.30	4.27	13.62	0.17	0.060
12/16/92	Low	1	0.02	1.53	6.12	24.48	1.34	0.28	53.88	6.45	34.39	0.65	0.090
12/16/92	Low	4	0.03	2.20	6.10	25.79	1.58	0.25	61.65	6.10	36.71	0.74	0.085
06/03/93	Low	1	4.83	0.70	0.20	26.60	0.20	0.08	13.83	1.64	6.50	0.17	0.023
07/07/93	Low	1	3.67	0.60	1.90	22.10	1.30	0.29	20.08	2.43	9.30	0.24	0.034
08/04/93	Low	1	4.58	0.60	0.10	28.20	0.80	0.59	27.58	4.43	11.40	0.33	0.062
09/08/93	Low	1	4.67	1.30	1.60	26.40	1.60	1.00	30.17	3.29	9.80	0.36	0.046
11/19/93	Low	1	2.25	2.90	1.50	27.20	0.50	0.10	27.17	3.50	28.00	0.33	0.049

Table 3.26. Nutrient concentrations at the Parker River by the Newbury Old Town Landing (MAS15), 1992-1993.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (µM)	NO2+ NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	2.09	3.62	2.40	37.42	1.62	0.38	29.61	4.40	20.59	0.36	0.062
04/28/92	Low	0.5	1.26	4.89	5.78	41.26	0.97	0.62	35.51	4.53	39.25	0.43	0.063
06/11/92	High	1	19.46	1.21	1.20	22.48	0.96	0.21	23.59	3.47	15.72	0.28	0.049
06/11/92	Low	0.5	16.88	5.62	4.00	37.20	1.26	0.47	29.79	3.66	46.05	0.36	0.051
08/26/92	High	1	4.86	0.10	0.16	18.83	1.51	0.29	27.98	3.93	5.61	0.34	0.055
09/25/92	High	1	2.40	1.16	0.11	15.06	0.54	0.14	35.57	6.14	2.81	0.43	0.086
09/25/92	Low	1	1.71	3.49	2.79	31.93	1.92	0.84	32.86	4.63	21.84	0.39	0.065
12/16/92	High	1	0.02	1.30	6.10	30.33	0.99	0.30	30.61	6.01	23.61	0.37	0.084
12/16/92	Low	1	0.01	1.79	8.56	31.92	1.32	0.32	28.50	5.83	73.32	0.34	0.082
06/03/93	Low	1	5.92	0.80	0.90	20.80	0.30	0.10	14.50	1.07	13.80	0.17	0.015
07/07/93	Low	1	2.42	1.40	0.90	36.20	1.80	0.51	24.75	2.79	17.00	0.30	0.039
08/04/93	Low	1	4.42	0.50	0.70	37.80	0.80	0.45	29.58	3.64	27.50	0.36	0.051
09/08/93	Low	1	4.42	12.30	1.20	41.60	2.40	2.01	32.83	3.93	25.10	0.39	0.055
11/19/93	Low	1	1.25	5.10	1.30	39.80	0.80	0.34	31.42	4.64	57.70	0.38	0.065

Table 3.27. Nutrient concentrations at the Parker River at Route 1 (MAS21), 1992.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (µM)	NO2+ NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	1.13	2.26	6.73	45.16	0.97	0.18	43.51	5.64	50.63	0.52	0.079
04/28/92	Low	1	2.78	1.03	7.12	46.37	0.91	0.44	28.32	3.90	41.99	0.34	0.055
06/11/92	High	1	18.06	4.53	4.02	37.95	1.44	0.64	31.44	3.88	56.11	0.38	0.054
06/11/92	Low	1	22.51	1.04	3.95	44.29	1.01	0.56	85.31	12.14	66.79	1.02	0.170
08/26/92	High	1	10.35	3.11	2.34	41.13	2.48	1.01	35.44	3.62	33.95	0.43	0.051
09/25/92	High	1	4.32	4.56	3.58	35.17	0.85	0.10	60.45	7.26	31.11	0.73	0.102
09/25/92	Low	1	13.29	0.34	2.08	46.27	1.76	0.29	85.68	12.00	66.63	1.03	0.168
12/16/92	High	1	0.01	2.15	10.20	25.17	1.69	0.47	27.29	5.89	77.41	0.33	0.082
12/16/92	Low	1	0.01	1.94	15.17	35.79	1.26	0.50	33.44	4.03	133.39	0.40	0.056

Table 3.28. Nutrient concentrations at the Eagle Hill River (MAS22), 1992.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (µM)	NO2+ NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	1.59	0.45	1.09	27.48	1.56	0.51	35.35	4.18	12.11	0.42	0.058
04/28/92	Low	0.5	3.31	1.69	0.90	37.57	0.97	0.13	49.06	5.81	33.42	0.59	0.081
06/11/92	High	1	11.49	0.34	1.09	12.47	0.53	0.09	9.07	1.02	7.84	0.11	0.014
06/11/92	Low	0.5	31.89	0.70	0.76	22.41	1.04	0.12	13.11	1.56	14.51	0.16	0.022
08/26/92	High	1	1.64	0.23	0.14	9.16	1.27	0.12	13.42	1.55	4.56	0.16	0.022
09/25/92	High	1	3.36	0.31	0.30	10.42	0.39	0.36	31.13	6.62	6.32	0.37	0.093
09/25/92	Low	0.5	2.12	2.40	0.82	27.47	0.81	0.70	59.39	7.17	15.85	0.71	0.100
12/16/92	High	1	0.04	1.30	7.65	21.60	2.54	0.73	53.53	5.43	13.09	0.64	0.076
12/16/92	Low	0.5	0.04	2.23	5.49	26.10	1.50	0.17	102.58	8.86	34.48	1.23	0.124

Table 3.29. Nutrient concentrations in the Plum Island River at Jericho Creek (MAS23), 1992.

DATE	TIDE	DEPTH (m)	CHL_A (ug/L)	NH4 (µM)	NO2+ NO3 (µM)	TOTAL N (µM)	TOTAL P (µM)	DIP (µM)	PART. C (µM)	PART. N (µM)	SILICA (µM)	PART. C (mg/L)	PART. N (mg/L)
04/28/92	High	1	1.42	4.80	4.90	39.62	0.91	0.59	36.51	4.83	29.65	0.44	0.068
04/28/92	Low	1	2.05	7.85	6.02	51.58	2.11	0.64	40.35	4.89	39.22	0.48	0.068
06/11/92	High	1	11.96	6.28	3.27	30.04	1.17	0.61	26.45	2.61	33.49	0.32	0.036
06/11/92	Low	0.5	38.69	7.18	6.55	40.80	1.62	0.75	28.86	4.16	46.71	0.35	0.058
08/26/92	High	1	5.96	0.34	0.26	24.17	1.83	0.68	43.90	5.25	10.17	0.53	0.074
09/25/92	High	1	2.88	2.36	0.42	19.91	0.59	0.32	32.21	5.61	6.17	0.39	0.079
09/25/92	Low	1	2.12	0.75	0.07	11.54	0.55	0.41	32.44	4.81	7.16	0.39	0.067
12/16/92	High	1	0.03	2.00	6.00	27.24	1.29	0.29	64.54	8.32	38.26	0.77	0.116
12/16/92	Low	1	0.01	3.85	6.63	29.97	1.07	0.33	35.80	4.41	48.65	0.43	0.062

Nutrient sampling was also carried out by the Massachusetts Department of Environmental Protection (DEP) during their 1989 water quality survey of the Ipswich and Essex estuaries. Practically all their total Kjeldahl nitrogen, ammonia, and nitrate measurements were below the levels of analytic detection (<0.9, <0.1, and <0.73 mg/L respectively) for three sample stations that were near or at MAS1, MAS2, and DMF's OS4. The lower detection limits makes it difficult to compare DEP and Minibay data for nitrogen. Chlorophyll α concentrations measured by DEP in 1989 are similar to those measured by the Minibay project at the same time of the year (Table 3.30).

Table 3.30. Chlorophyll* α *concentrations (mg/L) in selected stations sampled by DEP in 1989.

Station	7/31/89	8/1/89	8/28/89	8/29/89
IP10 (=MAS1)		2.21		
IP07 (=MAS2)	2.91		1.28	
IP09 (=DMF's OS4)	2.32		1.74	2.41

Additional nutrient data is currently being collected by the Plum Island Sound Long Term Ecological Research project coordinated by The Ecosystems Center, Woods Hole, MA. Those data are posted on their web site, http://ecosystems.mbl.edu.

3.34 Flushing Characteristics

3.341. Measurements of Freshwater Inputs

Figure 3.3 illustrates flow rates of the Parker and Ipswich Rivers, as reported by USGS, for two weeks preceding each of the ten receiving water surveys. Axes for the two rivers are scaled to their relative drainage basin area. The two rivers show essentially the same pattern of flow per area, but it appears that the much larger Ipswich is slower to respond to changes and thus lags behind the Parker. The dramatic difference between 1992 and 1993 in freshwater flow to Plum Island Sound is quite evident in this figure.

3.342. Box Model Calculations

The box model was setup and applied for four of the receiving water surveys in 1992 and each of the five 1993 surveys as well as for the mean of the surveys within each year. The model requires a variety of input parameter values including volume of each box, freshwater flow and mean salinity. The results of the area and volume calculations for the model box subregions are shown in Table 3.31. Some of these areas are defined differently between years as the Minibay Project fine-tuned its sampling program.

Jerome et al. (1968) also calculated areas and volumes for the Plum Island Sound

System (see Chapter 2). They reported a low tide area about 36% greater than calculated by Applied Science Associates, Inc. for the Minibay Project and a nearly identical low tide volume. They found a high tide area only 3% greater than reported here with a high tide volume about 34% greater. These differences may represent changes in the Sound or differences in interpretation of data from the charts. The considerably larger range of mean depth found by Jerome et al. than found by the Minibay Project is very likely due to a difference in interpretation of bathymetry of intertidal areas at high tide.

Mean salinity values for each box were calculated from the mean for each station for each survey day. The results of these calculations are given in Table 3.32 for 1992 and Table 3.33 for 1993. The model assumes that freshwater runoff from land is diluting ocean seawater from Ipswich Bay. Consistent with this assumption is a gradient of decreasing salinity from the mouth of the Sound up the Sound and up the rivers. When this assumption is not met by the data, the model will not work properly. During the third survey in 1993 the salinity in the Sound and the Rowley River slightly exceeded the value at Station 1, representing the open boundary. The station 1 value was increased slightly (0.02 ppt) to correct this condition so that the model assumptions would be met. Both this problem and the correction are consistent with a high flushing rate of the Sound where values of a small tributary closely approximate that of oceanic conditions. While the flushing values thereby calculated may not be "correct", they should reflect the right order of magnitude.

Freshwater flow to Plum Island Sound by box, based on river flow per area from the Ipswich and Parker Rivers is given in Table 3.34 for the 1992 surveys and Table 3.35 for the 1993 surveys.

Data from Tables 3.31-3.36 were incorporated into setup files for the box model which was then run for each case. Flushing times for individual survey days represent a range of values (Table 3.36). Using the mean values, the box model calculates a flushing time for the Sound of 1.9 days and for the rivers (except for Plum Island River) a range of 0.3 to 4.5 days for 1992. Given the volume and tidal prism of the Sound system, these values seem to be of an appropriate scale.

The very long 43 day flushing time for Plum Island River suggests an error of the method or its assumptions. Since this high value carries through all sampling surveys run, it is unlikely to be a salinity measurement error. More probably, the error is in evaluating freshwater inflow. It was assumed that water from the Merrimack River does not routinely reach Plum Island Sound by way of the Plum Island River. However, this is the only probable source for what must be a significant amount of freshwater diluting the waters of the Plum Island River. We have no value for what this inflow from the Merrimack might be, but if the freshwater inflow to Plum Island River for the average 1992 case is increased from 0.11 m^3/sec (this is inflow based on assumed watershed, including marsh areas) to 2.2, a factor of 20, then flushing time is recalculated to be about 2.2 days, comparable to that of the Sound. This is a freshwater input value comparable to the concurrent input from the Parker River and about a quarter that coming in from the

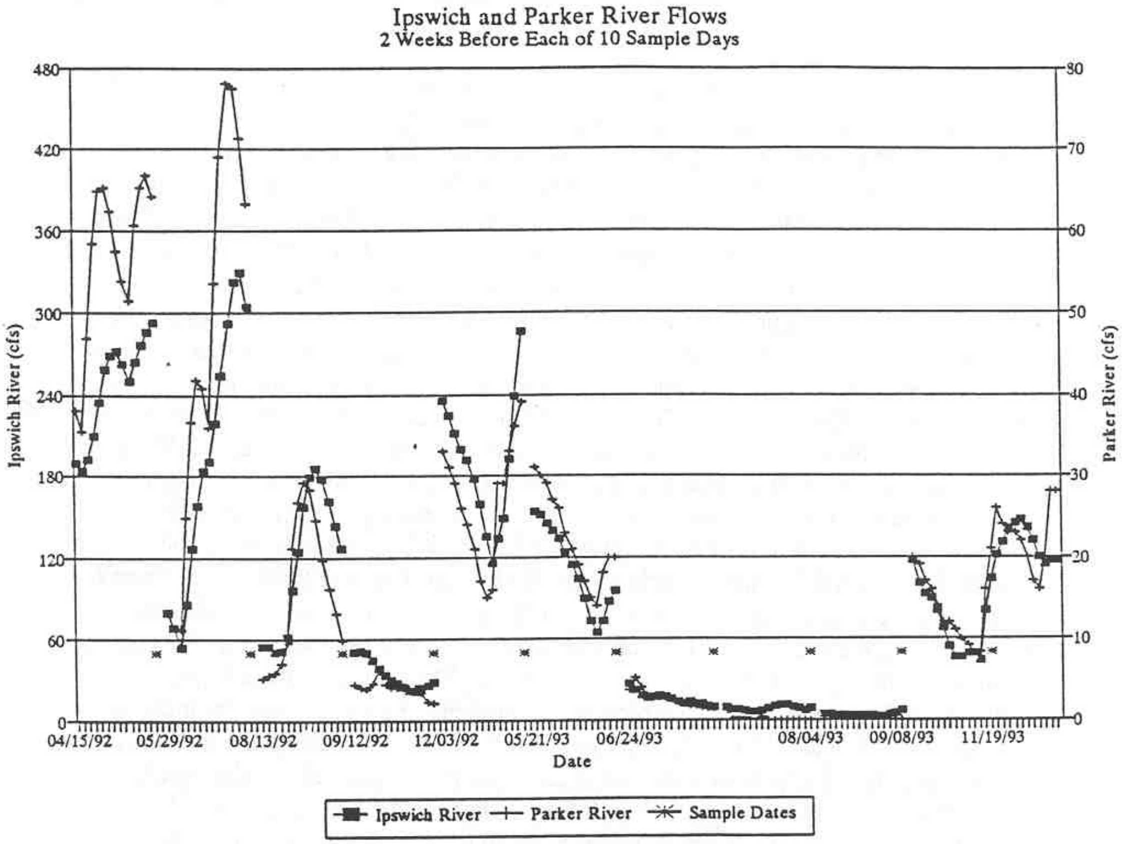


Figure 3.3. Streamflow in cubic feet per second reported by the Ipswich and Parker USGS gauges for two weeks preceding each of the ten receiving water surveys of Plum Island Sound carried out by ASA, Inc. The axes for the two curves (Ipswich = left axis, Parker = right axis) have been scaled to relative drainage area.

Ipswich River. Note also that since most of this freshwater will eventually pass to the Sound, an increased freshwater input to the Plum Island River also results in the calculation of a reduced flushing time for the Sound. In the case of the 20-fold increase discussed above, the corresponding flushing time for the Sound is reduced from 1.9 to 1.6 days.

Several aspects of the survey program changed in 1993. There were more salinity sampling stations, the arrangement of boxes was altered, and it was a very dry summer. The results of the flushing calculations were quite different as well. As in 1992, a wide range of values resulted from calculations from the five single surveys (Table 3.36). Flushing time for box 1, the main area of the Sound, for the average condition in 1993 was calculated to be only 0.76 days, half of that calculated for the Sound in 1992. At the same time, the model calculates flushing times in the rivers in 1993 that are about twice those calculated for 1992. These differences are due in some part to the increased coverage of salinity sampling that took place in 1993. Recalculating the 1993 average case using only the stations measured in 1992 (where data is available) gives flushing times of 1.05 days for the Sound, 0.76 days for the lower Ipswich, 6.0 days for the Rowley, 3.1 days for the lower Parker and 14.2 days for the upper Parker.

Table 3.31. Calculated areas and volumes for the model boxes for the 1992 and 1993 surveys.

Box	Name	Low tide area - m^2	Low tide volume - m^3	High tide area - m^2	High tide volume - m^3	Mean area - m^2	Mean volume - m^3
1992 Surveys							
1	Plum Island Sound	5,976,170	13,767,800	12,334,600	30,125,300	9,155,385	21,946,550
2	Ipswich River	193,690	157,244	1,666,298	2,493,023	929,994	1,325,134
3	Rowley River	448,059	511,345	950,424	1,848,710	699,242	1,180,028
4	Plum Island River	213,072	275,708	1,209,150	1,997,660	711,111	1,136,684
5	Lower Parker River	739,309	1,042,600	974,507	2,519,330	856,908	1,780,965
6	Upper Parker River	437,457	1,142,400	473,457	1,732,260	455,457	1,437,330
1993 Surveys							
1	South Plum Island Sound	5,339,796	12,805,219	10,733,447	26,462,420	8,036,622	19,633,820
2	Lower Ipswich River	173,013	143,004	1,581,600	2,352,530	877,307	1,247,767
3	Upper Ipswich River	20,677	14,240	84,698	140,493	52,688	77,367
4	Rowley River	448,059	511,345	950,424	1,848,710	699,242	1,180,028
5	North Plum Island Sound	849,446	1,238,289	2,810,303	5,660,540	1,829,875	3,449,415
6	Lower Parker River	739,309	1,042,600	974,507	2,519,330	856,908	1,780,965
7	Upper Parker River	437,457	1,142,400	473,457	1,732,260	455,457	1,437,330
Whole System							
Sum	Plum Island Sound/Rivers	8,007,757	16,897,097	17,608,436	40,716,283	12,808,097	28,806,690

Table 3.32. Average salinity by box for the 1992 surveys, with averages by box for surveys 1, 2, 4 and 5.

Survey	Date	Station	Box	Salinity	Comments
1992-1	04/28/92	1	Open Boundary	26.86	
1992-1	04/28/92	12,22	1	22.70	
1992-1	04/28/92	2	2	21.07	
1992-1	04/28/92	9	3	20.34	
1992-1	04/28/92	23	4	10.25	
1992-1	04/28/92	15	5	9.61	
1992-1	04/28/92	21	6	1.55	
1992-2	06/11/92	1	Open Boundary	28.03	
1992-2	06/11/92	12,22	1	25.43	
1992-2	06/11/92	2	2	23.05	
1992-2	06/11/92	9	3	23.77	
1992-2	06/11/92	23	4	14.85	
1992-2	06/11/92	15	5	16.42	
1992-2	06/11/92	21	6	10.59	
1992-4	09/25/92	1	Open Boundary	30.62	
1992-4	09/25/92	12,22	1	30.09	
1992-4	09/25/92	2	2	28.93	
1992-4	09/25/92	9	3	29.92	
1992-4	09/25/92	23	4	28.19	
1992-4	09/25/92	15	5	27.84	
1992-4	09/25/92	21	6	17.44	
1992-5	12/16/92	1	Open Boundary	29.98	
1992-5	12/16/92	12,22	1	26.50	
1992-5	12/16/92	2	2	22.27	
1992-5	12/16/92	9	3	25.61	
1992-5	12/16/92	23	4	19.90	
1992-5	12/16/92	15	5	20.95	
1992-5	12/16/92	21	6	6.53	
1992-avg	Surveys 1,2,4,5	1	Open Boundary	28.87	
1992-avg	Surveys 1,2,4,5	12,22	1	26.18	
1992-avg	Surveys 1,2,4,5	2	2	23.83	
1992-avg	Surveys 1,2,4,5	9	3	24.91	
1992-avg	Surveys 1,2,4,5	23	4	18.30	
1992-avg	Surveys 1,2,4,5	15	5	18.71	
1992-avg	Surveys 1,2,4,5	21	6	9.03	

Table 3.33. Average salinity by box for the 1993 surveys, with averages for surveys 2 - 5.

Survey	Date	Box	Stations	Salinity	Comments
1993-1	06/03/93	Open boundary	1	30.00	
1993-1	06/03/93	1	6,7,12	28.00	
1993-1	06/03/93	2	2,3,4	25.02	
1993-1	06/03/93	3	5	16.13	Set value
1993-1	06/03/93	4	8,9,10,11	25.10	
1993-1	06/03/93	5	13,14	ND	
1993-1	06/03/93	6	15,16,17	ND	
1993-1	06/03/93	7	18,19,20,21	ND	
1993-2	07/09/93	Open boundary	1	30.78	
1993-2	07/09/93	1	6,7,12	30.66	
1993-2	07/09/93	2	2,3,4	29.45	
1993-2	07/09/93	3	5	27.27	
1993-2	07/09/93	4	8,9,10,11	30.37	
1993-2	07/09/93	5	13,14	29.61	
1993-2	07/09/93	6	15,16,17	28.39	
1993-2	07/09/93	7	18,19,20,21	23.48	
1993-3	08/04/93	Open boundary	1	30.83	Set value
1993-3	08/04/93	1	6,7,12	30.82	
1993-3	08/04/93	2	2,3,4	29.18	
1993-3	08/04/93	3	5	27.52	
1993-3	08/04/93	4	8,9,10,11	30.81	
1993-3	08/04/93	5	13,14	30.32	
1993-3	08/04/93	6	15,16,17	29.77	
1993-3	08/04/93	7	18,19,20,21	26.98	
1993-4	09/08/93	Open boundary	1	30.74	
1993-4	09/08/93	1	6,7,12	30.70	
1993-4	09/08/93	2	2,3,4	29.82	
1993-4	09/08/93	3	5	28.11	
1993-4	09/08/93	4	8,9,10,11	29.89	
1993-4	09/08/93	5	13,14	30.48	
1993-4	09/08/93	6	15,16,17	30.18	
1993-4	09/08/93	7	18,19,20,21	28.55	
1993-5	12/02/93	Open boundary	1	29.83	
1993-5	12/02/93	1	6,7,12	29.27	
1993-5	12/02/93	2	2,3,4	21.95	
1993-5	12/02/93	3	5	15.48	
1993-5	12/02/93	4	8,9,10,11	24.55	
1993-5	12/02/93	5	13,14	26.79	
1993-5	12/02/93	6	15,16,17	23.59	
1993-5	12/02/93	7	18,19,20,21	16.31	
1993-avg	Surveys 2 to 5	Open boundary	1	30.54	
1993-avg	Surveys 2 to 5	1	6,7,12	30.36	
1993-avg	Surveys 2 to 5	2	2,3,4	27.60	
1993-avg	Surveys 2 to 5	3	5	24.59	
1993-avg	Surveys 2 to 5	4	8,9,10,11	28.91	
1993-avg	Surveys 2 to 5	5	13,14	29.30	
1993-avg	Surveys 2 to 5	6	15,16,17	27.98	

1993-avg	Surveys 2 to 5	7	18,19,20,21	23.83	

Table 3.34. Calculations for freshwater flow to model box subareas during the 1992 surveys. Areas are based on subbasin areas from Mass. GIS plus areas given by USGS for the Parker and Ipswich River gauges. Flow rates are based on flows reported by USGS for the Ipswich and Parker Rivers, weighted by area and extrapolated to the entire subbasin area.

Survey	Date	Box	Stations	Drainage Area	Stream Flow/Area	Stream Flow Rate
				km^2	$m^3/sec/km^2$	m^3/sec
1992-1	04/28/92	1	12,22	20.93	0.0267	0.559
1992-1	04/28/92	2	2	402.51	0.0267	10.747
1992-1	04/28/92	3	9	25.36	0.0267	0.677
1992-1	04/28/92	4	23	5.51	0.0267	0.147
1992-1	04/28/92	5	15	27.17	0.0267	0.725
1992-1	04/28/92	6	21	126.96	0.0267	3.390
1992-2	06/11/92	1	12,22	20.93	0.0274	0.573
1992-2	06/11/92	2	2	402.51	0.0274	11.029
1992-2	06/11/92	3	9	25.36	0.0274	0.695
1992-2	06/11/92	4	23	5.51	0.0274	0.151
1992-2	06/11/92	5	15	27.17	0.0274	0.744
1992-2	06/11/92	6	21	126.96	0.0274	3.479
1992-4	09/25/92	1	12,22	20.93	0.00223	0.047
1992-4	09/25/92	2	2	402.51	0.00223	0.898
1992-4	09/25/92	3	9	25.36	0.00223	0.057
1992-4	09/25/92	4	23	5.51	0.00223	0.012
1992-4	09/25/92	5	15	27.17	0.00223	0.061
1992-4	09/25/92	6	21	126.96	0.00223	0.283
1992-5	12/16/92	1	12,22	20.93	0.0243	0.509
1992-5	12/16/92	2	2	402.51	0.0243	9.781
1992-5	12/16/92	3	9	25.36	0.0243	0.616
1992-5	12/16/92	4	23	5.51	0.0243	0.134
1992-5	12/16/92	5	15	27.17	0.0243	0.660
1992-5	12/16/92	6	21	126.96	0.0243	3.085
1992-avg	4-day	1	12,22	20.93	0.0202	0.423
1992-avg	4-day	2	2	402.51	0.0202	8.131
1992-avg	4-day	3	9	25.36	0.0202	0.512
1992-avg	4-day	4	23	5.51	0.0202	0.111
1992-avg	4-day	5	15	27.17	0.0202	0.549
1992-avg	4-day	6	21	126.96	0.0202	2.565

Table 3.35. Calculations for freshwater flow to model box subareas during the 1993 surveys. Areas are based on subbasin areas from Mass. GIS plus areas given by USGS for the Parker and Ipswich River gauges. Flow rates are based on flows reported by USGS for the Ipswich and Parker Rivers, weighted by area and extrapolated to the entire subbasin area.

Survey	Date	Box	Stations	Drainage Area	Stream Flow/Area	Stream Flow Rate
				km^2	$m^3/sec/km^2$	m^3/sec
1993-1	06/03/93	1	6,7,12	17.16	0.00859	0.147
1993-1	06/03/93	2	2,3,4	12.83	0.00859	0.110
1993-1	06/03/93	3	5	389.68	0.00859	3.347
1993-1	06/03/93	4	8,9,10,11	25.36	0.00859	0.218
1993-1	06/03/93	5	13,14	9.28	0.00859	0.080
1993-1	06/03/93	6	15,16,17	27.17	0.00859	0.233
1993-1	06/03/93	7	18,19,20,21	126.96	0.00859	1.091
1993-2	07/09/93	1	6,7,12	17.16	0.00085	0.015
1993-2	07/09/93	2	2,3,4	12.83	0.00085	0.011
1993-2	07/09/93	3	5	389.68	0.00085	0.331
1993-2	07/09/93	4	8,9,10,11	25.36	0.00085	0.022
1993-2	07/09/93	5	13,14	9.28	0.00085	0.008
1993-2	07/09/93	6	15,16,17	27.17	0.00085	0.023
1993-2	07/09/93	7	18,19,20,21	126.96	0.00085	0.108
1993-3	08/04/93	1	6,7,12	17.16	0.00074	0.013
1993-3	08/04/93	2	2,3,4	12.83	0.00074	0.009
1993-3	08/04/93	3	5	389.68	0.00074	0.288
1993-3	08/04/93	4	8,9,10,11	25.36	0.00074	0.019
1993-3	08/04/93	5	13,14	9.28	0.00074	0.007
1993-3	08/04/93	6	15,16,17	27.17	0.00074	0.020
1993-3	08/04/93	7	18,19,20,21	126.96	0.00074	0.094
1993-4	09/08/93	1	6,7,12	17.16	0.00058	0.010
1993-4	09/08/93	2	2,3,4	12.83	0.00058	0.007
1993-4	09/08/93	3	5	389.68	0.00058	0.226
1993-4	09/08/93	4	8,9,10,11	25.36	0.00058	0.015
1993-4	09/08/93	5	13,14	9.28	0.00058	0.005
1993-4	09/08/93	6	15,16,17	27.17	0.00058	0.016
1993-4	09/08/93	7	18,19,20,21	126.96	0.00058	0.074
1993-5	12/02/93	1	6,7,12	17.16	0.00934	0.160
1993-5	12/02/93	2	2,3,4	12.83	0.00934	0.120
1993-5	12/02/93	3	5	389.68	0.00934	3.640
1993-5	12/02/93	4	8,9,10,11	25.36	0.00934	0.237
1993-5	12/02/93	5	13,14	9.28	0.00934	0.087
1993-5	12/02/93	6	15,16,17	27.17	0.00934	0.254
1993-5	12/02/93	7	18,19,20,21	126.96	0.00934	1.186
1993-avg	4-day	1	6,7,12	17.16	0.0029	0.050
1993-avg	4-day	2	2,3,4	12.83	0.0029	0.037
1993-avg	4-day	3	5	389.68	0.0029	1.130
1993-avg	4-day	4	8,9,10,11	25.36	0.0029	0.074
1993-avg	4-day	5	13,14	9.28	0.0029	0.027
1993-avg	4-day	6	15,16,17	27.17	0.0029	0.079
1993-avg	4-day	7	18,19,20,21	126.96	0.0029	0.368

Table 3.36. Model calculated flushing times in days for the two survey years with flushing times for the average conditions calculated for four of the surveys in each year.

1992 Surveys

Box	Name	Stations	Survey 1	Survey 2	Survey 4	Survey 5	Average
1	Plum Island Sound	12,22	2.42	1.41	3.24	1.99	1.93
2	Ipswich River	2	0.31	0.25	0.94	0.40	0.33
3	Rowley River	9	4.90	2.99	5.48	3.23	3.66
4	Plum Island River	23	55.34	40.97	87.01	33.01	43.39
5	Lower Parker River	15	3.22	2.02	5.44	1.66	2.33
6	Upper Parker River	21	4.62	2.98	25.30	4.22	4.46

1993 Surveys

Box	Name	Stations	Survey 1	Survey 2	Survey 3	Survey 4	Survey 5	Average (2, 3, 4, 5)
1	South Plum Island Sound	6,7,12	2.90	1.71	0.16	0.84	0.75	0.76
2	Lower Ipswich River	2,3,4	0.69	1.82	2.60	1.86	1.01	1.19
3	Upper Ipswich River	5	0.12	0.31	0.33	0.34	0.12	0.15
4	Rowley River	8,9,10,11	10.23	8.27	0.47	25.18	10.20	9.85
5	North Plum Island Sound	13,14		10.92	5.46	3.55	2.66	3.42
6	Lower Parker River	15,16,17		12.22	6.22	4.17	2.99	3.87
7	Upper Parker River	18,19,20,21		36.53	22.10	16.02	6.36	9.93

The greater density of stations in 1993 gives preference to the calculations for 1993. Thus, any corrections to these calculations should be made to favor the 1993 values. Given this assumption, there remains a range of a factor of two for flushing time estimates for most of the boxes. If 1992 values are corrected to reflect the sample area differences noted above, the following ranges result: Box 1, the southern sound, has a flushing time in the range of three quarters to one and a half days. The lower Ipswich, Box 2, flushes in half a day to just over a day. The upper Ipswich flushes in a few hours. Box 4, the Rowley River, flushes in about six to ten days. We have only a poor sense of the flushing time of the northern part of the Sound and Plum Island River due to the problem of unknown input from the Merrimack River. The lower Parker River flushes in three to four days while the upper Parker River flushes in three to ten days.

Comparing relative streamflow rates from Tables 3.34 and 3.35 with calculated flushing times in Table 3.36, on a survey-by-survey basis, indicates that shorter flushing times are generally associated with higher stream flows. Because there are several marked variations from this patterns, it is difficult to provide a rigorous predictive relationship of flushing time to streamflow. However, it can be expected that generally the shorter range of flushing times noted above will occur during times of high streamflow and longerflushing times from these ranges will occur during low streamflow periods.

It appears, then, that freshwater in the Ipswich River leaves the Sound system quickly as it is carried out to Ipswich Bay on each tide, while the waters draining to the Rowley and Parker Rivers get carried only partly out of the Sound on each ebb tide with most of it returning on the flood. The sound itself flushes quite rapidly so that once freshwater enters the Sound it is rapidly removed to the ocean.

3.343. Comparison of Minibay Flushing Study with Other Results

Plum Island LTER: The flushing times calculated by ASA, Inc. were similar to those published by Vallino and Hopkinson (1998) as part of the Plum Island Ecosystem Long Term Ecological Research (PIE-LTER) study. Vallino and Hopkinson estimated flushing times based on a one dimension tidally-averaged, advection dispersion model with inputs from salinity distribution and the release of rhodamine dye from three locations over one tidal cycle. They built on a previous 1D advection dispersion model by Vorosmarty and Loder (1994) that had incorporated marsh surface flooding. Based on their model, Vallino and Hopkinson estimated flushing times ranging from 0.5 days in the lower estuary to 34 days at the extreme upper part of the tidal section of the Parker River (the latter further "up estuary" than ASA's measurements). Once again the flushing times were strongly influenced by river flow. At the time of this writing, Vallino and coworkers were developing a two dimensional hydrodynamic model that was intended to drive a 2D advection-dispersion model for the Sound.

FDA and DMF: A dye study conducted by the FDA and Massachusetts DMF (Gaines et al., 1992) in May of 1992 provided some insights into processes that are occurring in Plum Island Sound. This study evaluated dye dispersion and time of travel from three points in the Plum Island Sound System: Plum Island River, Littler River and Greenwood Creek (on the Ipswich River). The primary goal of these studies was to evaluate the potential impact of bacterial pollution at these sources on shellfish beds in Plum Island Sound. The studies also give useful information on the transport of water in the Sound system.

The Plum Island River study demonstrated convincingly that, at least under some conditions, water apparently coming from the Merrimack River moves south into the Plum Island River on the rising tide and exits into Plum Island Sound on the following falling tide. There was not sufficient information to quantify this flow, but it at least verified a transport of water not considered in the present study, but proposed to exist based on flushing rates. This is discussed further in relation to fecal coliform contamination in section 3.42

The Little River study traced dye from the Route 1A bridge on the Parker River, near the mouth of the Little River, almost to the mouth of the Sound on an ebbing tide. The study demonstrated that this transport is quite rapid, with dye detectable at Little Neck in three and a half hours, covering almost the full length of the Sound. Thus, any flushing that occurs in the lower Parker River is inseparable from flushing that occurs within Plum Island Sound as a whole.

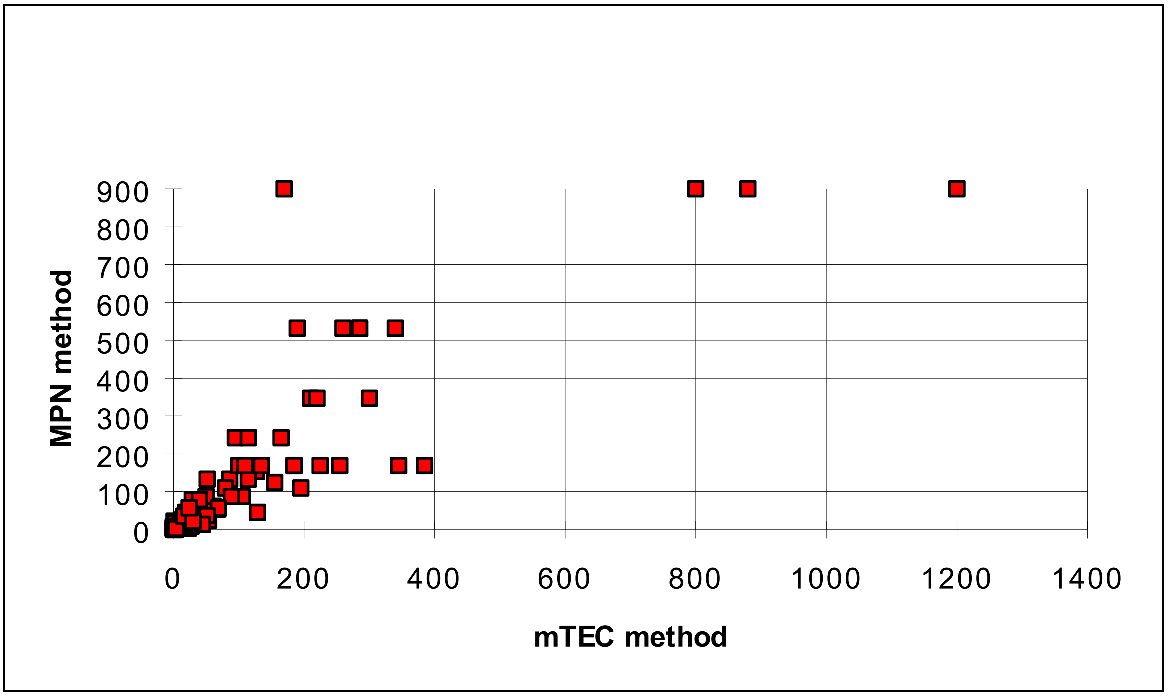
The Greenwood Creek study demonstrated that water in the Lower Ipswich River moves rapidly out of the river and is rapidly mixed vertically and horizontally in the process. At the turning of the tide, Ipswich River water overlay the Sound water and was carried into the Sound, slow mixing laterally and vertically. It became nearly indetectable before reaching Middle Ground. This reinforces what was learned in the present study, that the Ipswich River flushes rapidly and probably has a relatively small impact on flushing of the Sound as a whole.

3.35. Fecal coliform contamination of Plum Island Sound

3.351. Methodological Studies

There was a strong correlation between the fecal coliform concentrations measured by the mTEC membrane filtration method and DMF's results using the MPN procedures (Fig. 3.4). In general, the MPN data gave slightly higher readings for the same water sample, which is not surprising since the MPN method has been selected for use in sanitary surveys because it is conservative. There was also little difference between replicate samples, i.e. samples taken from either two different depths or the same depth at the same site (see Minibay Project report).

Fig. 3.4. Comparison of mTEC vs MPN methods for fecal coliforms in Plum Island Sound. Numbers are fecal coliforms per 100 ml of water.



3.352. Fecal coliform concentrations:

Plum Island Sound proper - The water of Plum Island Sound was characterized by low concentrations of fecal coliform bacteria during dry weather (Table 3.37). None of the geometric means calculated for dry weather indicated that levels were above 14 cfu per 100 ml, the state standard for harvesting shellfish. Only two sampling days were during wet weather, but this limited data indicated that fecal coliform levels are elevated above the state standard during rainfall events (Table 3.37). Not surprisingly, the Minibay Project sampling supported DMF's classification of most of the Sound as conditionally approved for shellfish harvesting.

Other than the Great Neck area in Ipswich, there were no obvious, significant direct sources of fecal coliform bacteria within the Sound proper. Instead, fecal coliforms entered Plum Island Sound through the Parker, Rowley and Ipswich Rivers, particularly during storm events.

Table 3.37. Geometric mean fecal coliform concentrations (as *E. coli*) in colony forming units per 100 ml. Plum Island Sound Stations.						
Station Location	**Station #**	**Station Type**	**# of Samples Dry**	**/ Wet**	**E. coli per 100 ml Dry Weather**	**Wet Weather**
Off Castle Hill	1	boat	7	2	3	38
Off Hellcat Swamp	12	boat	7	2	5	13
Eagle Hill River	22	boat	7	2	9	24
Rowley River Mouth	7	boat	3	1	2	8
Plum Island River at Jericho Creek	23	boat	6	2	10	12
Pine Island Creek	86	shore	4	3	15	51

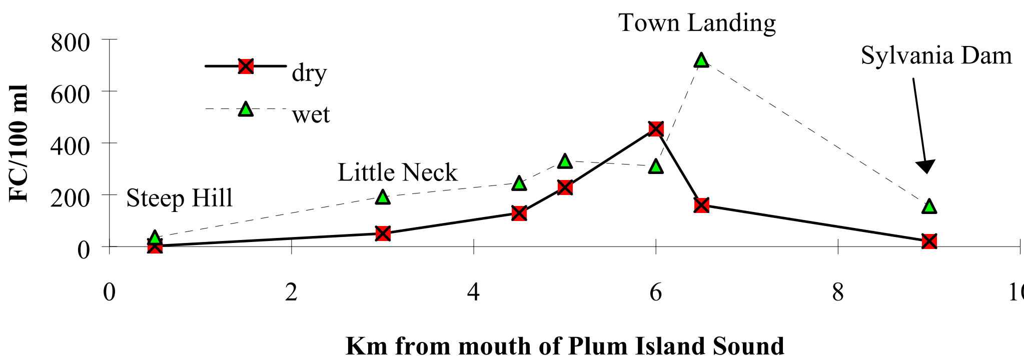
Ipswich River **-** High levels of fecal coliforms existed through much of the Ipswich River estuary and in three tributaries: Kimball Brook, Farley Brook, and Miles River during the study period (Table 3.38). Despite inputs from these tributaries, two of which are upstream of any stations on the main stem of the river, the main stem of the Ipswich River was relatively clean during dry weather before it enters downtown Ipswich (Fig. 3.5). This was based on relatively low concentrations of bacteria at the Sylvania Dam. Bacteria from upstream sources may settle out and die off behind the Sylvania Dam and in the extensive wetlands further upstream. As the water flowed between the Sylvania Dam and the town landing through downtown Ipswich, it received major inputs of bacteria. Farley Brook, which entered the Ipswich River after an underground passage of several hundred yards, was one of the major sources (but see below). Beyond the town landing station, bacterial concentrations gradually declined, probably through dilution and perhaps attenuation.

An extensive fecal coliform sampling program conducted by the Ipswich Coastal Pollution Control Committee (ICPCC) in Ipswich produced results similar to the Minibay Project. ICPCC's report indicated that Ipswich's faulty wastewater treatment plant and conveyance system contributed bacteria to the river as it makes its way through downtown Ipswich and that waterfowl, stormwater runoff and dogs were the other major contributors of fecal coliform to the main stem of the Ipswich River. According to ICPCC, horses and other agricultural inputs were believed to be significant sources of contamination to the Miles River (ICPCC, 1995).

The highest fecal coliform concentrations measured by the Minibay Project in the Ipswich River Basin were at the Kimball Brook station where average fecal coliform concentrations ranged from 804cfu/100 ml during dry weather to 3,605cfu/100 ml during wet weather. Based upon discussions with the Ipswich Board of Selectmen in November 1994, suspected illegal wastewater tie-ins to the stormwater drainage system were the major sources of contamination to the Kimball Brook.

Table 3.38. Geometric mean fecal coliform concentrations (as *E. coli*) in colony forming units per 100 ml. Ipswich River and its tributaries.						
Station Location	**Station #**	**Station Type**	**# of Samples Dry / Wet**		**E. coli per 100 ml Dry Weather**	**Wet Weather**
Miles River	74	shore	7	4	285	716
Kimball Brook	73	shore	8	5	804	3,605
Ipswich River at Sylvania Dam	71	shore	9	5	21	132
Farley Brook	72	shore	4	2	822	569
Ipswich River at Town Landing	5	boat	6	2	308	516
Ipswich R. at Labor in Vain Creek	4	boat	3	1	230	336
Ipswich River at Treadwell Island	3	boat	3	1	131	246
Ipswich River at Little Neck	2	boat	7	2	51	193

Fig. 3.5 Gradient of fecal coliforms – Ipswich River segment

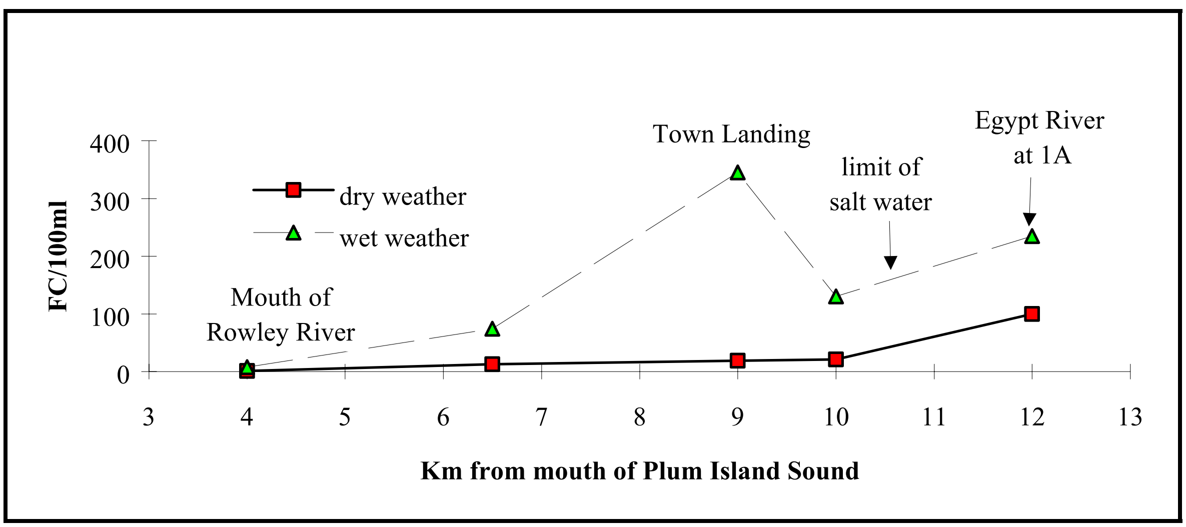


Rowley River - Fecal coliform concentrations in the Rowley River were relatively low during dry weather and moderately high after heavy rainstorms (Table 3.39). The main stem of the Rowley had average fecal coliform concentrations less than 25/100 ml during dry weather, slightly above the state standard for shellfishing. The moderate fecal coliform contamination throughout the Rowley River after heavy rainfalls suggests that there were inputs of contaminated stormwater. Average fecal coliform concentrations during wet weather ranged from 75/100 ml to 346. The higher bacteria concentrations during wet weather were apparently diluted before entering the Sound (Fig. 3.6).

Table 3.39. Geometric mean fecal coliform concentrations in the Rowley River and its tributaries. Results are expressed as cfu/100 ml.

Station Location	Station #	Station Type	# of Samples		E. coli per 100 ml	
			Dry	Wet	Dry Weather	Wet Weather
Egypt River at Route 1A	52	shore	14	4	105	236
Muddy Run at Paradise Road	53	shore	1	3	19	344
Rowley River at Town Landing	51	shore	5	2	22	131
Rowley River at Batchelder Lndg.	11	boat	3	1	20	346
Rowley River near Sound	9	boat	7	2	14	75

Fig. 3.6. Gradient of Fecal Coliforms - Rowley River Segment



Parker River - Although the main stem of the Parker River was relatively clean during dry weather, many of its tributaries, most notably Ox Pasture Brook, and the Mill and Little Rivers, regularly contained high concentrations of fecal coliforms even during dry weather (Table 3.40). The station with the highest level of contamination in the Parker River basin was a small tributary creek to the Mill River where average fecal coliform counts are 1998/100 ml during dry weather to 5624 after rainfall. These extremely high counts, which have exceeded 100,000 several times, were probably related to problems with the sewage treatment plant at the Governor Dummer Academy. The Academy has made repairs to the system under the guidance of DEP.

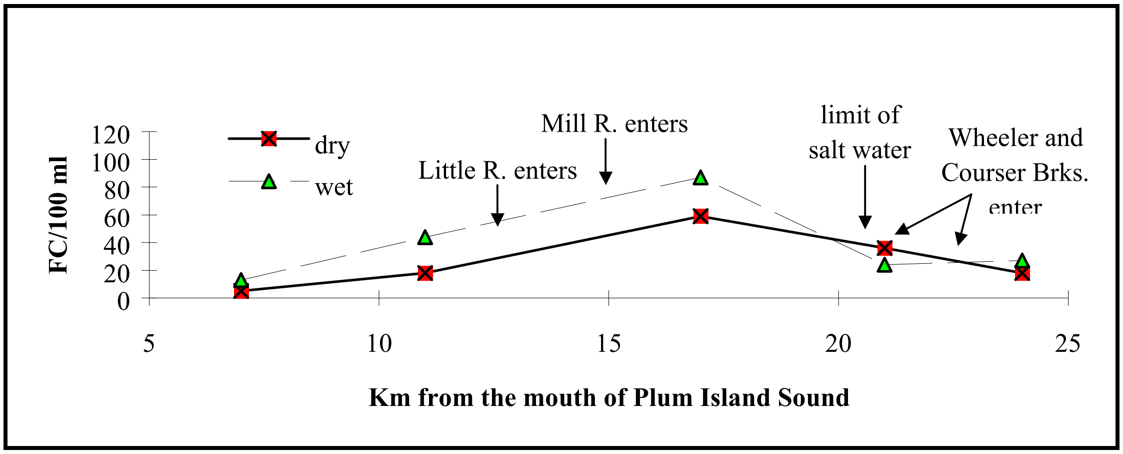
A shoreline survey conducted as part of the Minibay Project indicated that horses and agricultural inputs were major sources of contamination to the Mill River and Wheeler Brook. Possible sources of fecal coliforms in Ox Pasture Brook were horses, duck ponds and failing septic systems. Fecal coliforms in the Little River were most likely from failing septic systems. Fecal coliform concentrations actually declined during wet weather events in two of our sampling stations along the Little River, suggesting that contamination from faulty septic systems was diluted after rainfall. Domestic animals may have been another source of fecal contamination to the Little River.

Table 3.40. Geometric Mean Fecal Coliform Concentrations in cfu/100 ml. Parker River and its tributaries.

Station Location	Station #	Station Type	# of Samples Dry	/ Wet	E. coli per 100 ml Dry Weather	Wet Weather
Parker River at Main St. - Byfield	46	shore	5	5	18	27
Wheeler Brook at Larkin Rd.	48	shore	11	7	303	351
Courser Brook at Orchard Street	45	shore	10	8	130	243
Parker River at Central Street	44	shore	15	8	36	24
Parker River at Route 1	21	both	13	6	59	87
Parker River off Newbury Landing	15	both	12	6	18	44
Mill River at Wethersfield St.	32	shore	6	4	130	762
Bachelder Brook at Wethersfield St.	33	shore	5	4	32	162
Mill River at Glen Mills	31	shore	18	7	59	65
Creek near Governor Dummer	37	shore	11	5	1,998	5,624
Mill River near Parker River	24	boat	6	2	76	181
Ox Pasture Brook at Independ. St.	36	shore	4	2	788	3,246
Ox Pasture Brook at School St.	35	shore	4	1	615	1,081
Ox Pasture Brook at Fenno Drive	34	shore	16	7	414	982
Little River at Scotland Road	84	shore	4	3	38	548
Little River at Hanover Street	83	shore	12	2	380	556
Little River at Boston Street	82	shore	1	1	241	176
Little River at Newman Road	81	shore	5	2	165	157
Little River near Parker River	25	shore	6	2	38	98

The main stem of the Parker River (water coming over the dam in Byfield) was relatively clean (Fig. 3.7). However, within the estuarine part of this river, inputs from the Mill and Little Rivers caused a slight increase in bacteria which was then gradually diluted before the Parker River flowed into Plum Island Sound.

Fig. 3.7. Gradient of fecal coliforms - Parker River segment



Parker River National Wildlife Refuge - Fecal coliform samples from several sites in the Parker River National Wildlife Refuge (PRNWR) were collected to determine contamination levels in areas where wildlife was the only likely source (Table 3.6). Samples were taken in May 1993 and August - December 1994, and therefore covered times of spring and fall migrations when numbers of birds on the refuge were likely to be at the highest levels. Hellcat Swamp and Stage Island, two ponds with the heaviest concentrations of waterfowl on the refuge, had somewhat elevated levels of fecal coliforms (53 and 33 respectively). Other sampling stations had much less.

At the salt pannes wildlife viewing area, samples for bacteria that might be within the top layers of the sediment were taken by stirring up the sediment and then collecting the resulting sediment plume (Table 3.42). No fecal coliforms were detected in these samples, perhaps due to interference by the sediment with the membrane filtration procedure.

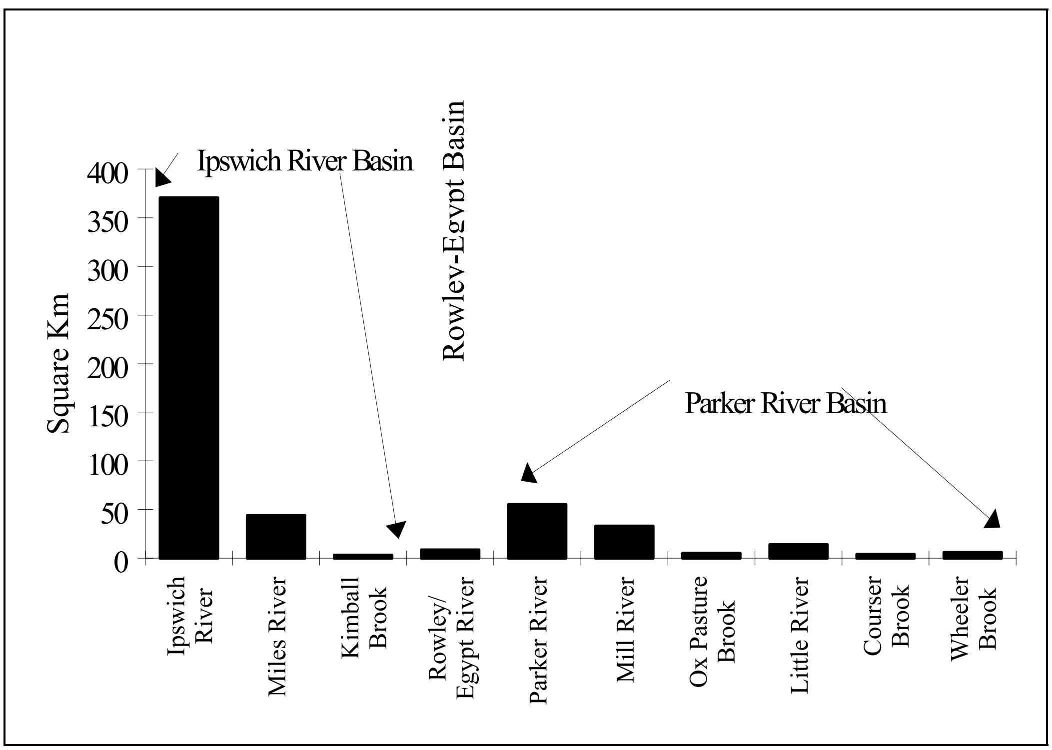
Only one wet weather event was sampled on the PRNWR. Fecal coliform concentrations were elevated at all stations with a one and two orders of magnitude increase over dry weather at the Hellcat Swamp and Salt Panne stations respectively.

Table 3.41. Geometric Mean Fecal Coliform Concentrations in cfu/100 ml. Parker River NWR.						
Station Location	Station #	Station Type	# of Samples Dry	Wet	E. coli per 100 ml Dry Weather	Wet Weather
Stage Island Outlet	61	shore	9	1	33	90
Pine Creek	62	shore	9	1	10	25
Hellcat Swamp Outlet	63	shore	9	1	53	661
Salt Pannes	64	shore	6	1	7	601
Sediment in Salt Pannes	64.5	shore	3	0	0	nd
Plum Island River	65	shore	6	0	8	nd

3.353. Loadings of fecal coliforms to Plum Island Sound from various sources

Fecal coliform bacteria are carried into Plum Island Sound by the Ipswich, Parker and Rowley rivers. The Ipswich basin is by far the largest, roughly 4 times larger than the Parker (Fig. 3.8). The Rowley River basin is relatively small compared to the other two basins.

Fig. 3.8. Drainage Basin Areas of Plum Island Sound.



The Ipswich River supplied roughly three fourths of the freshwater input to Plum Island Sound and was responsible for over 90 percent of the fecal coliform loadings to the Sound during both dry and wet weather (Fig. 3.9). Most of this loading (over 70% of the fecal coliforms during dry weather and 52% during wet weather) originated from the center of Ipswich between the Sylvania Dam and the town wharf. Because the Ipswich River enters the Sound at its mouth, this contamination was flushed rapidly out of the Sound into Ipswich Bay at low tides. Therefore, despite the large bacterial loads carried by the Ipswich River, the Ipswich did not likely have a major impact on water quality throughout most the Sound. The Ipswich River had negligible impact on the central and northern parts of the Sound where many clam flats are located.

The Parker River was the greatest source of fecal coliforms to the central and northern sections of the Sound (Figs. 3.9-3.10). Although the volume of freshwater input to Plum Island Sound from the Parker River was much lower than the volume contributed by the Ipswich River, the Parker River basin affected water quality throughout the Sound because it empties into the upper reaches of the Sound. The Little River in Newbury was the largest source of bacteria to the Parker River (about 40% in both dry and wet weather).

The Rowley River and the PRNWR did not contribute significantly to fecal coliform loadings in Plum Island Sound (Fig. 3.9-3.10). The volume of water contributed to the Sound from the Rowley River was relatively low, and the moderate concentrations of fecal coliform generally died off before they enter the Sound. Fecal coliform contamination from birds in the PRNWR did not contribute significantly to pollution loadings in the Sound because there is little or no flow from these areas into the Sound.

Fig. 3.9. Relative loadings of fecal coliforms to Plum Island Sound from all basins

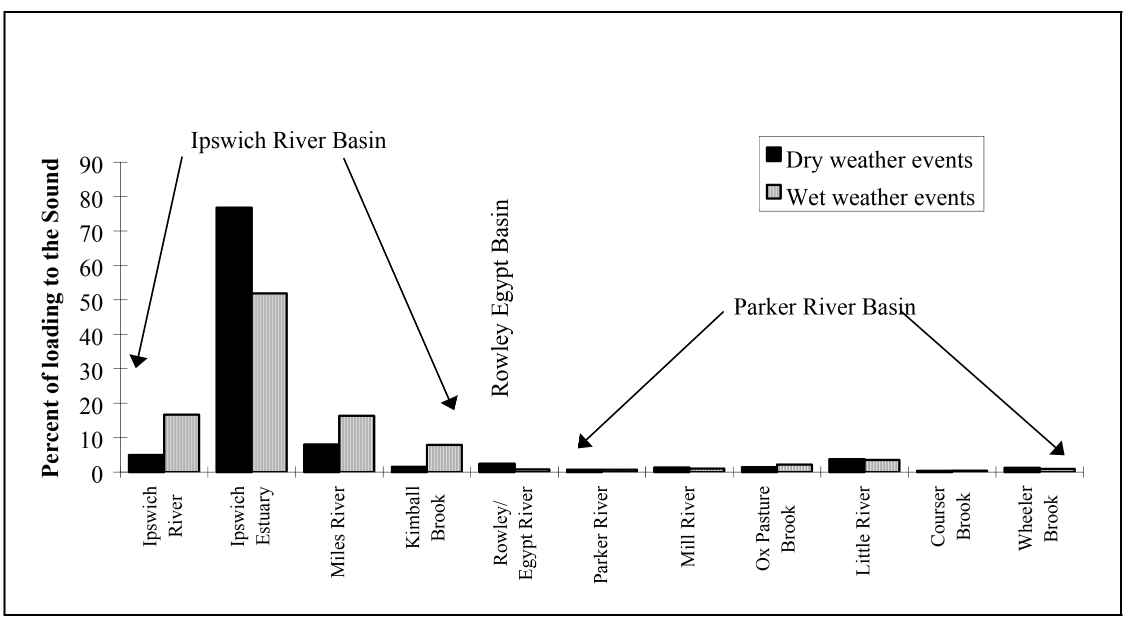
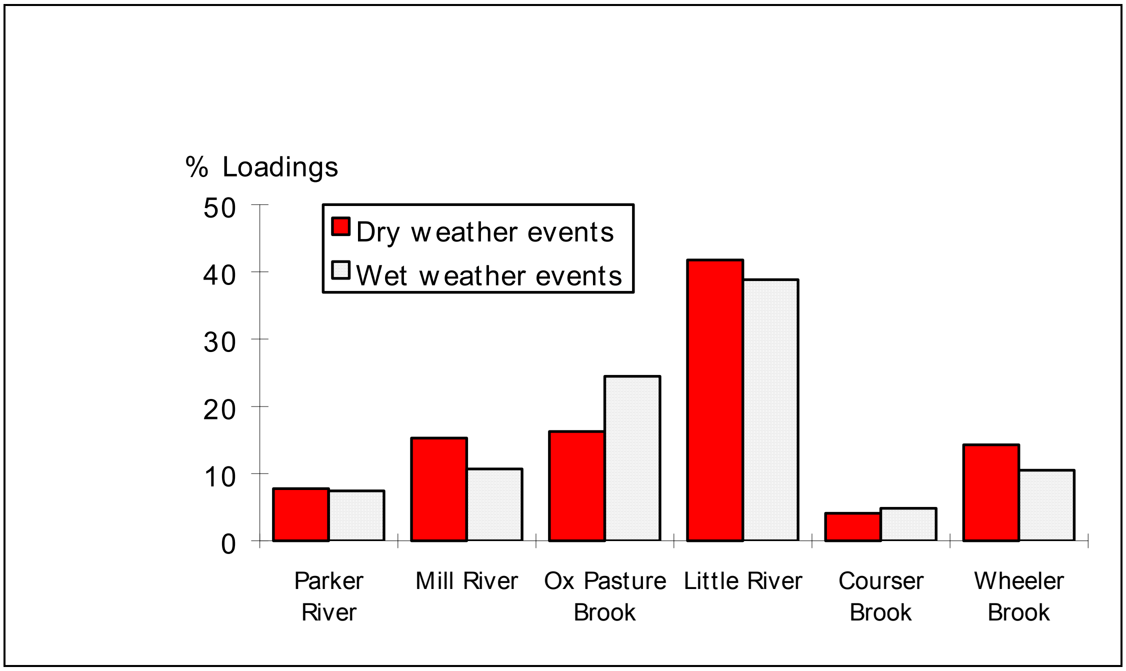


Fig. 3.10. Relative loadings of fecal coliforms to Plum Island Sound, Parker River basin only.

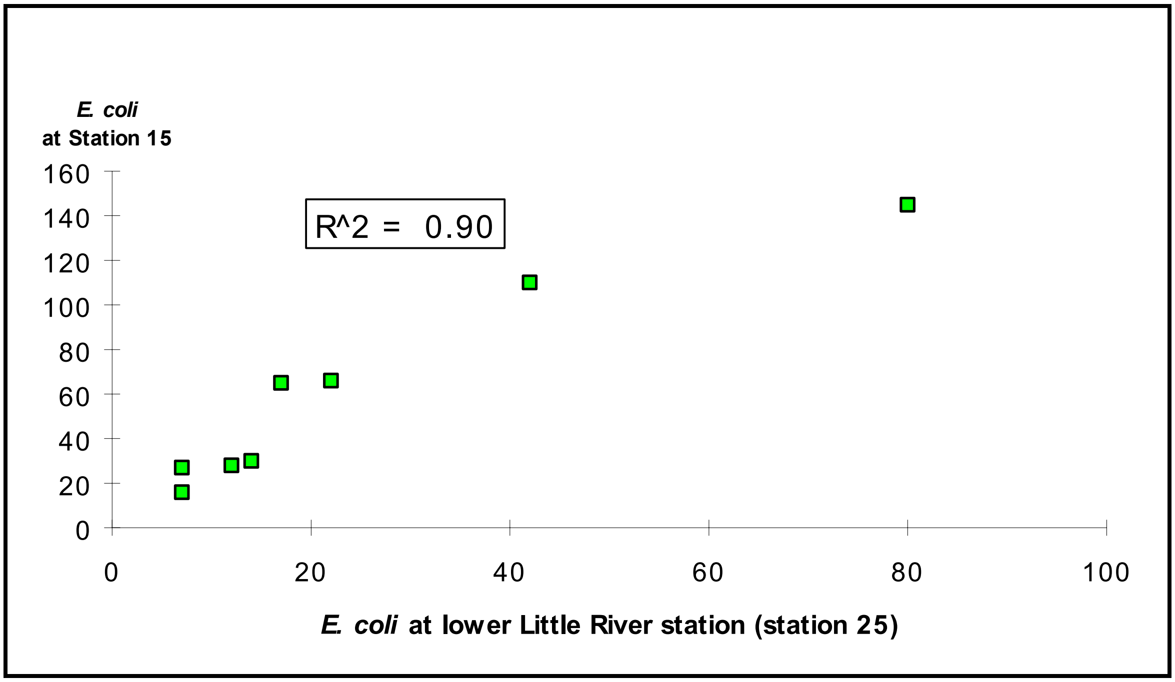


3.353. Correlations between sampling stations

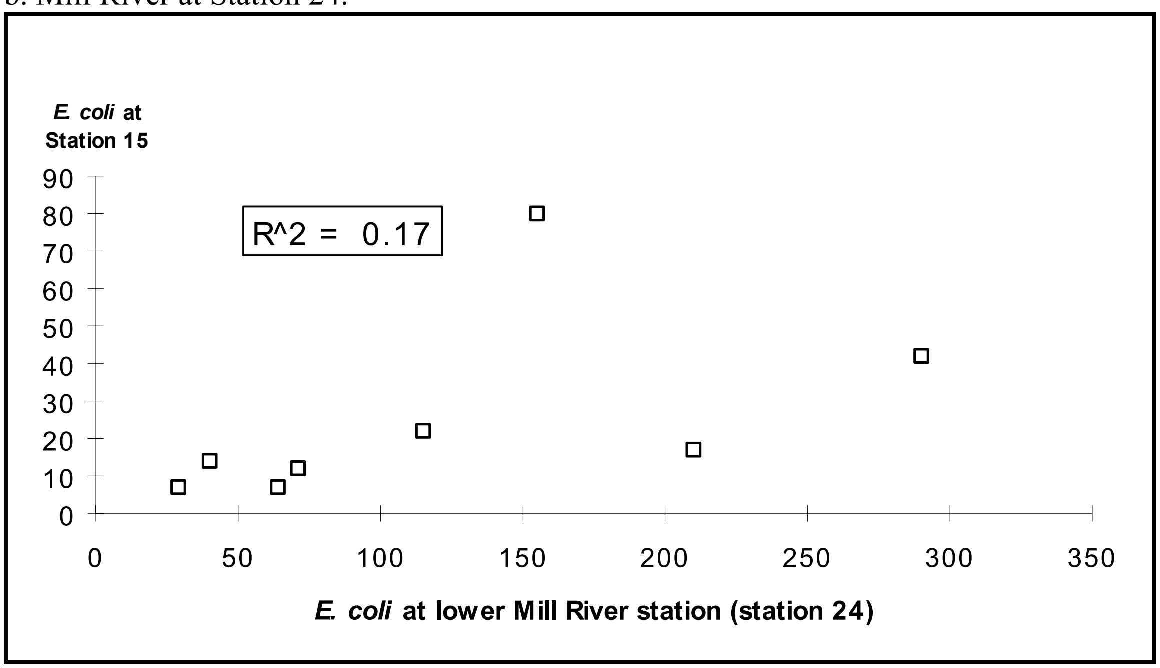
As a way of inferring which tributaries might be contributing to fecal coliform loads in the Sound, fecal coliform concentrations in upstream sampling stations were correlated with those downstream on the same sampling day. In the Parker River system, station MAS15, near the Parker's mouth, receives water from the main stem of the Parker as well as the Mill and Little Rivers. Sample station MAS25 on the Little, MAS24 on the Mill, and MAS21 on the Parker River are all within about 2 kilometers upstream of station 15. There is a strong correlation between the fecal coliform concentrations in the Little River and those at station 15 on the Parker (Fig. 3.11a). In contrast, there is no obvious relationship between station 15 and two upstream sampling stations on the Mill River and the main stem of the Parker (Fig. 3.11b-c). This suggests that the Little River has a major impact on clam flats that are in the region where the Parker River joins the Sound.

Fig. 3.11. Influence of three upstream stations on fecal coliforms in the lower Parker River at station 15. Low tide samples only.

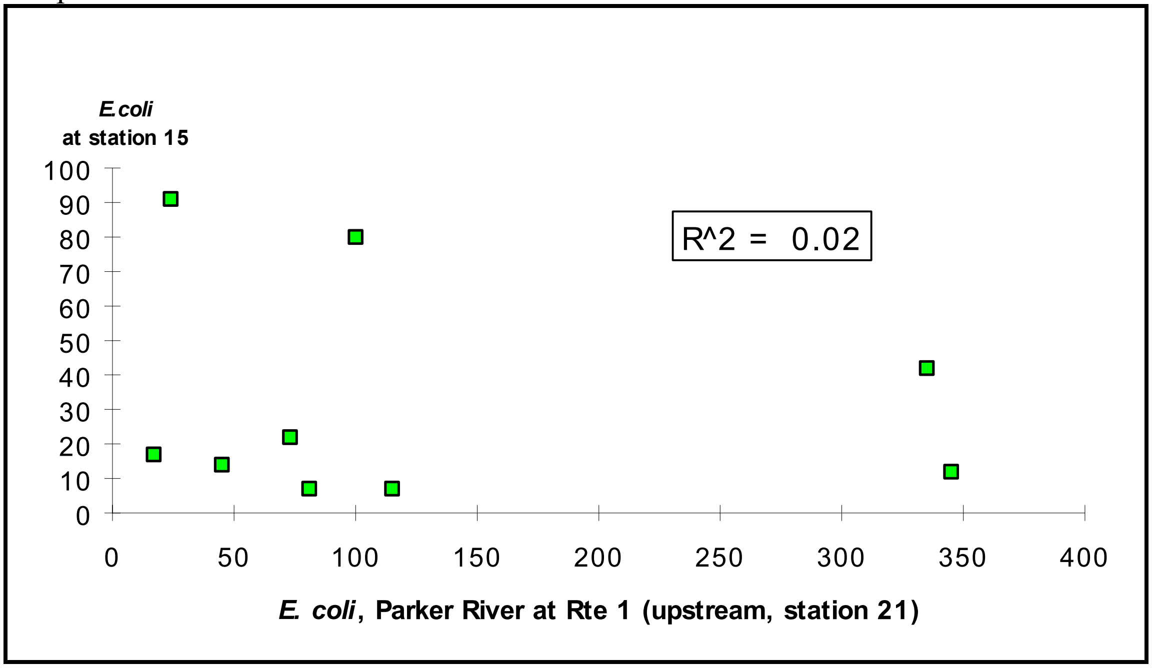
a. Little River at Station 25.



b. Mill River at Station 24.

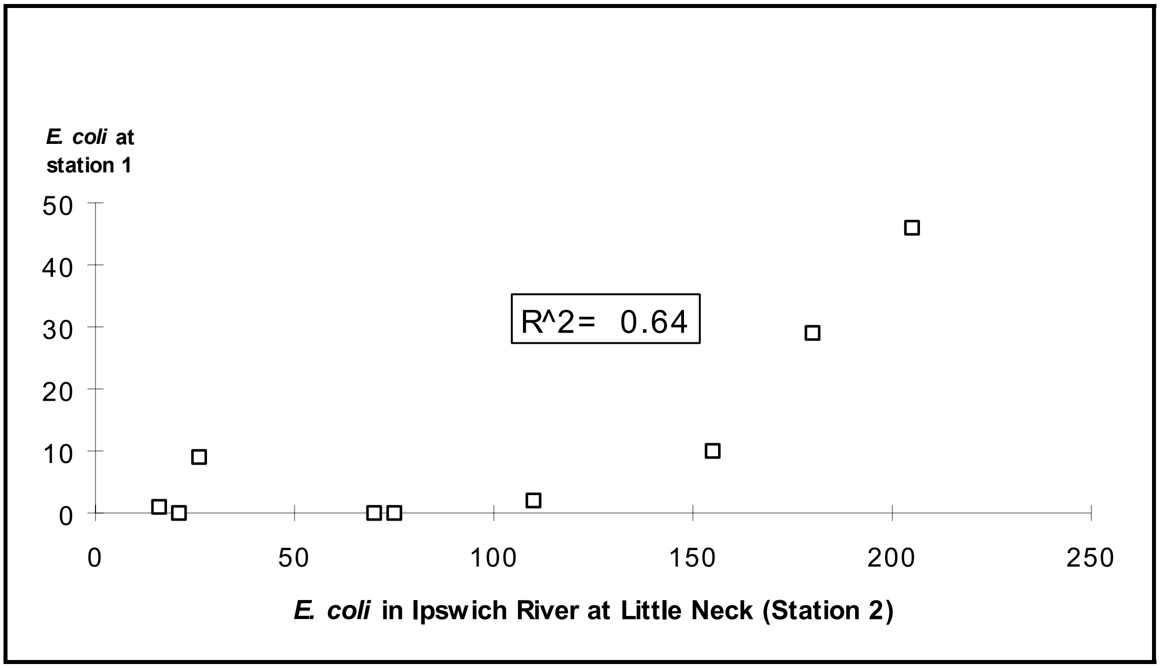


c. Upstream Parker River at Station 21.



Fecal coliform concentrations at the Little Neck station (MAS2) on the lower Ipswich River, about 0.5 km from its terminus in Plum Island Sound, correlates well (r^2=0.80) with those at our station 1 at the mouth of the Sound itself off Steep Hill (Fig. 3.12). This is not surprising since most of the freshwater flow leaving Plum Island Sound at this point is derived from the Ipswich River. Apparently, fecal coliforms concentrations above about 150 cfu per 100 ml in the Ipswich River at Little Neck are required to elevate fecal concentrations at the mouth of the Sound itself above baseline levels.

Fig. 3.12. Influence of Ipswich River on fecal coliform concentrations at the mouth of Plum Island Sound. Low tide samples only.



3.354. Effect of tidal range on fecal coliform concentrations

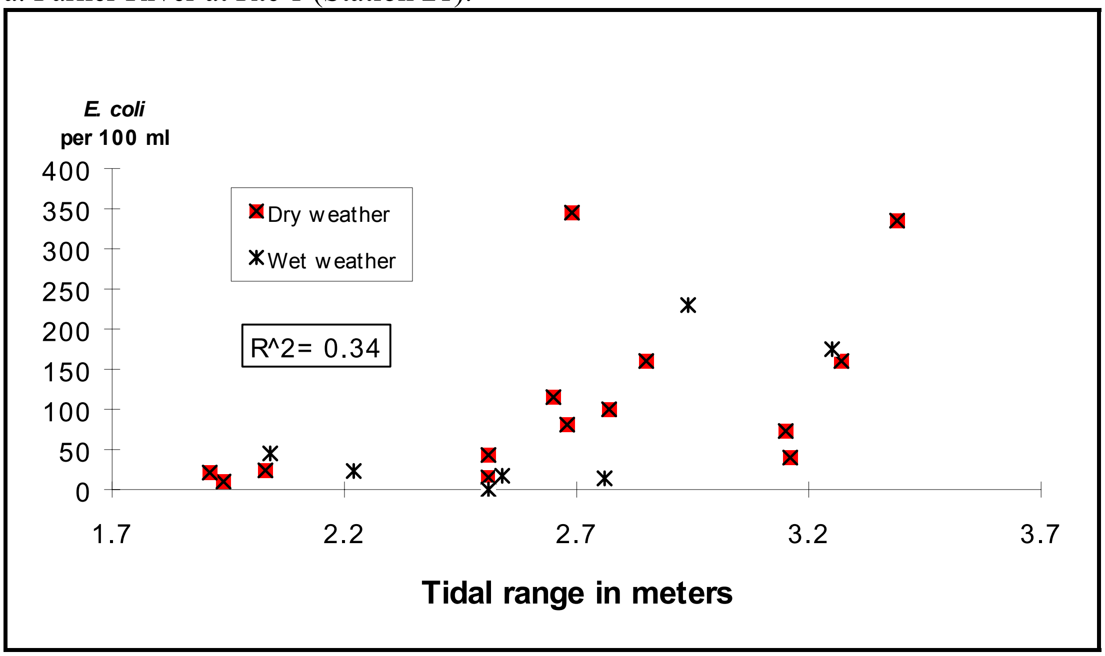
Vorsmarty and Loder (1994) described a relationship between nitrogen concentrations in the estuarine part of the Parker River and tidal range during the spring and neap tide cycle. They found that ammonia and nitrate concentrations in marsh creeks were higher during neap tide periods than spring tides. They concluded that when the marsh surface is flooded during a spring tide, the marsh acts as a sink for inorganic nitrogen due to plant uptake and denitrification processes. At neap tides, water remains within the salt marsh creeks and channels, and these processes do not occur, hence nitrogen concentrations are higher in the water.

Massachusetts Audubon carried out a similar analysis on stations in the estuarine part of the Parker River using fecal coliform bacteria rather than nitrogen. Concentrations of fecal coliforms on a sampling day were correlated with the tidal range on that day, estimated from NOAA tide charts for Plum Island Sound. At three of the four stations, concentrations of fecal coliform bacteria increased during periods when the tidal range was relatively high (Fig. 3.13). For stations MAS15 and MAS21, this analysis was repeated for wet and dry weather events separately (Fig. 3.13a-b). MAS15, which is near the mouth of the Parker River, was the one station where tidal range was not correlated with fecal coliform concentrations (Fig. 3.13b). At MAS21, approximately 2 km upstream, tidal range directly correlated with fecal coliform concentrations during both wet and dry weather events (Fig. 3.13a).

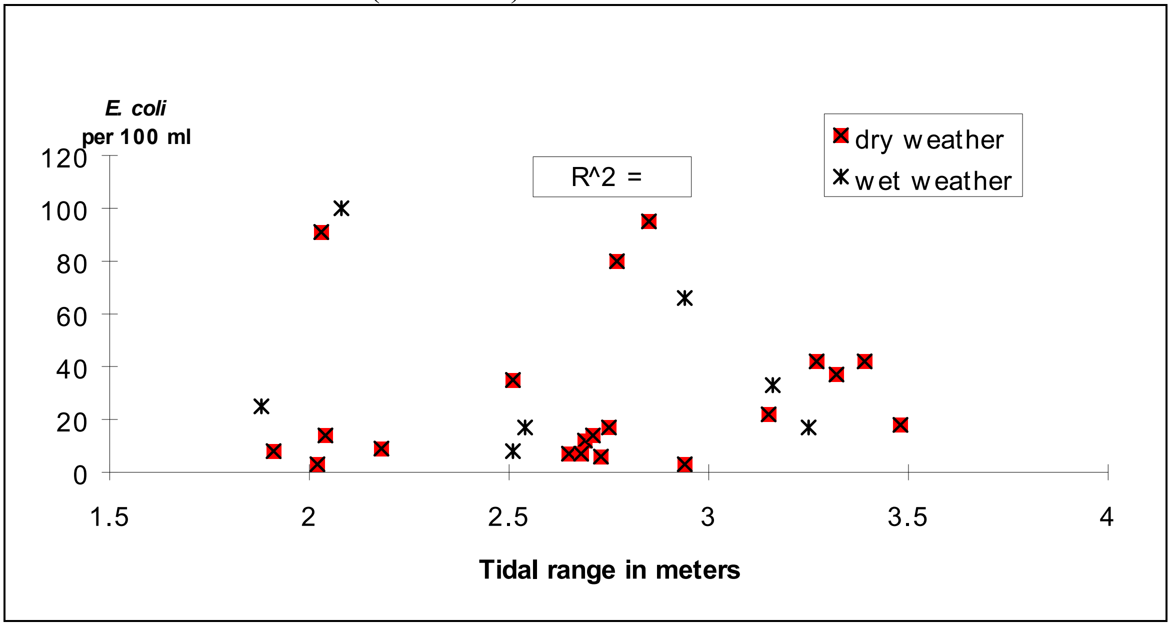
The increase in fecal coliform concentrations with increasing tidal range also occurred at the stations located at the lower ends of the Little and Mill Rivers (Figs. 3.13c-d). These stations are also upstream of station 15. One possible explanation of why the relationship occurred at stations upstream of station 15, but not at station 15 itself is that the relative volume of water to marsh surface area is much less at the three upstream stations, thus they would be subjected to greater impacts from processes occurring on the marsh surface when it is flooded.

Fig. 3.13. Fecal coliforms vs tidal range. Low tide samples.

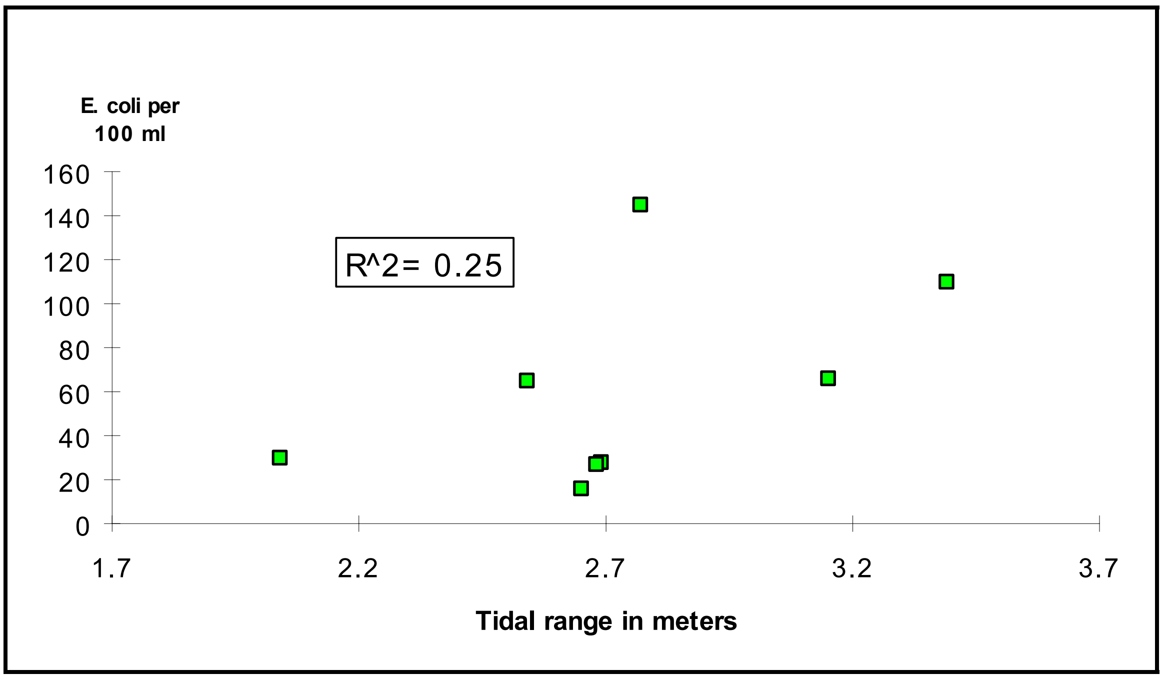
a. Parker River at Rte 1 (Station 21).



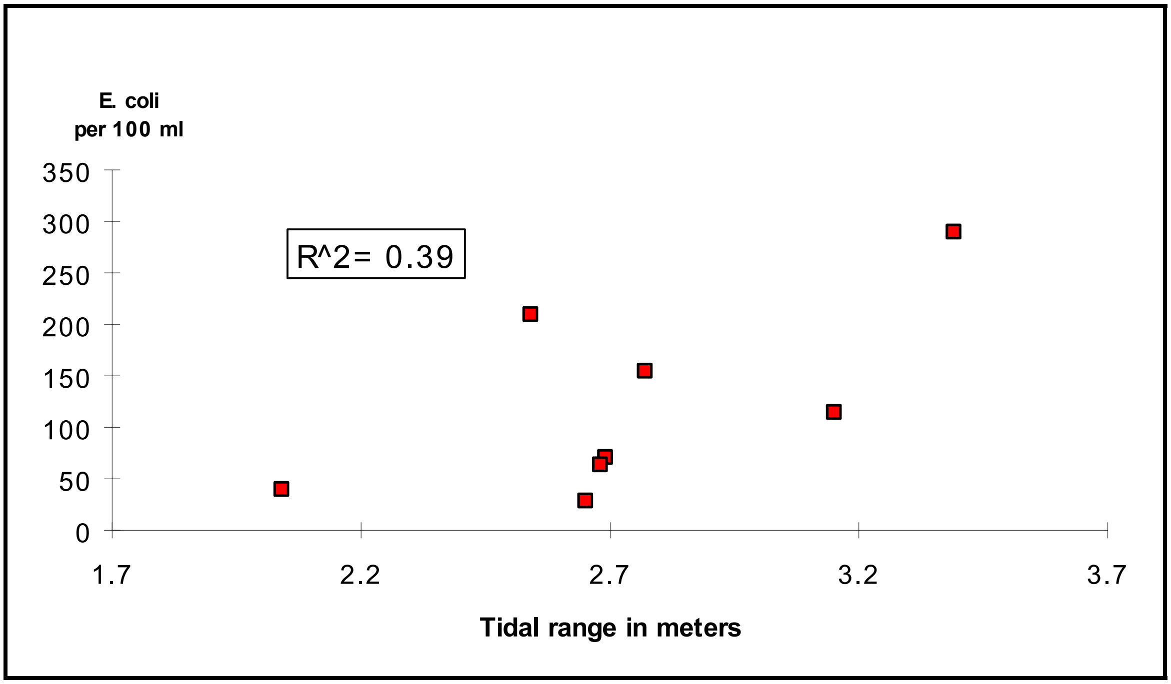
b. Parker River at Route 1A (Station 15).



c. Lower Little River station.



d. Lower Mill River station.

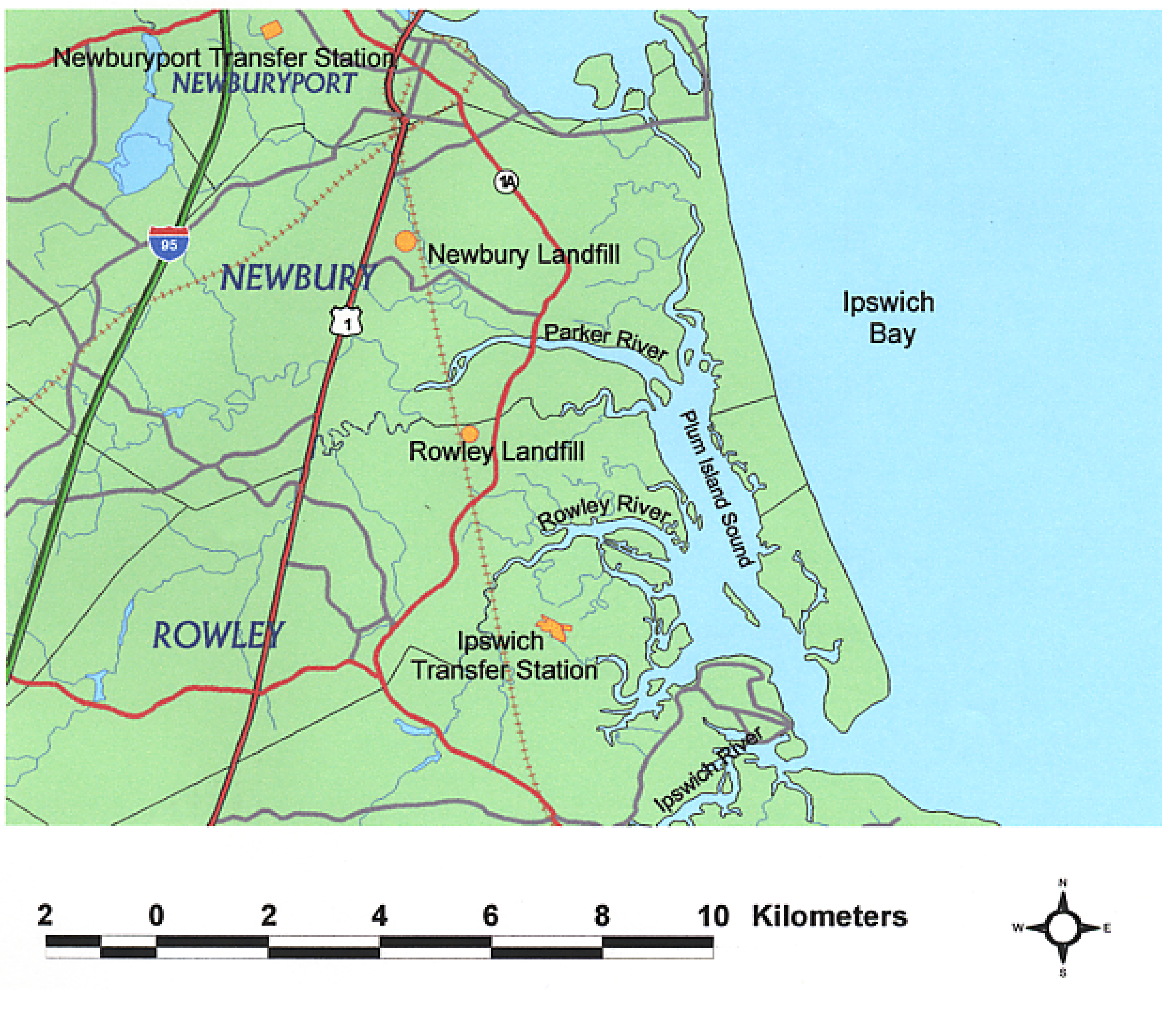


The analysis of the impact of tidal range on bacteria contrast with those reported by Vorsmarty and Loder for nitrogen. Bacteria behave differently from nitrogen when the marsh surface is flooded because the transport of bacteria is dependent primarily on physical processes whereas nitrogen transport is to a large extent mediated by biological processes. Thus fecal coliforms that are deposited in animal wastes on the marsh surface during the neap tide are apparently being mobilized from the marsh surface into the water column during spring high tides when the marsh is flooded. In contrast, nitrogen concentrations decrease as spring high tides exposes nitrogen to uptake processes on the marsh surface. This scenario suggests that a spring high tide is analogous to a stormwater event from a fecal coliform perspective.

3.4. Toxic Contaminants in the Plum Island Sound Region

The Parker River/Plum Island Sound Estuary, although relatively pristine, is not free of some contamination from metals, inorganics, volatile organic compounds, and total dissolved solids. Sources of these pollutants include the landfills (three of which are within the estuary and are perched on the edge of the salt marsh), private industries, marinas, junkyards and underground storage tanks (Figure 3.14). The degree of pollution from these sources is not completely known nor is the effect on the estuary biota. Data exist for one marina, two landfills and an abandoned plating industry.

Fig. 3.14. Location of landfills in the Plum Island Sound Region



3.41. Landfills

3.411. Ipswich

The Ipswich Transfer Station, located on Town Farm Road, is a closed and capped facility. The landfill, although capped, sits on the edge of the marsh presumably on portions of former salt marsh. It is located adjacent to Paine Creek, which flows into Plum Island Sound through the Eagle Hill River. Currently the former landfill is used as a transfer station for recyclables. The landfill was closed prior to monitoring requirements so little data exist on groundwater and adjacent water quality.

3.412. Rowley

The Rowley landfill, located off Old Rowley Road near Mud Creek, opened in the late 1950's and closed in 1992. Upon preparation for closure, a site assessment was preformed in 1990 for the Department of Environmental Protection (DEP).

The landfill is sited upon a moraine that is bounded by fresh and salt marsh, wetlands that are designated as an Area of Critical Environmental Concern. Six monitoring wells were installed in 1992 and soil samples were taken and sampled. The test results found that the well sites were devoid of harmful toxins with the exception of measurable levels of Dichlorodiphenyltrichloroethane (ddt) and heptochlor. Other compounds detected were arsenic, magnesium and lead. These compound levels exceeded the maximum contaminant level for safe drinking water. Due to relatively low levels of analytes detected, the engineering firm that prepared the report determined that the levels were not of concern and future analysis was deemed unnecessary. The landfill was slated to be capped in 1999 and under a consent order from DEP and was done so in that year.

3.413. Newbury

The Newbury Landfill, located off Boston Road adjacent to the Little River, has had a battery of environmental assessment tests taken in association with the transfer of the landfill from a non-mined landfill to a mined one. Landfill mining in Newbury started in the early 1990's and is a relatively novel approach to waste management; as a result the DEP has kept close tabs on the environmental effects.

A series of monitoring wells and surface sampling points were established to measure water quality. The results of these tests indicate that volatile organic compounds were not detected in 1989. The 1989 survey, which included two rounds of testing, indicated that metals (chromium, zinc and nickel) were present in some of the wells but these levels were below the maximum contaminant level (MCL). In one well chromium was slightly above the MCL and a surface water sample found that cadmium slightly exceeded the MCL. Concentrations of total dissolved solvents, chloride and sulfate in some of the wells exceeded the MCLs. Iron and Manganese, typical in areas underlain by igneous bedrock, were also above the MCLs. Silver was detected in one well at twice the level allowed by the Environmental Protection Agency standards. Seven pesticides: (endosulfan sulfate, gamma-bhc, delta-bhc, heptachlor epoxide, endodulfan II, heptachlor and 4,4' DDT were detected in three monitoring wells. Some of these did not exceed the MCLs, while four of these pesticides do not have established MCLs (Clark Engineers and Associates, 1990).

In 1993, water quality tests found that chlorobenzene, acetone and carbon disulfide were also present in some of the monitoring wells. (NEET, 1993)

In 1994, Port Engineering found that nitrate levels were slightly elevated in two test wells, total dissolved solids exceeded the MCL 3 to 3.5 times. Chromium, manganese and lead levels exceeded the MCL, in all wells, as well as in the baseline well site, indicating that the contaminants may not be disseminating from the landfill. Chlorobenzene and arsenic were also present in two wells (Port Engineering, Sept 1994).

In 1995 and 1996 water quality tests indicated similar results as 1994, with the trend since the 1989 tests showing reduced levels of containments. During the December 1995 study mercury exceeded the MCL in three wells and sulfates for one well were 4 times the MCL (Port Engineering Associates, 1995).

Soil conditions indicated in the 1989 tests that lead concentrations exceeded the MCLs for two sample points, the cause of these levels is unknown (Clark Engineers and Associates, 1990). In 1995 soil samples indicated that none of the samples exceeded Massachusetts DEP allowable contaminate levels for soil reuse at lined landfills (NEET, 1995).

The conclusion of Clark Engineers and Associates in 1990 was that the concentrations of pollutants were relatively low, but capping was recommended to stop the migration of water through the landfill to reduce contaminant mobility (Clark and Engineers and Associates, 1990). Despite this recommendation the landfill has been mined since the 1990s. In 2000 violations to the landfill permit were discovered by DEP. The Attorney General issued a complaint against the Town of Newbury to Suffolk Superior Court and sought an interim order to rectify on-site violations. According to the interim order the town was required to hire a qualified independent environmental consultant to oversee the landfill operations. The Town of Newbury hired Camp, Dresser and McKee, Inc. to comply with the order and furnish interim reports. The first consultant report has not yet been issued as of March 2001.

3.414. Newburyport

The Newburyport landfill is located off Crow Lane in a region of freshwater marshes at the headwaters of the Little River. At the time of this report, the landfill was not capped. Ransom Environmental Engineering conducted an assessment report, for a private client, this report is not available to the public.

3.42. Industrial Contamination

Circle Refinishing, Inc., formally located on the Route One traffic circle in Newburyport and Newbury, operated an electroplating and metal finishing factory from 1968 to 1993. Wastewater was discharged from copper, nickel and chromium plating, the byproducts of this process included zinc, cyanide and various acids. The Newburyport Wastewater Treatment Plant processed these byproducts. On December 20, 1993 a fire consumed the factory, releasing hazardous materials, mostly via water used to extinguish the blaze, into the surrounding wetlands.

The site is perched on an expanse of freshwater and brackish wetlands that feed the nearby Little River, which is tidal up to, and just west of Route 1. An imminent hazard evaluation completed by a local environmental firm found that there was no risk to human health but that there was potential risk to the environment, especially to benthic organisms from the exposure to polluted sediments and from a contaminated vegetative mat layer. Surface water quality, as well as ground water was affected, especially water overlaying the effected sediments (Letter from Ransom Environmental Consultants, Inc. to DEP, 1995). An effort to contain the spread of contaminants was temporarily performed by restricting water flow by the use of an in-stream air bladder.

It was found that the effects of the fire and the release of contaminants were mitigated by dilution by the Little River. Water quality tests found that zinc and nickel were present within the Little River but they were below the acute and chronic criteria (Letter from Ransom Environmental Consultants, Inc. to DEP, 1995).

During the clean up of the site, 15 tons of cyanide-impacted soil were removed and transported to Quebec, Canada. As of March 2001, a full scale clean up and reuse of the site has not been completed. The site is classified by the DEP as a Tier 1-B, meaning that it may be cleaned up with oversight from a Licensed Site Professional under a permit from the DEP.

3.43. Sediment Quality

The Parker River Watershed Team performed sediment quality tests in 1994 for three sites in the estuary (Table 3.42). Sites were specifically chosen to determine if metals were present in the aquatic soils near Riverfront Marina on the Parker River, below the Newbury Landfill, on the Little River, and downstream of the Lord Timothy Dexter Industrial Park in Newburyport, on the Little River. For the most part the data shows that the metal concentrations were below levels that are determined to cause significant detrimental impacts to biota, although levels of arsenic and aluminum were high for two of the samples.

Table 3.42. Sediment Quality Data (mg/kg dry weight) from the Parker River Watershed Team, Mass (EOEA 1996).

Station	Hg	As	Cu	Cd	Al	Zn
Concentration of Contaminant where no adverse impacts would be expected	0.2	6	16	0.06	NA	120
Concentration of Contaminant where significant detrimental impacts would be expected	2	33	110	10	NA	820
Little River, Parker Street	<0.0002	10.6	12	<0.03	1.510	78
Little River, Below Landfill	<0.0002	49.3	33	<0.03	1.310	179
Parker River, Riverfront Marina	<0.0002	3.57	17	<0.03	7236	54

The detrimental effects of toxins present in low levels in the estuary are not specifically known, although some wetland species are known to bioaccumulate toxins.

3.5. Pollution and Its Effect on Marine Resources - A Thirty Year Perspective

3.51. Water quality of Plum Island Sound past and present

Roughly the same acreage of shellfish beds are classified as prohibited in the 1990s as when the DMF carried out their study in 1965. In 1965 this included 138 ha of moderately contaminated flats (7.3 % of the total acreage of productive clam flats) and 307 ha of grossly contaminated flats (16.3 % of the total). Jerome et al. (1968) noted that the harvest of soft shell clams has been restricted in the Ipswich River and its tributaries since 1928. They noted that the quantities of raw industrial and domestic sewage directly entering the Sound had been much reduced from the early 1900s when many small factories and mills discharged raw sewage into tributaries. They also expressed optimism that the impending sewering of the core area of Ipswich should result in further reductions in the amount of sewage entering the river and therefore improved water quality.

DMF presently classifies most of Plum Island Sound as conditionally approved for shellfishing depending on rainfall (see Tables 5.3 and 5.4 in Chapter 5). Bacterial counts for most of the Sound do not exceed the standard for clean shellfish beds during dry weather. The exceedences that occur during wet weather are not great, generally in the range of 14 to 100 *E. coli* per 100 ml, but are still above the standard.

The Minibay and ICPCC studies carried out in the early 1990s supported classification of the Ipswich River estuary as prohibited for shellfishing due to high fecal coliform counts. Since that time, the Town of Ipswich has been active in addressing pollution problems; this has enabled the town to open some clam flats in the Ipswich River estuary (see Chapter 5).

The Parker River above Route 1A has recently been closed for shellfishing by DMF due to fecal coliform contamination. Fecal coliform concentrations as measured in the Minibay Project averaged between 38-176 per 100 ml in this newly closed region.

It is interesting to note how the major water quality issues, as reflected in the types of sampling carried out, changed from the 1960s to the 1990s. A central part of the report by Jerome et al. (1968) on the Parker River-Plum Island Sound Estuary (and in the other estuarine reports in the monograph series as well) was pesticide analysis. Jerome et al. reported detectable levels of DDT residues in some, but not all, samples of soft shell clams and white perch collected within the estuary. Levels were substantially lower than in finfish collected from the nearby Merrimack River estuary. With the banning of chlorinated hydrocarbons in the 1970s, DDT and related compounds never emerged as an issue in the Minibay Project. Instead, the major focus, driven to a large extent by both local and statewide expressions of concern, was on fecal coliform contamination and its impact on shellfish harvesting. Jerome et al. also raised fecal coliform contamination as an important issue, but no actual data were presented.

Stormwater runoff, an issue that receives much more attention now than it did thirty years ago, is considered a significant problem for the Sound as it is for most of the Massachusetts coast. Unfortunately, stormwater runoff is still very difficult to control. The rainfall closures for the entire Sound were not in effect in 1968, but this is likely the result of better monitoring now than in the past.

Some population growth and development has occurred in the region over the past 30 years, however unlike Cape Cod where shorelines have been the focus of intensive new housing construction, most new subdivisions in the Plum Island Sound region are located some distance from the Sound itself. Thus there is a better chance that the Sound has been somewhat buffered from pollutants generated by new developments. In sum, there is no hard evidence that the water quality within the Sound has deteriorated at least over the past 30 years despite recent recognition of the problem represented by stormwater.

3.52. Landscape factors that effect fecal coliform concentrations

Wetlands and the ponding of water behind dams likely attenuate bacteria before they enter the estuary. During dry weather Ipswich River water flowing over the Sylvania Dam is relatively low in fecal coliforms despite major sources upstream, i.e. the Miles River and Kimball Brook. Bacteria traveling downstream in the river are likely settling out when they reach the low flows behind the dam. In addition bacteria from farther upstream in the Ipswich may be trapped within the extensive wetlands system upstream in Topsfield and Wenham. The Woods Hole LTER project noted that nitrogen concentrations flowing over the Sylvania Dam were extremely low compared to those in the Ipswich upstream of the extensive wetlands (C. Hopkinson, unpublished results). The same effect on fecal coliform concentrations has been noted on two small artificially created ponds behind dams in the Mill River (Leahy and Buchsbaum, 1998).

This beneficial effect of ponding on water quality is subverted during wet weather events. Heavy rains resuspend the bacteria, causing them to reenter the water column and flow over dams. Once again, this points to the difficulty of controlling stormwater pollution.

3.53. A summary of suspected pollution sources to the Sound

The estuarine part of the Ipswich River is the major source of fecal coliforms to the region, contributing 70% and 52% of the total fecal coliform load during dry and wet weather respectively. The flushing study indicates that most Ipswich River water is quickly flushed out of the Sound and therefore does not affect the central and northern sections of the Sound. Nonetheless, some potential clam flats in the Ipswich River estuary are still closed due to contamination that enters the Ipswich River downstream from the Sylvania Dam. Recent management efforts of the town have focused on remediating sources of contaminants on this relatively well-defined part of the Ipswich River, such as upgrading the wastewater treatment facility, discouraging feeding of water birds, and searching for hidden direct discharge pipes in the downtown area. At the time of this writing these have already yielded benefits in terms of opening up some shellfish beds.

The Little River, a tributary of the Parker, is the major source of fecal coliforms to the upper part of Plum Island Sound. This conclusion is based on loading calculations from the Minibay Project and on the strong correlation between fecal coliform concentrations in the Little River and those near the mouth of the Parker.

Despite contributing a smaller bacterial load to the Sound than the Little River, the Mill River contained two particularly "hot spots". These were a small stream flowing into the Mill from the Governor Dummer Academy (GDA) and Ox Pasture Brook in the center of Rowley. Governor Dummer Academy has recently upgraded their treatment plant under the guidance of DEP. Water quality in Ox Pasture Brook may be affected by an increased number of septic system upgrades, although there is no coordinated management plan to improve water quality in the brook.

Based on the flushing study, the Merrimack River likely has very little influence on the Sound itself since little Merrimack River water routinely reaches the Sound. The dye study carried out by the FDA and DMF indicated that Merrimack River water is diluted about 600:1 by the time it reaches the upper boundary of Plum Island Sound at its junction with the Plum Island River. Thus fecal coliform concentrations in the Merrimack of 900 per 100 ml will be diluted to roughly the shellfish standard by the time it reaches the Sound.

Hellcat Swamp and Stage Island in the Parker River National Wildlife Refuge occasionally have elevated levels of fecal coliforms that may affect their immediate surroundings. Due to the minuscule flow from these sources compared to the Ipswich and Parker Rivers, the overall impact from wildlife from the Refuge on the water quality in the Sound is negligible.

Chapter 4. Fish

4.1. Changes in the fish community of Plum Island Sound from 1965 through 1994.

by Robert Buchsbaum[1], Linda Deegan[2], and Robert H. Garritt[2].

[1] Massachusetts Audubon Society
[2] Woods Hole Ecosystems Center

4.11. Introduction

Fish are one of the most obvious and ecologically important groups of organisms within the Sound and their population characteristics have been linked to the health of estuarine ecosystems (Deegan et al., 1993). They may also be indicative of trends in the Massachusetts Bays region, since many fish that inhabit Plum Island Sound are migratory and therefore make regular movements between the Sound, the Bay and depending on the species, even further beyond.

The 1968 DMF estuarine monograph on the Parker River and Plum Island Sound gave an excellent and thorough review of the history of the fisheries in the Plum Island Sound region since colonial times (Jerome et al., 1968). DMF also carried out an extensive one year program of field sampling to characterize the fish community of the region. A major initiative of the Plum Island Sound Minibay and the Woods Hole LMER (Land Margin Ecosystems Research, precursors to the current LTER) projects was to assess changes in the fish community of the Sound since the Jerome et al. study. This was accomplished by carrying out a program of fish sampling in 1993/4 similar to what Jerome et al. had done in 1965 and published in 1968.

4.12. Methods

Jerome et al. (1968) collected fish within the Sound at six beach seining stations and 11 trawl stations at monthly intervals over a period of one year in 1965. At each station, DMF biologists identified fish to species and counted the number of individuals of each species. Over a 16 month period in 1993-1994 researchers from Massachusetts Audubon Society and the Woods Hole Ecosystems Center (MAS/WH) sampled for estuarine fish using beach seines and trawls at the same stations as Jerome et al. The methods were almost identical as well. Sampling was carried out once a month from June 1993 through October 1994 except in January and February 1994 because of ice conditions on the Sound and in September 1994. Locations of the sampling stations are indicated in Figs. 4.1a-b.

4.121. Beach seining

Six shoreline stations (stations 1-6) were sampled with beach seines in both 1965 and 1993/4. The stations are described in Table 4.1.

At each shore station for the Jerome et al. survey, two 15.2 m hauls were made with a 6.1 x 2.4 m minnow seine that had a mesh size of 4.8 mm (3/16 inch). This was done for a qualitative assessment of the fish and invertebrates present (W. Jerome, pers. comm. April 1996). The data from the 6.1 x 2.4 m seine hauls were not included in the tables presented in the 1968 monograph. For quantitative work, two sets were made with a 15.2 x 1.2 m haul seine which had a mesh size of 3.2 mm (1/8 inch). The net contained a bag in the middle also with a 3.2 mm mesh. All quantitative results reported in Jerome et al. (1968) were based on these seine hauls.

The following description of the exact seining procedure was based on conversations with W. Jerome (pers. comm. April 1996). Each end of the net was attached to 15.2 m ropes. One person standing on shore held the unattached end of the rope while a small boat containing the seine moved perpendicular to the shoreline until the 15.2 m rope was played out. The boat then turned and released the net into the water parallel to the shoreline. When the net was completely played out, the boat returned perpendicular to the shoreline. The net was then hauled in using the 15.2 m ropes and eventually the ends of the seine itself. Thus the seine haul described a rectangle with 15.2 x 15.2 meter sides or 231 m^2. Fish were identified and counted in the field.

The seines used by MAS/WH were 15.2 m length and either 1.2 or 1.8 m in height with a 4.8 mm (3/16 inch) square ace mesh. The middle of the seines were fitted with a bag (1.8 x 1.8 m) of the same mesh size as the wings of the net. A lead line insured that the bottom of the net remained in contact with the substrate. Once a locus was selected, one person held one end of the net and stood at a fixed position at the edge of the water. A second person took the other end of the net and walked out in the water perpendicular to the shoreline at the point where the first person was standing. When the net was straight, it would be checked along its length to insure that it was deployed correctly. The person at the deep water end would then move toward shore describing an arc while the person at the water's edge remained fixed. Thus each seine tow covered a quarter of a circle with a radius of 15.2 m and an area of about 180 m^2.

When the far end of the net was almost at the shoreline, the two people holding the ends of the net would walk toward each other and then move slowly up the beach until the net was completely out of the water. Fish and selected macroinvertebrates (decapod crustaceans) were then placed in plastic bags and stored in a cooler for later identification and enumeration back at the laboratory. Triplicate seine hauls were taken at all stations, with care taken in the second and third haul to avoid areas that had been impacted by the previous haul.

A seine team typically consisted of three or more people. In addition to the two people holding the ends of the seine, a third person checked along its length while it was being deployed to insure that it was sampling properly, i.e. lead line down, no tangles, etc. Additional people, often volunteers, helped with collecting the samples from the net after it was hauled ashore.

At each seine station, temperature and salinity (by refractometer) were measured, and the depth at the deep end of the net was estimated. Almost all depths were between 0.4 and 1.0 meters.

Table 4.1. Shoreline stations sampled by beach seine. Stations 1-6 were selected to be as close as possible to shoreline stations sampled by DMF in 1966.

Station 1. Great Neck, Ipswich near Pavilion Beach, a narrow strip of land that separates Great Neck from Little Neck on the western shore of Plum Island Sound. MAS/WH located their station 1 several hundred meters north of DMF's 1965 Little Neck station because they found the DMF station too cobbly at this point to reliably seine. MAS/WH Station 1 was located on a flat, very gently sloping sandy beach just north of an area of small rocks interspersed with salt marsh vegetation that separates the site from the northern end of Pavilion Beach. Sampling was always carried out within two hours of low tide.

Station 2. Bluffs, Ipswich. This station was located on the eastern side of Plum Island Sound several hundred meters south of the private residence on Stage Island. It was in a relatively sandy area at the seaward edge of a tidal flat that extends out from Stage Island. It was sampled at low tide. The gradient was gentle.

Station 3. Knobs. This station was a small gently sloping sandy beach bordered by salt marsh on three sides. The station is at the end of the dirt road that extends west past the southern border of the Bill Forward pool on the Parker River National Wildlife Refuge (PRNWR). It was seined at mid to low tides. New salt marsh vegetation covered the upper edge of the beach, thus unlike DMF who reported that the beach was devoid of vegetation, this area could no longer be seined at higher tides in 1993/4.

Station 4. Nelson's Island. This station, also on the PRNWR, was located at the edge of a tidal flat at the end of the dirt road that runs from the refuge parking lot at the end of Stackyard Road across the salt marsh to Nelson's Island. The substrate was a muddy sand with occasional disturbance by commercial clammers. Since the upper edge of the station was bordered by a steeply-banked salt marsh, it was seined at mid to low tides (2-3 hours on either side of a low tide) when the marsh was not flooded. Extreme low water was avoided because the flat sloped steeply into a channel that was too deep to allow to extension of the net to its proper length.

Station 5. Subheadquarters. This station was located on the extensive mud flat just west of the maintenance buildings of the PRNWR. In sampling this station we were faced with the greatest time constraint since it was too dry during much of low tide, but could also not be seined from mid to high tide because of the steeply banked salt marsh at the upper edge of the mud flats. There was generally a 45 minute "window" between two to three hours before or after dead low where this station could be seined. This mud flat was frequented by commercial clammers.

Station 6. Newbury Town Landing. This station was located on mud flats on the north shore of the Parker River several hundred meters downstream from the Newbury's old town landing at the end of Cottage Street. The DMF sampling station was at the landing itself. MAS/WH moved downstream slightly to be out of the influence of the mooring and launching area for boats. The mud flats bordered a steep salt marsh bank on the PRNWR. The soft sediments were interspersed with occasionally "clumps" of salt marsh peat that had probably slumped from the edge of the bank, thus care had to be taken to find a flat area for seining. Sampling was done within three hours of maximum low water. This station had strong tidal currents, particularly as the tide approached mid tide.

Fig. 4.1a. DMF Fish Sampling Stations

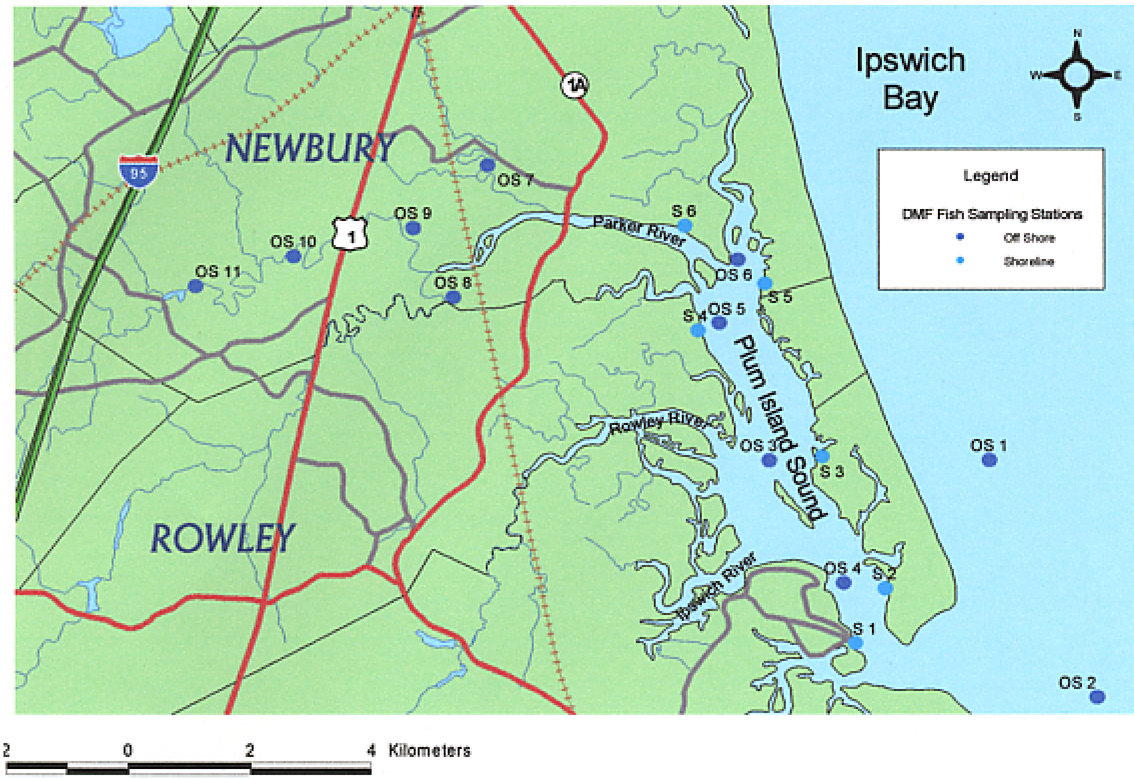
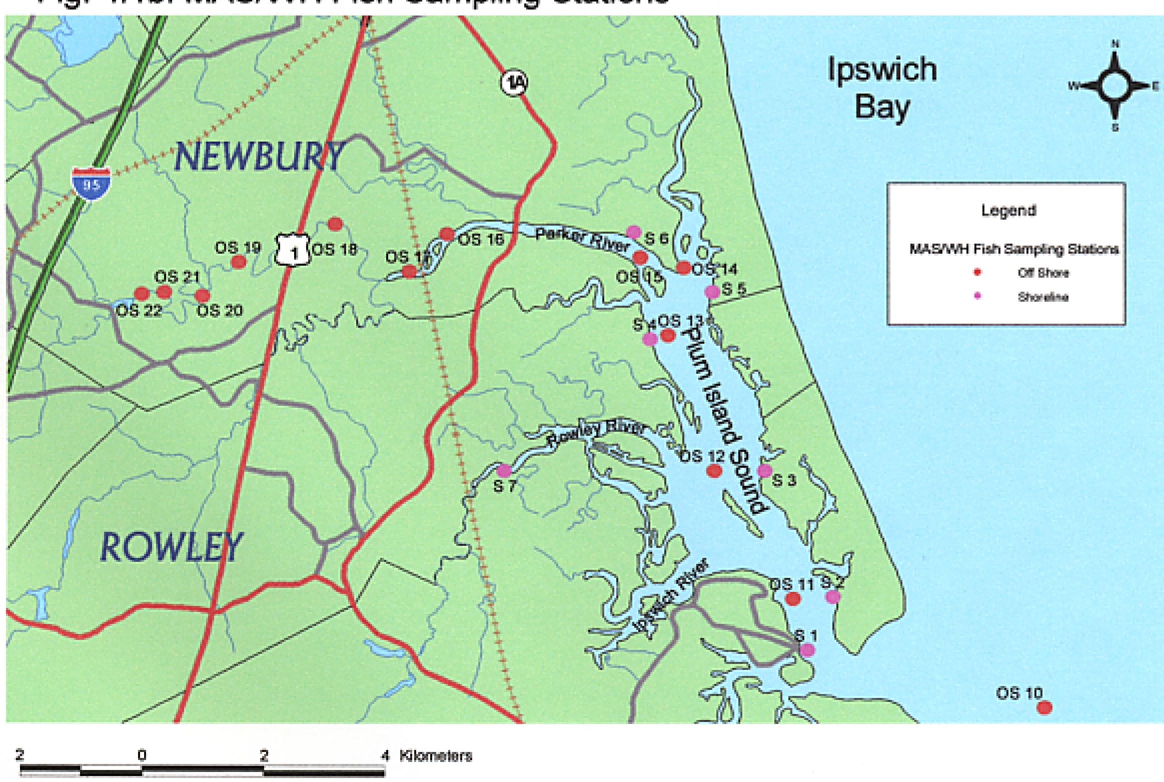


Fig. 4.1b. MAS/WH Fish Sampling Stations



4.122. Trawling

DMF used the 40-foot commercial dragger *Peggybell* to sample two offshore stations near the mouth of the Sound and one in Ipswich Bay. One twenty minute tow was made at each station with a trawl having a sweep of 14.8 meters and a headrope of 11.5 m. The stretched-mesh size of the twine in the wings and cod end was 12.7 cm and 10.2 cm, respectively. Finfish were examined to determine species composition, relative abundance and size distribution.

DMF used a shrimp trawl, with a sweep of 9.1 m and a headrope of 7.6 m at eight additional stations in the northern part of the Sound and in the Parker River to provide supplementary finfish data. The stretched-mesh size of the twine in the wings and the cod end was 3.8 cm and 2.5 cm, respectively. A five-minute tow was made at each station with the aid of a 16-foot outboard powered work boat.

For the 1993/4 study, trawling was carried out with a 4.9 m otter trawl (mesh size of 1.91 cm in the wings and 0.48 cm in the cod end) towed behind a 16 foot Boston Whaler. Trawls in Plum Island Sound (stations 10-15) were generally carried out for 2 minutes at speeds of about 1.5 m s^{-1}. Trawls in the Parker River (stations 16-21) were carried out for only one minute, due to obstructions within the river that precluded longer trawls. Shorter tows were noted on the data sheets and factored into our calculations. Each station was trawled in triplicate at each sample date, however the narrow confines of some Parker River stations (see below) often forced us to trawl over the same area.

The location of trawl stations in Plum Island Sound in the 1993/4 study was based largely on those sampled by Jerome et al. (Table 4.2) with a few modifications. MAS/WH did not sample DMF’s offshore station OS1 (Camp Sea Haven) in Ipswich Bay, because they were limited by a smaller boat. The MAS/WH survey also did not include the station off Great Neck (DMF's OS4) because the area now contains a large number of moorings. MAS/WH did add a station at the entrance to the Parker River.

Trawling in the Parker River itself presented a challenge because of the large number of underwater obstacles and meanders. Rather than attempting to resample the same stations as in the DMF study, MAS/WH selected six stations that ran the length of the tidal part of the river that we felt could be reliably trawled for at least one minute (Table 4.2).

Table 4.2. Trawl Stations. Stations in Plum Island Sound were selected by MAS/WH to be as close as possible to the DMF offshore stations except where noted. In the Parker River upstream from Route 1A, there was no attempt to overlap exactly with DMF sites because of the existence of obstacles, such as underwater snags, that limited what could be trawled now. Nonetheless, the six Parker River stations of MAS/WH should represent similar habitats to what DMF sampled there.

<u>Plum Island Sound Stations:</u>

Station OS1. Camp Sea Haven. This station was located southeast of Camp Sea Haven in Ipswich where the water depths averaged 9 meters at mean low water. It was sampled by DMF, but not MAS/WH.

Station 10. Castle Neck. This station was at the mouth of Plum Island Sound and could be sampled at all tides. It was similar to DMF's OS2, however MAS/WH trawled in shallower water. The substrate was sand. Depth was about 1.5 m at low water.

Station 12. Middle Ground. This station was located just north of the Middle Ground, a salt marsh island in the southern section of Plum Island Sound. Equivalent to DMF's OS3. The substrate was sand. Depth was about 1.5 m at maximum low tide, and the station was sampled at all tides except for maximum low.

Station 13. Nelson's Island. This station was located in the channel offshore of Nelson's Island and shoreline station 4 on the west side of Plum Island Sound. Equivalent to DMF's OS5. Depth was about 1.6 m at low tide, and the station was sampled at all tides except for maximum low.

Station 14. Cape Merrill. This station was located in the Plum Island River just beyond its confluence with the Parker River at the north end of Plum Island Sound. Equivalent to DMF's OS6. The substrate was sand and its minimum depth was about 1.35 m. The station was sampled at all tides.

Station 15. Entrance to Parker River. This station was located north of Dole Island where the Parker River enters Plum Island Sound. The substrate was sand, and it had a depth at low water of about 1.45 m. The station was sampled at all tides. DMF did not sample in this area.

<u>Parker River Stations:</u>

Station 16. Parker River. This station was on the Parker River between the Little and Mill Rivers, several hundred meters east of the railroad bridge. The substrate was mud. No equivalent DMF station was within 2 km in either direction. Depth at low water was about 1.5 m.

Station 17. Parker River. This station was two hundred meters to the west of the railroad bridge. The substrate was mud. The nearest DMF stations were OS8 (Mill River) and OS9 (South Shore). Depth at low water was about 1.5 meters. Sampling was carried out at mid to high tides.

Station 18. Parker River. This station was just east of the first meander in the river east of U.S. Route 1, approximately 0.8 km east of this road. The substrate was mud. This station was just west of DMF's OS9 (South Shore). Depth at low water was about 1.5 meters. Sampling was carried out at mid to high tides.

Station 19. Parker River. This station was several hundred meters west of Thurlow's Bridge (Middle Road). The substrate was mud. The nearest DMF station was OS10 (Thurlow's Bridge). Depth at low water was about 1.6 m, and this station was trawled at all tides.

Station 20. Parker River. This station was about two km west of Thurlow's Bridge (Middle Road). The substrate was mud. No DMF station was located in the immediate vicinity. Depth at low water was about 1.8 m, and this station was trawled at all tides.

Station 21. Parker River. This station was about one km east of the falls at Orchard and Central Street in Byfield. The substrate was mud. Depth at low water was about 1.2 m, and this station was trawled at all tides. This station was several hundred meters east of DMF's OS 11 (Woolen Mill), which in 1993/4 contained a number of underwater obstacles.

4.123. Identification, enumeration, and biomass of fish and decapods

Fish identifications were based on Bigelow and Schroeder (1953), Robins et al. (1986), Scott and Scott (1988) and an estuarine fish key developed by the Fish Ecology Laboratory of University of Massachusetts at Amherst (Basher 1989). Decapod crustaceans, including *Crangon septemspinosa*, *Palaeomonetes* spp. and crabs, were routinely collected in the MAS/WH study. These were identified using Smith (1964) and Gosner (1971, 1978). Fish numbers were expressed as fish per 100 m^2.

4.124. Comparison of results of the two studies

The areas covered by each seine haul done by DMF and MAS/WH were roughly the same (231 v 180). Jerome et al. (1968) carried out two seine hauls at each station on each date and presented results in the monograph as the sum of the two seine hauls. To make the data comparable, the results from the three seine hauls per station per date from the MAS/WH data were summed and then normalized to the same area swept as Jerome et al. by multiplying the sums by 0.667 to adjust for 2 v 3 seine hauls and then by 231/180 to adjust for the differences in area swept. Thus MAS/WH fish numbers x 0.85 represented the same area swept as Jerome et al. These numbers should be considered as catch per unit effort (CPUE) based on the assumption that the catch efficiencies of DMF and the MAS/WH studies were the same.

Another difference was that Jerome et al. sampled from January through December in 1965, whereas the MAS/WH monthly sampling began in June 1993, ran through December 1993, then continued from March - October 1994 (September 1994 was not sampled). Thus comparisons were made only between samples collected during the same months. 1993 and 1994 were considered two separate years and were not pooled together since they likely represent two different recruitment events for marsh fish.

DMF used their larger trawl for the more exposed stations near the mouth of Plum Island Sound, and the shrimp trawl for stations in the Parker River and more protected parts of the Sound. Since both their trawls were larger than that used by MAS/WH and DMF trawled for longer periods of time but used a larger mesh size, only qualitative comparisons (i.e. species lists) have been made. Since MAS/WH did not trawl at the Camp Sea Haven station (DMF’s station OS1) in Ipswich Bay, results from that station are not included in the comparison.

4.13. Results

Twenty-eight species of finfish were collected by DMF at the shore and offshore stations in Plum Island Sound and the Parker River in 1965 (Table 4.3). Thirty-four species were collected by the MAS/WH study in 1993/4. The species that were collected by DMF but not by MAS/WH included spiny dogfish, Atlantic sturgeon, Atlantic cod, sea raven, longhorn sculpin, Atlantic wolffish, ocean pout, yellowtail flounder, and goosefish. These were species from trawl samples, a number of which were caught at the Camp Sea Haven station (OS1) that was not sampled by MAS/WH. The species that were caught by MAS/WH but not by DMF included four species of herring, four freshwater species (golden shiner, banded killifish, yellow perch, and bluegill), brown trout, one stickleback species (black-spotted), grubby, striped bass, bluefish, cunner, rock gunnel, and one species (moonfish) from southern waters.

Table 4.3. A check list of finfish species collected at all sampling stations in the Parker River-Plum Island Sound Estuary, 1965 (DMF study) and 1993/4 (MAS/WH study). The year(s) at which the fish were observed is noted.

Class & Order	Family	Genus & Species	Common Name	Years seen 1965	Years seen 1993/4
CHONDRICHTHYS					
Squaliformes	Squalidae	*Squalus acanthias*	spiny dogfish	X	
Rajiformes	Rajidae	*Raja erinacea*	little skate	X	
		Raja ocellata	winter skate	X	
		Raja spp.	skate species		X
OSTEICHTHYS					
Acipensiformes	Acipenseridae	*Acipenser oxyrhynchus*	Atlantic sturgeon	X	
Clupeiformes	Clupeidae	*Alosa aestivalis*	blueback herring	X	X
		Alosa pseudoharengus	alewife	X	X
		Alosa sapidissima	shad		X
		Brevoortia tyrannus	Atlantic menhaden		X
		Clupea harengus	Atlantic herring		X
		Opisthonema oglinum	thread herring		X
	Osmeridae	*Osmerus mordax*	American smelt	X	X
	Salmonidae	*Salmo trutta*	brown trout		X
Cypriniformes	Cyprinidae	*Notemigonus chrysoleucus*	golden shiner		X
Anguiliformes	Anguillidae	*Anguilla rostrata*	American eel	X	X
Cyprinodontiformes	Cyprinodontidae	*Fundulus heteroclitus*	mummichog	X	X
		Fundulus diaphanous	banded killifish		X
Gadiformes	Gadidae	*Gadus morhua*	Atlantic cod	X	
		Microgadus tomcod	Atlantic tomcod	X	X
		Urophycis spp..	hake	X	X
Gasterosteiformes	Gasterosteidae	*Apeltes quadricus*	four-spined stickleback	X	X
		Gasterosteus aculeatus	three-spined stickleback	X	X
		Gasterosteus wheatlandi	black-spotted stickleback		X
		Pungitius pungitius	nine-spined stickleback	X	X
	Syngnathidae	*Syngnathus fuscus*	northern pipefish	X	X
Perciformes	Percicthyidae	*Morone americanus*	white perch	X	X
		Morone saxatilis	striped bass		X
	Centrarchidae	*Lepomis macrochirus*	bluegill sunfish		X
	Percidae	*Perca flavescens*	yellow perch		X
	Pomatomidae	*Pomatomus saltatrix*	bluefish		X
	Carangidae	*Vomer setapinnus*	moonfish		X
	Labridae	*Tautogolabrus adspersus*	cunner		X
	Ammodytidae	*Ammodytes americanus*	American sand lance	X	X
	Cottidae	*Hemipterus americanus*	sea raven	X	
		Myoxocephalus octodecemspinousus	longhorn sculpin	X	
		Myoxocephalus aenaeus	grubby		X
	Cyclopteridae	*Cyclopterus lumpus*	lumpfish	X	X
	Anarhichadidae	*Anarhichus lupus*	Atlantic wolffish	X	
	Zoarcidae	*Macrozoarces americanus*	ocean pout	X	
	Atherinidiae	*Menidia menidia*	Atlantic silversides	X	X
	Pholidae	*Pholis gunnellus*	rock gunnel		X
Pleuronectiformes	Bothidae	*Scopthalmus aquosus*	windowpane	X	X
	Pleuronectidae	*Limanda ferruginea*	yellowtail flounder	X	
		Pleuronectes americanus	winter flounder	X	X
Lophiformes	Lophiidae	Lophius americanus	goosefish	X	

The 34 species of finfish collected by MAS/WH represented 143,616 individuals. The total number of individual fish collected by DMF was 10,790.

4.131. Shore stations: Comparison of 1993/4 and 1965 data

The 1965 study by DMF was carried out over the course of one year. In order to make the MAS/WH data more directly comparable, data only from the first year of the MAS/WH study (i.e., from June 1993 through May 1994) were used when calculating the average number of fish per 100 m^2.

Fish numbers and species richness - There was a large difference in the number of fish caught by beach seining in 1993/4 compared to the 1965 DMF study (Table 4.4). The average CPUE of fish was about 6 times higher in 1993/4 compared to 1965 (2521 v 405 per 100m^2). This large increase is attributable to a 5-fold increase in mummichogs and a 11 fold increase in Atlantic silversides, the two most common species in both studies. Aside from these two species of "bait fish", the number of other species did not differ very much between the two studies. The 4-fold increase in "river" herring is largely the result of a particularly large catch on one sample day rather than a consistent overall increase throughout the course of the study. Two species that have apparently declined based on the differences in the two studies are three-spined sticklebacks (*Gasterosteus aculeatus*) and rainbow smelt (*Osmerus mordax*). It is clear that the fish community in 1993/4 is even more dominated by mummichogs and Atlantic silversides relative to other species than it was in 1965 (Fig. 4.2a-b).

Since MAS/WH collected data from two summers, the total number of fish caught in each year of that study were compared to the 1965 study (Fig. 4.3). Although numbers of fish were generally higher at most seining stations in 1993 compared to 1994 (compare for example July), fish numbers were higher in both years of our study than in 1965. Species richness based on beach seining was higher in the MAS/WH study compared to the earlier study - 15 vs. 13 species (Table 4.4).

This large increase in fish in Plum Island Sound and the Parker River noted for the entire water body in the 1965 v 1993/4 study occurred at all sampling stations as well (Tables 4.5-4.10). Once again this was primarily related to increases in silversides and mummichogs. Silversides were higher in numbers in 1993/4 compared to 1965 at all stations, the increase ranging from 2.3 times at Newbury Landing to 57 times at Little Neck and 62 times at Nelson's Island. Mummichogs increased at four of the six stations sampled by both us and DMF, increasing 56 times at Great Neck, but declining substantially at the Bluffs and slightly at Nelson's Island.

Table 4.4. Difference in the catch per unit effort of fish by DMF in 1965 and the MAS/Woods Hole study from June 1993 through May 1994. Averages for all shoreline stations sampled with beach seines. Numbers are expressed as individual fish per 100 m^2 to normalize for slight differences in sampling areas during seining.

Year of study

Table 4.4

Species	*1965*	*1993/4*
mummichog	18.402	128.972
Atlantic silverside	5.834	110.006
ninespine stickleback	2.115	2.455
threespine stickleback	0.942	0.325
river herring	0.673	4.107
rainbow smelt	0.393	0.187
American sand lance	0.190	
fourspine stickleback	0.027	0.028
Atlantic cod	0.023	
winter flounder	0.020	0.157
northern pipefish	0.010	0.061
longhorn sculpin	0.003	
Atlantic tomcod	0.003	0.015
blackspotted stickleback		0.123
hake		0.006
bluefish		0.006
grubby		0.018
American eel		0.006
	28.635	246.436

Fig. 4.2a. Distribution of fish caught by seine, DMF 1965 survey.

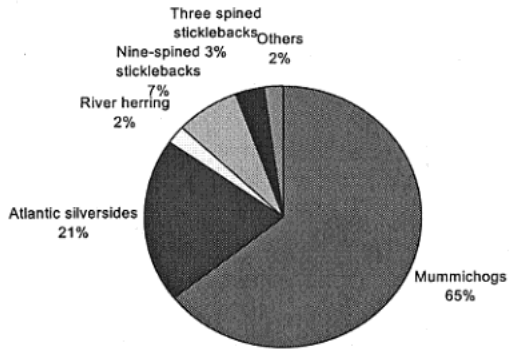


Fig. 4.2b. Distribution of fish caught by MAS/WH at shoreline stations. 1993-4.

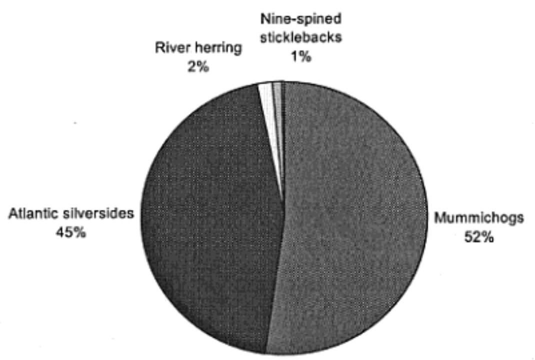
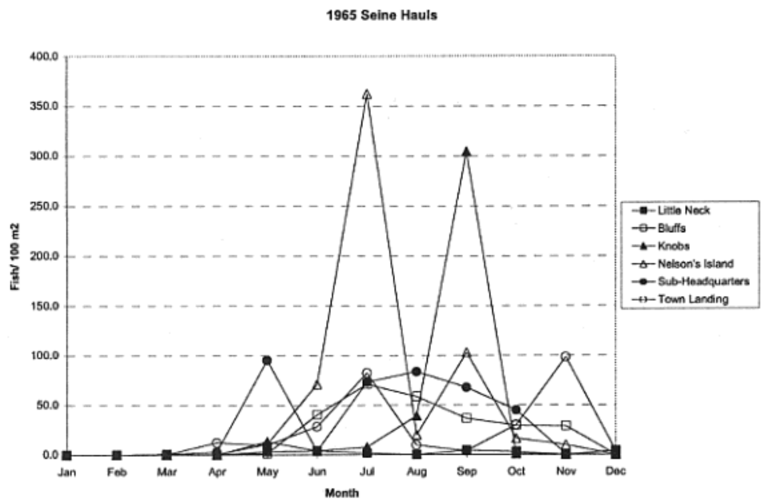
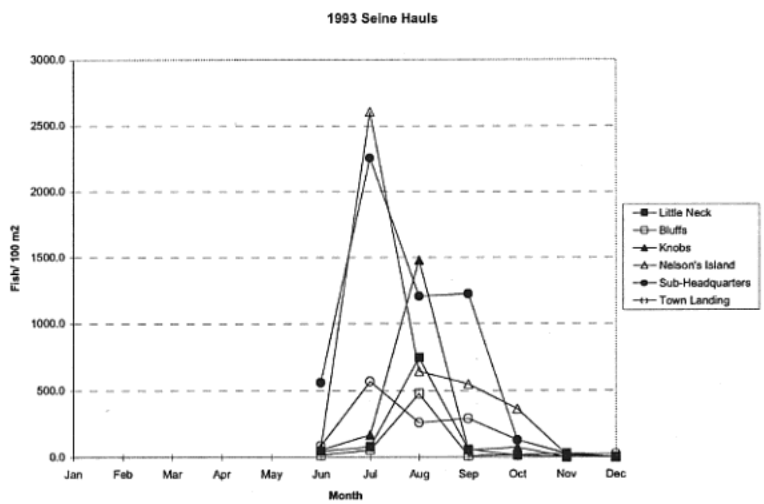


Fig. 4.3. Yearly comparison of fish numbers over months of both studies





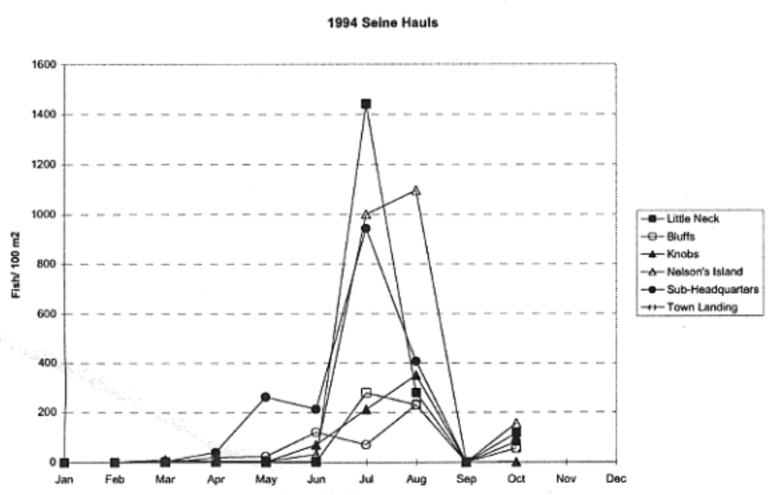


Table 4.5. Catch per unit effort (CPUE) of fish using beach seines at Little Neck, Ipswich. DMF Station S1. MAS/WH Station 1. Numbers are # fish caught per 100 m^2 of area swept by beach seines. This is averaged over a full year of monthly sampling for both studies. Percents are % of catch.

Common name	**1965**		**1993/4**	
	number	percent	number	percent
Atlantic silverside	0.541	32.3	39.411	50.0
mummichog	0.451	26.9	32.366	41.1
3-spine stickleback	0.325	19.4	0.261	0.3
9-spine stickleback	0.198	11.8	6.384	8.1
Atlantic cod	0.108	6.5	0.000	0.0
winter flounder	0.018	1.1	0.015	0.0
rainbow smelt	0.018	1.1	0.123	0.2
longhorn sculpin	0.018	1.1	0.000	0.0
northern pipefish	0.000	0.0	0.153	0.2
grubby	0.000	0.0	0.077	0.1
black-spotted stickleback	0.000	0.0	0.031	0.0
hake sp.	0.000	0.0	0.015	0.0

Table 4.6. CPUE at Bluffs, Ipswich. DMF Station S2. MAS/WH Station 2. Numbers as in Table 4.5.

Common name	**1965**		**1993/4**	
	number	percent	number	percent
mummichog	9.697	36.3	0.221	0.4
9-spine stickleback	7.403	27.7	1.179	1.9
Atlantic silverside	5.714	21.4	58.029	95.3
3-spine stickleback	3.874	14.5	0.239	0.4
blackspotted stickleback	0.000	0.0	0.589	1.0
winter flounder	0.000	0.0	0.460	0.8
Atlantic tomcod	0.000	0.0	0.074	0.1
northern pipefish	0.000	0.0	0.037	0.1
rainbow smelt	0.000	0.0	0.018	0.0
grubby	0.000	0.0	0.018	0.0

Table 4.7. CPUE at Knobs, Rowley. DMF Station S3. MAS/WH Station 3. Numbers as in Table 4.5.

Common name	1965		1993/4	
	number	percent	number	percent
mummichog	31.948	86.3	93.867	51.3
Atlantic silverside	1.883	5.1	84.033	46.0
rainbow smelt	1.710	4.6	0.000	0.0
3-spine stickleback	1.234	3.3	0.074	0.0
9-spine stickleback	0.173	0.5	4.457	2.4
winter flounder	0.043	0.1	0.313	0.2
northern pipefish	0.022	0.1	0.055	0.0
blackspotted stickleback	0.000	0.0	0.018	0.0
American eel	0.000	0.0	0.018	0.0
4-spine stickleback	0.000	0.0	0.018	0.0

Table 4.8. CPUE at Nelson's Island Shoreline Station. DMF Station S4. MAS/WH Station 4. Numbers as in Table 4.5.

Common name	1965		1993/4	
	number	percent	number	percent
mummichog	46.006	87.5	59.061	13.8
Atlantic silverside	4.191	8.0	367.403	86.0
river herring	1.555	3.0	0.000	0.0
3-spine stickleback	0.374	0.7	0.239	0.1
rainbow smelt	0.256	0.5	0.074	0.0
9-spine stickleback	0.118	0.2	0.129	0.0
4-spine stickleback	0.039	0.1	0.037	0.0
Atlantic tomcod	0.020	0.0	0.000	0.0
northern pipefish	0.020	0.0	0.000	0.0
blackspotted stickleback	0.000	0.0	0.055	0.0
bluefish	0.000	0.0	0.037	0.0
winter flounder	0.000	0.0	0.037	0.0

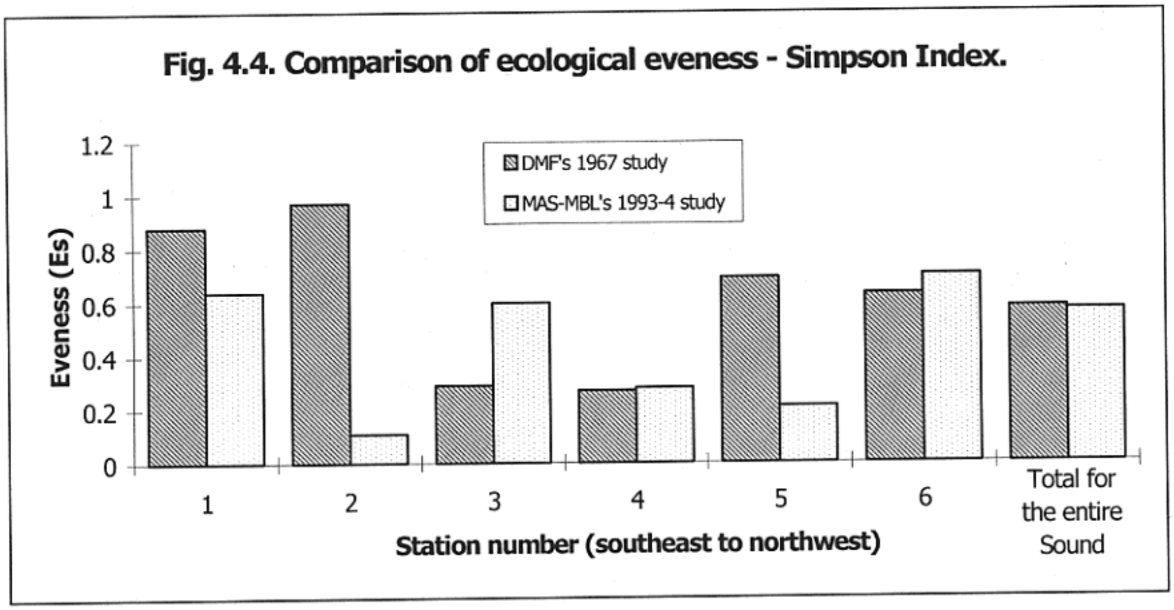
Table 4.9. CPUE at Subheadquarters. DMF Station S5. MAS/WH Station 5. Numbers as in Table 4.5.

Common name	1965		1993/4	
	number	percent	number	percent
mummichog	19.589	55.7	514.770	90.2
Atlantic silverside	8.550	24.3	54.420	9.5
9-spine stickleback	4.524	12.9	0.829	0.1
river herring	2.121	6.0	0.000	0.0
3-spine stickleback	0.173	0.5	0.681	0.1
4-spine stickleback	0.130	0.4	0.018	0.0
rainbow smelt	0.065	0.2	0.000	0.0
winter flounder	0.022	0.1	0.018	0.0
northern pipefish	0.022	0.1	0.000	0.0
blackspotted stickleback	0.000	0.0	0.018	0.0

Table 4.10. Newbury Town Landing. DMF Station S6. MAS/WH Station 6. Numbers as in Table 4.5.

Common name	1965		1993/4	
	number	percent	number	percent
Atlantic silverside	13.763	60.3	48.858	34.2
mummichog	6.025	26.4	67.072	47.0
9-spine stickleback	1.064	4.7	0.479	0.3
American sand lance	1.028	4.5	0.000	0.0
rainbow smelt	0.397	1.7	0.884	0.6
river herring	0.451	2.0	24.641	17.3
3-spine stickleback	0.036	0.2	0.405	0.3
winter flounder	0.036	0.2	0.092	0.1
Atlantic cod	0.018	0.1	0.000	0.0
northern pipefish	0.000	0.0	0.092	0.1
4-spine stickleback	0.000	0.0	0.092	0.1
American eel	0.000	0.0	0.018	0.0
blackspotted stickleback	0.000	0.0	0.018	0.0
Atlantic tomcod	0.000	0.0	0.018	0.0

Evenness - The more complete domination of the Plum Island Sound fish community by two species in 1993/4 compared to 1965 might lead to the conclusion that diversity had declined at the shoreline stations. This was examined by looking at Ecological Evenness (E_S). E_S is based on the Simpson diversity index and is the ratio of the actual diversity to the maximum possible diversity if individuals were completely evenly distributed among all species. Surprisingly, the overall evenness for the entire Sound did not decline, although it did decline in a number of the stations (Fig. 4.5). Station 2 which had a sharp increase in silversides and station 5 which had an order of magnitude increase in mummichogs experienced the steepest decline in E_S from 1965 through 1993/4.



4.132. Trawl stations

The MAS/WH 1993/4 study caught a higher number of species at DMF's shrimp trawl stations than did DMF in 1965 (33 v 13 species, Table 4.11). These stations were in the northern part of Plum Island Sound and the Parker River. The studies are not directly comparable quantitatively since DMF used a larger trawl with a larger mesh size and trawled for long periods of time.

Table 4.11. Species caught in shrimp trawl by DMF in 1965 and the MAS/WH 1993/4 study of Plum Island Sound. The stations included in this table are DMF's OS4-OS11 and MAS/WH's stations 13-22, all in the northern part of Plum Island Sound and the Parker River.

Species	1965 DMF Study	1993/4 MAS/WH Study
skate species	X	X
river herring	X	X
shad		X
Atlantic menhaden		X
Atlantic herring		X
thread herring		X
American smelt	X	X
brown trout		X
golden shiner		X
American eel	X	X
mummichog	X	X
banded killifish		X
Atlantic tomcod	X	X
hake	X	X
four-spined stickleback		X
three-spined stickleback		X
black-spotted stickleback		X
nine-spined stickleback		X
northern pipefish	X	X
white perch	X	X
striped bass		X
bluegill sunfish		X
yellow perch		X
bluefish		X
moonfish		X
cunner		X
American sand lance		X
sea raven		
longhorn sculpin	X	
grubby		X
lumpfish	X	X
Atlantic silversides		X
rock gunnel		X
windowpane	X	X
winter flounder	X	X

Differences in gear type also make it difficult to compare the fish caught at individual trawl stations. Not surprisingly, the differences in species caught is most striking at the two stations where DMF sampled with their large trawl for twenty minutes using the *Peggybell* and MAS/WH sampled for two minutes with their smaller trawl (Tables 4.12-4.13).

Table 4.12. Castle Neck Offshore Station (DMF OS2, MAS/WH Station 10). Total number of fish caught over a one year time period. DMF used a trawl with a sweep of 14.8m and a mesh size of 12.7 cm in the wings and 10.2 cm in the cod end. MAS/WH's trawl had a sweep of 4.9 m and a mesh size of 1.91 cm in the wings and 0.48 cm in the cod end.

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Table 4.13. Middle Ground Offshore Station (DMF OS4, MAS/WH Station 12). Total number of fish caught over a one year time period.

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4.133. Macroinvertebrates

The MAS/WH study kept records of several species of macroinvertebrates caught with the beach seine and shrimp trawl along with finfish (Table 4.14). They recorded a total of 131,909 macroinvertebrates, most of which were the sand shrimp, *Crangon septemspinosa* (130,141). Eighty-seven percent of their beach seining samples included at least one sand shrimp. Other frequently caught macroinvertebrates were the grass shrimp, *Palaeomonetes pugio;* green crab, *Carcinus maenus*; and white fingered mud crab, *Rhithropanopeus harrissi*.

Table 4.14. Frequency of occurrence of macroinvertebrates in seine and trawl samples.

	Beach Seine		Shrimp Trawl	
	frequency caught	percent frequency*	frequency caught	percent frequency*
sand shrimp	249	84.69%	152	33.78%
grass shrimp	93	31.63%	23	5.11%
green crab	44	14.97%	32	7.11%
rock crab	21	7.14%	28	6.22%
lady crab	2	0.68%	3	0.67%
white-fingered mud crab	0	0.00%	72	16.00%
horseshoe crab	0	0.00%	2	0.44%
Say's mud crab	0	0.00%	2	0.44%

*Percent frequencies based on a total of 294 seine tows and 450 trawls

4.134. Overall patterns of species distribution

The overall distribution of fish and decapod species in Plum Island Sound reflects differences in habitat types within this body of water (Table 4.15). The lower part of the Sound consists mostly of sandy substrate. These areas tend to be dominated by Atlantic silversides and sand shrimp. Mummichogs are also quite abundant. Mud flats closely associated with salt marshes are also dominated by these three species plus grass shrimp. The Parker River, which becomes increasingly brackish upriver, has a different assemblage of organisms, dominated by white perch and white fingered mud crab. Anadromous species, particularly "river herring" (alewives and blueback herring) were also frequently caught within the river.

Table 4.15. Dominant organisms associated with different habitats within Plum Island Sound

Open water with sandy substrata
- Atlantic silversides
- mummichogs
- sand shrimp

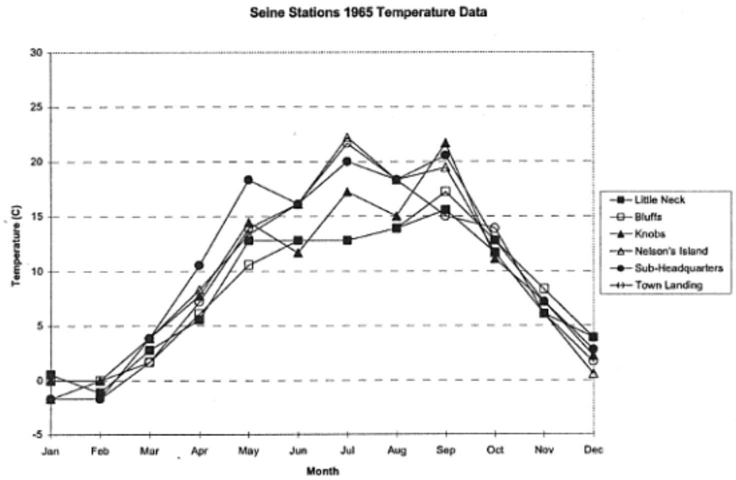
Muddy salt marsh habitats
- mummichogs
- Atlantic silversides
- sand shrimp
- shore shrimp

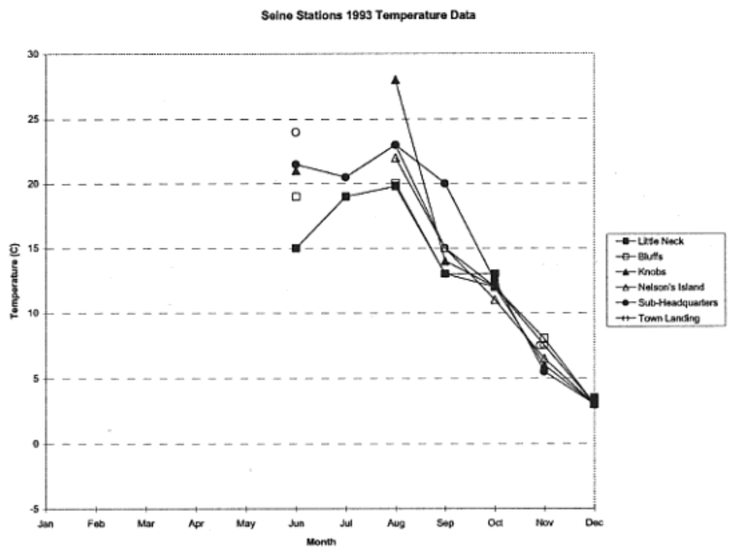
Brackish riverine habitats
- white perch
- river herring
- white-fingered mud crab

4.135. Measurements of physical parameters

Water temperatures were higher at most stations in the MAS/WH study compared to the DMF study for the three summer months and in April (Fig. 4.5). Spring and autumn salinities were much lower in our study, and this was particularly pronounced at two stations that were the most closely associated with riverine discharge: the Town Landing (Station 6) which is on the Parker River and Nelson's Island (Station 4), which is just downstream from the Parker (Fig. 4.6). Not surprisingly higher springtime riverine discharges occurred in the region in the springs of 1993 and 1994 compared to 1964 and 1965, (Fig. 4.7) based on United States Geological Survey discharge data from gauging stations on the Parker and Ipswich Rivers.

Fig. 4.5. Water temperature over time of two studies





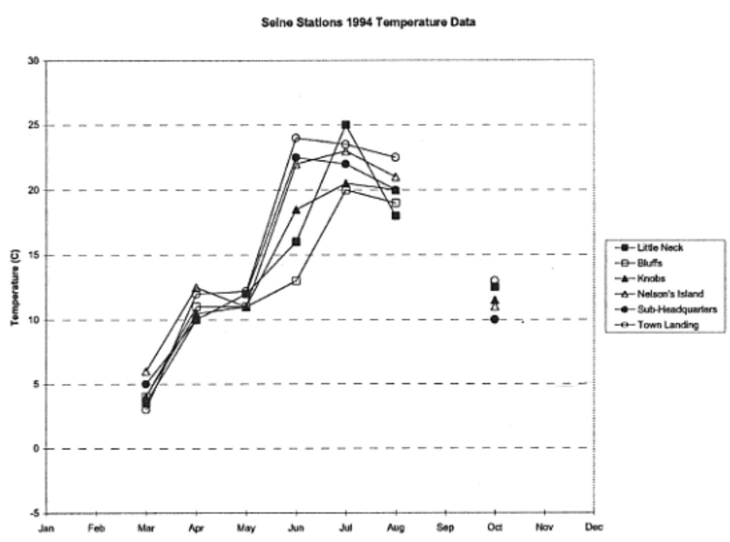
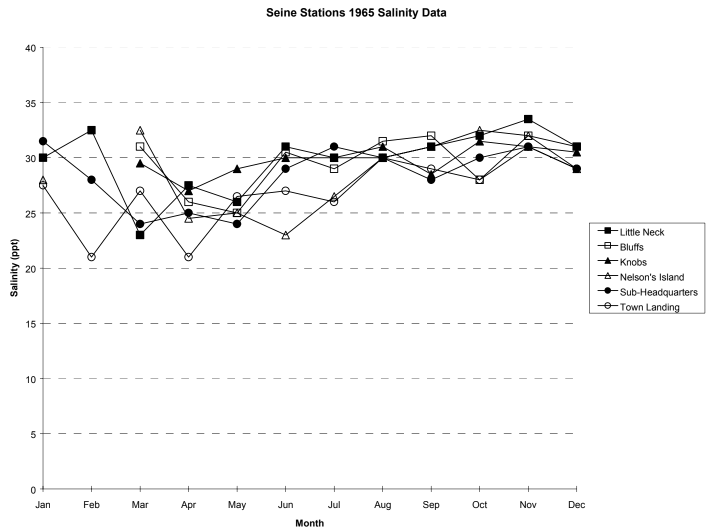
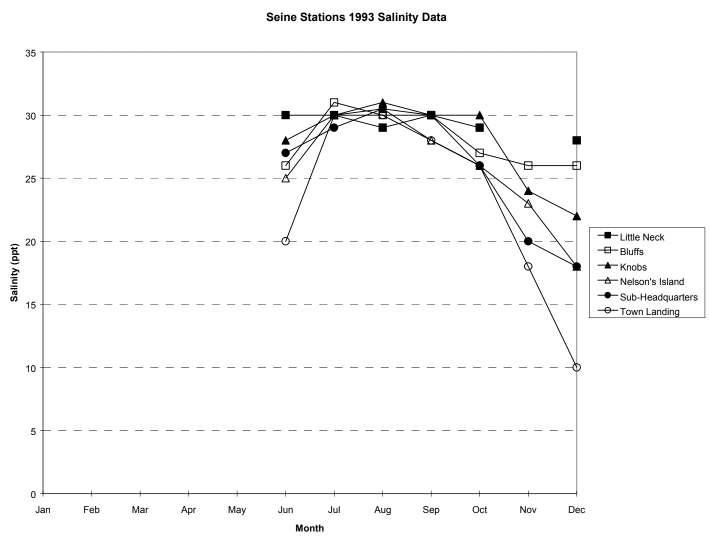


Fig. 4.6. Salinities over time of two studies





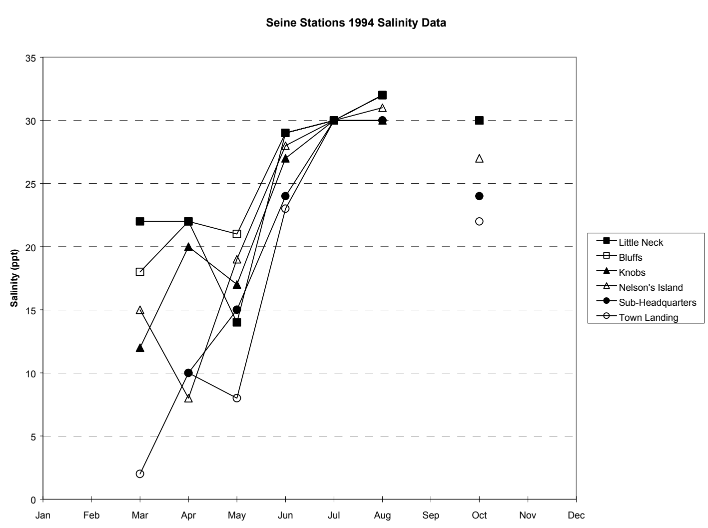
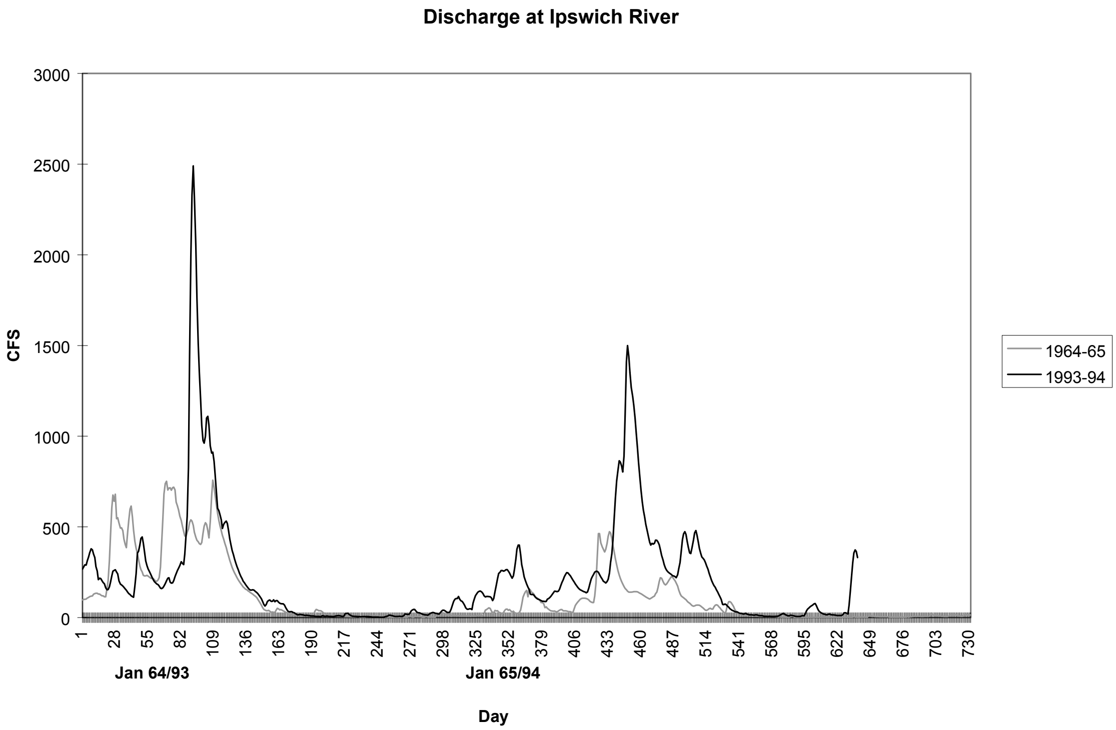
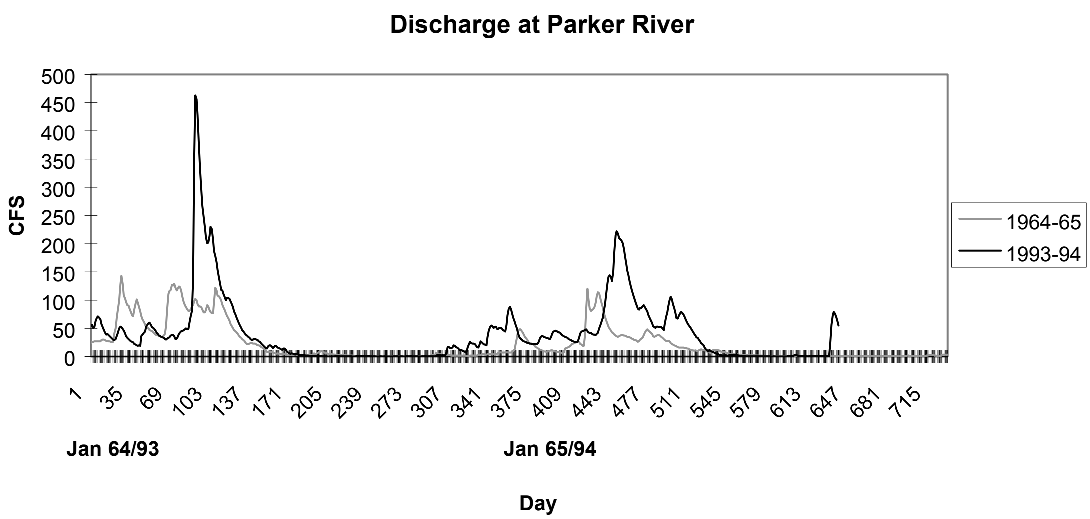


Fig. 4.7 Daily discharge at Ipswich and Parker Rivers over time of two studies





4.14. Discussion

4.141. The reason for differences between the two studies

The large increase in the number of total fish found by beach seining in Plum Island Sound and the Parker River in 1993/4 compared to that found by DMF in 1965 was the result of 6 and 11-fold increases in mummichogs and Atlantic silversides respectively. The major differences between the two studies occurred in summer months. The obvious question is whether this was the result of methodological differences or was a real response to local or regional changes in the habitat.

Differences in methodologies - We do not believe that the substantial differences between the two studies in the number of fish caught by beach seining were the result of differences in methodologies. Both the MAS/WH and DMF studies used 15.2 m beach seines with a central bag. If anything, the slight differences in methods should have favored a greater catch for DMF since DMF used a smaller mesh size (3.2 mm v 4.8 mm). The only station that was somewhat different in exact location was station 1. DMF's Little Neck station had patches of small cobbles and shells in 1993/4 that made it difficult to reliable keep the lead line of the net on the bottom. This was why MAS/WH moved station 1 several hundred meters north to a smoother beach and renamed it Great Neck. Although MAS/WH did catch more fish at this new seining station than did DMF in the earlier study, they also caught more fish at every other station as well.

Differences in physical parameters - The period in which DMF carried out their survey was characterized by higher salinities and lower freshwater discharges to the Sound than in the MAS/WH study. Mummichogs and silversides are tolerant of a wide range of salinities so its doubtful that differences in salinities alone could explain such a large increase in the number of fish caught. According to Bigelow and Schroeder (1953), Atlantic silversides need summer temperatures as high as about 20^{o}C for successful spawning, so the lower water temperatures recorded in 1964 compared to 1993-1994 may have resulted in reduced spawning success, assuming the lowered temperatures recorded once a month on sampling days reflected patterns throughout the entire summer.

Random fluctuations - It is possible that fish numbers fluctuate drastically from year to year and that the two studies happened to cover different extremes of a natural cycle. If such a cycle does exist, it likely extends for a longer period than one year, since two summers of data both indicated higher numbers of fish in 1993/4 compared to the 1965. The possibility that there are such drastic natural variability in fish numbers cannot be ruled out, and hopefully future monitoring can contribute information that would assess its plausibility.

Local changes in the ecosystem - Fish communities are very sensitive to changes in estuarine habitat quality. Deegan et al. (1993) has developed metrics based on a number of aspects of fish communities that are influenced by water quality parameters, particularly eutrophication. These fish community metrics can then be used to assess the biological integrity of an estuary. Deegan et al. (1993) found a similar increase in "bait fish" in Waquoit Bay on Cape Cod based on a comparison of a 1960s DMF assessment and recent sampling. The Waquoit Bay watershed has undergone rapid development between the time period of the two fish surveys and much of the change in fish communities may be related to the resultant eutrophication and habitat degradation.

In contrast to Waquoit Bay and many other east coast estuaries, Plum Island Sound has remained relatively pristine in the last 25 years. There is no indication that eutrophication is an issue in the Sound itself at this time. Nitrogen loading has likely increased in the largest watershed draining into the Sound, the Ipswich River, due to the extensive suburban growth in some upstream communities, however most of this nitrogen is apparently filtered out in an extensive wetlands system before it ever reaches the Sound (C. Hopkinson, unpublished results of the LMER project). Some smaller streams, such as Ox Pasture Brook in Rowley have serious water quality issues (see water quality chapter), and these may have had effects on the spawning of anadromous and freshwater species in those particular water bodies. B. Chase (pers. comm.) of DMF has suggested that algal growth in some tributaries has degraded the spawning sites of rainbow smelt and thereby contributed to the decline of this once thriving recreational fishery in the region. Despite degradation in certain tributaries, the overall loading of nutrients to the Sound itself from these smaller tributaries is by all indications negligible. Yet the results indicate that, like Waquoit Bay, the fish community of Plum Island Sound has still changed since the 1960s even without any obvious environmental degradation.

One speculation is that mosquito control practices may have impacted the populations of silversides and mummichogs in estuaries in the 1960s. Pesticide used for mosquito control on salt marshes likely included DDT or other chlorinated hydrocarbons. These may have impacted small fish, many of which are very susceptible to many insecticides. DMF found DDT residues in concentrations of 0.132 and 0.246 ppm (live body weight) of body muscle tissue from two white perch analyzed as part of the 1968 Plum Island Sound report. No such residues were present in winter flounder. Four finfish from the Merrimack River estuary had DDT residues ranging from 0.8 to 10 ppm. It is possible that pesticide sampling of mummichogs and silversides might have revealed the presence of pesticide residues in the 1960s and that this may have played a role in their relatively small numbers compared to what was recorded in the 1990s. Although pesticides are still sprayed on the marshes for mosquito control, the ones used in the 1990s, such as malathion and resmethrin, are less persistent, and the spraying is likely less widespread than in the past due to budgetary and environmental concerns from the local communities.

Regional changes - The similarity of changes in the fish community at both Waquoit Bay and Plum Island Sound since the 1960s raises the possibility that both estuaries are responding to regional changes that are occurring within New England. A number of changes in populations of predators on small fish may be at least partially responsible for the results, although as discussed below, the relationship is not entirely clear.

One of the most obvious, recent ecosystem changes experienced by all of New England is the severe decline in groundfish as a result of overfishing by the New England fishing fleet. Some groundfish could have been significant predators on small estuarine fish. Bigelow and Schroeder (1953) list silversides as one of the small fish that are routinely part of the diet of Atlantic cod. The 1960s were also a time of intense overfishing, at that time by foreign vessels whose major groundfish target was haddock (Murawski, in prep.). All groundfish populations in the 1990s have been particularly low thus the loss of piscivorous fish may at least partly explain the apparent population "boom" of small fish in both estuaries.

Striped bass, a major estuarine predator on small fish, was still relatively abundant in the 1960s, and is therefore not likely to have been responsible for differences between fish populations in the 1960s and the 1990s. This fish experienced a crash in the 1970s and a recovery in the 1990s,

Certain species of piscivorous birds have also declined since the 1960s. Populations of tern, which feed on small fish, are down across New England and within the Plum Island region (see bird chapter). The populations of other aquatic birds, such as cormorants, herons, and egrets, that also eat small fish, have increased in the region over the same time period, so it is not clear what the net effect on estuarine fish has been.

4.142. The importance of sand shrimp to Plum Island Sound trophic dynamics

The large number of sand shrimp (*Crangon septemspinosa*) caught in beach seines, and its frequent presence in both seines and trawls points to the importance of this species within the Plum Island Sound estuary. Larger individuals filled the stomach of one striped bass examined in the MAS/WH study, and smaller individuals were a common item in the stomachs of silversides, mummichogs, windowpane flounder, and rainbow smelt. This shrimp is omnivorous, feeding on algae, small animals, and detritus. It clearly plays a major role in the transfer of energy from both benthic algae and detritus to higher trophic levels.

4.143. Future research needs

The differences between the results of 1965 and those in 1993/4 points to the need for more frequent monitoring of the biological communities of Plum Island Sound and other estuaries. Although a number of possible explanations for the differences have been described, more frequent monitoring is needed to adequately explain whether there has been a trend caused by regional environmental factors over the thirty years between the two studies or whether fish populations, particularly those of mummichogs and silversides, naturally exhibit temporal variability within the ranges of the MAS/WH and DMF studies.

4.2. River Herring

by David Mountain, Parker River Clean Water Association

4.21. Commercial Landings

Belding (1921) documented the establishment of a public in-river alewife fishery in 1793 with an annual production of approximately 100 barrels. Beldings' report chronicled other important landmarks in the history of both the management and abuse of the Parker River alewife resource. The first fishing restrictions were established in 1793 limiting the fishing period, net size, number and mesh. In 1805 provisions were made for fish passage at dams. In 1808 the Town of Newbury appointed a herring committee that immediately enacted regulations concerning the location of where herring could be harvested as well as the prohibition of ice fishing. The fact that a herring committee was established and regulations were adopted indicates that the annual herring run was important to the local residents.

Massachusetts commercial landings of alewives peaked in 1958 at 33,814,700 pounds and then dropped dramatically in the late 1960's. The decline continued through the 70's and 80's to the point where the 1990-93 average was only 19,650 pounds.

4.22. Dams

The annual migration of alewives and other anadromous fish in the Plum Island Sound basin has been hampered by dams for over three centuries. In 1636, a year after the first European settlement along the Parker River, a dam for a sawmill was built at the lower falls (Central Street). About the same time a grist mill was built in Ipswich. The Mill River in Rowley was dammed in 1643 and the Egypt River in 1687. By the early 19th century, all the usable tributaries appear to have been dammed and the Parker River had at least seven dams on the mainstem.

The Massachusetts General Court attempted to improve the declining fish populations by passing an act on March 8, 1806 that required Mill owners to make a way sufficient for the passage of fish over their mill dams. It directed them to keep the fishway open and well supplied with water from the fifteenth of April to the first of June.

According to Belding (1921), the construction of dams without adequate provisions for fish passage and the decline of water quality in the rivers caused a considerable reduction in the alewife population within the study area. Belding implied in his report that the alewife fishery in the study area could be restored by the construction of fishways at the dam sites along the rivers.

4.23. Fishways

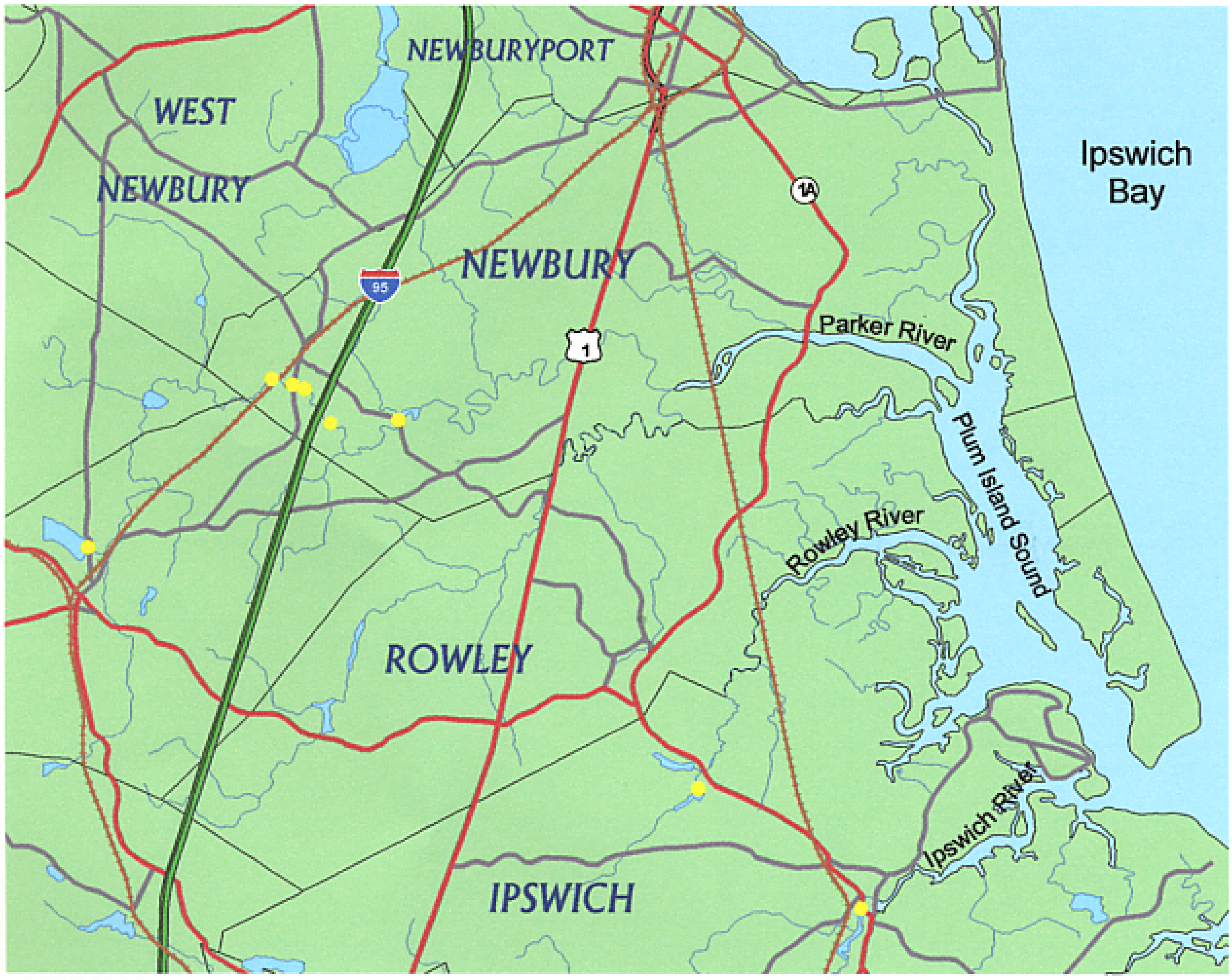
Since Belding's report, fishways have been constructed at six locations along the Parker River leading to Pentucket Pond in Georgetown (Fig. 4.8). With the exception of the relatively new fishway and dam at the outlet of Pentucket Pond, the fishways were built during the 1930's with the aid of Works Progress Administration (WPA) funds. The condition of these fishways is summarized in Table 4.16.

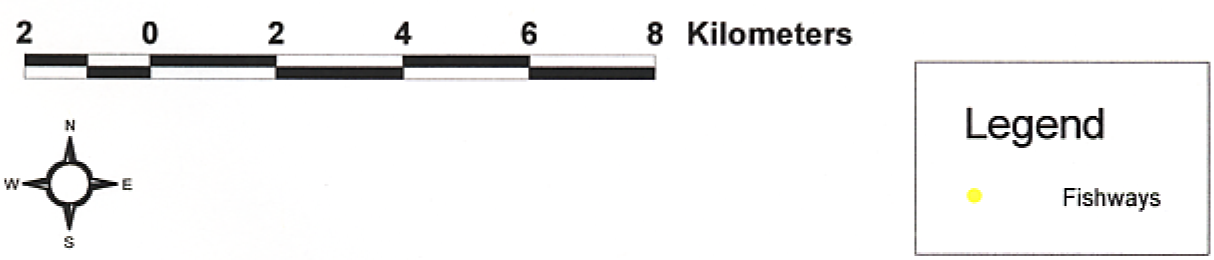
Table 4.16. Description and Condition of Fishways in the Parker River, 1997.

			DAM			FISHWAY			CONTROL BOX		
Fishway Number	Town	Owner	length	Height	Condition	length	No. Of Steps	Condition	Size	Flash Boards	Condition
1	Byfield	Byfield Water District	45'	18'	?	100'	12	repaired 1997	3'x3'x11'	satis-factory	good
2	Byfield	Town of Newbury	45'	8'	Poor	125'	13	repaired 1997	3'x3'x11	missing	repaired 1997
3	Byfield	J. Beck	65'	12 "	Good	105'	11	needs repairs + cleaning	3'x3'x11'? ?	missing	?
4	Byfield	J. Batchelder	75'	18'	Good	335', but now bypassed	21	Alaskan Steep Pass installed in 2000	3'x3'x11	missing	?
5	Byfield	B. Pearson	35'	12'	Needs new cap?	55'	9	needs repairs + cleaning	3'x3'x11	missing	?
6	Georgetown	Town of Georgetown	7 1/2'	14	?	10'	5	rebuilt 2000	no control box		

All fishways needed repairs at the time of the 1968 report by Jerome et al. In the late 1990s, a number of organizations and agencies working together under the Great Marsh Initiative have promoted improvements. Some repairs to sites #1 and #2 were done in 1997 through funding from the Eight Towns and The Bay Committee. For several years, the Essex County Sportsmen's Association annually installed a wooden temporary fishway to get the alewives over the dam at Pentucket Pond (site #6) during the run. In 1999, the town of Georgetown rebuilt this dam and fishway completely, with guidance from the Division of Marine Fisheries and the U.S. Fish and Wildlife Service. Minor adjustments still need to be completed to optimize fish passage. The fishway at site #4 was replaced in November 2000 by an Alaskan Steep Pass installed right into the face of the dam with funding secured by the NOAA Restoration Center and FishAmerica Foundation. These improvements, some additional work on other fishways, and continued maintenance will hopefully lead to enhancement of the alewife run.

Fig. 4.8. Location of Fishways in the Plum Island Sound Area





In 1965, an alewife fishway and pond were constructed by the Town of Ipswich at the confluence of Bull and Dow Brooks by the municipal electric generating plant on Route 1A. The project provided a reserve industrial cooling pool which could be utilized by the alewives as a spawning area. Bull Brook had been used by alewives for many years as they traveled upstream to reach the spawning grounds. Although some alewives were initially observed using the fishway soon after its construction (Jerome et al., 1968), this run has been nonexistent in the 1990s.

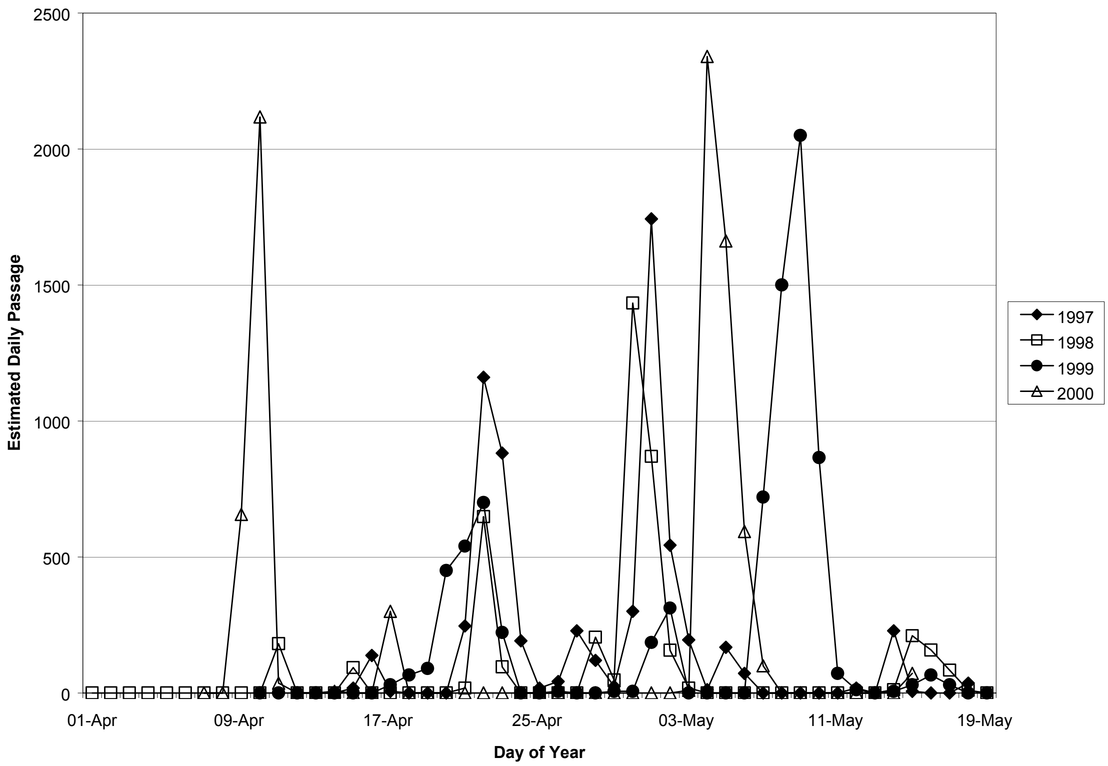
In the 1968 monograph it was reported that the spawning migration of alewives into the upper reaches of the Ipswich River was apparently blocked at the main dam in the center of Ipswich on Route 1A. Although a fishway existed at this site, few if any alewives were observed or reported passing through it. The report recommended that the possibility of reestablishing an alewife run in the upper reaches of the Ipswich River should be investigated. Since that time, emphasis has changed to restoring a blueback herring run instead of alewives. Although Wenham Lake was a historical spawning area for alewives, the Division of Marine Fisheries concluded that the number of potential spawning ponds favored by alewives was limited along the Ipswich. A new fishway was completed in 1997 after a habitat assessment carried out by Trout Unlimited and the Ipswich River Watershed Association under the guidance of DMF and the Riverways Program of the Department of Environmental Management indicated that there was potential spawning habitat for bluebacks in a number of locations above the first dam in the Ipswich.

4.24. Alewife Counts

There is little information on the numbers of alewives that ascended the Parker River annually before or during the period of large commercial landings which peaked in the 1950s. Local residents uniformly maintain that the numbers of alewives have declined dramatically in recent years. In 1973 and 1974, fish were counted as they ascended the fishways at dams #1, #5, and #6 as part of a study conducted by the University of Massachusetts (Beltz, 1975). The counting procedure consisted of estimating the total number of fish by counting for ten minutes every hour and multiplying the count by six. The 1973 total estimated count (Dam 1) was 38,102 and in 1974 the count was 34,638. Using the same method, counts coordinated by the Parker River Clean Water Association estimated that 6,397, 4,232, 7,965, 7,894 alewives passed up the Parker River to Pentucket Pond in 1997-2000.

In 1973, 61% of the fish passing dam #1 passed dam #5 and 39% made it past dam #6 into Pentucket Pond. In 1974, fractions were only 29% and 18% respectively.

Fig. 4.9. Alewife counts on the Parker River at the Central Street dam carried out by the Parker River Clean Water Association.



4.25. Blueback herring

Unlike alewives, there has been little documentation of blueback herring populations in the Parker River-Plum Island Sound region. Studies by the University of Massachusetts-Amherst in the 1970s indicated that bluebacks in the Parker River do not use the fishways, thus spawning is limited to such sites as the below the Woolen Mill on the Parker River in Byfield and below the dam at Glen Mills on the Mill River in Rowley. In 1997 large numbers of bluebacks were observed in the Little River for the first time in years. As discussed above, the rebuilding of the fishway around the Sylvania Dam in the center of Ipswich will hopefully allow access to more spawning sites. The Ipswich River Watershed Association conducted a volunteer count of bluebacks in 1999 and 2000 and recorded seeing 53 and 35 fish respectively. A volunteer count is being organized for the 2001 run. A fishway constructed at the Glen Mills dam would open up several more miles of potential spawning habitat to bluebacks. At the present time, this dam is a barrier to further upstream migration .

4.3. Striped Bass

The striped bass has been an important commercial and recreational fish species in the Parker River-Plum Island Sound area for over a century. Large numbers of stripers migrating along the coast from major spawning areas in Mid Atlantic estuaries appear in the spring and remain until fall. Fishermen congregate during the season to fish from shore and from boats in the estuary and in the adjacent waters of Ipswich Bay.

Jerome et al., (1968) summarized the history of commercial striped bass fishing in the Parker River through the mid 1960s. Bass weighing as much as 75 pounds were reported seined in the area and sold in Boston for one cent per pound in the spring of 1866 and 1867. Large numbers of striped bass wintering in the Parker River and weighing from one to 12 pounds were taken in November, December and January by bow netting. In 1874, one to twelve pound fish caught this way were sold in Boston for $20.00 a barrel in 1874. In 1920 four fishermen netted between 200 and 300 pounds per tide. The total catch for the 1920-21 season was about three tons.

Striped bass were particularly important to local residents during the Great Depression. Legislation passed in 1915 had made bow netting for striped bass illegal, however in 1931, the towns of Rowley, Newbury, and Georgetown were given permission to allow unemployed persons to use this method to catch the fish. A total of 4.4 tons of striped bass were caught by this method during a five week period in February and early March in 1931. During the winter of 1934-35, 26 tons of bass were caught with 40 bow net permits. Size composition of the catch was as follows: 7 to 8 pounds, 50 percent; 12 to 13 pounds, 30 percent; and 16 to 24 pounds, 20 percent. Large numbers of 6 to 10 inch bass were netted and released. In the 1936-37 season only six applications for fishing permits were received because many of the fishermen were employed on W.P.A. projects. Between five and six tons of stripers were caught and sold for an estimated $3,850. Bow netting was again prohibited by state law in 1938.

In 1965, an estimated 1,000 pounds of striped bass, taken by anglers, were sold commercially for $250 at $0.25 per pound (Jerome et al., 1968).

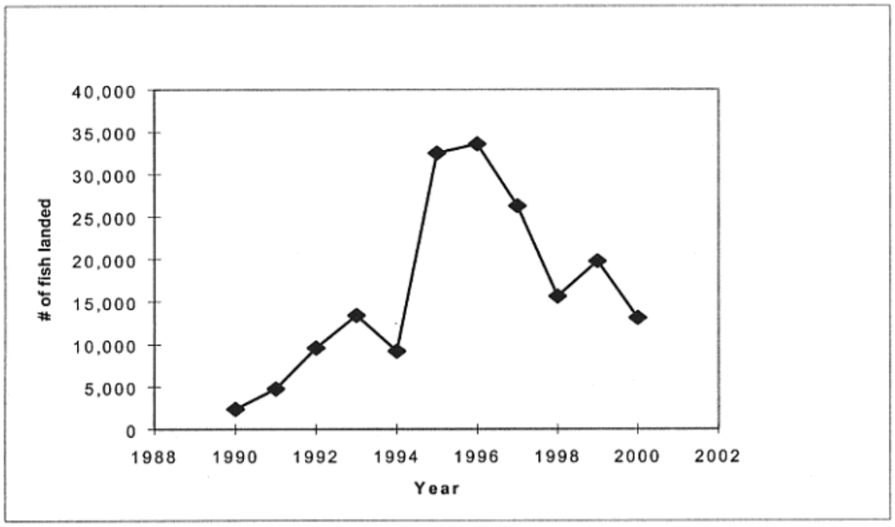
An interesting issue that still has not been resolved is whether striped bass have ever spawned in the Parker River. Bigelow and Schroeder (1953) cite a 1941 publication of Merriman in which he seined a few striped bass fry, ranging in size from 2 3/4 to 3 1/4 inches (7.1-8.5 cm long), from Parker River. The presence of striped bass fry in the river would indicate successful spawning activity by this species since they remain in their natal estuary for their first two years before beginning their seasonal migrations. No recent studies, such as those described earlier in this chapter and by the University of Massachusetts in the Parker River in the 1970s, have corroborated this result, so the issue still remains open.

In the 1980s, striped bass numbers were very low all along the east coast of the United States as a result of overfishing and pollution of their spawning areas. Strict management measures implemented in the 1980s drastically reduced both the commercial and recreational take. The resurgence of stripers in the early 1990s has been touted as a fisheries management success story.

In 1999 commercial fishing regulations included a minimum total length of 34 inches, a limited season of 40 days, required commercial fishing licenses and permits to sell the fish, and mandatory catch reports. The overall commercial quota for the east coast set by the Atlantic States Marine Fisheries Commission was 782,000lbs. Dealers purchasing and selling striped bass were required to have special authorization from the DMF in order to buy fish directly from fishermen. Dealers also had to file weekly and seasonal purchase reports. During 1999, the recreational fishing regulations included a minimum total length of 28 inches and a daily bag limit of one fish per person, no licensing or reporting was necessary.

The resurgence in striped bass numbers has led to a huge jump in the amount of fish caught since the 1980's (Fig. 4.10). The numbers of fish commercially landed in the Ipswich Bay to NH border area increased from 2,354 in 1990 to a high of 33,579 in 1996. Since 1996, Ipswich Bay numbers have decreased, with 13,087 caught in 2000. Across the state, there was a high in the amount of fish commercially caught in 1998, with a decrease shown in 1999.

Fig. 4.10. Commercial Striped Bass Landings from Statistical Area #1 (Ipswich Bay to NH border). Massachusetts Division of Marine Fisheries. Courtesy of David C. McCarron, Fisheries Economist, Massachusetts Division of Marine Fisheries Annisquam River Marine Fisheries Station



4.4 Smelt

Thomas Gage (1840) gives a feeling for the historical abundance of smelt in the region. "Mill River, which forms the dividing line, (in part) between this parish and Newbury, abounds with small fish of various kinds. Many thousand score of smelts are here taken and sold in Boston market yearly."

Smelt, *Osmerus mordax*, spend most of their lives in salt water, running up into fresh water to spawn. Five spawning sites were used by smelt in the study area during the period 1965 through 1967: at the Woolen Mill on Parker River, Newbury; Cart Creek, Newbury; Glen Mills on Mill River, Rowley; Rowley Town Brook, Rowley; and Egypt River, Ipswich. During this period, the bulk of the smelt ran during the month of April when the water temperatures were in the 40's (°F). In 1967, spawning runs occurred at all five sites. Research by the University of Massachusetts-Amherst in the 1970s documented only the first three of those spawning sites (Clayton, 1976).

Winter smelt fisheries formerly existed at five principal locations within the estuary: near Town Wharf on the Ipswich River, Ipswich; Rowley River, Rowley; Wood Island, Mill River, Rowley; and at South Shore and Thurlow's Bridge, Parker River, Newbury. The fishery commenced at the first safe ice and continued for indefinite periods depending on ice conditions controlled by winter thawing and tidal action. Usually smelt houses or screens were used to give protection from the wind and cold. The bulk of the fishing occurred at night.

attributes the decline in Parker River smelt to algal growth in their spawning areas (B. Chase, pers. comm.).

4.5. White Perch

The white perch is a common species in the low salinity, upper part of the estuary. Fishing is centered around Lee's Bridge in Little River and at Thurlow's Bridge in Parker River, Newbury since these sites are easily accessible by road. Traditionally, in the spring at apple blossom time, scores of fishermen with long cane poles would take this fish in considerable quantities although it can be caught from spring to fall (Jerome et al. 1968).

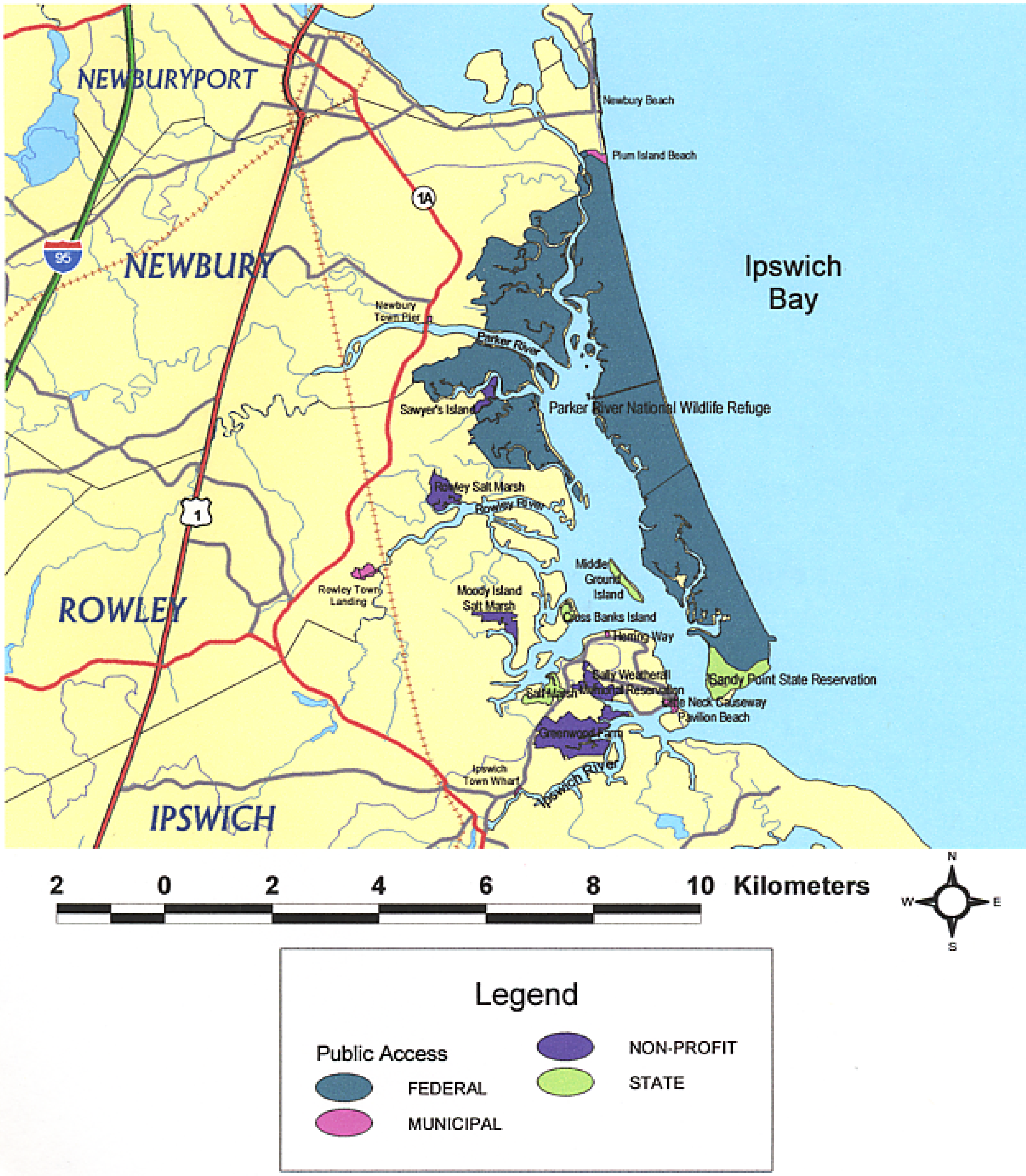
Bigelow and Schroeder (1953) state the white perch occasionally weigh two pounds or a little more, with the average being one pound or less. In the tidal creeks of the study area, white perch weighing two pounds are often taken. In 1966, seven white perch weighing 16 3/4 pounds were included in a catch taken by a single individual. At present, there are no size or harvest restrictions for this species.

Jerome et al. (1968) reported that during 1965, many anglers fished for white perch. In the 1990s, anglers were also observed fishing for white perch on the Parker River, but the general consensus was that the fishery was not as productive as in the past.

4.6. Boat launching ramps

The finfish species described above, such as white perch, winter flounder, and striped bass, have made the Parker River-Plum Island Sound Estuary a center for the sport fishing industry. Although much of this is carried out from shore, the presence of boat launching ramps provides the public with enhanced recreational opportunities.

Fig. 4.11. Public Access Sites (based on CZM map)



Note: Some town landing sites may be restricted
to residents only, please check with local officials.

In 2000, there were four paved boat launching ramps in the study area, two of which were located on the Ipswich River, Ipswich. One is owned by the Ipswich Bay Yacht Club (formerly the Ipswich Outboard Club), and its use is restricted to members of the club. The second ramp**,** located at Town Wharf, is a public facility. A third launching ramp, is the town landing for Rowley and is located off Warehouse Lane on the Rowley River. Newbury’s town landing is located on the Parker River at Route 1A and is heavily used by clammers for access to the Sound. There are a number of unpaved landings, including one on the Eagle Hill River in Ipswich, Bachelder Landing on the Rowley River in Rowley, and the lower landing off Cottage Road in Newbury (to the Parker River). Jerome et al. compiled daily use figures for the launching facility of the Ipswich Bay Yacht Club in 1965 (Table 4.17).

Table 4.17. Boat launchings at the Ipswich Bay Yacht Club in 1965. This ramp was used for approximately 26 weeks, from May through October.

Average number of boats launched per week (Monday thru Friday)	*15*
Average number of boats launched on weekends (Saturday and Sunday)	*50*
Average number of people per boat	3
Percentage of boats used for fishing	10
Launching fee per boat	$1.25
Total number of launchings (fishing)	169
Total revenue from launching fees (fishing)	$211.25
Total number of fishermen	507

In addition to the facilities for launching motor boats, a number of canoe access points have been developed in the estuary. These include put in places on the Ipswich River downstream from the Sylvania Dam, on the Mill River at Route 1 in Newbury, and on the Parker River off Middle Road near Thurlow’s Bridge and at Newbury’s lower landing. During 1965 and 1993/4, no party or charter boats operated out of the study area. Depending on the tides, boats from the Merrimack River occasionally take excursions into Plum Island Sound.

4.7. Summary

Historically, the finfisheries of the Parker River-Plum Island Sound area were of major economic importance. The commercial fisheries declined by the early 1900's and no longer make substantial contributions to the economy of the area. Recreational fishing, although fluctuating greatly over the years depending on the abundance of popular fish species is still a popular activity in the Sound. Striped bass are now a particular favorite species, as they have largely recovered from past overfishing. Mackerel, flounder, white perch, and Atlantic cod still are sought after by anglers in the Sound and off Plum Island beaches. Unfortunately smelt have declined to the point where the traditional Parker River winter recreational fishery for this species no longer exists.

From an ecological perspective, the estuary still provides spawning, nursery and feeding areas for many species of finfish. Abundant forage species, including the mummichog, silversides, and sand shrimp inhabit the shoal areas and marsh creeks. These areas are also used by winter flounder as a nursery habitat and seasonally by schools of young predatory striped bass and bluefish.

Anadromous species, including smelt, alewife and blueback herring, spawn in the headwater streams and spend one or more phases of their life cycle in the estuarine environment. The repair and maintenance of existing fishways, the physical improvement of certain spawning areas, and the construction of new facilities are needed to improve and insure the future of the anadromous fish populations (alewife, blueback and smelt) within the study area.

CHAPTER 5. SHELLFISH

5.1. Soft shell Clams

The soft shell clam is the most important fishery in Plum Island Sound. The financial impact of this bivalve can be felt along many economic lines; from the harvesters to the distributors, from the processors to the restaurant owners. The industry is powerfully influenced by a variety of external factors which effect the productivity of this fishery. Pollution, over-harvesting, and predation are the main issues facing the fishery. Balancing these influences with economic need is critical to the long-term sustainability of the resource and the industry that depends on it.

The shellfish resources of the estuary have not been inventoried in the field since the 1968 monograph. For purposes of updating shellfish data, shell fishermen in the region were interviewed, town harvest and license statistics were compiled, and published and unpublished reports were reviewed. Harvest statistics, which are submitted to the Division of Marine Fisheries (DMF) from the individual towns, were also reviewed. Shell fishermen estimated current shellfish population locations and the relative productivity of these areas. Although this report is primarily concerned with the soft shell clam, *Mya arenaria,* information on surf clams, *Spisula solidissima*, quahogs, *Mercenaria mercenaria*, and American oysters, *Crassostrea virginica*, is also included. The location of productive mussel (*Mytilus edulis)* beds, razor clams (*Ensis directus)*, and lobstering (*Homarus americanus*) areas have been documented as well.

5.1.1. Historical Background

The early history of the soft shell clam industry in Massachusetts was described well by Belding (1930) as cited by Jerome et al. (1968). Belding stated that this clam was a vital resource for Native Americans and vital to the commercial fisheries as a means of bait, in the eighteenth and nineteenth century. Felt (1834) reported that a sizable bait industry was thriving in Ipswich in 1789 when 1,000 barrels of clams were dug annually and sold in Boston and elsewhere for $5 to $6 a barrel. An estimated $27,000 worth of clams were dug in Ipswich in 1866 *(Ipswich Bulletin,* June 7, 1867). In 1867, Ipswich clammers were earning from $3 to $6 a day as a result of their efforts.

Belding documented that in 1875, the local consumption of the clam became popular, and subsequent years saw a rapid decline in the resource due to a lack of harvesting controls. However, Felt attested to some historical attempts to control harvesting, specifically, "The commoners forbid any more clams to be dug than are necessary for the use of people in the Town, and of fishing vessels. They allow one barrel for each of a crew to the banks, and in proportion for boats in the bay." A law that prohibited clamming on Sunday was passed in Ipswich in 1883. Over-harvesting was undoubtedly a result of an initial philosophy that the resource was inexhaustible.

Clamming boomed in Plum Island Sound during the early 1920's when other shellfishing areas were struggling with pollution problems. In 1927 for example, 47,550 barrels of whole clams were reported harvested and of that 35,225 gallons of shucked clams were registered (Jerome et al., 1968).

Pollution has been a significant constraint on shellfishing in the Sound. In 1928 and 1929, many of the Ipswich shellfish flats, including all of the Ipswich River, were closed by the Massachusetts Department of Public Health because of pollution. An estimated $50,000 and $70,000 was lost in 1930 due to the closure (Annual Report, Ipswich, 1930). The same report emphasized the impact of the closure stating that, "it was probable that nearly one-fifth of the people of the town are dependent on the clam flats. A barrel of clams may bring into Ipswich anywhere from $6.00 to $30.00." In 1931, clamming in Ipswich provided more employment and revenue than any other business. By 1937, the Ipswich shellfish industry was estimated to be worth $200,000 and had a potential value of $500,000 to $1,000,000. In 1939, the soft shell clam industry in Rowley provided an income of approximately $75,000 to the residents of the town (Jerome et al., 1968).

On May 11, 1945, the *Ipswich News and Chronicle* reported that the flats of Treadwell Island and Fox Creek were declared open by the Massachusetts Department of Public Health. At that time, the soft shell clam industry in Ipswich was in poor condition. The Ipswich Annual Report (1945) listed the following causative factors: clam flats invaded by mussels, sea gulls feeding on small clams, the large numbers of nonresidents digging the flats and the need for new regulations. The Ipswich Annual Report (1947) stated, "the clam industry is at its lowest ebb since 1932" (Jerome et al., 1968). Unfortunately, the opening of the Treadwell and Fox Creek flats lasted only a short time due to pollution problems.

Since 1950, landings have varied greatly from year to year, and from town to town. Flats today are more closely regulated and monitored, although shell fishermen still complain of over harvesting and problems with flat productivity. Brousseau (2001) noted that based on the available data, there is no evidence that soft shell clams are being over harvested in the region, however she qualified this by noting a lack of rigor in the collection of harvest statistics. On a positive note, after much effort by the town of Ipswich to clean up pollution sources, the flats of Treadwell Island and Fox Creek were reopened conditionally in 1999. According to Jeff Kennedy of DMF, the soft shell clam from Plum Island Sound, although a fragile resource, still has a national reputation for quality.

5.1.2. A Brief Life History

Soft shell clams inhabit the intertidal flats of estuaries. Like many estuarine organisms, they can tolerate a wide range of temperatures and salinities. In Plum Island Sound the clams inhabit soft sediments where salinities are typically around 30 ppt. Those that inhabit the midpoint between high and low water tend to grow the fastest, consequently this is the region where they are most often harvested. The depth to which they burrow depends on the substrate and the size of the clam.

In general, the substrate composition of Plum Island Sound intertidal clam flats is primarily sand and a sand-silt mixture. Sand is found in areas exposed to strong tidal currents and wave action, and in areas having good subsurface drainage. Sandy muds are found in rivers, creeks, and areas where tidal currents are more restricted. According to Jack Grundstrom, a long-time clammer in Rowley, sand flats are generally less productive than mudflats.

Clams in the region spawn primarily in the summer, and the larvae then drift with the plankton for several weeks (Brousseau, 1999). Those that survive eventually settle to an appropriate substrate, sometimes at a considerable distance from the parent clams. Like many marine animals with planktonic larvae, larval mortality of soft shell clams is high. In addition, recently settled juveniles are susceptible to predation from crabs and other animals as well as mortality from abiotic factors (e.g., low dissolved oxygen, temperature fluctuations). As a result, soft shell clams show tremendous annual variation in recruitment success. As they grow and are able to burrow deeper into the substrate, predation intensity declines. Soft shell clams take two years to reach sexual maturity. At that point they are roughly at the legal minimum size for harvest, which is 51 mm. They can live from 10-12 years.

5.1.3. Aquaculture

Continuing efforts have been made since the 1930's to improve and protect the soft shell clam resources in Ipswich and Rowley by seeding barren flats, removing mussels and controlling predator populations, i.e., green crabs, horseshoe crabs, and moon snails). In 1939, over 440 barrels of seed clams were planted in Ipswich and 120 barrels in Rowley. Twenty-five bushels of seed were transplanted in Ipswich in 1964. Recent experimental efforts by the Merrimack Valley Planning Commission (MVPC) in partnership with local clammers have resulted in small scale restoration of shellfish beds in the Town of Ipswich and Gloucester. MVPC identified flats that were deemed consistently under-productive but appeared suitable for aquaculture. These flats included an area in the Eagle Hill River, portions of Paine Creek, and the south side of the Rowley River. MVPC calculated that these flats could yield approximately 7,000 bushels per year (MVPC, 1997). In 1995 and 1996 MVPC established test plots on the Eagle River Flat (50 12'x12' and 4 12'x50' plots - total area of approximately one acre). These plots were staked and some were netted with polypropylene. The preliminary results of these test plots were encouraging: a survival rate of approximately 55% over two growing seasons. In 1996 the survival rate was calculated to be over 90% (MVPC, 1997).

In Rowley the MVPC identified the Nelson Island Bank as having potential to yield a harvest of $125,000 annually. Currently the flat is considered under productive (MVPC, 1997).

The potential for privately run aquaculture is a source of tension within the clamming community. Some clammers and town officials feel that private leases would take away areas of clamming from the general public, others have embraced the concept of private aquaculture, at least in Ipswich (W. Castonguay, pers. comm). One way to address this concern is to have public aquaculture projects that are carried out with the cooperation of town officials and the clamming community (MVPC, 1997). In reality, since all flats within the Sound, excluding the prohibited Ipswich and Parker River flats, are classified as conditionally approved, and DMF allows private aquaculture only on areas approved unconditionally (i.e. areas that are free from pollution even during heavy rain), completely private aquaculture projects are not possible in Plum Island Sound at this time. Public aquaculture projects on the other hand, are permitted on conditionally approved flats. As a result there is an opportunity for towns to partner with technical organizations to develop aquaculture projects.

5.1.4. Predators of Soft shell Clams

The major predators of soft shell clams have changed over time depending on the relative abundance of each predator species over the years. Moon snails, *Lunatia heros,* locally called cockles, are commonly seen on many of the Plum Island Sound flats. Their presence is marked by drill holes in the shell of the soft shell clam (Jerome et al., 1968). In Newbury there was concern over the abundance of moon snails in the Plum Island River East Flats in 1965, but the productivity of this region is currently fine. Efforts to destroy moon snails have been loosely organized in Rowley in the past years, and the success of these efforts is unknown.

Horseshoe crabs, *Limulus polyphemus*, are also common in the Sound, and their feeding activities are noted by the presence of puddling in the exposed mud flat. In 1949, over 32,000 horseshoe crabs were reportedly destroyed in Ipswich because they were considered a serious menace to soft shell clam seed populations. Horseshoe crabs were so abundant at that time that planting seed clams was deemed inadvisable (Jerome et al., 1968).

In the fall of 1938, vast numbers of green crabs appeared in the estuary. WPA projects were initiated in Ipswich and Rowley to protect soft shell clam resources from this predator. Over 2,500 bushels of green crabs were destroyed in Ipswich in 1939. By 1940, it was reported that the numbers of green crabs had been drastically reduced. In Rowley, the reduction in numbers was estimated at 90 percent (Jerome et al., 1968). In 1992 the town of Ipswich attempted to deter the green crab population by initiating a trapping program. 1/2" wire traps, 12" square and 24" long were used and set on the small clam flats on the Eagle Hill River and other small tributaries (this was also done for harvesting bait for the sport fishery). The traps were quite effective but there were no scientific studies to determine what effect it had the soft shell clam population. It was discontinued because of a lack of a sustainable commercial market. In Ipswich, the MVPC in the establishment of aquaculture sites in the Eagle Hill River identified the green crab as the main predator of the soft shell clam (MVPC, 1997).

In 1965 predation by the green crab, *Carcinus maenus*, was not indicated as a major threat to the soft shell clam (Jerome et al., 1968). Today, its abundance makes it a concern to clammers throughout the region. The amount of predation by the green crab is likely influenced by the abundance of striped bass and gulls, which feed on the crab. According to Wayne Castonguay (Ipswich Shellfish Advisory Board) green crabs are now considered major predators capable of wiping out entire shellfish beds (pers. comm.).

Mussels occasionally compete with clams for space on the flats. They were considered a serious problem by Ipswich clammers in 1944 when one-fifth of the flats were covered with mussels. By 1946, mussels had taken over one-third of the best soft shell clam producing habitat. A barge was purchased in 1948, rigged as a dragger, and utilized for mussel control work. During that year, 750 tons of mussels were removed and destroyed. Another 650 tons were removed in 1949. Mussel control continued to be an important phase of the Ipswich shellfish management program as evidenced by the windrows of mussels gathered and piled on the flats of Grape Island in 1965 (Jerome et al., 1968). Presently mussel replacement is not of grave concern to local clammers.

Bird predation of soft shell clams has not been quantified. The herring gull, *Larus argentatus*, and the great black-backed gull, *Larus marinus*, have been observed feeding on soft shell clams exposed on the flats by diggers. Undersized clams turned up by the diggers during the harvesting process are especially susceptible to predation. Gulls also feed on green crabs, so their net effect on clams is difficult to evaluate.

In addition to gulls, the estuary is heavily utilized by waterfowl. The most important species in relation to shellfish, in terms of abundance and feeding habits, is the black duck, *Anas rubripes*. Locally, in the fall and winter of 1967, the black duck reached a peak population of approximately 20,000 individuals (unpublished data from the U. S. Fish and Wildlife Service, Parker River National Wildlife Refuge, 1967). Maximum counts in the early 1990s were about 1500 (See Table 6.1). This species uses the salt marshes, tidal creeks and clam flats of the study area and the Merrimack River estuary for food and cover. The actual amount of predation damage caused by this species is not known, but evidence points to some feeding on seed clams that are found on or near the surface of the flats. Black duck numbers have declined overall in the east coast and in Plum Island Sound since the 1950s so predation by this duck is likely less of a factor now than in the past.

5.1.5. Licensing

The number of shellfish permits issued has varied greatly throughout the years. In many cases, it is not known whether the permits were sold for commercial or non-commercial purposes. In 1922, 47 permits were issued in Ipswich. Of the 300 permits issued in 1935, 250 were held by "regular diggers" and the remaining 50 by "transients" (Ipswich Annual Report, 1935). As a result of the manpower shortage brought about by World War II, only 40 men were reported digging in 1942. During the period of 1956 -1964, excluding 1960, the average of commercial permits for the Town of Ipswich was 93 and for non-commercial permits it was 1,585 (Jerome et al., 1968). In recent years, however, more complete records have been compiled in the Towns of Ipswich, Newbury and Rowley (Table 5.1).

In addition to the commercial harvest, substantial numbers of individuals harvest shellfish from local flats for their own personal use. A breakdown of the total permits issued in Rowley in 1997 indicate the following: 38% were from resident recreational diggers, 10% were from non-resident recreational diggers, 5% were one day non-resident permits and 16% were issued to diggers over 60. Commercial permits were 31% of the total permits issued in 1997 for the Town of Rowley.

Recreational permits issued in Newbury and Rowley are almost exclusively used to gather soft shell clams, while those in Ipswich included both soft shelled and surf clams (EOEA, 1996).

Table 5.1. Commercial Licenses Issued for Shellfishing (From Town Records).

Year	Newbury*	Rowley **	Ipswich
1994	102	20	111
1995	88	16	120
1996	94	35	160
1997	84	52	186
1998	85	65	206
1999	87	37	153
2000	74	26	125

* Includes senior and minor commercial licenses
** Defined by fiscal year

Table 5.2. Recreational Licenses Issued for Shellfishing (Does not include non resident recreational licenses, licenses issued for over 60 years of age and one day non-resident and resident permits).

Year	Newbury	Rowley*	Ipswich**
1994	54	33	228
1995	70	41	278
1996	58	65	299
1997	68	62	319
1998	74	45	282
1999	77	41	312
2000	55	46	252

* Defined by Fiscal Year
** Includes Family and Resident Permits

5.1.6. Associated Fauna

Several species of larger marine invertebrates are commonly found in the tidal flats along with the soft shell clam. They include the blue mussel, *Mytilus edulis;* duck clam, *Macoma balthica;* false angel wing, *Petricola pholadiformis;* razor clam, *Ensis directus;* ribbed pod shell, *Siliqua costata;* northern moon snail, *Polinices heros;* clam worm, *Nereis virens;* and bloodworm, *Glycera dibranchiata*.

5.1.7. Mortality of Shellfish on the Flats

No evidence of catastrophic shellfish mortality was observed or reported in the flats of

Ipswich or in the estuary as a whole during 1990s. In the late 1960s, however, Arthur Moon, Ipswich Shellfish Constable, reported that high mortality rates were noted on some Ipswich flats. This was attributed to the accumulation of excessive amounts of a marine algae, *Enteromorpha sp.* In 1997, neither Verne Noyes, Newbury Shellfish Constable nor Philip Kent the Ipswich Shellfish Constable, could recollect any significant soft shell clam mortality events in recent years.

5.1.8. Pollution

The National Shellfish Sanitation Program (NSSP) was established in response to increased concern about the human health risks associated with bacteria contamination. The NSSP requires Massachusetts to regularly test water in shellfish growing areas and to classify them according to standards set to protect human health (I.S.S.C., 1988). The Massachusetts Division of Marine Fisheries (DMF) monitors Plum Island Sound and other coastal waters and classifies them based on fecal coliform bacterial levels. Each area has a sanitary classification (Table 5.3) and a status that indicates if an area is open or closed.

In 1996, all shellfish areas in the main section of the Sound were “conditionally approved”, which means that the flats are closed for five days if rainfall levels exceed a minimum of 0.5 inches in a 24 hour period. If more than one inch of rain falls the flats are closed for at least eight days. In such cases, a short-term assessment may extend the time of closure. A specific area may be closed if bacteria levels rise in dry weather. If this condition persists, the sanitary classification might change from “conditionally approved” to “prohibited.” Some areas are “seasonally approved”; for these areas closure may occur in the summer when bacteria counts generally rise.

In 1996 the “conditionally approved” acreage in Plum Island Sound, not counting the Ipswich River estuary, included 3,484.92 open and 349.47 closed acres (Table 5.3). This classification system, based on a draft report of the Parker River Watershed Team, includes open water as well as shellfish beds, so it overestimates the percentages of open areas that actually contain shellfish (EOEA, 1996).

For much of the past century, all of the 180 acres of intertidal shellfish beds in the Ipswich River estuary were classified as “prohibited” for shell fishing because of chronic high levels of fecal coliform bacteria. In a very positive step mentioned above, those at Treadwells Island and Fox Creek were reclassified as “conditionally open” to harvesting in 1999. In 1965 out of a total acreage of clam flats estimated at that time of 755 acres, 574.3 acres (68.6%) were

Table 5.3. CLASSIFICATIONS OF SHELLFISH BEDS IN MASSACHUSETTS. Adapted from the Massachusetts Division of Marine Fisheries, Shellfish Sanitation Program (I.S.S.C., 1988).

Approved: Suitable for human consumption. Sanitary surveys complete, monitoring indicates low levels of fecal coliform bacteria averaging less than 14 fecal coliforms bacteria per 100 ml of seawater with no more than 10 percent of the samples higher than 43.

Seasonally Approved: Approved for shellfishing, except during a certain season. Most seasonally approved shellfish beds are closed during the summer because of higher human activity from summer residents and tourists. Suitable for human consumption during approved periods.

Conditionally Approved: Approved for shellfishing, except during intermittent and predictable pollution events such as rainfall or sewage system overflows. These beds require detailed water quality monitoring during rainfall events. Shellfish are suitable for human consumption during approved periods.

Conditionally Restricted (soft-shelled clams): Areas that are affected by intermittent and predictable pollution events, and meet "restricted" area criteria when a pollution event is not occurring. Fecal coliforms concentrations averaging between 14 to 88 per 100 ml seawater with no more that 10% of the samples greater than 260. Beds are closed after a rainfall of 0.5 inches or more. Shellfish harvested from conditionally restricted areas are not suitable for direct consumption and must be either relayed to an approved area or to a shellfish purification facility and allowed to purge themselves of the pollution over time. These shellfish must be closely monitored and determined to meet strict sanitary standards prior to being marketed for consumption. Shellfish in restricted or conditionally restricted areas can only be harvested by specially licensed commercial diggers; recreational harvesting is not allowed.

Restricted: Averaging between 18 and 88 fecal coliforms per 100 ml seawater with no more than 10% of the samples greater than 260. No rainfall component. Hard shelled clams are other species must be relayed to clean water before harvesting. Not suitable for direct human consumption.

Prohibited/Restricted: Closed due to fecal coliform levels consistently exceeding 80 fecal coliforms per 100 ml seawater. Not suitable for human consumption.

Management Closure: Closed because no sanitary survey was performed by local officials due to lack of manpower, knowledge that the area is unproductive for shellfish, or an assumption that the area is grossly contaminated. These areas are not sufficiently monitored to meet NSSP guidelines. Faced with limited resources, shellfish officials often decide that their first priority is to keep clean beds open rather than address existing pollution.

classified as clean, 124.4 acres (21.7%) were grossly contaminated, and 55.9 (9.7 %) were classified as moderately contaminated. In 1997 before the opening of the Treadwells Island and Fox Creek flats, the total acreage of intertidal flats in Ipswich was estimated as 693 acres, of which 435 (62%) acres were “conditionally approved”, 180 acres (26%) were “prohibited” and 78 acres (12%) were “seasonally closed” (MVPC, 1997). Thus, the percentages of contaminated flats has stayed roughly the same in the past 30 years in Ipswich.

Table 5.4. Classifications for Shellfish Areas in Plum Island Sound, Jan 1, 1996 (EOEA, 1996). These figures include open water as well as harvestable areas.

Town/Area	Classification	Status	Acres
Ipswich/Plum Island Sound	Conditionally Approved	Open	1,894.65
Ipswich/Upper Rowley River	Conditionally Approved	Open	23.02
Newbury/Plum Island Sound	Conditionally Approved	Open	640.82
Newbury/Lower Parker River	Conditionally Approved	Closed	160.87
Newbury/Mill River	Conditionally Approved	Closed	159.47
Rowley/Plum Island Sound	Conditionally Approved	Open	920.11
Rowley/Mill River	Conditionally Approved	Closed	29.13
Rowley/Upper Rowley River	Conditionally Approved	Open	6.32

Plum Island Sound is located between the Ipswich and the Merrimack river watersheds, both of which are plagued by pollution problems that affect the Sound at its margins. A 1991 estimate of the economic loss due to the closure of the Ipswich River clam beds was $ 500,000 (Castonguay, 1991). At the Merrimack River end, Newbury clammers have expressed concern that the proposed dredging of the Plum Island River will change the hydrology of the Sound. The fear is that dredging will allow more contaminated Merrimack River water into the upper portions of the Sound, resulting in more closed clam flats.

The extensive salt marshes of the study area likely act as a buffer between the coastal waters and the uplands. By filtering pollutants, the marshes may mitigate to some extent the impacts of shoreline development on water quality over the clam flats.

5.1.9. Soft Shell Clam Investigations - Town of Ipswich

5.1.9.1. General Description

The intertidal shellfish flats of Ipswich are located in Plum Island Sound, its tributaries including the Ipswich River estuary, and parts of Essex Bay (Fig. 5.1. and Fig. 5.2.). In 1965 the total soft shell clam habitat within the Plum Island Sound part of Ipswich was composed of 574.3 productive and 40.5 unproductive acres. In 1997 the acreage of intertidal flats was estimated at 693.

Ipswich is a major producer of clams in the region. The estimated total population of legal sized clams in the flats of Ipswich in 1965 was 78,648 bushels (Jerome et al., 1968). Between 1985 and 1996, landings ranged from about 5000 to greater than 20,000 bushels per year (Table 5.4). The relatively high harvest levels in 1985 and 1986 were a result of a temporary opening of flats within the Ipswich River estuary. This area was subsequently closed to shellfishing in 1986 due to pollution.

Table 5.5. Ipswich landings of soft shell clams in bushels. Numbers includes flats outside of Plum Island Sound and Ipswich River (e.g. Essex Bay) since the reports do not distinguish actual locations. Based on reports by the Ipswich Shellfish Constable submitted to DMF.

Year	Commercial Landings	Recreational Landings
1990	15,400	1,400
1991	16,957	1,550
1992	19,356	1,600
1993	9,533	1,725
1994	7,043	1,550
1995	12,594	1,475
1996	19,007	1,550
1997	25,284	1,900
1998	20,939	1,750
1999	19,577	1,875

Fig. 5.1. Marine Resources – Town of Ipswich (Ipswich River)

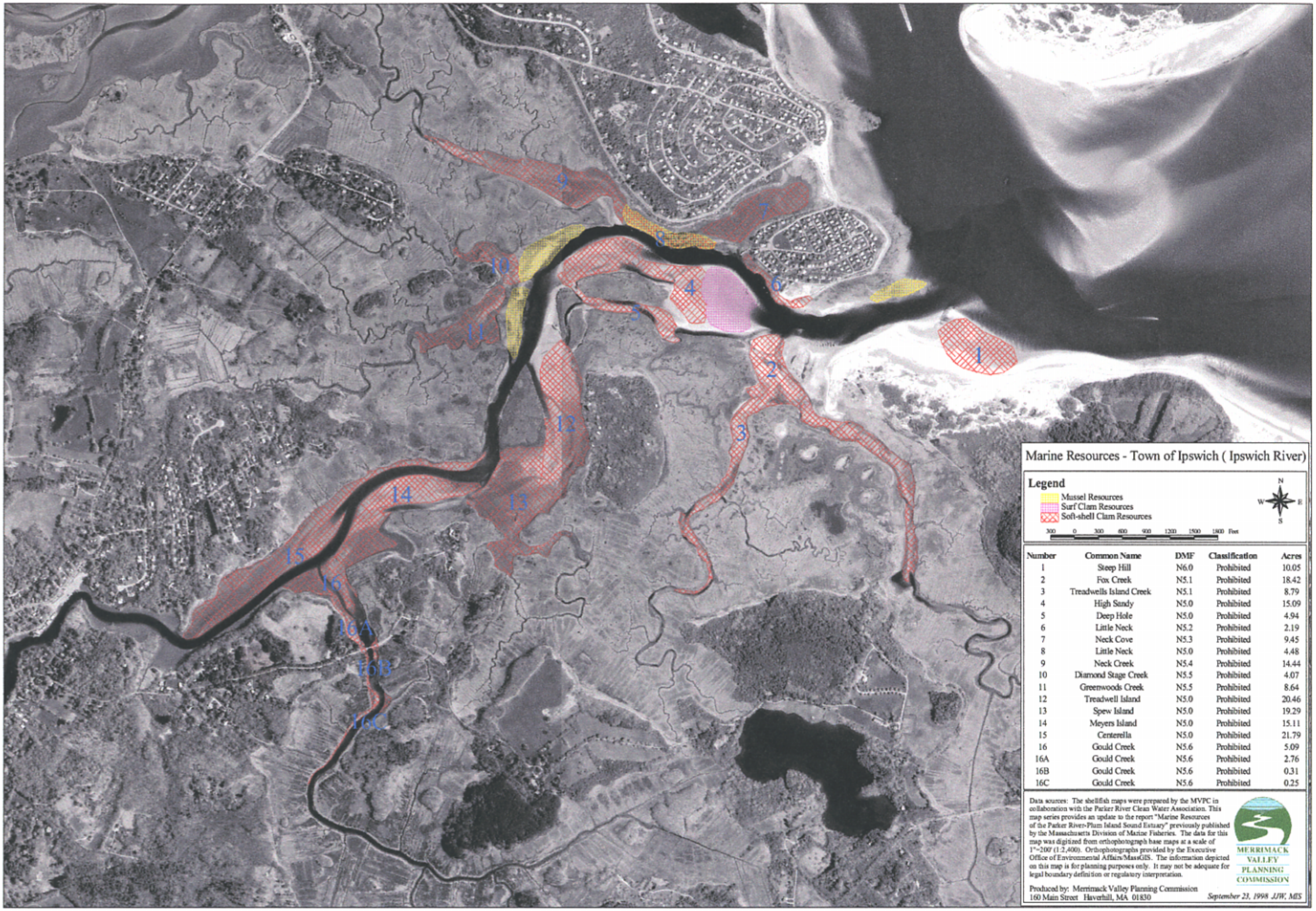
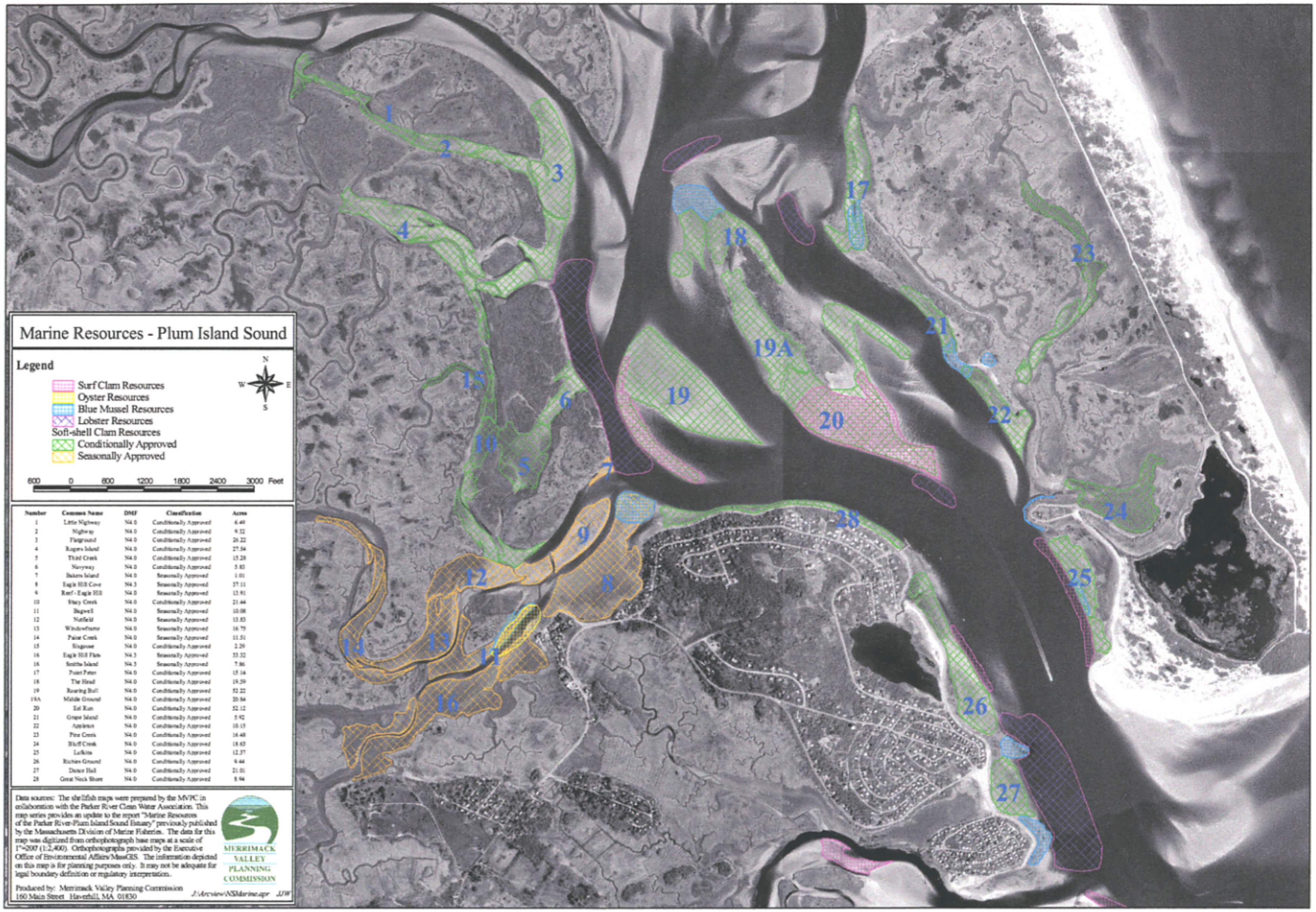


Fig. 5.2. Marine Resources – Town of Ipswich (Plum Island Sound)



Number	Common Name	DMF	Classification	Acres
1	Little Nighway	N4.0	Conditionally Approved	6.40
2	Nighway	N4.0	Conditionally Approved	9.32
3	Flatground	N4.0	Conditionally Approved	26.22
4	Rogers Island	N4.0	Conditionally Approved	27.54
5	Third Creek	N4.0	Conditionally Approved	15.28
6	Navyway	N4.0	Conditionally Approved	5.83
7	Bakers Island	N4.0	Seasonally Approved	1.01
8	Eagle Hill Cove	N4.3	Seasonally Approved	37.11
9	Reef - Eagle Hill	N4.0	Seasonally Approved	13.91
10	Stacy Creek	N4.0	Conditionally Approved	21.44
11	Bagwell	N4.0	Seasonally Approved	10.08
12	Nutfield	N4.0	Seasonally Approved	13.83
13	Windowframe	N4.0	Seasonally Approved	16.75
14	Paine Creek	N4.0	Seasonally Approved	11.51
15	Singpost	N4.0	Conditionally Approved	2.29
16	Eagle Hill Flats	N4.3	Seasonally Approved	33.32
16	Smiths Island	N4.3	Seasonally Approved	7.86
17	Point Peter	N4.0	Conditionally Approved	15.14
18	The Head	N4.0	Conditionally Approved	19.59
19	Roaring Bull	N4.0	Conditionally Approved	52.22
19A	Middle Ground	N4.0	Conditionally Approved	20.84
20	Eel Run	N4.0	Conditionally Approved	52.12
21	Grape Island	N4.0	Conditionally Approved	5.92
22	Appleton	N4.0	Conditionally Approved	10.15
23	Pine Creek	N4.0	Conditionally Approved	16.48
24	Bluff Creek	N4.0	Conditionally Approved	18.63
25	Lufkins	N4.0	Conditionally Approved	12.37
26	Richies Ground	N4.0	Conditionally Approved	9.44
27	Dance Hall	N4.0	Conditionally Approved	21.01
28	Great Neck Shore	N4.0	Conditionally Approved	8.94

Since the 1960s the productivity of the soft shell clam flats has been fairly good. New flats such as the productive Roaring Bull, which was not present in the 1968 study, have insured the stability of the clamming industry. One historic constant has been the closed status of Ipswich River flats for most of the past thirty years with the exception of 1985 and 1986 and the Fox Creek and Treadwells Island conditional openings starting in 1999.

Overall, the most productive flats have been Niaway, Third Creek, Rowley River, Stacey Creek, Roger Island River, Eagle Hill River, and Middle Ground, respectively. These flats are all located on the west side of Plum Island Sound, between the Eagle Hill and Rowley Rivers, where commercial digging was carried on intensively in 1965. Middle Ground had the largest acreage followed by Ipswich River South, Eagle Hill River, Ipswich River North, Fox and Treadwell Creeks, Roger Island River and Eagle Hill Cove. Today the largest flats and their associated acreage can be estimated from figures 5.1. and 5.2.

The estimated harvest of soft shell clams in Ipswich in 1965 by commercial and non-commercial diggers (30,000 bushels) had a wholesale value of approximately $255,000 ($8.50 per bushel, Jerome et al., 1968). Of the total bushels harvested in 1997 (14,069), the wholesale value ($60.00/bushel) was approximately $844,140. The price paid to diggers varied as multipliers increased the price per bushel cost.

5.1.10. Soft shell Clam Investigations - Town of Rowley

5.1.10.1. General Description

All of the intertidal shellfish flats in Rowley are located in Plum Island Sound and its tributaries (Fig. 5.3.). The Town of Rowley has approximately 950 acres of shellfishing areas and open water (MCZM 1996). All of the tidal waters and shellfish flats in Rowley were classified as clean and were open to the digging of shellfish by licensed digger in 1965. In 1996 most were classified as conditionally approved and some, such as the flats in the Mill River were closed due to high fecal coliform levels.

Rowley produces the least amount of soft shell clams of the three towns bordering the Sound. The estimated combined total population of legal sized clams in the flats of Rowley in 1965 was 3,707 bushels. From 1985 to 1996 landings ranged from 60 to 5,500 bushels (Table 5.6).

Fig. 5.3. Marine Resources – Town of Rowley

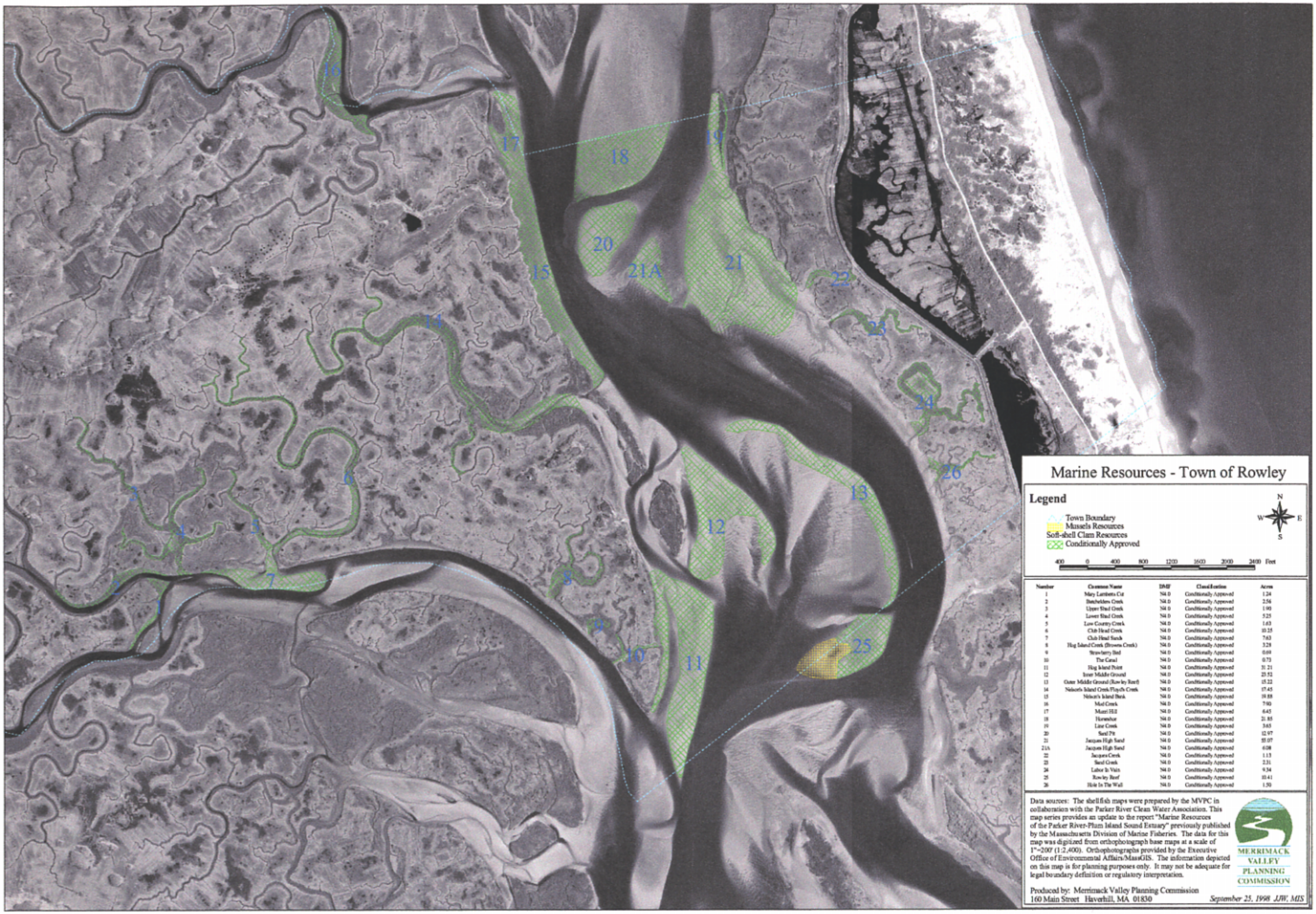


Table 5.6. Bushels of soft shell clams landed in Rowley, 1985-1994. Based on reports of Rowley shellfish constables submitted to DMF (no data submitted to DMF from 1995-2000).

Year	Commercial Landings	Recreational Landings
1985	240	18
1986	720	70
1987	60	50
1988	200	60
1989	5,500	610
1990	3,800	275
1991	No Report	No Report
1992	No Report	No Report
1993	1,400	120
1994	640	70

5.1.10.2. Discussion

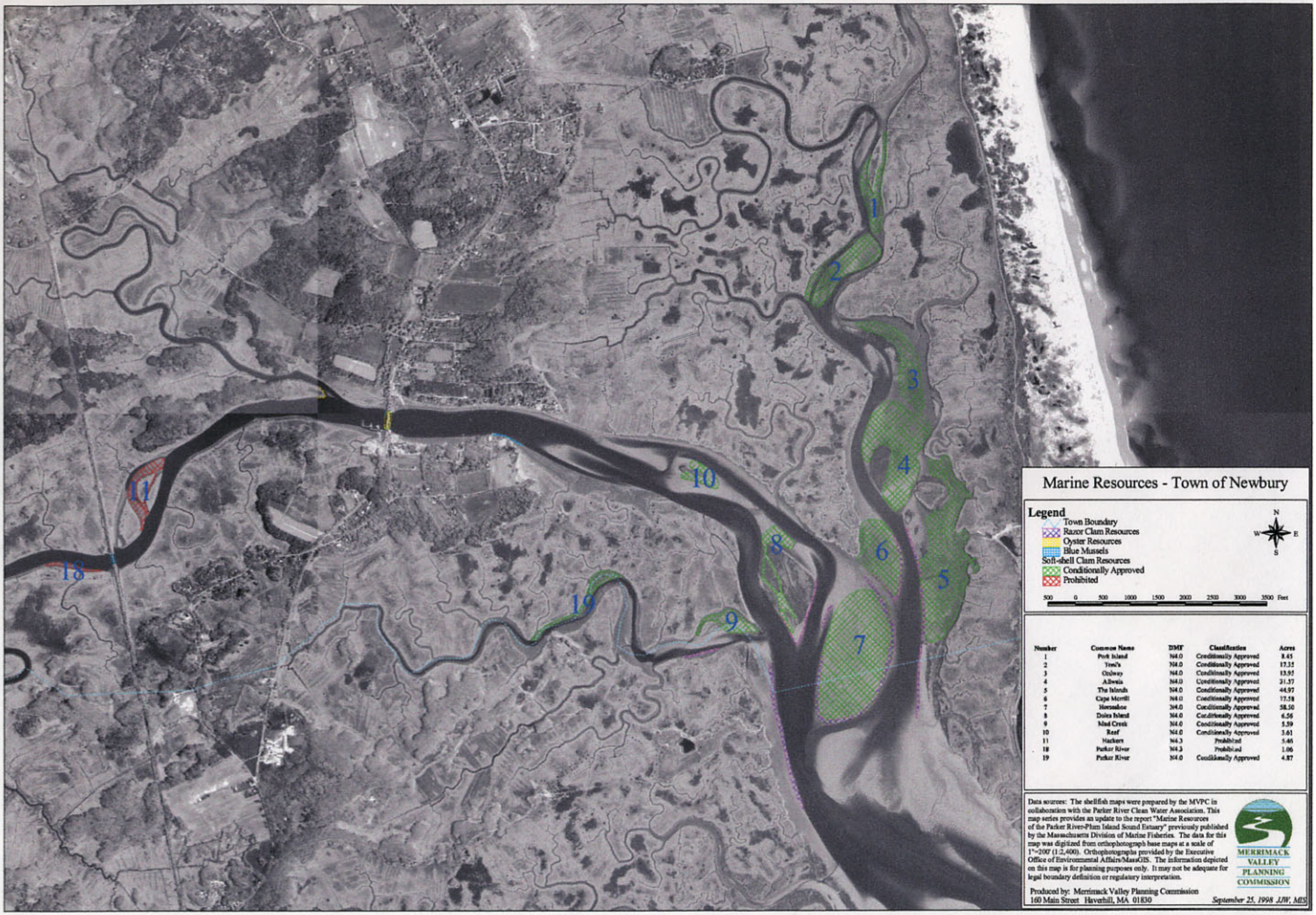
Rowley contained 47.7 acres of productive soft shell clam habitat in 1965 (Jerome et al., 1968). The commercial harvest of soft shell clams reported for Rowley in 1965 was estimated at 5,200 bushels, valued at approximately $44,200. In 1985 the commercial harvest of soft shell clams was estimated at 240 bushels, valued at $12,000. In 1965 Jerome et al. noted that the relatively small acreage of Rowley flats were under intensive use. Since 1985 the total bushels of commercial landings have not approached the 1965 harvest numbers (see Table 5.6).

5.1.11. Soft Shell Clam Investigations - Town of Newbury

5.1.11.1. General Description

The intertidal shellfish flats of Newbury contained within the study area are located in the Parker and Plum Island Rivers and in Plum Island Sound and its tributaries (Fig. 5.1). In 1965 all the tidal waters and shellfish flats in Newbury contained within the study area were classified as clean and were open to the taking of shellfish by diggers licensed by the Town of Newbury. In 2001, clamming was prohibited in the waters north of Pine Island Creek in the Plum Island River and in the Parker River west of Cottage Road due to poor water quality. The remainder of Newbury flats was conditionally approved.

Fig. 5.4. Marine Resources – Town of Newbury



Number	Common Name	DMF	Classification	Acres
1	Pork Island	N4.0	Conditionally Approved	8.45
2	Trod's	N4.0	Conditionally Approved	17.35
3	Ordway	N4.0	Conditionally Approved	13.95
4	Allwels	N4.0	Conditionally Approved	31.37
5	The Islands	N4.0	Conditionally Approved	44.97
6	Cape Merrill	N4.0	Conditionally Approved	17.58
7	Horseshoe	N4.0	Conditionally Approved	58.50
8	Doles Island	N4.0	Conditionally Approved	6.56
9	Mud Creek	N4.0	Conditionally Approved	5.59
10	Reef	N4.0	Conditionally Approved	3.61
11	Hackers	N4.3	Prohibited	5.46
18	Parker River	N4.3	Prohibited	1.06
19	Parker River	N4.0	Conditionally Approved	4.87

Newbury rivals Ipswich in the amount of soft shell clams harvested and in some years the commerical landings exceed that of Ipswich. Between 1985 and 1996, landings ranged from 5000 to 8000 bushels (Table 5.7).

Table 5.7. Newbury Landings of Soft shell Clams in bushels. Based on reports of the Newbury Shellfish Constable submitted to DMF (no data submitted to DMF from 1997-2000).

Year	Commercial Landings	Recreational Landings
1985	6,000	745
1986	6,500	598
1987	5,590	269
1988	8,000	426
1989	5,000	1,149
1990	6,000	650
1991	6,772	788
1992	7,879	2,207
1993	5,927	287
1994	5,400	698
1995	6,890	562
1996	5,000	249

5.1.11.2. Discussion

Commercial diggers harvested approximately 1,680 bushels of soft shell clams in Newbury in 1965, valued at $14,280. In 1985 the value of the commercial harvest of 6,000 bushels was $276,420. From 1985-1994, the mean number of bushels of clams harvested by commercial diggers was 6,307. In 1994 Newbury was responsible for 41% of the total harvest of clams (5400 of 13,083 bushels) dug by commercial diggers in the Sound.

Most of the clams taken today in Newbury come from a variety of flats whereas in the late 1960's, the Ordway flat produced the most clams. Today the Ordway flat (36.4 acres), although still productive, is not the dominant clam producing flat.

5.2. Surf Clams

A recreational surf clam fishery exists and has existed in the subtidal portions of the lower estuary. The large clams are valued primarily for their use in chowders. Generally, the extreme low tides (neap tides) are considered best times to harvest the clam because the deeper portions of the beds are more accessible (Jerome et al., 1968).

The surf clam beds in the Sound are located mainly in Ipswich (Figs. 5.1. and 5.2). One of the largest beds is southeast of Middle Ground in Ipswich. According to shell fisherman Jack Grundstrom, the presence of surf clams in Rowley can be attributed to large storms that move the clams up the estuary into Rowley waters. In 1981, a peak year, Rowley recorded 50 bushels of surf clams (recreational and commercial) harvested valued at approximately $1,500. Newbury has no surf clam harvest.

Ipswich recorded a total of 1,385 bushels of surf clams harvested from 1991 to 1999. These were recorded as recreational catches. Reporting is generally inconsistent.

5.3. Razor Clams

The razor clam harvest has become an important shellfish resource since the 1968 monograph. The bulk of the harvesting takes place in Ipswich. Reporting of the razor clam catch is not consistent annually, and peak harvests usually correspond to high market value. Razor calms are usually found at the lower margins of the soft shell clam flats, and are often dug at the neap tidal cycles. From 1990 to 1999, 15,965 bushels of razor clams were harvested commercially and 767 bushels were harvested recreationally in Ipswich. From 1990 to 1994, 223 bushels of razor clams were harvested commercially and four bushels were harvested recreationally in Newbury. In Rowley in 1990 and 1994, commercial and recreational diggers harvested 22 and 38 bushels respectively.

5.4. Oysters

Oysters were reportedly quite abundant in the estuary when the early settlers first arrived. Ewell (1904) says that, “As lately as 1840, Coffin tells us that there was not a day in the year in which the inmates of the Newbury almshouse, which was more recently the home of Mr. Alfred Ambrose, could not obtain oysters enough for their own use.” [This is now the location of the Triton Regional School.] Today, as in 1965, oysters are known to be present in limited numbers in only a few locations. The locations correspond to rocky substrates where oysters cling. These oysters may be survivors of those planted in the estuary in 1950 (Table 5.8, Jerome et al., 1968).

Table 5.8. Oyster Stocking Records.

Annual Report	Quantity Planted	Location Planted
1938	16 bushels	Rowley River, Rowley
1950	50 bushels	Rowley
1950	50 bushels	Ipswich

Oysters were reportedly stocked in Newbury in 1950. One hundred bushels of adult oysters were planted in the Parker River, 50 bushels near the mouth of Little River and 50 bushels at a location approximately 200 yards east of the Route 1A bridge. In 1964 Division of Marine Fisheries personnel placed two strings of scallop shell cultch containing approximately 6,300 oyster spat beneath a float in Parker River near the Route 1A bridge. Two months later, on November 5, the average length of the spat had increased from 2.2 mm to 8.6 mm, a gain of 6.4 mm. Survival was estimated at 36.5 percent. The experiment was discontinued because of winter conditions. DMF reported in 1968, that the plantings were unsuccessful although today oysters were present just below the Route 1A bridge. The Route 1A site was reportedly used for many years by a Newburyport restaurant owner to store quantities of oysters until needed (Jerome et al., 1968). Today this area (west of Cottage Road) is closed to the harvesting of oysters.

According to the constable's reports the majority of the oyster harvest is recreational, and harvest totals vary considerably from year to year. From 1985-1996 the peak oyster harvest in Newbury was 300 bushels in 1989. In Ipswich 135 bushels were taken in 1990 (the peak harvest number from 1989-1999), and in Rowley there has been no recent recorded harvest.

5.5. Blue Mussels

The mussel harvest for the past decade has been sparse, and what data is available comes from constable reports. In Ipswich from 1990-1999 a total of 1,795 bushels of blue mussels were harvested. The peak year was 1991 when 330 bushels were harvested. These were recorded as recreational harvests. In Newbury and Rowley the mussel harvest in the past decade has totaled less than ten bushels.

5.6. Sea Worms, Family Nereidae and Family Glyceridea

Although the intertidal flats of the study area were used primarily for harvesting soft shell clams and other bivalves, they also can yield commercially viable blood and clam worms (sea worms) used for bait. Regulations governing worm digging and available harvest data vary for each town.

According to the Jerome et al. (1968), 30 men dug clam and blood worms commercially for the bait industry in 1960. Each man averaged about 2,000 worms per day. In 1968, based on available statistics, the total estimated wholesale value of the commercial worm harvest within the study area was $5,000. There are little data on the more recent harvests of sea worms. Boston Harbor and Salem Sound sustain a larger and more developed commercial harvest, possibly because they have substrates more favorable to these species (Castonguay, 1997).

5.7. American Lobster

Plum Island Sound contains a recreational fishery for lobsters. According to the 1968 study, lobstermen/women fished on a seasonal basis from about the 30th of May to the 30th of September, and most of the pots were fished singly. This still holds true today.

For purposes of this study a lobster pot marker survey was conducted on the 29th of August, 1997. Of the 224 pot markers within the Sound, most were clustered in the deepest portions of the Sound. The largest cluster, near the mouth of the Ipswich River, contained 56 pot markers. There were many areas of lone pot markers.

5.8. Green Crab

The green crab harvest in 1965, according to Marchant of the U. S. Bureau of Commercial Fisheries, Gloucester, Massachusetts, amounted to 9,300 pounds with a wholesale value of $775. According to Wayne Castonquay, there is no current commercial green crab harvest, although there have been attempts at commercial harvesting, notably in the early 1990s by a Rowley based harvester. The green crab is primarily used as bait for the sport fish industry.

5.9. Quahogs

According to DMF reports the Town of Ipswich recorded 10 bushels of mixed quahogs harvested in 1968 and 1969. Quahogs are not typically found in the Sound as the northern extent of their range is considered Cape Cod. This harvest may be the result of a pro-active attempt to introduce the species to the Sound although there is no data to support this claim.

5.10. Summary

The soft shell clam fishery in the Parker River-Plum Island Sound estuary is by far the most valuable commercial fishery. In 1996 the commercial value of the soft shell clam harvest in Ipswich, Rowley, and Newbury was over one million dollars. The value of other marine resources wax and wane, but none stands the test of time as well as this clam. There is a need for more rigorous data collection on soft shell clams.

More areas are now listed as closed to shellfishing than in the 1960s, most notably along the Parker River. Most of the Sound is classified as "conditionally approved" now as opposed to "approved" as it was in the 1960s. This may be due to more complete monitoring rather than an overall decline in water quality.

As in the 1960's, much of the contaminated acreage in the Sound is located in the Ipswich River and its tributaries. In 1999 some of these Ipswich River flats opened, illustrating the success of local pollution abatement efforts. The reopened flats provide renewed hope that more beds will open as pollution control efforts widen. Overall it is safe to say a burgeoning population, aging infrastructures and increase in impervious surfaces pose a measure of threat to the regions shellfish resources. It will therefore require constant vigilance and continued proactie efforts to maintain the health of the clam flats in the region.

CHAPTER 6. Birds at Plum Island: A comparison of present and historical observations

6.1. Background

The Plum Island Sound ecosystem is a particularly valuable and world-renowned habitat for migratory birds. During the 1940s, the United States Fish and Wildlife Service (USFWS) began acquiring land on Plum Island to create a wildlife refuge. Today, the Parker River National Wildlife Refuge (PRNWR) includes over 1,850 hectares of protected salt marshes, tidal flats, barrier beach, and upland areas on Plum Island and the mainland. More than 300 species of birds have been recorded on the Refuge, many during spring and fall when large numbers of migratory birds stop over to feed and rest (USFWS, 1990).

In addition to the actual federal refuge itself, some adjacent areas in the region contribute to the overall vitality of the region for wildlife. The tidal flats (Joppa Flats) near the mouth of the Merrimack River in Newburyport, just north of the Refuge, are a major regional migration stopover for shorebirds, particularly in late summer and fall, and for wintering waterfowl (Veit and Peterson, 1993). Two state parks, Sandy Point and Salisbury Beach, contain barrier beaches and salt marshes that are also attractive to birds and other wildlife. Important sections of the salt marshes and uplands along the western shore of Plum Island Sound and the Parker River have been designated as state wildlife management areas. The combination of large acreages of protected land and strategic location along the Atlantic flyway make the greater Plum Island Sound region a magnet for birds (and birders).

Despite the recognized importance of the Plum Island Sound ecosystem to wildlife and the large numbers of people who visit the area to observe birds, little data exist on the historical trends in bird numbers for this area. National Audubon Christmas Bird Counts and winter waterfowl surveys conducted by the Massachusetts Division of Fisheries and Wildlife provide some long term information. Since the late 1980s, members of the Brookline Bird Club, in cooperation with staff biologists at the Refuge, have carried out weekly surveys of waterfowl, raptors, and shorebirds during migration, and biweekly surveys at other times of the year. PRNWR personnel have recently been monitoring brood success of waterfowl, and carrying out yearly monitoring of tern populations as part of a statewide survey of coastal nesting birds. The Eastern Massachusetts Hawk Watch Association carries out weekend monitoring of raptors flying over Plum Island during spring hawk migration season.

As part of the Plum Island Sound Minibay project, the Massachusetts Audubon Society (MAS) evaluated historical and current information on the use of Plum Island by water birds, waterfowl, shorebirds, gulls and terns.

6.2. Methods

Massachusetts Audubon used two major sources of data for the evaluation of birds on Plum Island from the 1930s through the 1990s. For the 1990s they analyzed the results of bird surveys conducted by the Brookline Bird Club in the Refuge during 1990, 1991, and 1993. These surveys were conducted weekly during migration periods (March to May and mid-July to October), and biweekly during the remainder of the year. Each survey included sightings made from several viewpoints along Refuge Road as well as the North Pond, Bill Forward Pool, Crossfarm Hill and the Stage Island area. The Parker River National Wildlife Refuge and the Brookline Bird Club made the results of their bird surveys available. The journals of the noted Massachusetts state ornithologist, Ludlow Griscom, provided the historical comparison. Griscom kept notes on the birds he observed on field trips throughout the state during the 1930s, the 1940s and the 1950s. Many of Griscom's weekly trips were to Essex County and Plum Island. Griscom's journals are currently housed in their original form at the Peabody/Essex Museum in Salem, Massachusetts.

There are some obvious limitations to the data available from the 1930s through the 1950s, since they were not collected in a systematic manner and did not include exact locations on Plum Island. Many of the entries in Griscom's journals are noted as Essex County but do not specify whether or not the sightings were recorded on Plum Island. Only those sightings clearly attributed to Plum Island were included in the evaluation. We do not know, however, if he included a noted tern colony on Woodbridge Island in the Merrimack River in his surveys for Plum Island. In addition, there are much less data available for the 1930s through 1950s than for the 1990s. During the 1940s, coverage of coastal birds by Griscom was probably lower because of the difficulty of accessing parts of the coast during World War II (W. Petersen, pers. comm.). The data for the 1990s are more comprehensive since the surveys were carried out regularly and sightings were clearly attributed to Plum Island. Table 1 compares the total number of surveys conducted each month from the 1930s to the 1950s, to the total number of surveys conducted during the 1990s.

Based on an evaluation of the adequacy of data, four shorebirds (black-bellied plover, greater yellowlegs, semipalmated plover, and semipalmated sandpiper), six waterfowl (American black duck, common loon, green-winged teal, mallard, red-breasted merganser, and white-winged scoter), one gull (Bonaparte's gull), and one tern (common tern) were included in the analysis. Since most of these species are migratory and are therefore not present at Plum Island all the time, the highest number of birds observed each year at Plum Island at any one time was used as an estimate of their numbers at Plum Island for that year. By examining the results of several bird surveys, averages for the maximum number of birds observed in Plum Island Sound during the 1930s, the 1940s, the 1950s and the 1990s were calculated. Comparisons were then based on the three highest numbers (peak migration numbers) during each decade for each species.

6.3. Results

The comparison between bird numbers recorded in Griscom's 1930-1950s journals and the more recent data from the PRNWR suggests that historical changes have occurred in the populations of several species of birds at Plum Island (Table 6.1). Because there are less data available during the 1930s to 1950s than during the 1990s, any decreases in bird populations over time are likely more significant than our analysis demonstrates since there is less chance of getting a higher peak count with a smaller sample size. This is reflected in the higher coefficients of variations for the three decades of historical data collected by Griscom compared to the 1990s.

Table 6.1. Average of the three highest numbers of birds observed at one time at Plum Island during the indicated decade. Numbers are means $\pm$ 1 standard deviation. NR indicates that no observations from Plum Island were recorded by Griscom of that species during that decade.

See next page for Table 6.1.

6.31. Loons and waterfowl

6.311. Common Loon (Gavia immer)

Common loons are common migrants and winter residents along the coast of Massachusetts. Loons appear to be higher in numbers since the 1950s than in the 30s and 40s. The average peak number of common loons recorded has varied from a low of 7 in the 1940s to a high of 55 in the 1990s.

6.312. Green-winged Teal (Anas crecca)

Green-winged teal are commonly found in the coastal marshes of Plum Island and have been confirmed as breeders there since 1954. The average peak number of green-winged teal observed on Plum Island has increased greatly since the 1940s when a peak average of 20 were seen on the Island. During the 1950s, a peak average of 117 green-winged teal were seen on Plum Island and in the 1990s an average peak of 462 were seen.

6.313. American Black Duck (Anas rubripes)

American black ducks are present throughout the year in the salt marshes of Plum Island Sound. One of the main reasons the PRNWR was established was to protect the breeding and wintering habitat of American black ducks. The number of black ducks on Plum Island has been steadily declining since the 1940s when a peak average of 1,800 were observed. During the 1950s, the average peak number of American black ducks

Table 6.1. Average of the three highest numbers of birds observed at one time at Plum Island during the indicated decade. Numbers are means ± 1 standard deviation. NR indicates that no observations from Plum Island were recorded by Griscom of that species during that decade.

Bird Species	**1930s**	**1940s**	**1950s**	**1990s**
Common Loon	13 (±9)	7 (±5)	49 (±32)	55 (±26)
Green-winged Teal	NR	20 (±26)	117 (±58)	680 (±122)
Black Duck	567 (±404)	1800 (±1513)	1552 (±1296)	1426 (±272)
Mallards	2 (±1)	3 (±1)	113 (±162)	209 (±90)
Red-breasted Merganser	21 (±25)	NR	72 (±68)	151 (±33)
White-winged Scoter	1400 (±1442)	684 (±1140)	267 (±208)	417 (±102
Black-bellied Plover	392 (±527)	1183 (±898)	267 (±208)	254 (±32)
Semipalmated Plover	533 (±451)	227 (±323)	NR	989 (±102
Greater Yellowlegs	217 (±247)	310 (±426)	22 (±6)	118 (±13)
Semipalmated Sandpiper	4500 (±4924)	3000 (±1803)	4000 (±5196)	1571 (±91)
Bonaparte's Gull	150 (±132)	142 (±63)	138 (±146)	215 (±112
Common Tern	600 (±361)	NR	267 (±208)	61 (±10)
Avg. Coefficient of Variatio	91.2	94.6	84.8	23.5

recorded on Plum Island declined to 1,552, and in the 1990s the number decreased to 1,048. The U.S. Fish and Wildlife Service (USFWS), which has been monitoring black duck populations in the marshes of Plum Island since the 1950s, has also documented a steady decline in American black duck populations since the early 1960's and has also noted declines throughout the northeast (USFWS as cited in Veit & Petersen, 1993). The decline of black ducks may be in part related to the growth in mallard populations. It is thought that interbreeding between black ducks and mallards has led to a reduction in the number of genetically pure black ducks.

6.314. Mallard (Anas platyrhynchos)

Mallards are known to breed in the marshes of Plum Island Sound (Veit & Petersen, 1993). The average peak number of mallards on Plum Island has increased dramatically between the 1930s and the 1990s. The sharpest increase took place between the 1940s and 1950s when mallards observed in Plum Island Sound rose from an average peak of fewer than 10 during the 1930s and 1940s to 113 during the 1950s. The number of mallards seen at Plum Island has continued to increase to an average peak of 133 observed during the 1990s. This trend is consistent with a documented increase in mallards in the state of Massachusetts since approximately 1910. Mallards have thrived and been attracted to freshwater ponds in many city and town parks as a result of feeding by humans.

6.315. Red-breasted Merganser (Mergus serrator)

Red-breasted mergansers are often observed at Plum Island as migrants and winter residents, with peak populations from late March to May and October through November. These diving ducks feed on small fish such as silversides that they catch with their serrated bills. The average peak number of red-breasted mergansers observed at Plum Island has steadily increased since the 1930s.

6.316. White-winged Scoter (Melanitta fusca)

White-winged scoters are migrants and winter residents along the coast of Massachusetts. The average peak number of white-winged scoters using Plum Island Sound dropped sharply and steadily from 1,400 during the 1930s to 684 in the 1940s and then down to 267 during the 1950s. The average peak number of white-winged scoters observed in the Sound during the 1990s was 417, slightly higher than Griscom's numbers seen during the 1950s. This decline may be related to changes in breeding habitat in the boreal and Arctic regions (Veit & Petersen, 1993).

6.32. Shorebirds

6.321. Black-bellied Plover ((Pluvialis squatarola)

Black-bellied plovers are a common migrant along the Massachusetts coast. During the 1940s, the peak number of black-bellied plovers recorded on Plum Island by

Griscom tripled in size from what it had been in the 1930s to almost 1,200. It then declined to roughly 250 in the 1950s and 1990s. Statewide trends indicate that the population of black-bellied plovers has been relatively stable since the 1930s (Veit & Petersen, 1993).

6.322. Semipalmated Plover (Charadrius semipalmatus)

Semipalmated plovers are another common coastal migrant. The average peak number of semipalmated plovers observed on Plum Island have ranged from 533 during the 1930s to 227 during the 1940s and then to almost 1000 during the 1990s.

6.323. Greater Yellowlegs (Tringa melanoleuca)

Greater yellowlegs are primarily birds of mud flats and salt marshes. Some individuals may spend winters in Massachusetts and others move as far south as South America depending on the weather. The peak number of greater yellowlegs observed on Plum Island has decreased from an average of 217 during the 1930s to 118 during the 1990s. This has not been a steady decline; during that time period, the observations of greater yellowlegs on Plum Island rose to 310 during the 1940s and then dropped to only 22 during the 1950s. One suggestion is that the decline in harvesting salt marsh hay has made the area less desirable to greater yellowlegs since they prefer short grass meadows (W. Petersen, pers. comm.).

6.324. Semipalmated Sandpiper (Calidris pusilla)

Semipalmated sandpipers are the most numerous shorebird in Massachusetts, where they occur primarily in extensive tidal flat areas during migration. The average peak number of semipalmated sandpipers recorded on Plum Island has declined significantly from about 4,500 during the 1930s to approximately 1,500 in the 1990s. Prior to the 1990s, the peak number of semipalmated sandpipers observed in the Sound remained high with about 3,000 seen during the 1940s and 4,000 in the 1950s. These data are consistent with a documented decrease in the number of semipalmated sandpipers that spend time in Massachusetts (Veit & Petersen, 1993). It's possible that a shift in migration routes rather than a population decline has occurred since more than three to four million semipalmated sandpipers have been estimated during July in the Bay of Fundy, New Brunswick, Canada (Harrington and Morrison as cited in Veit & Petersen, 1993).

6.33. Gulls/Terns

6.331. Bonaparte's Gull (Larus philadelphia)

Bonaparte's gulls are common migrants and winter residents in Massachusetts. They move about continuously in response to the availability of food during their non-breeding season. The average peak number of Bonaparte's gulls observed in Plum Island

Sound was slightly higher in the 1990s compared to earlier decades. This may represent fluctuations in migration patterns rather than an actual decline. These fluctuations are evident in the numbers of Bonaparte's gulls observed during the 1990s when the peak per year ranged from 21 to 215.

6.332. Common Tern (Sterna hirundo)

Common terns breed along the coast of Massachusetts and winter in Central and South America. The peak number of common terns observed at Plum Island has decreased significantly since the 1930s when an average of 600 were observed on the Island. During the 1950s, an average peak of 267 were seen at Plum Island, and only a maximum of 61 were observed during the 1990s. This trend is consistent with a significant decline in the population of common terns in Massachusetts since 1910 (Veit & Petersen, 1993). This decline has been attributed in large part to the massive expansion of herring and great black-backed gull populations. The 1930s data for common terns may underrepresent the actual number of birds using Plum Island at the time since Griscom conducted few surveys for common terns during that period, and did not conduct any surveys during some of the peak months that common terns are in Massachusetts.

6.4. Conclusions

Trends and changes in bird numbers and migratory patterns have been inferred by comparing data from the recent bird surveys at the Parker River Wildlife Refuge to data from the recorded field observations from the 1930s through 1950s of the noted ornithologist, Ludlow Griscom who was active. During the period between the 1930s and the 1950s, the average peak numbers of three out of four shorebird species evaluated (greater yellowlegs, semipalmated sandpipers, and black-bellied plovers) decreased at Plum Island, while semipalmated plovers remained relatively stable. In contrast there were greater recorded numbers of three out of five waterfowl species in the 1990s compared to the earlier observations. Mallards, green-winged teal, red-breasted mergansers, and common loons observed in the Plum Island Sound showed overall increases, while white-winged scoters and American black ducks declined. The average peak number of Bonaparte's gulls using the Sound has increased slightly with large fluctuations on a year-to-year basis. The peak number of common terns observed during this period has declined. Loons showed no obvious trends.

It is difficult to attribute population trends for the birds measured in this report to specific local changes since most of these birds are migratory. In general, there is little evidence that Plum Island Sound as a habitat for birds has changed significantly between the 1930s and today. We do know that ditches, which have been dug throughout the marshes to reduce mosquito breeding habitat, have reduced the number of salt pannes available to birds, and that humans have affected mallard populations by feeding them. We suggest that the changes in the average peak numbers of birds in Plum Island may be related to regional and global factors such as the following.

- Changes in the adequacy of breeding habitat in other regions may impact the bird species that come to Plum Island Sound during the non-breeding season.

- Shifts in the number and type of fish found in Plum Island Sound caused by overfishing in the Gulf of Maine and other factors may have increased some of the food species available to birds in the Sound.

- Migratory birds often shift their migration patterns in response to weather conditions and the availability of food.

In addition to identifying historical trends for birds recorded at Plum Island, this analysis provides valuable baseline data about the birds found in the Sound today. This information can be used in the future to evaluate changes in the use of this important habitat by birds.

CHAPTER 7. The Vegetation of Plum Island

7.1. Types of plants occurring in the Plum Island Sound region

A number of notable botanists, such as Jacob Bigelow, John Robinson, Arthur Stanley Pease, and Stuart K. Harris included plants from Plum Island in their surveys and writings (e.g., Harris, 1975). Up until the 1970s, only Harris had made a rigorous attempt to do a complete floral inventory of the island. His *Flora of Essex County* notes 320 plant taxa occurring on Plum Island (cited in McConnell, 1979). The 1968 DMF monograph contained a plant and seaweed list developed from collections made at each seashore fish sampling station and "at other locations throughout the study area." Additional information was obtained from a vegetative transect made by Waldo Kennedy, a student assistant on the Parker River National Wildlife Refuge in 1950. These lists reflected the most common species and were not intended to be comprehensive.

The most complete survey of plants on Plum Island was carried out in the late 1970s by Mark McConnell of the University of New Hampshire for his master's thesis (McConnell, 1979). McConnell compiled a total of 514 taxa from Plum Island. This included his own collections as well as verified records of others. His voucher specimens were deposited at the Hodgdon Herbarium, University of New Hampshire. McConnell described a number of plant associations and the dominant plants in each (Table 7.1). He notes that the vegetation community of the backdune is "very diverse."

Table 7.1. Major habitats and dominant vegetation on Plum Island. Based on McConnell (1979).

<u>Beach</u>	
Ammophila breviligulata	Beach grass
Salsola kali	Saltwort
Cakile edentula	Sea-rocket
Raphanus raphanistrum	Wild radish
<u>Foredune</u>	
Ammophila breviligulata	Beach grass
Salsola kali	Saltwort
Lathyrus japonicus	Beach pea
Euphorbia polygonifolia	Seaside spurge
Artemisia stellariana	Dusty miller
Solidago sempervirens	Seaside goldenrod
<u>Interdune</u>	
*Ammophila breviligulat*a	Beach grass
Andropogon scoparius	Blue-stem
Scirpus cyperinus	Wool-grass
Cyperus spp.	Sedge

Xyris torta	Yellow-eyed grass
Juncus balticus	Rush
Salix spp.	Willow
Populus tremuloides	Trembling aspen
Myrica pensylvanica	Bayberry
Alunus spp.	Alder
Polygonella articulata	Jointweed
Drosera intermedia	Sundew
Spiraea tomentosa	Steeple-bush
Prunus spp.	Wild cherry
Amelanchier canadensis	Shadbush
Pyrus arbutifolia	Red chokeberry
Lathyrus japonicus	Beach pea
Euphorbia polygonifolia	Seaside spurge
Toxicodendron radicans	Poison ivy
Ilex verticillata	Winterberry
Acer rubrum	Red maple
Parthenocissus quinquefolia	Virginia creeper
Hypericum boreale	St. John's-wort
Hudsonia tomentosa	False heather
Lechea maritima	Pinweed
Vaccinium corymbosum	Highbush blueberry
Vaccinium macrocarpon	Cranberry
Lyonia ligustrina	Maleberry
Viburnum recognitum	Arrow-wood
Artemisia stellariana	Dusty miller
Solidago sempervirens	Seaside goldenrod
Aster linariifolius	Aster

<u>Backdune</u>

Pinus nigra	Austrian pine
Pinus strobus	White pine
Pinus rigida	Pitch pine
Agropyron repens	Witch grass
Lolium perenne	Common darnel
Phleum pratense	Timothy
*P*oa spp.	Bluegrass
Agrostis spp.	Bentgrass
Festuca spp.	Fescue
Secale cereale	Rye
Carex pensylvanica	Sedge
Maianthemum canadense	Canada mayflower
Smilax rotundifolia	Common greenbrier
Myrica pensylvanica	Bayberry
Quercus velutina	Black oak
*Celtis occident*alis	Hackberry
Rumex acetosella	Sheep sorrel
Arenaria lateriflora	Grave sandwort
Ranunculus repens	Creeping buttercup
Sassafras albidum	Sassafras
Ribes hirtellum	Gooseberry
Rosa carolina	Rose
Rosa spp.	Rose
Rubus spp.	Blackberry
Prunus maritima	Beach plum

Prunus serotina	Black cherry
Amelanchier canadensis	Shadbush
Vicia spp.	Vetch
*Trifoliu*m spp.	Clover
Toxicodendron radicans	Poison ivy
Celastrus scandens	Bittersweet
Acer rubrum	Red maple
Vitis spp.	Wild grape
Nyssa sylvatica	Black gum
Aralia nudicaulis	Wild sarsaparilla
*Daucus caro*ta	Wild carrot
Vaccinium spp.	Blueberry
Arctostaphylos uva-ursi	Bearberry
Trientalis borealis	Star flower
Convolvulus sepium	Hedge bindweed
Teucrium canadense	Wood-sage
Lonicera morrowi	Honeysuckle

<u>Freshwater Habitats</u>

Onoclea sensibilis	Sensitive fern
Thelypteris palustris	Marsh fern
Typha spp.	Cat-tail
Potamogeton perfoliatus	Pondweed
Potamogeton pectinatus	Sago pondweed
Sagittaria latifolia	Arrowhead
Phragmites australis	Reed grass
Eleocharis parvula	Spike rush
Lemna minor	Duckweed
Iris versicolor	Blue flag
Lythrum salicaria	Purple loosestrife
Lythrum hyssopifolia	Hyssop-leaved loosestrife
Ludwigia palustris	Water purslane
Lycopus spp.	Water-horehound
Bidens spp.	Beggar-ticks

<u>Salt Marsh</u>

Triglochin maritima	Arrow-grass
Spartina alterniflora	Saltwater cordgrass
S. patens	Saltmeadow grass
S. pectinata	Freshwater cordgrass
Puccinellia maritima	Goosegrass
Bassia hirsuta	
Salicornia europaea	Samphire
Sueada spp.	Sea-blite
Spergularia marina	Sand-spurrey
Potentilla egedei	
Glaux maritima	Sea milkwort
Limonium carolinianum	Sea lavender
Gerardia maritima	Gerardia
Plantago oliganthos	Seaside plantain
Iva frutescens	Marsh-elder
Aster subulatus	Salt marsh aster

<u>Roadsides and Disturbed Areas</u>

Bromus tectorum	Wild oats
Mullugo verticillata	Carpetweed
Saponaria officinalis	Soapwort
Spergularia rubra	Sand-spurrey
Euphorbia esula	Leafy spurge
Oenothera biennis	Evening primrose
Asclepias syriaca	Common milkweed
Lepidium virginicum	Poor-man's pepper
Verbascum thapsus	Common mullein
Achillea lanulosa	Yarrow
Ambrosia artemisiifolia	Ragweed
Artemisia vulgaris	Common mugwort
Solidago spp.	Goldenrod
Chrysanthemum leucanthemum	White daisy

7.2. The Salt Hay Industry

Jerome et al. (1968) gave a brief review of salt marsh haying that is still relevant:

> Salt hay, primarily high water cord grass [e.g., salt marsh hay, *Spartina patens*], has long been valued by residents of the area. It was used by the early settlers for thatching roofs, and for cattle bedding and fodder. Although still used for the latter two purposes, it is much in demand as a mulch for gardens and areas freshly seeded for grass. Salt hay makes an excellent mulch because its seeds do not germinate under conditions normally found in upland areas.
>
> For many years, the hay was cut, raked and stacked by hand on hay staddles in the marsh. Later, horses with "bog shoes" to prevent them from sinking into the marsh were used to draw mowing machines. Huge scows or gundalows were poled and floated up the creeks to reach many areas of salt marsh which were inaccessible from the upland. The gundalows were often floated over the marsh on extreme high tides, filled with hay, and floated out on the next high tide. In recent years, tractors pulling mowers and mechanical hay balers have been used for harvesting salt hay.

An excellent, entertaining history of the old method of salt marsh haying is given in Jewett (1949).

Bird (1999) provided a comprehensive review of current haying practices and also described some of the potential ecological consequences of salt marsh haying. These include potential effects on marsh surface elevation, succession and species diversity, primary production, nutrient dynamics, and impacts on higher trophic levels. She suggested a number of studies that would address these issues. From a management perspective, it is important to determine whether haying at different levels of intensity is compatible with other marsh values.

The Plum Island Ecosytems Long Term Ecological Research Project (PIE LTER) was examining salt marsh haying at the time of this writing. From an ecological perspective, haying is analogous to large scale herbivory, something that does not normally occur in New England salt marshes. Haying removes large amounts of vegetation that would otherwise go into the detritus-based food chain and ultimately into the surrounding estuary, a major energetic pathway in many salt marsh-estuarine ecosystems. Haying may also stimulate plant and algal productivity by allowing greater light penetration to the marsh surface through removal of standing dead plant material. By reducing the build up of litter, haying may also increase the foraging efficiency of fish and birds on salt marsh invertebrates. In addition to direct removal of plant material, hayers usually manipulate water levels in areas they routinely hay, thus causing localized changes in hydrology.

At least five individuals harvested salt hay from the marshes of the Parker River-Plum Island Sound area in 1965 (Jerome et al., 1968). In the late 1990s, there were three individuals carrying out haying on a relatively large scale. Based on conversations with local hayers, at least 400 hectares of the salt marsh are hayed on a regular basis, usually once every two years (PIE LTER, unpublished results).

CHAPTER 8. Habitat issues faced by the Plum Island Sound Estuary

From a habitat perspective, the Plum Island Sound region is fortunate to be relatively undeveloped compared to other parts of eastern Massachusetts. Much of the natural habitat remains intact as protected open space (Fig. 8.1) and probably does not greatly differ in appearance from what the first European settlers saw when they arrived in the area. Nonetheless, there are still a number of threats to the future integrity of Plum Island Sound as a thriving, productive coastal ecosystem. There are also habitat issues that, while not necessarily "threats", will require some consideration in the future. These issues include:

- Decline in water quality, particularly eutrophication
- Marsh degradation caused by tidal restrictions and the invasion of aggressive, alien plant species
- Restoration of marsh areas impacted by past mosquito control practices
- Loss of anadromous fish habitat
- Fragmentation and loss of wetlands buffers and wildlife corridors
- Protecting vulnerable species of barrier beach wildlife
- Managing the potential expansion of aquaculture
- The impact on the Sound of regional changes in fish and wildlife populations
- Rising sea level

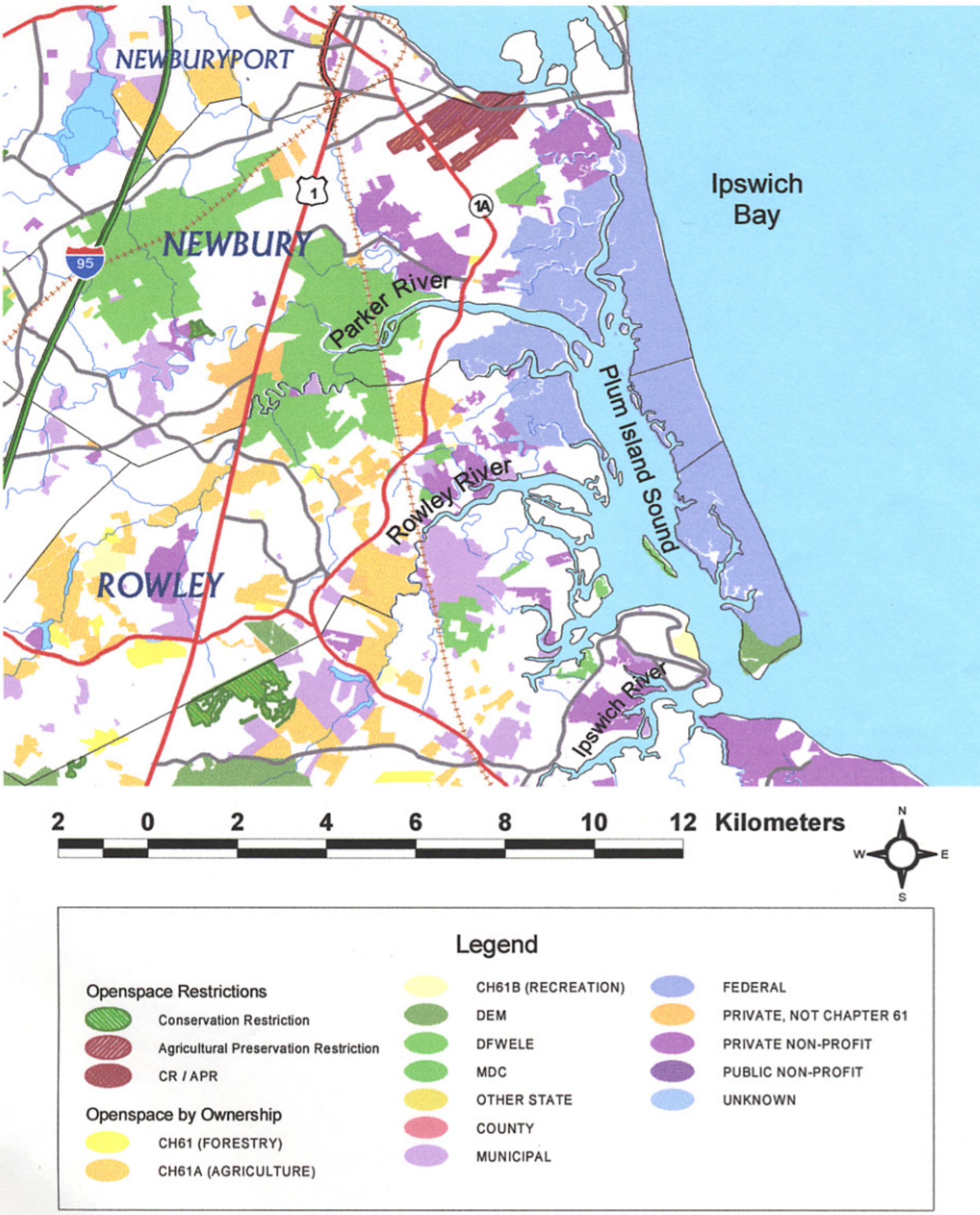
Some of these habitat issues are interrelated, yet are best discussed individually. Some are not specific to Plum Island Sound, but are reflections of regional or even global changes. In this section we describe those issues most specific to the coastal habitats, although we recognize that habitats in the surrounding watershed are also faced with a broad range of issues associated with anticipated future development.

8.1. Water Quality Decline and Eutrophication

Poor water quality directly affects human uses and may also degrade habitats. Some of the tributary rivers to Plum Island Sound suffer from poor water quality, however there is no indication that the intertidal and subtidal habitats of the Sound itself have been degraded. The large amount of tidal flushing in the Sound insures adequate dilution of the present levels of pollution entering from the watershed. In the future, however, with increased development anticipated for the region, managers will need to consider the potential impacts of additional runoff into the Sound.

Of particular concern will be insuring that nitrogen loads do not increase to the point where eutrophication effects will occur. Local sources of nitrogen to Plum Island Sound include wastewater plants, septic systems, and fertilizers used for lawns and golf

Fig. 8.1. Open Space



courses. It is clear from our nutrient analyses that nitrogen concentrations increase in a gradient from the mouth of the Sound "upstream" to the rivers. This indicates that the uplands provide higher concentrations of nitrogen than does Ipswich Bay. In larger watersheds (e.g. Chesapeake Bay, Merrimack River), the atmosphere can also be a major source of nitrogen, but the relatively small size of Plum Island Sound makes this less likely.

Eutrophication can have a devastating effect on estuaries. Some of the impacts include:

- Lowered dissolved oxygen levels - results in emigration of mobile fish and invertebrates, alteration of benthic (bottom) communities, and, if severe, fish kills
- Increased growth of plankton - causes reduced water clarity
- Increased growth of certain seaweeds to nuisance levels- smothers important species of submerged aquatic vegetation
- Changes in the biological community to favor those species that can tolerate the above conditions - diversity and abundances typically decline (Deegan et al., 1993).

The potential for Plum Island Sound to become eutrophic due to nitrogen loading has been investigated by the Massachusetts Bays Program (Menzie Cura, 1996). Their results, based on estuarine morphology, suggest that Plum Island Sound is moderately sensitive to nitrogen, and the Parker River is highly sensitive. The large amount of tidal flushing makes Plum Island Sound less sensitive to nitrogen than other estuaries where eutrophication has been well documented, such as Waquoit Bay on Cape Cod. The Parker River is more susceptible to eutrophication than the Sound because it is closer to sources of nitrogen and less well flushed by seawater.

At the time of this writing, the Plum Island Ecosystems Long Term Ecological Research Project (PIE LTER) was carrying out monthly measurements of nutrients in the Parker River at the Central Street dam. The focus of this study is on how land use changes in the surrounding watershed might effect the estuary in the future by effecting the input of inorganic nutrients and organic matter. In addition, MCZM was carrying out further investigations of the potential for excess nitrogen loading to the Parker River.

The issue of eutrophication should not be ignored since its effects, which are so devastating, are evident in many estuaries all over the world. Preventing eutrophication should be part of any future planning for the region.

8.2. Impacts of Tidal Restrictions on Vegetation

Roads and railways have been built across the Plum Island Sound marshes since historical times to facilitate travel. The location of many of these roads corresponds to colonial era farm and trade routes. Often the roads link portions of adjacent upland separated by the salt marsh. Where the roads cross a tidal creek, culverts have been installed to allow passage of tidal waters beneath the roadway. In many cases, the culvert or bridge opening is too small to pass sufficient tidal water to maintain salt marsh vegetation upstream and to allow passage of aquatic organisms.

The hydrologic changes caused by a restrictive crossing can significantly alter the salinity of the upstream salt marshes. By limiting the flow of seawater into a section of marsh, it creates more brackish or fresh water conditions. This freshening of salt marshes can cause a major transformation in the vegetation -- salt marsh grasses and rushes are displaced by common reed (*Phragmites australis*) or other brackish and freshwater species (e.g., cattails - *Typha angustifolia,* purple loosestrife - *Lythrum salicaria*), or in some cases upland plants.

Phragmites, a familiar tall grass with the tassel at its top, is an invasive species of much current concern. It is likely native to our region, since it evidently has been present in New England at least since colonial times. Recently, according to current thinking among botanists, an aggressive genetic stock has appeared in New England and has been rapidly invading many coastal and inland wetlands (Roman et al., 1984). Common reed often forms a monoculture of tall plants (up to two meters), leading to both lowered plant diversity and a change in vegetative structure (from a low grassy meadow to a tall reedy thicket). In Ipswich alone, 43.2 hectares of wetland are *Phragmites* dominated (WRBP, 1997).

Phragmites is already widespread in Plum Island Sound. It thrives in marshes where the natural flow of seawater is restricted by culverts or dikes such that the ratio of salt to freshwater is reduced. Initial invasions occur at the upper edges of salt marshes, areas that normally are occupied by brackish water species, such as cattails (*Typha angustifolia*) and bulrushes (*Scirpus* sp.). *Phragmites* may also move out over the salt marsh, crowding out the native salt marsh hay (*Spartina patens*). It thrives in salinities between 10 and 20 ppt (Roman et al., 1984), thus the seaward extent of its migration over the salt marsh is limited by higher salinities (typically above 25 ppt in much of the main part of Plum Island Sound). The growth of *Phragmites* may also be enhanced by higher nutrient levels, which occur where septic system leaching fields intersect groundwater near the edge of a marsh. Occasionally, *Phragmites* will grow in the middle of the marsh as well, perhaps in an area of slightly higher elevation than the surrounding marsh or where there is a source of fresh water.

The largest patch of *Phragmites* in the Plum Island Sound region covers several acres off Pine Island Road. Most patches in the area are much smaller. The large stands occur in Stage Island Pool and Hellcat Swamp on the Parker River National Wildlife Refuge are behind dikes that were built to create fresh and brackish water ponds thought to be more desirable for nesting waterfowl.

Phragmites is a concern to coastal managers because the plants are considered of less value to wildlife than native salt marsh species. It is also a concern for managers whose goals are to restore and maintain the historical marsh. *Phragmites* in the United States is not consumed to any great extent by wildlife, nor is it considered an important nesting habitat for birds that are of most concern to managers. Much of the evidence for this is anecdotal since no one has rigorously compared *Phragmites* and native *Spartina* marshes. (In Europe, reed beds of *Phragmites* are considered very valuable to wetland wildlife and the plants are consumed by geese.) Dense *Phragmites* marshes are particularly difficult to study since access is such a problem, and it is likely that *Phragmites* does provide cover and nesting habitat for some wildlife species, such as redwing blackbirds and marsh wrens, in certain situations (Buchsbaum and Hall 1990, Buchsbaum 1994, Holt and Buchsbaum 1999). Nonetheless, based on what we know about habitat requirements, certain species of marsh birds, particularly rails, waterfowl, and sharp-tailed sparrows, have likely suffered as *Phragmites* has expanded along the east coast of the United States. These are species that thrive in *Spartina* or *Typha* marshes.

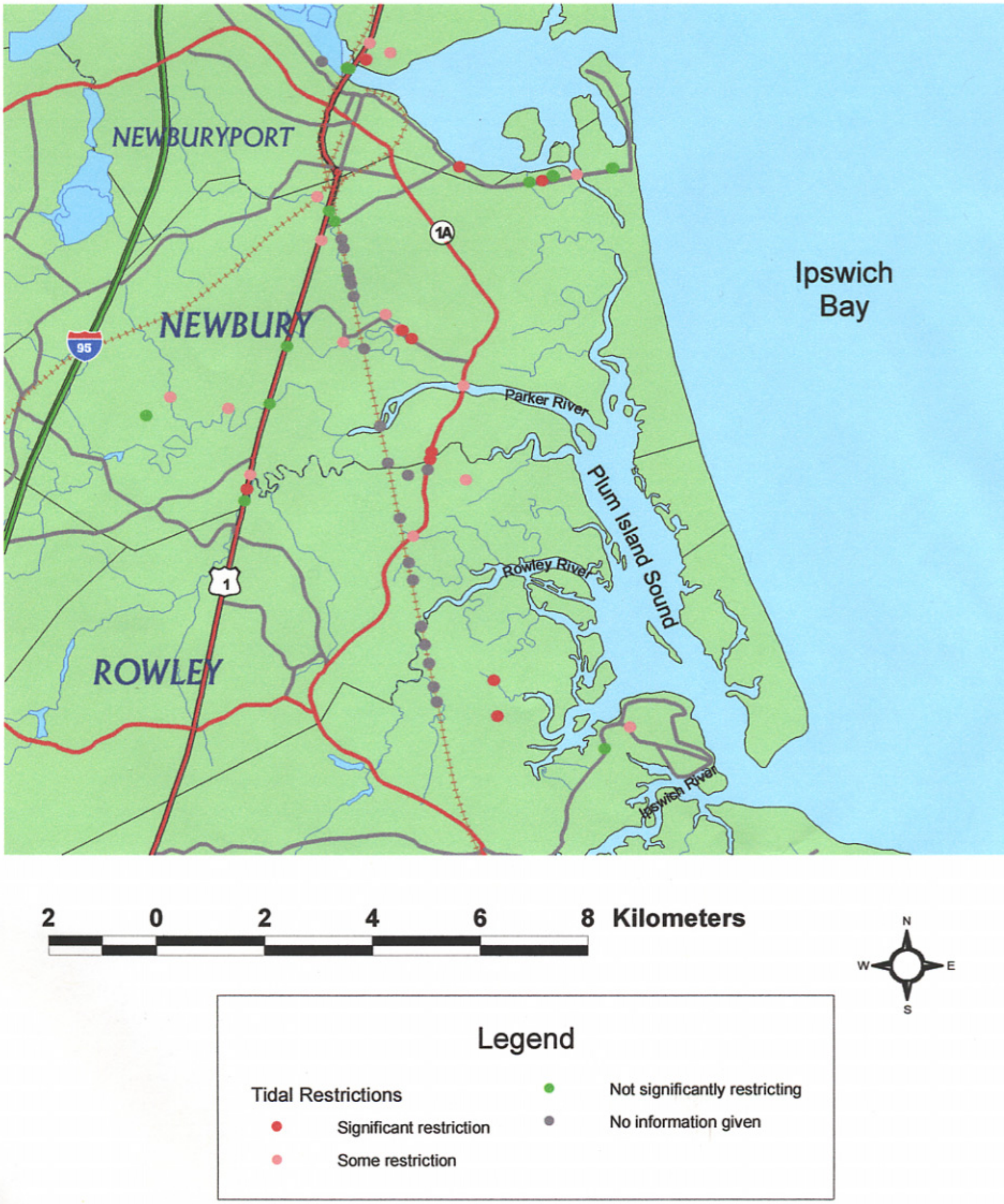
Because of management concern about the impact of road and railroad crossings across the salt marshes, the Parker River Clean Water Association (PRCWA) was funded in 1997 to inventory tidal crossings on the upper North Shore, including the Plum Island Sound region. Forty-six tidal crossings were identified within the towns of Newbury, Rowley, and Ipswich (Table 8.1, Fig. 8.2).

Table 8.1. Tidal Crossings by town in the Plum Island Sound region. Based on PRCWA, (1997).

Town	**Total Tidal Crossings***	**Restrictive Tidal Crossings****
Ipswich	14	3
Newbury	28	5
Rowley	4	3

*Railroad Sites are not included
**Sites were determined to be restrictive if they limited tidal flow more than five inches between the upstream and the downstream sides of the crossing.

Fig. 8.2. Tidal Restrictions



A direct way to control *Phragmites* is to increase tidal flushing to impacted marshes. Replacing all the culverts in which water flows under roadways and railroad beds is obviously a major undertaking, however the need to periodically repair bridges and culverts provides an opportunity to make incremental changes over time.

Management of *Phragmites* should focus on control rather than elimination. Total elimination is likely not possible and perhaps not even desirable from a wildlife management perspective. To set management priorities, it is important to evaluate the status and trends of *Phragmites* expansion in Plum Island Sound. Smaller patches of *Phragmites* that have reached an equilibrium with the salt marsh and surrounding upland are probably not detrimental to the ecosystem and are therefore not worth the effort and expense of elimination. The Massachusetts Audubon Society and the Jackson Estuarine Laboratory of the University of New Hampshire have set up long term vegetation transects in Rowley, Newbury, and Ipswich to monitor whether patches of *Phragmites* are expanding or are stable. Some of the transects are described in Buchsbaum et al. (1997).

Open Marsh Water Management (OMWM) is a mosquito control technique (see below) that has been used to control *Phragmites*. OMWM perimeter ditches at the upper edge of the salt marsh channel freshwater from the upland away from the marsh, thus insuring that salinities in salt marshes remain high enough to prevent further *Phragmites* encroachment. In a number of cases in the Plum Island Sound region, perimeter ditches form an effective barrier to *Phragmites* movement onto the salt marsh.

Purple loosestrife, *Lythrum salicaria*, is another invasive wetland plant that occurs in the Plum Island Sound region, although it is more of a problem in freshwater wetlands than in salt marshes. Like *Phragmites*, purple loosestrife is considered a pest by many wetlands managers because it has little documented value to wildlife compared to the native plant community. It is less tolerant of higher salinities than *Phragmites*, but still can invade the upper regions of salt marshes in tidally restricted areas. Research at the University of New Hampshire indicates that it cannot tolerate salinities above 8 ppt (Dzierzeski, 1993).

As with *Phragmites*, management measures that restore natural tidal flushing are the best means for controlling purple loosestrife that is invading brackish marshes. Other techniques have been used, particularly where increasing tidal inundation is either impractical or conflicts with management goals. The Parker River National Wildlife Refuge has experimented with herbicides (glyphosate), mowing, controlled burning, and drawdowns to control purple loosestrife and *Phragmites* in their Bill Forward and Stage Island Pools. They have also experimented with the introduction of a beetle that consumes purple loosestrife (and hopefully nothing else).

8.3. Salt Marsh Mosquito Control

Mosquito control practices have resulted in perhaps the most widespread impacts on the marshes surrounding Plum Island Sound. Past grid ditching is responsible for the lattice-like pattern of narrow creeks, often bordered by dredge spoils that characterize much of the "Great Marsh". Mosquito control activities are still exempted from the Massachusetts Wetlands Protection Regulations; fortunately current water management practices are more environmentally sensitive than those carried out in the past. The major activity of the Northeast Mosquito Control and Wetlands Restoration District (NEMCWRD-formerly the Essex County Mosquito Control Project) on the Plum Island marshes in recent years has been OMWM. A system of reservoirs and shallow canals are created to allow predatory fish, primarily the mummichog, *Fundulus heteroclitus*, access to pools where mosquito larvae live.

OMWM is touted as having much less ecological impact on salt marshes than past grid ditching practices. Most OMWM sites around Plum Island are less than ten acres in size, are designed to be site specific, and incorporate existing ditches and natural features as much as possible into their design. The NEMCWRD and Massachusetts Audubon have worked together to develop guidelines based on monitoring suspected mosquito breeding sites that enable managers to determine when installing an OMWM system is justified. OMWM has also been used to restore salt marshes, since standard procedures are to plug old grid ditches so that they no longer drain, to maintain and enhance salt pannes, and to channel freshwater from uplands away from the salt marsh. One such marsh where mosquito control and restoration have been combined in an OMWM system is on the Parker River Refuge near the subheadquarters.

OMWM is labor intensive and the installation work can be done only in the nongrowing season, thus only a few sites can be done each year. A more immediate solution though less permanent, is the use of the larvicide Bti (*Bacillus thuringiensis israelensis*). This bacterial-produced toxin, which is currently being used in Ipswich, is considered specific in its toxicity to mosquitoes and closely related flies and thus is considered better for the environment than broad-spectrum pesticides such as malathion and resmethrin. An important research question is the role mosquitoes themselves play in the ecology of the marsh, since they are periodically quite abundant and are eaten by fish and birds.

8.4. Restoration of Anadromous Fish Habitat

Although fish and wildlife are still generally abundant and diverse in the Plum Island Sound region, one group that has fared poorly is anadromous fish. Dams and overfishing have taken their toll, such that today's anadromous species are only a remnant of what formerly existed. Sturgeon have not been commercially harvested in the Ipswich and Parker Rivers since the mid 1800s and once abundant shad are rare. The causes of the decline in anadromous fish are discussed more fully in Chapter 4.

Although it is unlikely that fish populations can be brought back to the point they were at during precolonial times, there is great potential to enhance the fish populations that are present. Efforts to increase blueback herring received a tremendous boost with the reconstruction of the fishway at the Sylvania Dam in the center of Ipswich in 1999. This allows the fish access to a long stretch of the river, parts of which have the potential to be spawning habitat. This project was a collaborative effort between the Division of Marine Fisheries and the Riverways Program, with volunteer labor coming from members of the Ipswich River Watershed Association and Trout Unlimited.

Alewives migrating up the Parker River and its tributaries have also benefited from recent fishway activities promoted in large measure by the Essex County Sportsmen Association and the Great Marsh Anadromous Fish Restoration Team (a collaborative of federal, state and local officials and nonprofit organizations). Six fish ladders on the Parker River facilitate the movement of alewives from Plum Island Sound to their spawning area in Pentucket and Rock ponds. Two of the fishways that were in most serious disrepair, as determined by DMF and the USFWS, were redesigned and upgraded in 2000. An Alaskan steep pass was installed on the dam near Main Street in Byfield to enable the fish to bypass a fishway that did not channel fish adequately away from the main flow of the river spilling over the dam. The reconstruction of the fish ladder at the entrance to Pentucket Pond occurred in 2000 as part of a project by the town of Georgetown to repair the Pond Street bridge and berm. The pool at the bottom of the fishway at Central Street was redesigned to better channel the fish toward the fishway.

The Essex County Sportsmen's Association has adopted the Parker River alewife run as part of DMF's Fishway Stewardship Program. The Association carries out routine maintenance, such as cleaning out brush and setting water levels.

There is potential for enhancing blueback herring populations in the Mill River. Spawning of blueback is currently limited to a small section of the river below the first dam near the old Jewell Mill at Glen Street. Constructing a fishway for this small dam would open up several more river miles of potential blueback habitat in the Mill River as well as Batchelder Brook.

Another issue that affects anadromous fish is low flows during the summer. This not only degrades the habitat but also hinders the return of juveniles to the sea. Low late summer flows on the Ipswich River have been the subject of particular attention from the media and state and national environmental organizations, but the same problem has also been noted in drier years on the Parker.

8.5. Maintenance of Coastal Wetlands, Wetlands Buffers, and Wildlife Corridors

Coastal wetlands in the Plum Island Sound region are well protected under the Massachusetts Wetlands Protection Regulations. In addition, much of the salt marsh habitat is currently under ownership or control by conservation-oriented agencies, such as the U.S. Fish and Wildlife Service, the Massachusetts Division of Fisheries and Wildlife, the Essex County Greenbelt Association, the Trustees of Reservations, and the

Massachusetts Audubon Society. Although we do not anticipate future direct losses due to human activities, there is always the possibility that the political climate that has stimulated wetlands protection efforts could change in Massachusetts, rendering other private parcels of land vulnerable to greater human impacts than are now allowed by law.

Wetlands buffers enhance wildlife habitat values by reducing the amount of disturbance to wildlife on wetlands (Desbonnet et al., 1994). In addition to the disturbance factor, a large number of semi-aquatic birds and animals depend on a combination of wetland and upland habitats, foraging in wetlands and using the surrounding upland for nesting, resting, and as a migration corridor. Maintaining an undeveloped strip of land around a wetland insures that all these life functions will be carried out. A naturally vegetated buffer also enhances scenic values.

A number of authors have suggested that a minimum buffer of 100 m is ideal for supporting a wide variety of wildlife (Brady and Buchsbaum 1989, Desbonnet et al. 1994). In many parts of eastern Massachusetts, such a buffer distance is impractical since development has already occurred within 100 m of the border of many wetlands. Because much of the Plum Island Sound region is relatively undeveloped and contains a great deal of conservation land, maintaining wide buffers is still possible in many places. Land use planning incorporating natural buffers around wetlands would go a long way toward protecting both water quality and wildlife habitat. This is an opportunity for towns to work with conservation organizations and state environmental agencies to insure that the most critical wetlands habitats (e.g. those surrounding anadromous fish spawning areas) have as wide a buffer as possible and that buffer maintenance is part of the normal planning process for any new proposed development. Even where 100 m is not possible, research indicates that some buffer is much better for wetland functions than none at all.

A related issue to wetlands buffers is maintaining wildlife corridors along rivers. Since the Ipswich River runs right through the center of Ipswich, there is no obvious possibility for a wildlife corridor there. The Parker River and its tributaries and the Rowley River still contain long stretches of undeveloped, naturally vegetated shorelines that can function as corridors for the movement of animals. Land use planning and land acquisition priorities can be targeted toward maintaining wildlife corridors along these rivers.

8.6. Protecting Vulnerable Species of Wildlife on Barrier Beaches

The major habitat protection controversy in the Plum Island Sound region in recent years has been the closure of beaches on the ocean side of the Parker River National Wildlife Refuge during the breeding season of piping plovers, roughly April through August. Since the primary mandate of the Refuge is to protect wildlife, the priority given to protecting endangered species over potentially conflicting uses is straightforward. The need to close large sections of the beach during much of the summer to protect these birds is likely to continue for a number of years.

Unlike the Parker River Refuge, the management of Crane Beach Reservation gives equal consideration to the enjoyment of area by the public and to the protection of wildlife habitat. Disturbance of resting migratory shorebirds by people, many of whom have come by boat has been an issue of concern to the Trustees of Reservations who manage the property. The Trustees have attempted to resolve this problem through public education and symbolic fencing. Trampling of beach grass and erosion of dunes has also occurred in more remote sections of Crane Beach that are not easily patrolled. Management guidelines published in *Guide to Barrier Beach Management in Massachusetts* (Massachusetts Barrier Beach Task Force, 1994) provide a framework for resolving potential conflicts.

8.7. Aquaculture

Although there are presently no plans for widespread development of aquaculture in the Plum Island Sound region, the Commonwealth's recent interest in promoting aquaculture raises the possibility that it may become an issue in the future (MCZM 1995). Plum Island Sound has extensive intertidal flats, and water quality is still relatively good compared to other estuaries on the North Shore, thus bivalve aquaculture is conceptually possible. The major habitat issue that aquaculture raises is in insuring that aquaculture is compatible with the native fish and wildlife. Potential conflicts with other user groups, such as clammers harvesting natural bivalves and recreational boaters, need to be addressed.

8.8. Regional and National Issues that Affect Plum Island Sound

The seven habitat issues discussed above are those that are amenable to some level of local control. Plum Island Sound, however, is also influenced by changes occurring on a much broader level. Overfishing throughout New England waters may have influence the types of fish found in Plum Island Sound. The changes in bird populations described earlier have also been attributed to regional factors rather than local changes. Plum Island Sound has been an accurate reflection of regional trends for fish and birds. Rising sea levels resulting from global warming will likely cause changes in as yet unanticipated ways for salt marsh and barrier beach habitats.

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