Technical Report

Massachusetts Division of Marine Fisheries
Technical Report TR-30

Rainbow smelt (*Osmerus mordax*) spawning habitat on the Gulf of Maine coast of Massachusetts

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EXECUTIVE SUMMARY

Rainbow smelt (*Osmerus mordax*) is a pelagic, schooling fish that is common to the fish community in embayments and estuaries on the Gulf of Maine coast of Massachusetts. Similar to other anadromous species, smelt spend a period of maturation in marine waters then migrate above tidal influence to natal freshwater streams on spring spawning runs. Smelt populations in Massachusetts have long been valued for supporting popular sportfisheries, small-scale commercial fisheries and for the forage they provide to many species of fish and wildlife. Smelt fisheries are a unique cultural feature to our coastline as anglers pursue smelt in the fall and winter when most other fishing opportunities fade as gamefish migrate away from the coast. Smelt fishing is valued as much for the camaraderie and fine tasting catch as it is for the sport of reeling in this small fish.

Concerns for the status of smelt populations in Massachusetts manifested from the sportfishing communities in the 1980s and were supported by observations from Massachusetts Division of Marine Fisheries biologists. A common description of the smelt resource in the latter half of the 20th century included the scenario of robust fall and winter fisheries and large spring smelt runs in the 1960s and most of the 1970s, followed by sharply declining fisheries and smelt runs in the 1980s. Throughout these periods, there has been little attention given to the assessment of smelt populations and their spawning habitat. In order to support the management of this valuable resource a monitoring project was develop in the late 1980s to delineate all smelt spawning habitat along the Gulf of Maine Coast in Massachusetts.

During 1988-1995, most freshwater drainages (162) from the New Hampshire border to the Cape Cod Canal were surveyed for the presence of potential smelt spawning habitat. Sixty-four spawning habitat stations were established and monitoring focused on the spatial and temporal presence of demersal, adhesive smelt eggs. The monitoring resulted in the designation of smelt runs at 45 specific locations within 30 river systems in the following four major drainages: South Coastal Drainage Area (12), Boston Harbor Drainage Area (15), North Coastal Drainage Area (12), and Plum Island Sound and the Merrimack River (6).

In each smelt run except the Charles River, smelt began spawning at riffle habitat near the interface of salt and freshwater. Spawning progressed upstream beyond tidal influence for as much as a kilometer. The upstream limits of egg deposition for many rivers were physical impediments that prevented further passage. There was a wide range to the size of smelt spawning habitats in the study area. More than half were less than 200 m in stream length and less than 1,000 m^2 in substrate area. Only two specific spawning locations exceeded 10,000 m^2 in available spawning substrate (Jones River and Ipswich River). The Charles, Neponset, Fore, and Mill River were all in the range of 9,000 – 10,000 m^2; and all other locations in the study area were considerably smaller. Although no quantitative assessments were conducted on smelt populations, monitoring observations indicate that during the study period only the Neponset River, Fore River and Back River contained large smelt runs that produced egg deposition approaching the capacity of available spawning habitat (observed only during 1989 and 1994).

The typical spawning period was from mid-March until the mid-May. Egg deposition usually peaked in April and was light and intermittent for most of May. The total temporal range when smelt eggs were present was March 3rd to May 28th. The average water temperature at the onset of spawning runs was 5.3 °C. However, the water temperature, date at the onset of spawning, and the duration of the spawning period varied widely with some dependence on the size of spawning habitat and seasonal weather. The presence of smelt larvae was detected with ichthyoplankton net sampling at 14 river stations. Smelt larvae were present in the tidal waters downstream of the spawning habitat from April 14th through the end of the monitoring period (May 31st), with peak catches occurring from mid-April to mid-May.

Water chemistry measurements were made at the 64 spawning habitat stations for temperature, dissolved oxygen, pH, salinity and specific conductivity and compared to Massachusetts Surface Water Quality Standards. All water temperature and dissolved oxygen measurements during the spawning season were supportive of aquatic life, both favorably influenced by the cool air temperature and higher discharge during the spring freshet. Routine violations of Water Quality Standards (<6.5) for pH were observed in many rivers. Only two rivers in the South Coastal Drainage Area maintained spawning season mean pH above 6.5. Most rivers in this region had routine acidification that could be a threat to smelt egg survival.

Seven other diadromous fish species were observed during smelt spawning habitat monitoring. Only river herring (both alewife and blueback herring) and American eel were observed routinely. Adult river herring were observed making upstream spawning migrations during May in 19 of the 30 river systems. American eel were seen in 23 of the 30 river systems; typically as glass eels migrating to freshwater habitats starting in late-March.

The monitoring project raised substantial concerns for the health of smelt spawning habitat and status of smelt populations on the Gulf of Maine coast of Massachusetts. The following nine physical and chemical conditions were identified as clearly degrading the quality of stream habitat for migrating adult smelt and smelt egg survival:

sedimentation, eutrophication, passage impediments, channel alterations, stream flow reduction, stormwater, tidal influence, vegetative buffer loss, and acidification. Qualitative scores were applied to rank degradation in all smelt runs, resulting in the highest summed scores for sedimentation and eutrophication. The effects of eutrophication in the form of excessive periphyton growth on substrate where smelt eggs incubate were nearly ubiquitous in the study area and may represent the most significant threat to smelt spawning habitat in Massachusetts. It is likely that cumulative affects from all the negative influences are combining to reduce the quantity and quality of spawning habitat and causing lower smelt egg survival and population recruitment.

The objective of documenting where smelt spawn on the Gulf of Maine coast of Massachusetts was met by this study. The next practical steps towards the goal of improving the Commonwealth's smelt runs involve applying the monitoring information to habitat and population restoration. Better information on smelt population status and the cause of habitat degradation is necessary for resource management and to identify restoration strategies for both smelt spawning habitat and smelt populations. Specific recommendations are made to achieve these goals. Concerns over smelt populations remain high as this report is published. In 2004, the National Marine Fisheries Service designated rainbow smelt as a "Species of Concern". This status applies to species for which there is concern and uncertainty over their biological status and population threats, and is a precursor to the designation of "Candidate Species" under Endangered Species Act review.

Rainbow smelt from Parker River spawning run. M.Ayer

CONTENTS

LIST OF ACRONYMS

ACOE	U.S. Army Corps of Engineers
cfs	cubic feet per second
CSO	Combined Sewer Overflow
CWA	Clean Water Act
CPUE	catch per unit effort
MDEP	Massachusetts Department of Environmental Protection
DMF	Massachusetts Division of Marine Fisheries
DFW	Massachusetts Division of Fish and Wildlife
DO	dissolved oxygen
EOEA	Massachusetts Executive Office of Environmental Affairs
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
LWSC	Lynn Water and Sewer Commission
m^3/s	cubic meter per second
MBTA	Massachusetts Bay Transportation Authority
mg/L	milligram per liter
MLW	mean low water
MHW	mean high water
MHD	Massachusetts Highway Department
NCB	North Coastal Basin
NH_4	ammonium
NMFS	National Marine Fisheries Service
NO_2	nitrite
NO_3	nitrate
NPDES	National Pollutant Discharge Elimination System
PO_4	ortho-phosphate
RPD	relative percent difference
SA	class of DEP water quality criteria that is highly supportive of aquatic life
SB	class of DEP water quality criteria that is supportive of aquatic life
SRWC	Saugus River Watershed Council
USGS	United States Geological Service
WQS	Water Quality Standards (of Mass. Dept. of Environmental Protection)
YOY	young-of-the-year

CONVERSION FACTORS

Multiply U.S. Customary Units	By	To Obtain Metric Units
inch (in.)	2.54	centimeters (cm)
foot (ft.)	0.3048	meters (m)
mile (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
acre (A)	0.004047	square kilometers (km^2)
cubic feet (ft^3)	0.02832	cubic meters (m^3)
Gallons (gal)	3.785	liters (L)
Temperature Conversions		
Celsius degrees (°C)	1.80*(°C) +32	Fahrenheit degrees (°F)
Fahrenheit degrees (°F)	0.5556*(°F-32)	Celsius degrees (°C)

CHAPTER 1. INTRODUCTION

The rainbow smelt *(Osmerus mordax)* is an anadromous fish that inhabits the Atlantic coast of North America from Newfoundland to New Jersey. Landlocked populations of smelt also naturally occur in freshwater lakes, and have been introduced to many freshwater systems including the Great Lakes. Anadromous smelt mature in coastal waters and estuaries, then ascend into freshwater drainages to spawn during spring spawning runs. Smelt use coastal rivers for spawning habitat, presumably with fidelity to natal rivers, during the cool, spring freshet which is suitable for egg survival and to reduce predation exposure. Fertilized eggs are negatively buoyant and adhere to the substrate and aquatic vegetation. Newly deposited eggs are approximately 1 mm in diameter and transparent. The duration of egg incubation is directly related to water temperature, with cooler temperatures resulting in longer incubation (McKenzie 1964). Smelt eggs in Massachusetts typically hatch in the range of 10 to 21 days after fertilization. Upon hatching, larvae are immediately transported downstream into the tidal zone where feeding on zooplankton begins.

Smelt are a small, short-lived species that seldom exceed 25 cm in length or five years of age in Massachusetts populations (Murawski and Cole 1978; Lawton et al. 1990). By age-2, smelt are fully mature and recruited to local fisheries and spawning runs. Life history appears to be influenced by latitude as few age-1 smelt become mature and participate in Canadian smelt runs (Collette and Klein-MacPhee 2002). In Massachusetts, most age-1 spawners are males (Murawski and Cole 1978; Lawton et al. 1990). Fecundity estimates of approximately 33,000 eggs for age-2 smelt and 70,000 eggs for age-3 smelt were reported by Clayton (1976). Recent size composition data show that smelt runs in Massachusetts are dominated by age-2 smelt with few older smelt (Chase 1992, 1996). Smelt serve an important role in coastal food webs as forage for a wide range of marine fish and wildlife, and as active predators of zooplankton, and small crustaceans and fish.

Across their distribution range, smelt spawning runs are variable in regard to habitat use, spawning substrata, spawning period, and water temperature range (Kendall 1926; Bigelow and Schroeder 1953; Rupp 1959; Hurlbert 1974; and Pettigrew 1997). Investigations of Massachusetts smelt runs have found that spawning begins between late February and mid-March when water temperatures reach 4-6 °C and concludes in May (Crestin 1973; Lawton et al. 1990; Chase 1992 and 1996). Spawning smelt concentrate at shallow riffles upstream of the salt and freshwater interface at night during flood tides (Clayton 1976; Murawski et al. 1980). After spawning, smelt usually return downstream to subtidal habitats during daylight. For most smelt runs in Massachusetts, there is little specific information available on spawning locations. Nocturnal spawning, a spawning season closure for fishing, and low economic value all contribute to a lack of familiarity and documentation of smelt spawning habitat.

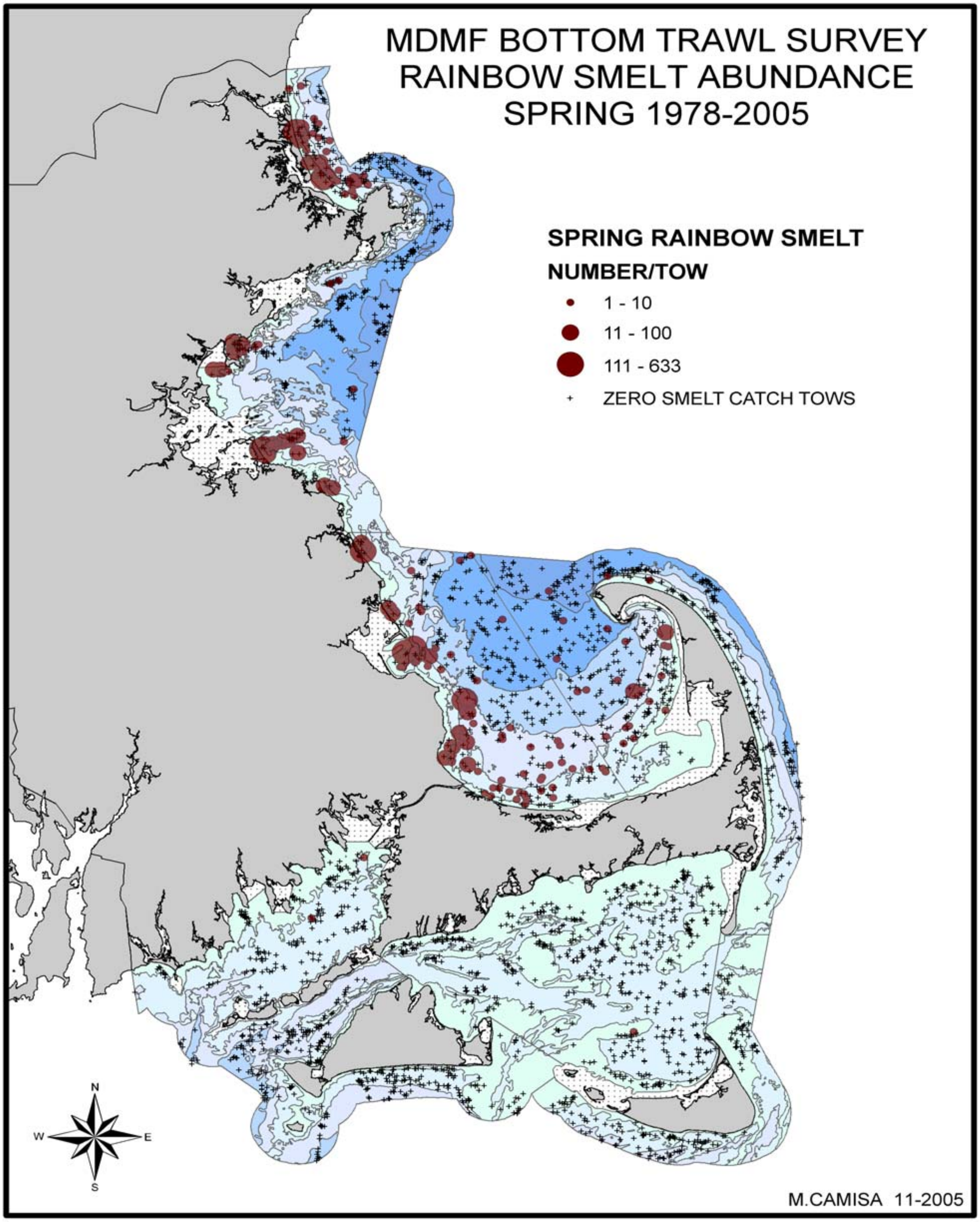
Status of Smelt Populations and Fisheries

Fall and winter aggregations of smelt on the Massachusetts coast have supported traditional recreational fisheries and modest commercial fisheries since the 19th century (Kendall 1926). By 1874, the threat of overfishing in net fisheries was evident and restrictions were made to limit smelt fishing to hook-and-line and prohibit fishing during the spawning season (Kendall 1926). The present fishery is managed by the Massachusetts Division of Marine Fisheries (DMF) with no size limit or bag limit and a closed season from March 15th to June 15th to protect spawning fish. Smelt fishing typically occurs at shoreline structures in embayments and through the ice in the upper estuary when there is sufficient ice cover. The smelt runs of the early 20th century supported important fall and winter fisheries that attracted large numbers of anglers along coastal wharfs and to winter ice-shack fisheries in the upper estuaries (Kendall 1926). Limited references from the 1960s and 1970s indicate the presence of relatively healthy smelt runs. The DMF Estuarine Research Program of the 1960s and 1970s reported on estuarine resources in 17 coastal bays and estuaries in Massachusetts (Chesmore and Peterson 1970) and included references to popular smelt fisheries with substantial catch and effort in many of the study locations on the Gulf of Maine coast. The DMF Anadromous Fish Survey of the late 1960s noted that because the optimum smelt egg density was exceeded in many smelt runs consideration should be given to eliminating the closed season and allowing a limited fishery on spawning smelt (Reback and DiCarlo 1972).

The status of smelt populations in Massachusetts is uncertain because no ongoing assessments are conducted on smelt fisheries or populations. The only fisheries-independent sampling project that routinely catches smelt is the DMF Bottom Trawl Survey that has been conducted each spring and fall in Massachusetts coastal waters since 1978. The DMF trawl survey is informative for showing general distribution of smelt in Massachusetts coastal waters. Both spring (Figure 1.1) and fall survey catches have been highest in less than 60 feet from the Cape Cod Canal to the New Hampshire border. The spring and fall catch rates are variable and do not appear to reveal a consistent trend in abundance. Timing of smelt movements in coastal rivers and embayments may vary in relation to survey timing, resulting in inconsistent availability of smelt to the survey.

Despite the uncertain status of smelt populations, wide-ranging concerns developed over the health of the smelt resource in the 1980s based on observations from the fishing community and DMF biologists. A summary

Figure 1.1 Rainbow smelt catch in Massachusetts Division of Marine Fisheries trawl survey.



of these observations indicate that smelt fisheries in Massachusetts declined sharply during an approximate 10-year window starting in the late 1970s. Presently, most smelt runs attract only a small fraction of the interest and fishing effort of 25 years ago. Commercial landings of smelt on the U.S. East Coast show a peak harvest of 163 mt in 1966 followed by steep decline to a series low of 1.3 mt in 1988 (NOAA 2004) at the start of this monitoring project. Causal factors in this population decline have not been previously investigated, although watershed alterations such as obstructions to passage and spawning habitat degradation are suspected influences.

Smelt fishing along docks in Boston Harbor. B. Chase

Study Objectives

Concerns over declining smelt catches prompted DMF to initiate a monitoring project on smelt spawning habitat on the Gulf of Maine coast of Massachusetts. The primary objectives of this investigation were to document temporal, spatial and biological characteristics of smelt spawning on the Gulf of Maine coast of Massachusetts. The resulting baseline data can be applied to the resource management goals of protecting valuable estuarine and river habitats, sustaining the Commonwealth's smelt fisheries, and developing fishery independent and dependent investigations on smelt populations. Secondary objectives of the program were to contribute to the characterization of these river systems through the collection of baseline water chemistry, stream discharge, and ichthyoplankton data, and document the of occurrence of other diadromous species. The investigation began in 1988 and was conducted by the Sportfish Technical Assistance Program and funded by the Federal Aid in Sportfish Restoration Act.

STUDY AREA

The study area was the Gulf of Maine coast of Massachusetts from the New Hampshire border to the Cape Cod Canal (Figure 1.2). Monitoring began in the Boston Harbor and North Shore regions and expanded to the South Shore and Ipswich Bay as the initial watersheds were completed. Cape Cod was not surveyed or monitored by this investigation because no evidence of a smelt run has ever been recorded on Cape Cod (B. DiCarlo, R. Lawton, K. Reback, P. Brady, DMF biologists, *pers. comm.*) nor have anecdotal reports been noted. Presumably, the geological history of Cape Cod has resulted in stream characteristics (low discharge, sandy substrate, and low elevation gradient) that are not suitable for smelt spawning habitat.

The physical appearance of the Gulf of Maine coast in Massachusetts is most influenced by the retreat of the Wisconsin glacial sheet approximately 10,000 to 20,000 years ago. Glacial scouring was a major influence on the present coast and glacial drift provides the dominant surficial structure. Bedrock is an earlier geological influence that is found in each region with the highest occurrence on the North Shore. Other important influences on the coast include erosion, semi-diurnal tides with mean amplitude of about 2.75 m, and human development. Approximately half of the coastal drainages monitored for this study were relatively small, containing drainage areas less than 10 km^2. Each region contained several glacially carved estuaries with drainage areas over 50 km^2, and only eight river systems in the study area exceeded 100 km^2. The Merrimack River was unique among all study locations as the only large river with a watershed drainage area of nearly 13,000 km^2.

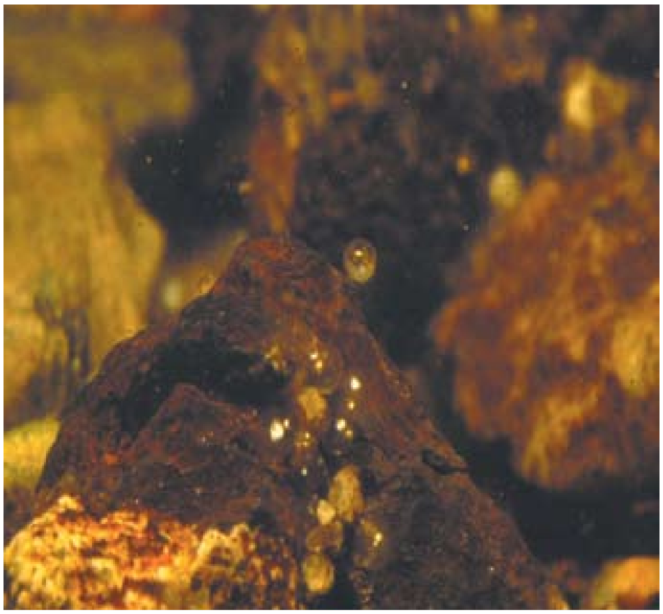
METHODS

All freshwater drainages in the study area were surveyed for potential smelt spawning habitat. Monitoring stations were selected based on survey results and the locations of known smelt spawning runs as indicated by DMF staff biologists and Reback and DiCarlo (1972). Each season, eight to twelve monitoring stations were visited twice each week from March 1st through May 31st. Observations of deposited eggs formed the basis for delineating smelt spawning habitat. Smelt spawning habitat is defined as the river water and substrate where smelt egg deposition was observed. Potential smelt spawning habitat is defined as habitat that possessed suitable conditions to attract smelt spawning but either was not previously know to be occupied by spawning smelt or no egg deposition was observed during study monitoring.

During each station visit, stream substrata were inspected for adhesive smelt eggs, and water chemistry was measured. Cobble were inspected by hand to look for adhesive smelt eggs and a stainless steel basket attached to a broom handle was used to scoop up gravel for egg inspection. Egg monitoring initially focused on the first riffle found

Figure 1.2 Smelt spawning habitat study area separated by the four watershed regions: South Coastal Basin (SCB), Boston Harbor, North Coastal Basin (NCB), and Plum Island Sound and Merrimack River.

upstream of tidal influence. Once egg deposition was identified, monitoring expanded upstream and downstream of this riffle until the upstream and downstream limits of egg deposition was recorded. Qualitative observations were recorded on egg densities and viability (dead eggs were opaque white versus near transparent viable eggs). Eggs were identified on the basis of size, oil globule, and seasonal comparison with other species (Cooper 1978; Elliot and Jimenez 1981)



Smelt eggs attached to gravel. R. Michelson, Photography by Michelson, Inc.

During 1988-1990, the following water chemistry parameters (with accuracy in parentheses) were measured at sampling stations during each visit: water temperature (±0.5°C), dissolved oxygen (±0.2 mg/l), salinity (±1.0 ppt), and pH (±0.1). Stem thermometers were used for temperature data and accuracy was confirmed using a certified thermometer. Dissolved oxygen (DO) was measured with a YSI 51B meter that was calibrated prior to each sampling trip and every three hours with ambient water-saturated air. Salinity was measured with a Reichart temperature compensated salinity refractometer that was zeroed with distilled water each week. Water pH was measured with an Orion SA 250 pH meter that was calibrated prior to each sampling trip and every three hours with standard pH buffers (4.0, 7.0, and 10.0). From 1991-1995, a Hydrolab Surveyor II was used with the following specifications: water temperature (±0.15° C), DO (±0.2 mg/l), specific conductivity (±0.075 mmho/cm), salinity (± 0.7 ppt), and pH (±0.1). Each morning prior to deployment the Hydrolab was calibrated using standard solutions for pH and conductivity, and DO was calibrated to ambient water-saturated air.

In rivers where U.S. Geological Survey (USGS) stream flow gauge stations were not available, discharge was measured at suitable spawning riffles using a Teledyne-Gurley 622-G water current meter. Stream flow characteristics were measured once or twice each month by sampling a minimum of one velocity/depth cell per meter across the selected transect. The multiplication of average velocity and average depth by stream width provided a discharge estimate (m^3/sec). Tidal conditions for Boston Harbor (White 1988-1995) were used along with local observations to determine tidal influence and record tidal stage (±0.5 hour).

Ichthyoplankton samples were collected for the purpose of confirming the presence and timing of smelt larvae movement into tidal waters. A rectangular plankton net (0.14 m^2) with 0.505 mm mesh, was used to sample the ebb flow of surface water shortly after high tide. The net was deployed from bridges downstream of spawning habitat. A 2030-R General Dynamics flowmeter attached to the net frame was used to measure stream flow rates (m/sec) and water volume (m^3). Samples were preserved in 5% phosphate buffered formalin and returned to the laboratory for sorting and microscopic analysis. All finfish eggs and larvae were measured to the nearest 0.1 mm and identified with the aid of manuals by Colton and Marak (1969), Scotton et al. (1973), Lippson and Moran (1974), and Elliot and Jimenez (1981).

Once adequate monitoring was completed to delineate the range of spawning habitat within a river system (1-3 seasons, depending on previous knowledge of location), stream measurements were made of the habitat where egg deposition was found. The wetted perimeter of the streambed where eggs were found was measured to the nearest 0.1 m using a tape measure. Mid-stream length measurements were applied to average width measurements to produce spawning substrate area (m^2). Spawning substrate area for a river was summed by stream reach. Reach lengths were assigned a maximum length of 60 meters, or were shorter due to the presence of natural bends or physical structures. The latitude and longitude of the downstream and upstream limits of egg deposition were recorded in each river using a Garmin GPSmap 76. The spawning period was estimated each season for each river based on observations of egg deposition. Spawning period was defined as the period when viable eggs were present, or in other words, the time between the date of first egg deposition and the date when hatching is complete. This definition differs slightly from the time period in which spawning occurred and was selected because of the difficulty in determining the maturation of deposited eggs. The start and end dates of spawning period were estimated as the mid-point date between the sample visits when viable eggs were first (or last) observed and the nearest sample visit when no eggs were observed.

CHAPTER 2. SPAWNING HABITAT SYNOPSIS FOR ALL REGIONS

All freshwater drainages leading to coastal waters on the Gulf of Maine coast of Massachusetts were surveyed from 1988-1995. A total of 162 specific locations were surveyed from Cape Cod to the New Hamsphire border to determine if potential smelt spawning habitat was present. From these surveys and previous knowledge of smelt spawning habitat, 64 spawning habitat monitoring stations were selected. Most stations were monitored for two seasons to delineate temporal and spatial habitat use by spawning smelt. Smelt egg deposition was recorded at 44 specific locations in 29 river systems (Figure 2.1, Tables 2.1 and 2.2). Smelt eggs were not found in the Merrimack River or its tributaries, however, smelt larvae were caught during ichthyoplankton sampling, resulting in the designation of the Merrimack River as a smelt run. This addition brings the total to 45 spawning locations within 30 river systems in the study area.

Previous records on smelt spawning habitat in the study area are limited. Seven of these drainages were not previously known to contain smelt spawning habitat, and for the majority of these locations the available information only noted the presence or absence of a spawning run and fishery. A general summary of spawning habitat characteristics will be presented in this chapter, followed by specific details on each spawning run in the chapters on the four major regions of the study area – South Coastal Drainage Area, Boston Harbor Drainage Area, North Coastal Drainage Area, and Plum Island Sound and the Merrimack River.

PHYSICAL CHARACTERISTICS

Spawning habitat stream length. The average stream length where smelt eggs were found was 261 m, and the range of stream length was 16 m to 1,111 m (Table 2.1). Only three rivers have approximately a kilometer of stream length identified as spawning habitat (Jones River, Fore River, and Mill River). In every case except the Charles River, the downstream limit of smelt egg deposition occurred near the interface of salt and freshwater. The upstream limits of egg deposition for many rivers were physical impediments that prevented further passage. When passage allowed, smelt would continue spawning upstream to freshwater riffles beyond tidal influence. In the case of the three smelt runs with a kilometer of spawning habitat, spawning continued from the tidal zone up until the first obstruction. At 11 spawning locations, the stream length receiving egg deposition was less than 100 m. In most of these cases, a short stretch of spawning habitat was available between the tidal zone and the first upstream obstruction.

Spawning substrate area. The average area of stream substrate where smelt eggs were observed was 2,336 m^2, with a range of 16 to 13,898 m^2 (Table 2.1). The single largest area of spawning habitat was identified in the Ipswich River. Only five other river systems had combined areas spawning habitat near 10,000 m^2 (Jones River, Charles River, Neponset River, Fore River and Mill River) (Table 2.2). Several spawning locations were limited in space; containing less than 100 m^2 of substrate at the first available riffle upstream of tidal influence. The Merrimack River may have a very large area of substrate suitable for spawning habitat in the main stem, but this study was not able to confirm the location of egg deposition due to the size and depth of the river.

Stream morphology. A quantitative assessment of stream morphology was beyond the scope of this study. It would require a dedicated investigation to assess these characteristics given the variation found among streams, within streams, and within seasons. Spawning locations were separated by drainage area (Halliwell et al. 1982; Wandle 1984; and Wandle and Morgan 1984) and the following general classification: main stem spawning habitat >10 km^2 with direct exit to marine waters; tributary spawning habitat >10 km^2; tributary spawning habitat <10 km^2; and small stream spawning habitat <10 km^2 with direct exit to marine waters.

Measurements of stream depth were made as part of discharge measurements and stream width was measured for calculations of spawning habitat area. These measurements along with routine habitat observations allow for limited reporting on stream morphology. The average width of stream channels where smelt eggs were found was 6.8 m (39 locations). The average width for main stem and larger tributaries was 10.3 m (21 locations), and the average width for smaller tributaries and streams was 2.8 m (18 locations). Depth measurements are limited to discharge transects in 16 streams that were located at spawning riffles. The average depth for these 16 transects was 0.28 m, and the range of average depths was 0.1 - 0.5 m. The depth data illustrate the shallow water depth found in typical smelt spawning runs; however, more information is needed to consider all smelt runs in the study area. Smelt eggs were found in depths up to 1.0 -1.5 m (with no tidal influence present) only in the Ipswich, Neponset and Charles rivers, and may occur in greater depths in the Merrimack River.

Channel morphology. Similar to stream morphology, the assessment of channel morphology was beyond the scope of this study. However, a description of the channel types observed is useful for understanding the characteristics that make a stream stretch suitable for smelt spawning. Very few smelt spawning locations had stream channels that were not modified. Only Third Herring Brook had a natural stream channel, no crossings, and no passage impediments throughout the stretch were smelt eggs were found. Four other locations (Island Creek, Essex River, Satuit Brook,

Figure 2.1 Location of smelt spawning habitat on the Gulf of Maine coast of Massachusetts. The red dots indicate the 45 locations designated as smelt runs in the study area.

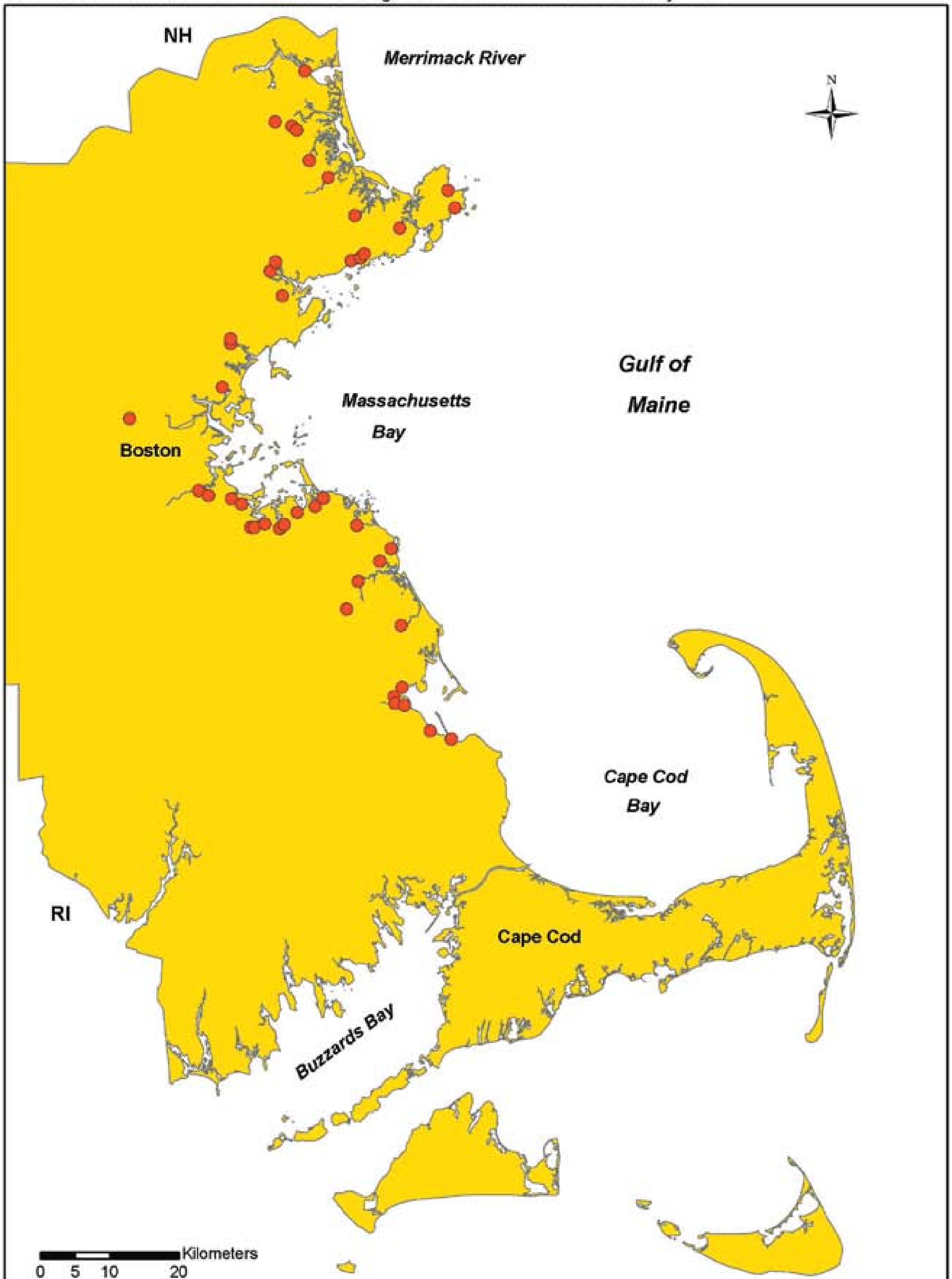


Table 2.1 List of rainbow smelt spawning locations on the Gulf of Maine coast of Massachusetts. The length and area values refer to spawning habitat where smelt egg deposition was observed. Discharge values are averages from March-May measurements for this study, except the values in bold are mean April discharges from USGS stations. Drainage area values are the closest location to river mouth reported by Wandle (1984) and Wandle and Morgan (1984).

Name	River System/ Region	Town	Length (m)	Area (m^2)	Discharge (m^3/s)	Drainage Area (km^2)
Eel River	Eel River	Plymouth	255	1,505	0.744	38.1
Town Brook	Town Brook	Plymouth	107	778	0.444	23.4
Smelt Brook	Jones River	Kingston	126	347	0.108	<7.8
Jones River	Jones River	Kingston	1,111	10,943	**1.555**	76.7
Halls Brook	Jones River	Kingston	66	260	0.237	10.3
Island Creek	Island Creek	Duxbury	304	978	0.068	<7.8
South River	South River	Marshfield	229	1,732	0.682	56.2
First Herring Brook	North River	Scituate	190	798	0.521	<7.8
Second Herring Brook	North River	Norwell	205	1,427	0.419	8.2
Third Herring Brook	North River	Norwell	345	1,958	0.663	25.3
Satuit Brook	Satuit Brook	Scituate	55	80	0.155	<7.8
Bound Brook	Bound Brook	Cohasset	166	912	0.670	29.5
Mill Creek	Chelsea	Chelsea	33	127	NA	<7.8
Charles River	Charles	Watertown	311	9,896	**17.273**	805.5
Neponset River	Neponset	Milton	334	9,495	**17.726**	303.0
Gulliver Creek	Neponset	Milton	370	1,739	NA	<7.8
Furnace Brook	Furnace Brook	Quincy	485	1,623	0.538	9.9
Town Brook	Town Brook	Quincy	800	3,241	**0.320**	10.9
Fore River	Fore River	Braintree	1030	9,839	1.580	93.5
Mill Cove creek	Fore River	Weymouth	128	249	NA	<7.8
Smelt Brook	Fore River	Weymouth	170	819	NA	5.4
Back River	Back River	Weymouth	392	3,714	1.631	45.3
Dump Creek	Back River	Weymouth	73	174	NA	<7.8
Fresh River	Back River	Hingham	168	379	0.116	<7.8
Town Brook	Town Brook	Hingham	115	200	0.082	<7.8
Weir River	Weir River	Hingham	305	2,683	NA	37.8
Turkey Run	Weir River	Hingham	149	319	0.150	<7.8
Saugus River	Saugus River	Saugus	175	1,215	1.223	124.8
Shutes Brook	Saugus River	Saugus	147	810	0.115	<7.8
North River	Danvers River	Salem	195	1,209	0.680	29.8
Crane River	Danvers River	Danvers	120	513	0.541	14.8
Porter River	Danvers River	Danvers	80	350	0.211	11.4
Chubb Creek	Manchester Bay	Manchester	58	71	0.013	<7.8
Bennett Brook	Manchester Bay	Manchester	172	296	0.045	<7.8
Sawmill Brook	Manchester Bay	Manchester	98	339	0.415	13.0
Little River	Cape Ann	Gloucester	88	192	0.066	<7.8
Sawmill Brook	Cape Ann	Rockport	28	35	NA	<7.8
Mill Brook	Cape Ann	Rockport	16	16	NA	<7.8
Essex River	Essex River	Essex	123	921	0.500	24.4
Ipswich River	Ipswich	Ipswich	544	13,898	**12.318**	404.0
Egypt River	Rowley	Ipswich	363	1,989	0.230	25.7
Mill River	Parker	Rowley	934	9,990	0.720	33.2
Ox Pasture Brook	Parker	Rowley	21	82	NA	5.6
Parker River	Parker	Newbury	300	4,630	**2.356**	156.4
Merrimack River	Merrimack	several	unknown	unknown	**547.648**	12,970.0

Table 2.2 List of 30 river systems with rainbow smelt spawning locations on the Gulf of Maine coast of Massachusetts. The area of spawning habitat is combined for all tributaries in the river system where smelt egg deposition was observed. Drainage area values are the closest locations to the mouth of the river system reported by Wandle (1984) and Wandle and Morgan (1984).

River	Town	Watershed	Spawning Habitat (No.)	Area (m^2)	Drainage Area (km^2)
Eel River	Plymouth	South Coastal	1	1,505	38.1
Town Brook	Plymouth	South Coastal	1	778	23.4
Jones River	Kingston	South Coastal	3	11,550	87.0
Island Creek	Duxbury	South Coastal	1	978	<7.8
South River	Marshfield	South Coastal	1	1,732	56.2
North River	Norwell/Scituate	South Coastal	3	4,183	272.0
Satuit Brook	Scituate	South Coastal	1	80	<7.8
Bound Brook	Cohasset	South Coastal	1	912	29.0
Mill Creek	Chelsea	Boston Harbor	1	127	<7.8
Charles River	Watertown	Boston Harbor	1	9,896	805.5
Neponset River	Milton/Dorchester	Boston Harbor	2	11,234	303.0
Furnace Brook	Quincy	Boston Harbor	1	1,623	9.9
Town Brook	Quincy	Boston Harbor	1	3,241	10.9
Fore River	Braintree/Weymouth	Boston Harbor	3	10,907	98.9
Back River	Weymouth/Hingham	Boston Harbor	3	4,267	45.3
Town Brook	Hingham	Boston Harbor	1	200	<7.8
Weir River	Hingham	Boston Harbor	2	3,002	37.8
Saugus River	Saugus	North Coastal	2	2,025	124.8
Danvers River	Danvers/Beverly/Salem	North Coastal	3	2,072	59.6
Chubb Creek	Manchester	North Coastal	1	71	<7.8
Bennett Brook	Manchester	North Coastal	1	296	<7.8
Sawmill Brook	Manchester	North Coastal	1	339	13.0
Little River	Gloucester	North Coastal	1	192	<7.8
Sawmill Brook	Rockport	North Coastal	1	35	<7.8
Mill Brook	Rockport	North Coastal	1	16	<7.8
Essex River	Essex	North Coastal	1	921	24.4
Ipswich River	Ipswich	Ipswich River	1	13,898	404.0
Egypt River	Ipswich/Rowley	Parker River	1	1,989	25.7
Parker River	Newbury	Parker River	3	14,702	195.2
Merrimack River	several towns	Merrimack River	1	unknown	12,970.0

and Egypt River) had natural stream channels and no passage impediments where smelt eggs were found, but each of these had single road crossings and modest riparian alterations that reduced the quality of the spawning habitat. All other spawning runs were challenged with a range of stream crossing structures, channelization, and passage impediments. The ideal channel configuration for smelt spawning habitat may begin with a deep channel estuary where the salt wedge rises to meet a moderate gradient riffle at the tidal interface and follows into the freshwater zone with ample vegetative buffer and canopy and an extended pool-riffle complex that spreads egg deposition out and provides resting pools. Because of extensive channel alterations, this scenario is only approximated in the Fore River- the largest smelt run in the study area.

Smelt spawning habitat at the tidal interface in the Parker River. B. Chase

A typical scenario of channel alteration includes channel walls upstream of the tidal interface that contain high flows in an urban setting and one or more road crossings and stormwater pipes before a former mill dam precluded passage further into the freshwater zone. In addition to direct physical alteration these locations are also subject to higher sediment loads, reduced riparian buffer and reduced canopy. Numerous small creeks in long-settled urban areas had narrow streams bordered by vertical channel walls for most of the stream length where spawning occurred. This channel type provided suitable water velocity to induce spawning and assist incubation; however, these conditions can lead to egg crowding, often lack resting pools, and receive concentrated stormwater pollutant loading. A less common type of urban channelization is the widened channel with vertical walls that results in very shallow depths and low velocity. Both approaches to channelization were designed to improve drainage and flood control.

Substrate type. Quantification of average substrate conditions in each spawning run was not conducted because of the time and effort required for the wide range of stream velocity and channel morphology found. A qualitative summary of routine habitat observations places gravel, pebble and cobble as the most common substrate sizes for all smelt runs in the study area. These are the particle sizes expected given the range of water velocities found at spawning riffles. Coarse cobble in the range of 10-20 cm diameter may be more suitable than smaller sizes because it is associated with higher water velocity and provides ample surface area for egg deposition and survival. Along a given reach of spawning habitat it would not be unusual to see egg deposition across a range of substrate particle sizes from sand to boulder.

Aquatic plants were a common feature of smelt spawning substrata. Few rooted, vascular plants were found in locations where smelt spawning occurred during March and April. These plants became a common feature in some river systems towards the end of the spawning season. Aquatic moss was found in some locations and was a superior substrate for smelt egg attachment and survival. Aquatic mosses are Byrophytes or attached nonvascular plants. *Fontinalis* is one of the few completely aquatic, native mosses in North America and one of the few plants that can prosper in swift river flow. The health and abundance of *Fontinalis* appeared to be associated with water quality. It was not present in most urban streams with poor water quality. Two species of the *Fontinalis* genus were observed during monitoring. A less common species was observed with short leaves and branches. A longer stem (could exceed 0.5 m) and leaf species was seen more commonly and supported the highest smelt survival observed during this study on any substrata. Water moss was not typically abundant or ubiquitous as was the presence of periphtytic algae. Periphytic algae were found in all smelt runs, typically increasing in biomass during April and May. Under conditions of high growth, these matrices of algal species were observed to have a negative influence on smelt egg survival.

Stream discharge. Most of the smelt runs in the study area occur in small coastal rivers with low seasonal base flows convened from small drainage areas. Excluding the very large Merrimack River, only eight rivers had average spring discharges over 1 m^3/s (35 cfs), and only the following three exceeded a spring average of 10 m^3/s (353 cfs): Neponset River, Charles River, and Ispwich River. River discharge was clearly a limiting factor on spawning habitat use by adult smelt and egg survival. For nearly all rivers, March flows were enhanced by snow melt and precipitation, providing adequate flows to support spawning runs. Discharge typically declined progressively in April and May, and many runs were subject to low base flows later in the spawning period. Some streams had seasonal flows that were marginal for supporting adult attraction and egg incubation. For example, five of the nine river systems with smelt runs in the North Coastal Drainage Area had average spring flows under 0.08 m^3/s (<3 cfs).

Stream velocity. Stream velocities were measured at 32 of the spawning runs in the study area. These measurements were made primarily to determine discharge in streams with no stream flow gauge stations. The transects were selected at locations that would provide suitable discharge measurements. No attempt was made to assess stream velocity requirements of spawning smelt. Substantial spatial and temporal variability in velocity is found at smelt spawning riffles because of microhabitat changes related to substrate, precipitation, and tidal influence. The stream velocity data collected can be considered for the range of flow that smelt typically used. However, any determinations of spawning habitat requirements would need the support of a rigorous stream velocity investigation.

Sixteen of the stream flow transects sampled for this study occurred at spawning riffles that routinely received smelt egg deposition. The average velocity for the measurements at these transects was 0.39 m/s (N = 73, range = 0.1 – 0.9 m/s). Qualitative observations made of egg deposition associated with all discharge measurements indicate that velocities below 0.3 m/s may not induce much spawning activity while velocities over 1.0 m/s may reduce spawning activity due to the physical challenge of continuous swimming against this flow. The 0.39 m/s average for these measurements is in the spawning range but may be below optimal. Based on these observations, it is hypothesized that the optimal range to induce spawning and achieve high egg survival is in the range of 0.5 to 0.8 m/s. It is also hypothesized that velocities above 1.2 m/s will preclude the passage of average sized adult smelt and may increase egg mortality through scouring.

SPAWNING PERIOD

The smelt spawning period was delineated by direct observations of smelt eggs adhered to spawning substrate during the twice weekly visits to each monitoring station. A summary of 48 spawning periods in 30 rivers is reported in Table 2.3. In some cases (21 of 69 potential observations), the start or end date of the spawning period could not be determined. The accuracy of the spawning period estimates was not assessed. This is because of the undetermined error associated with low frequency of station visits, the extrapolation of start and end dates, and the possibility of overlooking smelt eggs. Observations were eliminated when I was not confident that the estimated dates were within three days of the probable start or end date. In a majority of observations, it was not difficult to identify the onset of spawning because smelt eggs were routinely targeted and found at the first riffle above tidal influence at the start of the season. The end date of the spawning period is the estimated last date with viable eggs present, and therefore an estimate of the end of hatching and not the actually end of egg deposition. The onset of blueback herring spawning in May required additional efforts for estimating the end date in some rivers. Questionable eggs were brought back to the laboratory to hatch and confirm identity. Despite the overlap, field identification of smelt and blueback eggs was confirmed with hatching in each case with one exception (alewife).

The overall pattern for the four regions was consistent: all spawning occurred in March, April and May with spawning usually beginning in the second or third week of March. A typical spawning season for the study area was the third week of March to the third week of May. The only regional trend identified was that the spawning runs in the Plum Island Sound region ended earlier than runs in the southern three regions. No smelt eggs were found in May during two seasons at three of the four spawning runs in Plum Island Sound. The average end date for Plum Island Sound runs was more than two weeks earlier than the other regions. The reason for this earlier run is not known but it is consistent with observations made by the author consequent to the study period. The early finish to the run in Plum Island Sound resulted in an average spawning period duration of 46 days, in contrast to approximately two months for the other regions. The maximum spawning period duration was recorded in the Neponset River in 1990 when smelt eggs were present for 85 days.

Despite similar seasonal trends, there were differences among runs that appeared to be most related to the size of the run and available spawning habitat. The larger runs routinely began earlier in March and as a consequence had longer spawning period durations. The 48 records of spawning period were separated into two groups: larger main stem rivers with at least 1,000 m^2 of spawning substrate (N = 26) and tributaries and independent streams with less than 1,000 m^2 (N = 22). For the entire study area, the average start date for the larger runs was March 15th and March 29th for the smaller runs. There was also a group of spawning runs represented by very small, independent creeks where the onset of spawning began considerably later than average. The start date for these streams was documented between April 5th and April 21st. Each of the four runs in this group had little available spawning habitat with apparently very low numbers of smelt participating in the run.

The average water temperature at the start of the spawning season ranged from 3.5 °C in Plum Island Sound to 6.3 °C in the North Coastal Basin. The average temperature at the start of the run for all 48 observations was 5.3 °C. The average was 4.7 °C when data for the four late-starting streams were removed. The influence of river size on the onset of the spawning season was also seen with water temperature. The 26 observations in larger main stem rivers had an average starting temperature of 4.0 °C, while the average was 6.9 °C for the 22 observations of small streams.

Table 2.3 Summary of smelt spawning period by region on Gulf of Maine coast of Massachusetts. The spawning period is defined as the period when observations of viable smelt eggs were recorded. The observations only include seasons when the start and end of the spawning period were delineated.

Region	Rivers (No.)	Records (No.seasons)	Spawning Period (Range)	Start Date (Ave.)	End Date (Ave.)	Start Water Temp. (Ave., ºC)
Plum Island Sound	4	7	March 10th - May 13th	3/15	5/1	3.5
North Coastal Basin	7	12	March 11th - May 27th	3/25	5/17	6.3
Boston Harbor	8	13	March 3th - May 27th	3/18	5/22	4.4
South Coastal Basin	11	16	March 5th - May 28th	3/25	5/19	6.2

Table 2.4 Massachusetts Surface Water Quality Standards (MDEP 1996). Under the Clean Water Act process, MDEP sets minimum water quality criteria to sustain designated uses in water bodies. The designated use most applicable to this study is *Aquatic Life* ("suitable habitat for sustaining a native, naturally diverse, community of aquatic flora and fauna"). The table parameters were measured during this study and used by MDEP to assess rivers as *Supporting* or *Impaired* in relation to designated uses.

Parameter	**Class**	**Unit**	**Note**
Dissolved Oxygen	Inland Waters (SA)	$\geq$ 6.0 mg/l	$\geq$ 75 % saturation
	Inland Waters (SB)	$\geq$ 5.0 mg/l	$\geq$ 60 % saturation
Temperature	Inland Waters (SA)	$\leq$ 29.4 ºC	$\leq$ 26.7 ºC max. daily mean
	Inland Waters (SB)	"	"
pH	Inland Waters (SA)	6.5 - 8.5	0.2 max. change from normal range
	Inland Waters (SB)	"	"

DEFINITIONS

CLASS SA *"These waters are designated as an excellent habitat for fish, other aquatic life and wildlife and for primary and secondary recreation. In approved areas they shall be suitable for shellfish harvesting without depuration. These waters have excellent aesthetic value."*

CLASS SB *"These waters are designated as habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. In approved areas they shall be suitable for shellfish harvesting with depuration. These waters have consistently good aesthetic value."*

Table 2.5 Summary of water pH at smelt spawning habitat stations in Massachusetts. Mean seasonal pH (all March-May measurements for a given river during one season) data were averaged by region during the period of 1988-1995.

Region	Rivers (No.)	Records (No. seasons)	Mean pH (Ave.)	Mean pH (SE)	Mean pH (Range)
Plum Island Sound	4	8	7.1	0.042	7.0 - 7.3
North Coastal Basin	8	20	7.0	0.116	6.2 - 7.6
Boston Harbor	11	19	7.1	0.071	6.5 - 7.5
South Coastal Basin	11	18	6.2	0.079	5.6 - 6.7

WATER CHEMISTRY

Water chemistry measurements of temperature, DO, salinity, specific conductivity, and pH were made during the twice weekly visits to the spawning habitat monitoring stations. These measurements were compared to Massachusetts Surface Water Quality Standards (WQS) issued by the Massachusetts Department of Environmental Protection (MDEP) and to references with water quality information related to rainbow smelt. Surface WQS provide minimum water quality criteria to support designated uses for rivers (Table 2.4). The designation of supporting "aquatic life" for Inland Waters (Class A and B) is most applicable to this study and will be referenced for the parameters of temperature, DO, and pH. It is important to note that only a few basic water chemistry parameters were measured for this study, and little information is available on the relation of water chemistry to the health and survival of smelt throughout their life cycle.

Water Temperature. No concerns of the affect of water temperature to support aquatic life were found during the smelt spawning season. The influence of ambient air temperatures in the spring and headwater storage kept stream flow cool throughout March and most of April. Seasonal air temperature increased stream temperature as May progressed, yet no violation of the water temperature criterion to support aquatic life (>28.3 °C) was measured during the spawning period. The seasonal climate resulted in consistent average spawning period water temperatures among rivers. The average water temperature of spawning periods was 10.5 °C for all observations where the spawning period was delineated (N = 45, 28 rivers; sd = 1.131; range = 8.3 – 12.7 °C). An investigation on the thermal tolerances of rainbow smelt larvae found no mortality for larvae exposed to the freshwater temperature of 26.8 °C for up to an hour (Barker et al. 1981). Barker et al. (1981) also found increasing mortality for larvae held at 28.8 °C and 100% mortality for larvae held a half hour or longer at 30.8 °C. Water temperature in the range that caused larval mortality was not encountered at spawning habitat stations during this study.

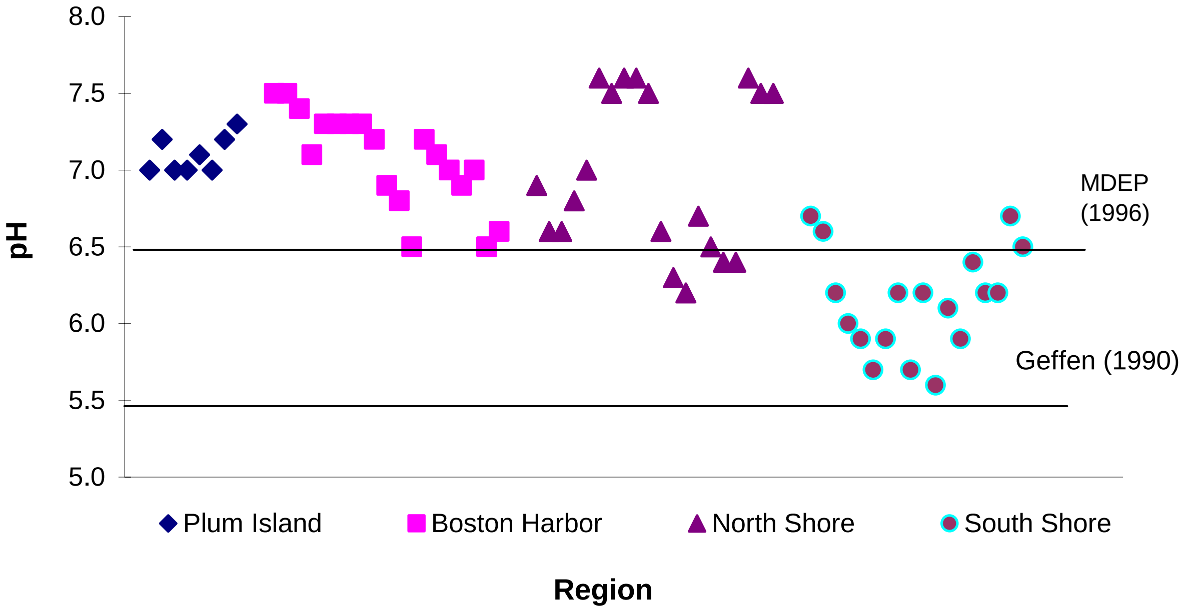
Dissolved Oxygen. No concerns on the influence of DO to support aquatic life were found during the smelt spawning season. The climatic conditions that keep stream temperatures cool during spring and the turbulence of lotic flow allows high concentrations of DO to persist throughout the spawning period. A large majority of DO measurements were at saturated or supersaturated concentrations. No violations of water quality criterion for DO (Class A = <6.0 mg/l) were found during any spawning period. A few DO violations were found among all samples and these were during the end of May and associated with river herring crowding. The average seasonal DO for smelt spawning runs during March/April/May was 11.4 mg/l (N = 54, 28 rivers; sd = 0.600; range = 10.4 – 12.5 °C).

Water pH. Evidence of acidification in freshwater flows was found in a majority of the smelt runs monitored. Acidity has been identified as a concern for smelt egg survival during episodic events of snow melt and high spring precipitation (Geffen 1990). The WQS give a range of 6.5 to 8.3 to support aquatic life for Class A Inland waters. Geffen (1990) identified 5.5 as a pH level where smelt eggs were tolerant of short-term exposure but experience high mortality with long-term exposure during incubation. The average seasonal pH for all stations with complete March-May measurements was 6.8 (N = 65 in 34 rivers). Water pH by region had near neutral averages for each region except the South Coastal Basin where acidity was a concern in most rivers (Table 2.5; Figure 2.2). Despite averages near neutral for the three northern regions, the pH in most rivers showed a tendency to pulse down after precipitation, and many rivers had individual violations of the WQS associated with rain events.

No seasonal monthly means for rivers in the Plum Island Sound region were below 6.5 pH. Boston Harbor smelt runs were generally near neutral pH and displayed the capacity to buffer episodic events. However, in this region, Weir River and Back River had monthly means for March below 6.5 pH. Smelt runs in the North Coastal Basin had the widest range of monthly means (6.1 – 7.8), and had several small creeks in Manchester Bay and Cape Ann that commonly experienced water pH below 6.5. Smelt runs in the South Coastal Basin displayed a consistent pattern of acidity at levels that could reduce smelt egg survival. Only two rivers in the South Coastal Basin had seasonal means above 6.5. In this region there was a stronger pattern than seen elsewhere of having the highest acidity early in the season. This would be expected with snow melt and may have been influenced by high precipitation in 1994 when the South Coastal Basin was monitored. The lowest seasonal mean pH among all smelt runs in the study area occurred in 1994 at Bound Brook (5.7), Third Herring Brook (5.7) and Island Creek (5.6). During March of 1994 these three smelt runs experienced routine pH levels in the low 5.0s, and their monthly means (5.3 - 5.5) represented a threat to smelt egg survival.

Specific Conductivity. Specific conductivity is a measure of the capacity of a solution to carry an electric current and is dependent on the ionic influences of the drainage area. The WQS do not have a criterion for specific conductivity, and no references are available on the influence of specific conductivity to the health of smelt. Higher conductivity in freshwater samples can be indicative of pollution discharges with dissolved metals. Specific conductivity was not measured until 1991; therefore, data are only available for 23 rivers. The average of mean specific conductivity for these 23 rivers is 0.274 mS/cm and the range is 0.133 to 0.641. Most of the sampled rivers were in a range of low conductivity.

Figure 2.2 Average water pH at smelt spawning habitat stations in the study area, 1988-1995. Values are mean seasonal pH (March-May) for rivers within each region. Lines are drawn at 5.5 and 6.5 to denote pH levels of concern for aquatic resources.



Salinity. The encroachment of salt water from flood tides did not commonly occur at the smelt spawning habitat stations. Water chemistry measurements were made at prime spawning riffles at the spawning habitat monitoring stations to characterize freshwater chemistry. At some stations, tidal influence was routinely observed as the flood tide backed up freshwater flow. In very few cases was saltwater detected in the tidal influence. At a few stations, brackish water could occur during high amplitude tides in late May as seasonal discharge declined. Raw data on salinity are provided in the Appendix, and unique findings are discussed in the chapters on individual rivers. In some rivers, the salt wedge would routinely move upstream of the lower limit of egg deposition. This was usually associated with a constriction such as a road bridge that would increase velocity and provide some attraction for spawning adults well-downstream of the prime spawning riffles. In these cases, I observed egg deposition and survival to late egg stages at substrata that was exposed diurnally to higher salinities (20-28 ppt).

Other Parameters. The water chemistry measured for this study was comprised of basic parameters that are easily measured in the field but are a small subset of parameters that characterize water chemistry. Two topics of concern were observed but not assessed during this study. Precipitation events brought rapid changes to water chemistry. Changes in specific conductivity and increasing acidity were measured responses to storm events. Also occurring during the first flush was rapidly increasing turbidity and often the presence of petroleum residues on the surface. The severity of declining water quality with storm events depended on the extent of urbanization of the watershed. There was a very clear difference in the water quality of base flows versus storm flows that could have a substantial episodic effect on smelt egg survival. Secondly, observations of the effects of cultural eutrophication were nearly ubiquitous at the 64 habitat monitoring stations. Typically, as water temperatures increase in late April, periphyton growth increased on the streambed. The dominant forms of periphyton were usually filamentous green algae or gelatinous matrices representing several taxonomic groups. There was much variation to when the periphyton growth began and peaked among seasons and rivers. There was also much variation in the biomass of periphyton among rivers and season. Periphyton could be present at low levels that may not represent eutrophic conditions or at such high concentrations that the substrate was completely covered, and complete sets of smelt eggs died. For most smelt runs, mid to late-season periphyton biomass was at nuisance levels, which raised serious concerns over the effects of eutrophication on smelt spawning habitat.

Table 2.6 Summary of all ichthyoplankton samples (N = 185) from 16 stations in rivers where smelt spawning habitat was monitored. The catch data shown summarize all samples except average density range is the range for sets when the given species occurred in each river. Average size is total length for larvae/juveniles and diameter for eggs.

Species		**Type**	**FOC** (No.)	**FOC** (%)	**Catch** (No.)	**Period**	**Ave. Size Range** (mm)	**Ave. Density Range** (No./100 m^3)
rainbow smelt	*Osmerus mordax*	larva	51	27.6	2038	4/14 - 6/7	5.5- 11.8	0.3 - 81.5
sand lance	*Ammodytes americanus*	larva	35	18.9	366	3/7 - 6/8	6.7 - 15.0	0.2 - 22.0
grubby	*Myoxocephalus aenaeus*	larva	29	15.7	115	3/7 - 5/23	5.6 - 11.2	0.1 - 4.7
Atlantic tomcod	*Microgadus tomcod*	larva	13	7.0	104	3/7 - 4/19	5.6 - 9.4	0.6 - 8.9
Atlantic silverside	*Menidia menidia*	larva	12	6.5	55	3/29 - 6/9	4.5 - 7.0	0.1 - 1.8
winter flounder	*Pseudopleuronectes americanus*	larva	10	5.4	68	4/3 - 6/7	5.0 - 8.2	0.1 - 4.3
radiated shanny	*Ulvaria subbifurcata*	larva	8	4.3	244	3/15 - 5/23	5.5 - 8.9	0.1 - 17.2
Atlantic herring	*Clupea harangus*	juvenile	8	4.3	9	3/3 - 4/30	28.0 - 38.0	0.1 - 0.4
rock gunnel	*Pholis gunnellus*	larva	6	3.2	43	3/18 - 6/8	12.3 - 22.0	0.1 - 1.7
Atlantic cod	*Gadus morhua*	larva	6	3.2	7	3/10 - 5/15	11.0 - 22.0	0.1 - 0.5
seasnail	*Liparis atlanticus*	larva	5	2.7	19	4/20 - 6/1	2.6 - 6.4	0.1 - 1.2
threespine stickleback	*Gasterosteus aculeatus*	adult	2	1.1	3	3/29 - 6/6	41.5 - 43.0	0.2
fourspine stickleback	*Apeltes quadracus*	adult	2	1.1	2	5/14 - 6/2	19.3 - 42.0	0.1 - 0.3
white sucker	*Catostomus commersoni*	larva	2	1.1	2	5/22 - 5/23	10.0	0.1
seasnail (not *L.atl.*)	*Liparis sp.*	larva	2	1.1	4	4/19 - 5/17	4.0 - 5.7	0.1 - 0.5
yellowtail flounder	*Limanda ferruginea*	larva	1	0.5	3	5/23	2.6	0.2
alligatorfish	*Aspidophoroides monopterygius*	larva	1	0.5	1	4/25	11.0	0.1
blueback herring	*Alosa aestivalis*	juvenile	1	0.5	1	5/20	46.0	0.1
mummichog	*Fundulus heteroclitus*	juvenile	1	0.5	1	5/24	31.0	0.1
ninespine stickleback	*Pungitius pungitius*	adult	1	0.5	1	6/6	28.5	0.1
northern pipefish	*Syngnathus fuscus*	larva	1	0.5	1	5/26	14.0	0.1
silver hake	*Merluccius bilinearis*	larva	1	0.5	1	4/8	9.1	0.1
L-L group	*Labridae-Limanda*	egg	15	8.1	703	4/25 - 6/8	0.9 - 1.0	0.6 - 37.0
P-S group	*Paralichthys-Scopthalmus*	egg	15	8.1	293	4/23 - 6/7	0.9 - 1.1	0.1 - 20.3
American plaice	*Hippoglossoides platessoides*	egg	7	3.8	31	4/5 - 6/1	2.2 - 2.4	0.1 - 4.9
rainbow smelt	*Osmerus mordax*	egg	5	2.7	75	4/16 - 5/4	1.0 - 1.2	0.2 - 26.7
G-G group	*Gadidae-Glyptocephalus*	egg	5	2.7	22	4/8 - 6/1	1.0 - 1.4	0.1 - 3.4
Atlantic silverside	*Menidia menidia*	egg	3	1.6	10	4/14 - 5/12	1.1	1.1
Atlantic mackerel	*Scomber scombrus*	egg	1	0.5	7	5/13	1.4	0.6
E-U-P group	*Enchelyopus-Urophycis-Peprilus*	egg	1	0.5	2	4/30	0.8	0.6

ICHTYOPLANKTON

A total of 185 ichthyoplankton samples were collected at 16 river stations in the study area during 1988-1995 (Table 2.6). Smelt larvae were caught during 51 sets and were present at all but two stations. The earliest catch of smelt larvae was April 14th, which occurred in the Fore River during both 1988 and 1989. Smelt larvae occurred throughout May with peak densities found from mid-April to mid-May (Figure 2.3). Only six sets had smelt larvae densities that exceeded $1/m^3$, and half of these were in the Fore River. The highest density of smelt larvae recorded was $10.7/m^3$ collected in the Fore River on April 14th, 1988. Smelt larvae caught in April were all yolk-sac larvae with an average total length of 6.6 mm. A large majority of smelt larvae caught during the first half of May were yolk-sac larvae with an average total length of 7.3 mm. By the latter half of May, the proportion of yolk-sac larvae declined, and the average total length was 8.6 mm.

At least twenty-seven species of fish were represented by the life stages of fish caught in ichthyoplankton samples. Because the objective of the sampling was to confirm the presence and timing of smelt larvae, these catch data should not be considered to represent the occurrence of all fish species in the tidal rivers sampled. Sampling was not random, occurred over a short season, and a small net ($0.14\ m^2$ frame opening) was used to sample the ebb flow of surface water. Few species of fish occurred frequently or abundantly. Following smelt, sand lance and grubby occurred most frequently and were found for most of the March-May sampling period. Two species were represented by a relatively high occurrence and abundance of eggs: the L-L group *(Labridae-Limanda)* and P-S group *(Paralichthys-Scopthalmus)* of fish eggs were caught during 15 sets. The L-L group is most likely cunner and the P-S

Table 2.7 Observations of other diadromous fish species during smelt spawning habitat monitoring on the Gulf of Maine coast of Massachusetts. The presence of a species is only noted when direct observations were made during the monitoring period.

River	Watershed	River Herring	American Shad	Sea Lamprey	American Eel	Atlantic Tomcod	White Perch
Eel River	South Coastal				X		
Town Brook	South Coastal	X			X		
Jones River	South Coastal	X			X		
Island Creek	South Coastal	X			X		
South River	South Coastal	X			X		
North River	South Coastal	X	X	X	X		
Satuit Brook	South Coastal						
Bound Brook	South Coastal	X			X		
Mill Creek	Boston Harbor						
Charles River	Boston Harbor	X	X		X		X
Neponset River	Boston Harbor	X	X		X		
Furnace Brook	Boston Harbor						
Town Brook (Q)	Boston Harbor				X	X	
Fore River	Boston Harbor	X			X	X	
Back River	Boston Harbor	X			X		X
Town Brook (H)	Boston Harbor						
Weir River	Boston Harbor	X			X	X	
Saugus River	North Coastal	X			X	X	
Danvers River	North Coastal	X			X		
Chubb Creek	North Coastal				X		
Bennett Brook	North Coastal				X		
Sawmill Brook (M)	North Coastal				X		
Little River	North Coastal	X			X		
Sawmill Brook	North Coastal						
Mill Brook	North Coastal						
Essex River	North Coastal	X			X		
Ipswich River	Ipswich River	X		X	X		
Egypt River	Parker River	X			X		
Parker River	Parker River	X		X	X		
Merrimack River	Merrimack River	X					

Smelt and alewives in the Back River. R. Michelson, Photography by Michelson, Inc.

Sediment plume in Furnace Brook, Quincy. B. Chase

group is most likely windowpane. Grouping was required because of overlap in egg characteristics among species within groups.

A single blueback herring juvenile caught in the Danvers River was the only other anadromous species caught other than smelt and Atlantic tomcod. The occurrence of Atlantic tomcod and Atlantic herring was distinct in terms of location of catch and seasonality. Atlantic tomcod were only found in the Weir River, Fore River, Town Brook (Quincy) and Saugus River during March and April. Atlantic tomcod were consistently present prior to mid-April in low densities in the Fore River each of the three seasons sampled there (N = 7, of 13 total tomcod occurrences). Atlantic herring were only caught in Furnace Brook, Saugus River and Porter River during March and April. Six of the eight total herring occurrences were in the Saugus River prior to mid-April.

OBSERVATIONS OF OTHER DIADROMOUS SPECIES

Diadromous fish species other than smelt were observed in all but six of the 30 river systems monitored with smelt runs (Table 2.7). Only river herring (both alewife, *Alosa pseudoharengus*, and blueback herring, *Alosa aestivalis*) and American eel (*Anguilla rostrata*) were observed commonly. River herring were seen in 19 of the 30 river systems and were not difficult to detect as adult herring were active during the daytime in May. On over 20 occasions, late-season eggs were collected for hatching to confirm the species. All 16 successful hatchings were smelt eggs except three samples of eggs collected between May 23rd and May 26th produced blueback herring (N = 3) and alewife (N = 1). American eel elvers were found in 23 of 30 river systems and were abundant in some systems. They were routinely picked up during April and May in the basket of the egg scoop used to sample gravel for smelt eggs. It is likely that eels were present and escaped detection in several of the seven rivers systems where they were not found. The monitoring effort was not suitable to fully detect the presence of the remaining diadromous species. A few individual American shad (*Alosa sapidissima*) and sea lamprey were observed on one or two occasions in three rivers each. Atlantic tomcod (*Microgadus tomcod*) and white perch (*Morone americana*) typically occupy habitat downstream from the tidal interface and therefore were rarely seen. Atlantic tomcod were caught only as larvae in four rivers during ichthyoplankton sampling, and two dead white perch adults were found in two rivers. River specific details are provided in the regional chapters on other diadromous fish.

Excessive growth of periphyton in the Porter River, Danvers. B. Chase

NEGATIVE INFLUENCES ON SPAWNING HABITAT

Observations from the monitoring project identified nine physical and chemical conditions that clearly degraded the quality of stream habitat for migrating adult smelt and smelt egg survival (Table 2.8). No quantitative assessments were made on the impact of degraded habitat features on smelt populations. Such an endeavor requires population time series data and investigations on the cause and effect of suspected negative influences. Currently, concerns for declining smelt populations are rising across their range

Table 2.8 Negative influences on the suitability of smelt spawning habitat on the Gulf of Maine coast of Massachusetts. The habitat score is a qualitative rank based on observations made during the spawning habitat monitoring, with increasing values indicating higher degradation.

Habitat Influence	Habitat Condition			
Sedimentation	not observed	minor and isolated presence	moderate substrate degradation	substantial substrate degradation
Eutrophication	not observed	minor periphyton fouling	moderate substrate degradation	substantial substrate degradation
Passage impediments	not observed	impediment present with minor limitation on spawning habitat	moderate limitation on spawning habitat	substantial limitation on spawning habitat
Channel alterations	not observed	alterations present with minor reduction in habitat suitability	moderate reduction in habitat suitability	substantial reduction in habitat suitability
Stream flow	no concerns	dry weather low flows with minor substrate exposure	water regulation causes moderate substrate exposure in most years	water regulation causes substantial habitat degradation
Stormwater flow	no concerns	single road drain in residential area	moderate loading of stormwater pollutants	substantial loading of stormwater polluntants in urban area
Tidal influence	no concerns	tidal influence may have minor effect on egg survivial	tidal influence exposes eggs to air and high salinity	routine tidal exposure to large portion of spawning habitat
Vegetative buffer	no concerns	minor loss of natural canopy and riparian buffer	moderate loss of canopy and buffer	No canopy and little vegetative riparian buffer
Water chemistry (acidification)	no concerns	Infrequent violations of Water Quality Criteria (<6.5 pH)	Routine violations of Water Quality Criteria (<6.5)	Chronic acidification of base flows (mean pH <6.5)
Score	**0**	**1**	**2**	**3**

with little information available on causal factors. A summary of each negative influence may benefit future investigations on this topic. This section briefly summarizes each influence and provides qualitative scores for each smelt run: site- specific details are provided in the chapters on the individual river systems.

Sedimentation. Following fertilization, demersal smelt eggs sink to the stream bed and adhere to any substrata upon contact. Irregular substrate such as gravel, cobble, and aquatic vegetation provide large amounts of surface area to receive high egg densities without crowding. The deposition of sediments can reduce this surface area. In areas with high-traffic roadways, the winter sanding of the roads can contribute large amounts of sand that degrade spawning riffles. High densities of smelt eggs on sand can result in fungal infestation which causes high egg mortality. Degradation associated with sedimentation is highly related to stormwater drain structures. The occurrence of sedimentation was seen in most rivers; however, the magnitude of negative impacts was related to the proximity and load of point sources to spawning habitat.

Eutrophication. Eutrophication is the natural and human-induced process of enriching a water body with nitrogen and phosphorus. Nutrient enrichment leads to increased plant production of organic matter which contributes to declining water and habitat quality. Observations from this study found nearly ubiquitous evidence of eutrophication in smelt runs in Massachusetts. The obvious impact observed was the excessive growth of periphyton on substrata used for smelt egg deposition. Depending on the timing and species composition of periphyton growth, eggs that attach to periphyton could experience high mortality. It is assumed that the plant growth causes increased egg mortality by disrupting normal egg metabolism or respiration. This study did not measure nutrient concentrations or investigate the cause and effect of the concern. However, the wide-spread occurrence of excessive periphyton growth and observed influence on egg mortality clearly identifies eutrophication as a serious threat to smelt spawning habitat.

Passage Impediments. Structures that limited the upstream movement of adult smelt were primarily dams, high gradient culverts or culverts covered over a long distance. Many of these structures are associated with mill industries and have turned upstream waters to lentic habitat that has little benefit to spawning smelt. In response, the dam spillway and footing often provides suitable high gradient riffles and becomes the upstream limit of smelt spawning habitat. Despite the common presence of dams, the construction timing for most of these impediments precludes the period in the late 1970s and early 1980s when smelt populations appear to have declined rapidly. More recently, flood control structures have been constructed in some rivers that inadvertently impede or obstruct fish passage.

Channel Alterations. The most common channel alteration is channelization where the walls of the stream are fortified with concrete or stone to accommodate storm flows. This alteration is not always degrading to the smelt habitat. Short stretches of channelized streams can increase velocity and produce suitable riffle habitat that receive the majority of egg deposition for a given run. Problems occur when channelization induces smelt to spawn in less suitable areas where eggs can become crowded or flushed to intertidal habitat downstream. These structures can also provide better access for bird and mammal predators of adult smelt that are vulnerable in the shallow channels. Channelization is often associated with stormwater inputs as well as reduced pool habitat, riparian buffer and canopy. Less common channel alterations are the widening of channels to facilitate flood control and the production of braided channels by diverting flow through several culverts. Both these structures can reduce velocity of attraction flows and expose eggs during incubation.

Stream Flow. Base flows in most monitored streams provided adequate flow for March and April. Declining flows later in the spawning season could reduce water velocity and the surface area of spawning habitat. In worst cases, observations were made of egg mortality occurring due to air exposure in shallow reaches as flows declined. Most rivers of concern were regulated for municipal water supplies. The combination of dry weather and regulation could lead to substantial degradation of spawning riffles later in the spawning season. This negative influence could also result from watershed or flood control alterations that increase stream flow flashiness by reducing groundwater infiltration. Concerns related to stream flow were site-specific and closely related to regulation with few exceptions. Declining spring flows appear to be an even greater threat to other anadromous species that spawn later in spring. Chronic flow reductions due to long-term regulation may also be causing spawning and nursery habitat degradation that is not easily detected by altering estuarine mixing zones where smelt larvae can be retained in high abundance (Ouellet and Dodson 1985; and Dodson et al. 1989).

Low flow with dead smelt in Second Herring Brook. B. Chase

Stormwater Flow. Stormwater flow could be considered a broader category that includes other listed influences because stormwater inputs deliver concentrated loads of sediments, nutrients and dissolved ions. Stormwater influence deserves independent consideration because point sources are readily identified and managed structures. Secondly, the relationship of stormwater flows (pollutant load, and impact) to smelt spawning habitat has not been investigated and requires more attention. Stream stretches subject to substantial stormwater loading appeared to have reduced presence of aquatic moss which is favorable to smelt egg survival. The pollutant loads delivered by stormwater systems to spawning habitats are dependent on the development of the drainage area, with urban areas showing a dramatic reduction in water quality from base to storm water flows.

Tidal Influence. A summary of published investigations on the effect of salinity on rainbow smelt and European smelt (*Osmerus eperlanus*) egg survival indicates that smelt eggs do not experience harmful effects below 10 ppt salinity, but mortality increases in the range of 12-16 ppt and full mortality can occur over 25 ppt (Unanian and Soin 1963; Baird 1967; Belyanina 1968). Therefore, locations where passage obstructions induce egg deposition in tidal zones with high salinity at flood tide may cause higher than natural egg mortality. Secondly, smelt that spawn during flood tides can deposit eggs in locations that will be exposed to air at low tide. These concerns were observed on a site-specific basis, primarily where mill dams were constructed near the tidal interface. Evidence was found during this study of higher than expected survival of smelt eggs when exposed to diurnal tides with salinity above 20 ppt.

Table 2.9 Habitat scores of nine listed negative influences on smelt spawning locations on the Gulf of Maine coast of Massachusetts. Refer to table 2.7 for categories and scoring of habitat influences. The scores are based on the observations of the author during the study period.

River	Sediment	Eutrophied	Passage	Channel	Flow	Storm	Tidal	Buffer	Acidity	Score
Eel River	1	1	1	1	1	1	1	1	2	10
Town Brook (Plym.)	3	2	2	1	1	2	1	2	2	16
Smelt Brook (King.)	1	2	1	1	1	1	1	1	2	11
Jones River	2	3	2	1	2	1	0	1	2	14
Halls Brook	1	1	2	1	0	1	0	1	2	9
Island Creek	2	1	1	1	1	1	1	0	3	11
South River	2	3	1	1	1	1	1	1	2	13
First Herring Brook	1	2	1	1	2	2	1	1	2	13
Second Herring Brook	1	2	1	2	2	1	0	0	2	11
Third Herring Brook	1	1	0	0	1	1	0	0	3	7
Satuit Brook	1	1	1	0	1	1	0	1	2	8
Bound Brook	1	1	2	1	1	1	2	1	3	13
Mill Creek	3	3	2	3	3	3	2	2	1	22
Charles River	2	3	3	1	1	3	0	2	1	16
Neponset River	2	3	2	1	1	3	3	2	1	18
Gulliver Creek	3	2	2	1	1	2	1	1	1	14
Furnace Brook	2	2	2	2	1	2	1	2	1	15
Town Brook (Quincy)	3	3	2	2	3	3	1	3	1	21
Fore River	2	2	1	1	1	2	1	2	1	13
Smelt Brook (Wey.)	3	2	3	3	2	3	3	2	1	22
Back River	3	3	2	3	1	3	2	3	2	22
Dump Creek	2	2	2	2	2	2	2	2	1	17
Fresh River	2	2	2	2	1	1	1	1	1	13
Town Brook (Hing.)	3	2	3	3	2	3	2	2	1	21
Weir River	1	2	2	1	2	1	1	2	2	14
Turkey Run	2	2	1	1	1	1	1	1	1	11
Saugus River	2	2	1	1	2	3	1	2	1	15
Shute Brook	3	3	3	1	1	2	1	1	1	16
North River	3	2	1	2	1	3	1	2	1	16
Crane River	3	3	1	2	1	3	1	1	1	16
Porter River	2	2	1	2	1	2	1	1	1	13
Chubb Creek	2	2	2	2	1	1	1	1	2	14
Bennett Brook	2	2	1	1	1	1	1	1	1	11
Sawmill Brook (Manch.)	2	1	3	1	0	1	1	1	2	12
Little River	3	2	3	3	2	1	2	2	2	20
Sawmill Brook (Rock.)	1	2	2	2	1	1	2	1	1	13
Mill Brook	1	2	2	2	1	1	1	1	1	12
Essex River	1	2	0	1	1	1	0	1	1	8
Ipswich River	2	1	1	1	2	2	1	2	1	13
Egypt River	1	1	1	1	2	1	0	0	1	8
Mill River	2	3	1	0	1	1	0	1	1	10
Parker River	1	2	2	1	1	1	1	1	1	11
Score by Influence	81	85	69	60	55	71	44	56	62	

Vegetative Buffer. Riparian vegetation and canopy above the stream bed are natural features that provide a range of benefits to the health of a river. Riparian vegetation can reduce sedimentation, filter stormwater, and contribute to stream bank habitat. Vegetative canopy is essential for shading the stream to mitigate solar warming and contributes to the stability of the riparian buffer. In urban areas, the riparian buffer has been reduced drastically and in some downtown locations no canopy remains. The reduction of canopy is especially detrimental in eutrophied rivers because the lack of shading fuels the growth of benthic algae.

Water Chemistry (acidification). The water chemistry measured for this study was limited to basic water chemistry parameters. No information was recorded on the presence of specific dissolved ions, hydrocarbons, or other compound molecules that could be harmful to smelt. The only substantial threat to smelt identified in the water chemistry sampling was acidification in specific rivers. Violations of the WQS for pH (<6.5) were found in a majority of rivers, and pH below 5.5 was recorded in several smelt runs in the South Coastal Basin.

Summary of Habitat Scores. The score ranking of smelt runs related to the nine negative influences on their spawning habitat (Table 2.9) provides a useful perspective on the threats to smelt habitat in the study area and can assist future considerations on the cause of smelt population declines. The qualitative origin and lack of weighting among influences should be considered when evaluating these scores. Eutrophication and sedimentation had the highest scores summed for all rivers. These two influences along with acidity and stormwater were the only categories with no zero scores; indicating that these threats are persistent throughout the study area. In most cases, I believe the scoring outcome provides a reasonable representation of the magnitude of threats to smelt spawning habitat across this portion of their range. As an example, the highest scores were for sedimentation and eutrophication, for which substrate effects were observed in each run and causal responses of egg mortality were evident. An example of where the scoring may be misleading is over the lack of separation of stormwater and water flow influences from passage and channel influences. Stormwater and water flow concerns are contemporary influences that appear to be increasing as a threat in a majority of smelt runs. Whereas, the structural changes to passage and channels typically occurred long ago and may have less influence on habitat or population dynamics in recent decades.

Among all rivers, the habitat scores range from 7 to 22. Five of the six scores over 20 were in the urban Boston Harbor region where the largest populations of smelt occur in the study area. Conversely, the lowest scores of 7-8 (Third Herring Brook, Satuit Brook, Egypt River and Essex River) were in rivers that appear to have suitable habitat yet very low densities of eggs were found in these rivers. There were some regional differences in dominant influences that reflect on watershed characteristics. The South Coastal Basin had higher scores for eutrophication and acidity. The Boston Harbor region had higher scores for sedimentation, eutrophication and stormwater. The North Coastal Basin had higher scores for sedimentation and eutrophication. The signal for Plum Island Sound was not as clear with slightly higher scores for sedimentation, eutrophication and water flow. The four rivers of Plum Island Sound had relatively low habitat scores, despite having smelt runs that have declined as sharply as any others in the study area in the last three decades. For this region, the monitoring efforts and habitat scores do not provide clear direction on establishing a relationship between habitat degradation and smelt population abundance. Rivers with apparently suitable spawning habitat but declining smelt runs raise questions over additional negative influences not identified during monitoring, cumulative effects of negative influences, and influences on later life-stages in estuarine and marine habitats.

DISCUSSION

This study identified 45 smelt spawning locations in 30 river systems along the Gulf of Maine coast. The presence of a large number of spawning runs in this area is encouraging. However, many of these runs were supported by a small number of spawning smelt, and several locations were on the list by virtue of finding several dozen eggs over 10 years ago when monitoring occurred. Few rivers in the study area presently support sportfisheries for smelt: a sharp contrast to a scenario of popular fall and winter fisheries existing in most estuaries and embayments only 10 years before this study began.

Discussion on changes to smelt spawning habitat in Massachusetts is limited and speculative. Only two rivers (Parker River and Jones River) have had previous investigations on smelt runs that include habitat references (Clayton 1976; and Lawton et al. 1990). An earlier reference to smelt in Massachusetts in 1957 listed only nine rivers with smelt runs (MDMF 1960). This accounting was probably focused on locations with large smelt fisheries. Eighteen smelt runs were noted in the study area by Reback and DiCarlo's (1972) anadromous fish survey that focused on alosids in the mid-1960s. By the study's inception in 1988, all but nine spawning locations were known to DMF sportfish biologists. Beyond the study objective of establishing the presence of a smelt run, much of the spatial data recorded are unique. Because smelt spawn at night during flood tides their presence often goes unnoticed. This habit and the paucity of previous habitat investigations provided little specific information on the extent of smelt spawning habitat in the region.

It is important to acknowledge that this monitoring effort could have underreported or missed individual spawning locations. The spatial delineation of spawning habitat recorded only the location where eggs were found. The spatial distribution of smelt eggs in some rivers could expand or retract with changes in spawning run abundance and river discharge. Some spawning locations were missed during the original surveys because they were not selected for monitoring because of poor habitat suitability, and subsequently, smelt eggs were found during later visits (small creeks in Chelsea, Weymouth and Rockport). In those four cases, the locations were not known as smelt spawning runs and very low numbers of individual smelt eggs were found in later years. In one case, the Ox Pasture Creek in Rowley, the existence of the creek was simply overlooked during original surveys. Secondly, management practices can result in favorable changes, as found in the North River and Crane River tributaries to the Danvers River estuary where no smelt eggs were found during monitoring (Chase 1993). The Crane River later received smelt egg transfers from 1995-1997 during a DMF restoration project (Chase *In Prep.*). Low numbers of smelt eggs were found in the Crane River starting in 1997, and since 2001 similar densities of eggs have been found in the neighboring North River.

Smelt do not appear to have the extent of fidelity for their natal streams as expressed by salmonids and alosids. It is likely that some of the small runs where eggs were found and some of the small creeks with minor potential but with no egg observations receive intermittent egg deposition from smelt that were hatched in nearby larger rivers and colonize the smaller creeks by chance of detecting the freshwater discharge. Overall, it is doubtful that there are many locations with annual smelt runs that are not reported here. Most potential candidate streams have been repeatedly visited since 1995. This effort of looking for eggs during the peak season and contact with local knowledge should uncover missing locations. Therefore, while it is possible that a repeat effort of this monitoring project may encounter new smelt spawning locations, the downward trend in smelt populations suggest the likelihood of finding locations that no longer support smelt may be higher.

The observations of a large number of smelt spawning habitats over several seasons did provide a good perspective on what constitutes suitable spawning habitat. A moderate change in stream gradient above the zone of tidal influence creates riffle habitat that is prone to scouring. These conditions result in cobble and gravel riffles that are free of fine particles. Features such as extended pool-riffle habitat in the freshwater zone above tidal influence, ample riparian buffer and canopy, and aquatic moss attached to the substrate are beneficial to survival of spawning adults and deposited eggs. A vital aspect to this scenario is having clean substrate. Few smelt runs in the study area approached this ideal condition, and most had varying states of degraded substrata. It is apparent that the successful adaptation of smelt using freshwater riffles to deposit high densities of adhesive eggs is presently challenged by watershed alterations. The tidal interface is often both a smelt spawning location and a center of commerce and urban development. These locations were physically altered to support hydropower for colonial mills, for transportation corridors and other commercial developments during the industrial revolution. More recently, these locations are receiving high loads of nutrient, sediment and stormwater pollutants as the landscape drainage has been altered to move flows quickly to the estuaries. Even in the absence of previous descriptions on smelt spawning habitat, it is not hard to imagine the degradation that has occurred to these locations in the 20th century.

This monitoring project provided only ancillary evidence of declining smelt populations in Massachusetts. It was not designed to assess the status of populations, and no long-term data series are available that specifically target smelt populations in Massachusetts. Despite this lack of information, monitoring did document higher egg deposition earlier in the study than in later years. The egg deposition observed in the North Coastal Basin and Boston Harbor in 1989 greatly exceeded that seen for the remainder of the study period and for any other smelt runs that I have observed since. Many smelt runs in 1989 had egg densities that exceeded the substrate capacity of prime spawning riffles and resulted in egg crowding that was several cm in depth across the stream channel. Although anecdotal, the comments I received during many monitoring visits from dozens of fishermen and neighbors to smelt runs contribute greatly to my perception on the status of smelt runs in Massachusetts. The comments on trends in the strength of smelt runs and the smelt fishery are surprisingly consistent among individuals and regions. Active fall and winter smelt fisheries and observations of strong spring runs of smelt (in specific rivers where viewing is possible) were routine in the 1960s and for much of the 1970s. This was followed by a period from the late 1970s into the 1980s of dramatic declines for the smelt runs and fisheries. By the start of the monitoring study, locals reported that most smelt fisheries were limited to a narrow window in the fall, and some have faded to very low levels of catch and participation. A common anecdote from neighbors regarding an adjacent smelt run was that they had not seen evidence of a spring smelt run in years and assumed that the run had ceased. Unfortunately, my visits to smelt runs since 1995 do not indicate a trend of improvement in run size or habitat condition, while egg deposition at some of the smaller runs has not been detectable in the absence of dedicated monitoring.

Observations throughout the Gulf of Maine point to a similar trend of smelt populations and fisheries declines in the latter half of the 20th century (Collette and Klein-MacPhee 2002; NOAA 2004; and Grout and Smith 2004).

Similar population concerns have been raised by fisheries professionals in southern New England (Stephen Gephard, CT DEP, *pers. comm.*, 2004), northern New England (Brian Smith, NH Dept. Fish and Game, *pers. comm.*, 2004; and Lewis Flagg, ME Dept. Fish and Game, *pers. comm.*, 1999) and for the St. Lawrence River in Quebec (Trencia 1999). Similar to Massachusetts, evidence to support their concerns are not well-documented because population data and cause and effect investigations have not been prioritized for this less-known anadromous species of limited economic value. The collective concern for smelt populations resulted in a symposium on rainbow smelt at the 2003 American Fisheries Society Annual Meeting in Quebec. The following year, the National Marine Fisheries Service (NMFS) designated rainbow smelt as a "Species of Concern" based on the criteria of significantly decreased harvest records and apparent truncation of their distribution range (NOAA 2004). The designation of smelt as a "Species of Concern" in 2004 is a step towards consideration as a "Candidate Species" to review under the Endangered Species Act.

Future Efforts

The primary objective of documenting where smelt spawn along the Gulf of Maine coast of Massachusetts was met by this monitoring effort. The next practical steps towards the overall goal of improving the Commonwealth's smelt populations involve moving from qualitative monitoring to quantitative research and restoration. Comprehensive information on smelt population status and the cause of habitat degradation is necessary for resource management and to identify restoration strategies for both smelt spawning habitat and smelt populations. The following recommendations address these future interests, and small-scale, habitat restoration recommendations are made in the chapters on individual river systems.

RECOMMENDATIONS

Habitat Monitoring

Changes to smelt spawning habitat delineated for this study have probably already occurred considering the time elapsed since monitoring was completed. The effort involved in monitoring and reporting was substantial, and an attempt to repeat this effort would require dedicated staff and funding. At some point in the future it would be useful to repeat this effort, although in terms of priorities, monitoring the southern coast of Massachusetts, improving our knowledge of habitat degradation, and habitat restoration should take precedence.

1. The Massachusetts region south of Cape Cod is known to possess smelt runs (Reback and DiCarlo 1972), but smelt spawning habitat south of Cape Cod has not been delineated. Concerns are growing that the southern end of smelt distribution is contracting. Recent efforts to document the presence of smelt in Connecticut and Rhode Island have resulted in few observations of smelt. It is **recommended** that smelt habitat monitoring be conducted for Buzzards Bay and Rhode Island border regions.

2. It is **recommended** that smelt spawning habitat in this study area be revisited approximately each decade. Future efforts should use similar methods with a dedicated staff while adopting improved technologies in global positioning systems and geographic information systems (GIS) to better document spawning habitat. Consideration should also be given to establishing stream transects where physical and chemical data can be consistently recorded, and enhancing the value of this field effort by using protocols to consistently record the presence of other diadromous species.

Population Monitoring

Although not an objective of this study, it has become clear that better population data are needed on smelt in Massachusetts. An annual sampling series is needed to provide catch and effort data for a relative index of population abundance and to provide age-structure data. Options that have been explored in other jurisdictions include: fishery-dependent creel surveys, fishery-independent net surveys during spawning runs and at foraging habitat, and smelt egg and larval density collections (Grout and Smith 1994 and 2004; and Pettigrew 1997).

1. Stationary net sampling during the spring spawning run at several representative rivers may provide the best opportunity to capture an index of relative abundance and age-structure for adult smelt. It is **recommended** that a population monitoring series be established and maintained annually in Massachusetts in at least one river of each of the four regions in the study area. Fyke nets are a good candidate for this effort because adult can be captured alive to sample and release or to collect gametes for smelt enhancement projects.

Habitat Research

More information is needed on causal factors involved with smelt habitat degradation and consequent influence on population dynamics. Observations made during monitoring identified habitat influences that affect smelt egg survival. These influences should be investigated with empirical research. These observations lead to the following hypotheses related to acidity, eutrophication, aquatic moss, water velocity, and watershed discharge:

1. Stream acidity was recorded at levels that could reduce smelt egg survival. Geffen (1990) identified 5.5 as a pH level that smelt eggs could tolerate for short periods but survival was poor with longer exposures. Water acidity poses a serious threat to smelt runs in Massachusetts and may be a significant contributor to declining smelt runs in the South Coastal Basin. It is **hypothesized** that episodic weather patterns are related to poor smelt recruitment in river systems with acidic base flows. It is **recommended** that Geffen's (1990) study be enhanced with more treatments in the range of 4.5 – 7.5 pH and the study design include episodic exposures to replicate precipitation events and spring snow smelt. These results can be applied to a modeling exercise to relate climatic patterns to smelt population recruitment.

2. The range and magnitude of periphyton growth on smelt spawning substrata leads to the conclusion that cultural eutrophication is the single largest threat to smelt spawning habitat in the study area. There are several characteristics of smelt reproductive biology that apparently are disadvantages in watersheds with elevated sources of anthropogenic nutrients. Smelt have demersal, adhesive eggs that require a stable substrate where the egg's membrane can be exposed to stream flow for the duration of incubation. In addition, smelt have adapted to use freshwater streams near the tidal interface when cold spring water temperatures minimize biotic activity. Spawning locations have become centers of residential and urban development in Massachusetts that receive high nutrient loads from the watershed. As smelt eggs remain attached over long incubation periods (10-20 days) they are susceptible to overgrowth by periphyton that can occur rapidly as photoperiod increases and water temperature warms. These observations lead to the **hypothesis** that anthropogenic sources of nutrients are elevating nutrient concentrations to induce high growth rates of periphyton and alter natural algal species composition, resulting in poor egg survival and chronically reducing smelt recruitment. This topic has not been investigated and could have serious implications for other diadromous species with demersal eggs that are deposited in eutrophied watersheds. It is **recommended** that studies are conducted on the effects of eutrophication on smelt eggs and population recruitment.

3. Smelt egg deposition on aquatic moss (*Fontinalis sp.*) produced superior survival to that observed on any other substrate. The topic of substrate factors effecting smelt egg survival or role of aquatic moss in smelt spawning habitat has received little attention. It is **hypothesized** that smelt spawning over aquatic moss results in higher proportions of attachment and survival than spawning over other substrate types. It is **recommended** that this relationship be investigated with treatments that identify water quality relationships to the health of aquatic moss and lead to recommendations on the role of aquatic moss in future habitat restoration projects.

4. The selection of spawning habitat appears to be more related to flow regime than substrate type. Substrate type certainly can affect the flow regime, but spawning adults appear to cue most to a specific range of water velocity and turbulence as opposed to the physical material that comprises the substrate. Channel alteration and the resulting flow dynamics can greatly influence egg distribution and survival by increasing (or decreasing) passage to upstream habitat, crowding eggs, flushing eggs, and exposing eggs to air desiccation. Channel alterations also can influence the survival of spawning adults by increasing exposure to predators or increasing metabolic demands as resting pools are eliminated. It is **hypothesized** that the optimal range to induce smelt spawning and achieve successful egg distribution and incubation is in the range of 0.5 to 0.8 m/s, and that velocities above 1.2 m/s will preclude the passage of average sized adult smelt and increase the displacement of eggs by scouring. Studies on smelt swimming speeds and spawning behavior are **recommended.** These studies will also benefit future channel restoration projects.

5. The negative influence of water flow regulation on maintaining suitable water depth and velocity to attract adult spawning and successful egg incubation was seen in specific watersheds. In some rivers, this influence may be the largest individual threat to the health of spawning habitat. It is expected that this concern will have even greater consequences for other anadromous fish species that arrive on their spawning run later in the spring. In addition to spawning habitat impacts, concerns were raised over the effect of discharge manipulations on estuarine habitat for smelt larvae and juveniles. The ichthyoplankton sampling found high fish larvae and zooplankton abundance at frontal boundaries in some larger rivers; however, few rivers in the study area display characteristics of stratified estuaries or have large salt and freshwater mixing zones. Estuarine mixing zones in the St. Lawrence River have been shown to be favorable habitat for smelt larvae growth and survival (Sirois and Dodson 2000). It is **hypothesized** that smelt recruitment suffers in rivers with substantial watershed alteration and water supply regulation because salinity gradients beneficial to larval and juvenile smelt survival have been degraded as base flows have been chronically reduced. Furthermore, this discharge dynamic appears to have potential relevance in the Plum Island Sound region where spawning habitat degradation scores are low, but smelt populations have drastically declined in the last 30 years. It is **recommended** that modeling exercises be conducted to relate watershed alterations and discharge data to estuarine hydrology and smelt recruitment.

Habitat Protection

The availability of more detailed information on smelt spawning habitat should enable local, state and federal authorities to provide consistent protection for these habitats during the environmental review process. At the local and state level, anadromous fish spawning habitats are protected by the Massachusetts Wetland Protection Act. The assimilation of DMF knowledge on anadromous fish spawning habitat to the permitting review process can improve this protection.

1. It is **recommended** that a summary of spawning locations and specific location concerns be provided to all Conservation Commissions and Departments of Public Works for cities and towns with smelt runs. These local authorities are charged with upholding the Wetlands Protection Act and have strong interests in resource stewardship. This information can be provided by individual contact and creating a link on the DMF web site to a GIS data layer on smelt spawning habitats.

2. Anadromous fish spawning habitat is protected during federal environmental permitting review through interagency coordination on large development projects with environmental consequences. This process needs improved coordination in regards to flood control and roadway projects that proceed under emergency actions or with limited design review and may not receive adequate environmental review. It is **recommended** that a memorandum of understanding be developed between EOEA authorities and transportation authorities in Massachusetts that outlines a process for checking on the presence of anadromous fish migratory or spawning habitat when beginning any projects that involve stream crossings. The establishment of a DMF web site list of anadromous fish habitats and a GIS datalayer on smelt spawning runs can be central features of this information exchange.

3. The negative influence of sedimentation was found in nearly all smelt runs monitored. The specific locations of substrate impact in a given system are not randomly distributed but are closely related to point sources for stormwater flows and other drainages. In many cases, annual maintenance of these structures could prevent substantial sediment loads from reaching the rivers. It is **recommended** that point sources with high sediment loads adjacent to smelt spawning habitat are identified on a GIS data layer and are provided to local authorities in order to prioritize annual drainage system maintenance and potential restoration projects.

4. Time-of-year work windows are commonly used permit restrictions to prevent negative impacts to smelt spawning runs. There has been some inconsistency in the application of no-work windows for smelt runs. This study found that viable smelt eggs were found throughout April and most of March and May for the study area. It is likely that for an uncertain period prior to the onset of egg deposition adult smelt are in the tidal zone directly downstream of the spawning habitat. In the interest of protecting spawning runs from in-stream and riparian construction activities, it is **recommended** that when work windows are necessary for smelt spawning runs they consistently include all of March through May for the Gulf of Maine coast.

Habitat Restoration

Few specific efforts have been made to improve smelt spawning habitat in Massachusetts. Because of the limited information on their spawning habitat, there has been little direction for addressing river-specific degradation in smelt spawning habitat. The next chapters on watershed regions contain specific recommendations on improving spawning habitat. Several generic recommendations are made here to encourage growth in this relatively unexplored field.

1. Smelt spawning habitat and other aquatic resources using these stretches of streams can benefit from improvements to vegetative canopy and riparian buffer. These improvements can have a modest cost and be organized locally. It is **recommended** that local authorities inspect smelt runs to find opportunities for enhancing canopy and riparian buffer and consider by-law changes to improve protection of these valuable habitats.

2. Stream restoration for inland resources has a longer history of conducting restoration projects than for coastal rivers. It is **recommended** that lessons from inland stream restoration relative to hydrology and stream morphology be explored and adopted as techniques for smelt spawning habitat restoration where applicable.

3. Several restoration features such as tidal dam removal, culvert daylighting, and in-stream sediment removal sumps have not been used in smelt runs in Massachusetts but could have much promise in the right location. It is **recommended** that these innovative restoration techniques be explored for smelt runs in Massachusetts.

4. The eutrophication of coastal rivers is clearly a concern for smelt spawning habitat and other aquatic resources. The origin of nutrient loads and cause and effect on smelt populations are not well-explained. Despite this information gap, it is expected that proactive reductions in nutrient loading would be beneficial to the health of these river systems. It is likely that significant reductions in nutrient loads in some rivers will produce measurable improvements to water quality. It is **recommended** that municipalities adopt DEP strategies for reducing nutrient loads from septic systems, lawn fertilizers, pet and wildlife waste, and sewage system leakage.

Population Restoration

Smelt population enhancement has been attempted by DMF in Massachusetts on numerous occasions in the 20th century in the form of egg transfers from robust donor runs to depleted smelt runs. This practice has also been conducted in New Hampshire (Grout and Smith 1994) and Maine as well with little documentation on successful population restoration for marine populations with some success moving eggs from the coast to inland lakes. The Crane River in Danvers was identified as a monitoring station where no eggs were found but had potential for population restoration (Chase 1993). An egg stocking project was conducted from 1995 to 1997 that resulted in returning adult smelt in 1997 and most of the following years (Chase et al. *In Prep.*). The project was encouraging as it resulted in returning adult smelt and the designation of the Crane River as a smelt run. The project was discouraging in the sense that the best available donor smelt runs in 1996 and 1997 could not provide egg collections beyond the equivalent of a few dozen female smelt, and that subsequent egg densities in the following years were at the lower end of the range for all runs observed.

1. It is **recommended** that smelt egg transfer projects in coastal streams in Massachusetts not be continued until the post-stocking results of the Crane River project are evaluated, and most importantly, a river in the study area demonstrates adequate egg production to support an egg transfer project.

2. The Crane River project, efforts in Quebec to stock smelt larvae hatched in stream-side incubators (Trencia and Langevin 2003) and smelt culture experiments in New Hampshire (Ayer et al. 2005) have demonstrated that substantial improvements in field egg survival can be gained under controlled incubator hatching. It is **recommended** that evaluations be conducted on incorporating incubator hatching into smelt population restoration through a controlled pilot project in the study area.

3. If successful methods can be established for smelt population restoration, it is **recommended** that several monitored rivers where no egg deposition was found be considered as restoration sites. The Crane River and Walker Creek (Gloucester) were identified as having the most potential for the North Coastal Basin (Chase 1990), and Johnson Creek (Groveland) and Cove Brook (Marshfield) are potential restoration sites described in later chapters. Rivers with no smelt present can be used as controls for experiments that stock smelt larvae possessing otolith markers. These experiments will allow the quantification of returning adult smelt and stocking contributions.

Smelt fishing in the Parker River during 1960s. R. Iwanowicz

CHAPTER 3. SOUTH SHORE REGION

The South Shore Coastal Drainage Area includes coastal rivers that drain into Massachusetts Bay from Cohasset Harbor to the Cape Cod Canal (Figure 3.1). This region is designated as a specific drainage area based on hydrologic features (Halliwell et al. 1982). Forty-four specific locations were surveyed within or adjacent to the following river systems: Bound Brook, Satuit Brook, North River, South River, Island Creek, Jones River, Town Brook, and Eel River. From these surveyed locations, 18 stations were routinely monitored as potential smelt spawning habitats from 1993-1995. Smelt spawning habitat was identified at 12 locations within the eight river systems (Table 3.1, Figure 3.1).

The South Shore region is bordered to the north by Boston Harbor where the largest contemporary smelt runs are found and to the south by Cape Cod where the presence of smelt runs has not been reported. Monitoring during 1993-1995 confirmed Plymouth Harbor as the southernmost location with smelt runs in the Gulf of Maine. Cape Cod acts as a biotic boundary for the distribution of numerous marine organisms. Presumably, the geological history associated with the last glaciation of Cape Cod limited the formation of drainage patterns that produced spawning riffles near the tidal interface. Smelt runs occur south of Cape Cod, but present abundance from Buzzards Bay south is well below that found farther north in the Gulf of Maine. The South Shore region is comprised of many small tidal streams and two larger rivers that are accompanied by large areas of estuarine habitat. The North River system and the Jones River provide a majority of the freshwater discharge from this drainage area to coastal waters and have the largest amounts of available smelt spawning habitat on the South Shore. The North River contains four spawning locations of moderate size that were not well-known prior to this study. The Jones River main stem contains one of the largest areas of smelt spawning habitat in the state (> 10,000 m^2) and when previously investigated during 1979-1981 (Lawton et al. 1990) was found to support local fisheries and one of the largest smelt runs in the state.

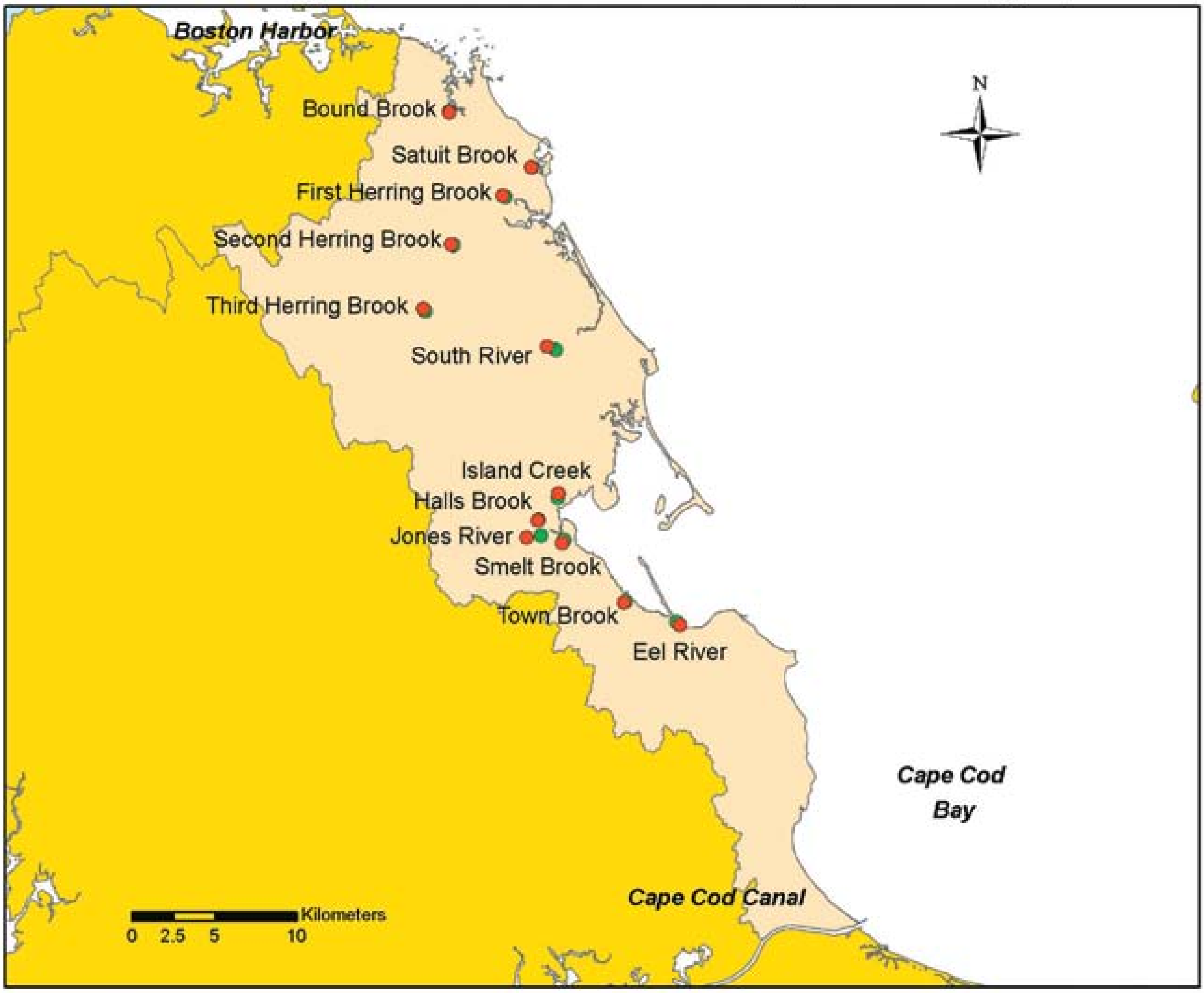
The average starting date of the smelt spawning period at 11 spawning locations was March 25th (N = 16). The average starting date for spawning was later than typical because of the unusual influence of Town Brook and Satuit Brook where spawning did not begin until after April 10th. The average completion of the spawning runs in this region was May 19th. Overlap of spawning habitat use by smelt and blueback herring was noted during the latter half of May in several South Shore smelt runs. The average duration of the spawning period was 56 days and the average starting water temperature was 6.2 °C. Both these values were influenced by the late onset of spawning in Town Brook and Satuit Brook. For all rivers combined, the overall range of dates when smelt eggs were observed was March 5th to May 28th.

Water chemistry was measured at 18 spawning habitat monitoring stations. The water chemistry sampled at the spawning habitat stations was adequate to support aquatic life considering the parameters measured, with the exception of common violations of pH criteria in some rivers. Five of the spawning runs had seasonal mean water pH under 6.0, which is a concern for smelt egg survival. Two other prominent threats to smelt spawning habitat

Table 3.1 Smelt spawning habitat locations in the South Coastal Basin. The reported positions are the downstream and upstream limits of observed egg deposition recorded with a Garmin GPSmap 76.

Name	River System	Town	Downstream Latitude	Downstream Longitude	Upstream Latitude	Upstream Longitude	Length (m)	Area (m^2)
Eel River	Eel River	Plymouth	41° 56.632'	70° 37.535'	41° 56.535'	70° 37.378'	255	1,505
Town Brook	Town Brook	Plymouth	41° 57.317'	70° 39.755'	41° 57.269'	70° 39.831'	107	778
Smelt Brook	Jones River	Kingston	41° 59.343'	70° 42.428'	41° 59.252'	70° 42.513'	126	347
Jones River	Jones River	Kingston	41° 59.506'	70° 43.439'	41° 59.447'	70° 44.071'	1,111	10,943
Halls Brook	Jones River	Kingston	42° 00.007'	70° 43.530'	41° 59.992'	70° 43.566'	66	260
Island Creek	Island Creek	Duxbury	42° 00.732'	70° 42.675'	42° 00.875'	70° 42.644'	304	978
South River	South River	Marshfield	42° 05.581'	70° 42.713'	42° 05.687'	70° 43.100'	229	1,732
First Herring Brook	North River	Scituate	42° 10.610'	70° 44.887'	42° 10.656'	70° 45.008'	190	798
Second Herring Brook	North River	Norwell	42° 09.049'	70° 47.187'	42° 09.072'	70° 47.283'	205	1,427
Third Herring Brook	North River	Norwell	42° 06.891'	70° 48.463'	42° 06.973'	70° 48.547'	345	1,958
Satuit Brook	Satuit Brook	Scituate	42° 11.584'	70° 43.694'	42° 11.588'	70° 43.724'	55	80
Bound Brook	Bound Brook	Cohasset	42° 13.440'	70° 47.324'	42° 13.391'	70° 47.332'	166	912

Figure 3.1 Smelt spawning habitat in the South Shore Coastal Drainage Area. The green dots indicate the downstream limit of egg deposition and the red dots indicate the upstream limit of egg deposition.



were identified during monitoring. Several rivers were threatened by declining water flow as the season progressed. These observations of declining water depth and velocity occurred mostly in regulated rivers. Secondly, symptoms of eutrophication were observed in the form of excessive periphyton growth that appears to smelt egg mortality. The increased growth of periphyton was seen during April and May in most rivers, while minor growth was observed in Bound Brook and Third Herring Brook.

Ichthyoplankton collections were made at only one station on the main stem North River. The water chemistry and ichthyoplankton sampling at this station indicate that the North River was one of the few stations in this study that possessed characteristics of a stratified estuary. The catch in the North River was the most diverse among all ichthyoplankton stations (15 fish species), although smelt larvae were only caught on one date in late-April.

PLYMOUTH HARBOR

STUDY AREA

Plymouth Harbor is located about 5 km south of the Jones River in the South Shore Coastal Drainage Area (Halliwell et al. 1982). Two known smelt spawning runs are found in Plymouth Harbor: Town Brook and the Eel River, both located in the Town of Plymouth. The two drainages are distinct but will be reported together because Plymouth Harbor is the southernmost location on the Gulf of Maine coast of Massachusetts with smelt runs. Town Brook originates in the large freshwater lake called Billington Sea and flows for approximately 2.5 km before discharging in Plymouth Harbor. The drainage area of Town Brook is 23.4 km^2 (Wandle and Morgan 1984). The primary headwater for Eel River is Russel Millpond in Plymouth. Eel River winds for about 5 km before discharging into Plymouth Harbor along the southern end of Plymouth Beach. The drainage area of Eel River is 38.1 km^2 (Wandle and Morgan 1984). Neither stream has a stream flow gauge station.

Town Brook is a known smelt run that has been referenced in previous DMF surveys (Reback and DiCarlo 1972; and Iwanowicz et al. 1974). No published smelt references were found on Eel River, but it was a known smelt run (K. Reback and P. Brady, DMF, *pers. comm.*). Both streams were historically known to have alewife runs (Belding 1921; and Reback and DiCarlo 1972). Based on existing knowledge of smelt spawning habitat, monitoring stations were selected near the interface of tidal waters for only one season of monitoring in 1995. Two unnamed creeks between Smelt Brook and Plymouth Beach were surveyed in 1995 and not selected for monitoring because they lacked suitable spawning habitat. Also reported in this section are surveys of three creeks from Plymouth Harbor to the Cape Cod Canal, the southern limit of the study area.

RESULTS

Spawning Habitat

Town Brook. Smelt eggs were found at Town Brook in 1995 from the upstream side of the Pleasant Street bridge downstream for 107 m to below Rt. 3A. The area of brook substrate where smelt eggs was found was 778 m^2. A majority of egg deposition occurred over a short stretch of substrate under the Rt. 3A bridge and 10 m downstream of the bridge. No eggs were found upstream of the Pleasant Street bridge, despite the presence of a 15 m stretch of suitable habitat. The stream gradient rises quickly above the bridge. The combination of grade rise and high spring water velocity appears to limit their movement above Pleasant Street. For 60 m below the lower limit of observed egg deposition there was potential spawning habitat that received no egg deposition. This stretch had marginal value for attracting spawning smelt because of the combination of tidal influence, declining grade, and sediment deposition. The total size of the two stretches of potential spawning habitat was estimated at 75 m in length and 492 m^2 in substrate area. With the exception of the brook channel under the two bridges, most of the Town Brook spawning habitat was clearly degraded by the deposition of road sand and other sediments.

Eel River. Smelt eggs were found at Eel River in 1995 from under the bridge at Rt. 3A downstream for 255 m as the river runs along the backside of Plymouth Beach. The area of river substrate where smelt eggs were found was 1,505 m^2. The highest densities of eggs were found within 30 m downstream of Rt. 3A. Passage upstream of Rt. 3A was not impeded. No eggs were found beyond the upstream face of the bridge. The river immediately changed to marshy habitat with fine sediments covering the substrate and low water velocity. The river runs parallel to the beach road downstream of Rt. 3A and contains several stretches of clean gravel and cobble. There were areas of sediment deposition also in this stretch that appeared to be receiving eroded beach sand. The lower limit of observed egg deposition was located well downstream in the tidal zone. At low tide, there appeared to be suitable riffles further downstream of the 1995 lower limit, although these riffles are probably obscured by each flood tide.

Spawning Period

Town Brook. Smelt spawning was detected later than expected in Town Brook during 1995. Despite existing knowledge of spawning habitat and extensive monitoring during March, no smelt eggs were found until early April (Table 3.2). It was surprising to find no eggs in March in Town Brook while mid-March spawning was found in neighboring smelt runs. Two smelt eggs were found on April 13th with two biologists covering all riffles expected to provide spawning habitat. Low densities of eggs were found extending upstream and downstream of Rt. 3A on each following visit. On April 20th, several eggs were returned to the laboratory and hatched to confirm they were not river herring. The larvae hatched on April 26th and were identified as smelt. By early May, observations of declining egg densities and low numbers of late-stage eyed eggs indicated that the run in Town Brook occurred briefly and did not involve large numbers of adults.

Eel River. The spawning period in Eel River during 1995 was more typical: mid-March to mid-May (Table 3.2). The onset of spawning was easily detected at the second riffle downstream of Rt. 3A. As the season progressed, egg densities were highest at the first riffle below the Rt. 3A bridge. From April 4th to April 20th, adult smelt were seen in the first riffle. On April 13th, several hundred adult smelt were seen there, and high densities of smelt eggs were observed downstream of this riffle. The egg densities observed in Eel River greatly exceeded that found in Town Brook during 1995. Spawning activity faded quickly after April until only a few late-stage eyed eggs were found by mid-May.

Table 3.2 Smelt spawning period at Plymouth Harbor spawning runs, Plymouth,1995. The spawning period is an estimation based on observations of viable smelt eggs.

River	Spawning Period	Days	Water Temperature (°C) Start	End	Range	Mean
Eel River	March 18th - May 14th	58	7.4	13.6	5.6 - 16.9	10.9
Town Brook	April 10th - May 24th	45	9.4	17.3	7.7 - 17.6	12.5

Table 3.3 Water chemistry and weather summary for Plymouth Harbor spawning habitat stations, 1995. Data are averages (Tables A.1 - A.2) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Plymouth-Kingston station (NOAA 1995).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
Town Brook								
March	9	3.8	7.6	6.4	0.0	6.3	11.7	0.156
April	8	7.6	6.6	10.7	0.0	6.2	10.3	0.168
May	8	12.6	6.1	14.3	0.0	6.2	9.4	0.169
Season	25	8.0	20.3	10.3	0.0	6.2	10.5	0.164
Eel River								
March	9	3.8	7.6	6.1	0.0	6.5	12.2	0.132
April	8	7.6	6.6	10.8	0.0	6.7	11.0	0.224
May	8	12.6	6.1	15.9	0.1	6.9	10.1	0.780
Season	25	8.0	20.3	10.7	0.0	6.7	11.2	0.369

Water Chemistry

Town Brook. Water chemistry was measured at the north bank of the downstream face of the Rt. 3A bridge during each site visit in 1995. For the parameters measured, water quality conditions were adequate to support aquatic life, with the exception of consistently low pH (Table 3.3, A.1). Dissolved oxygen was at or near saturation for all measurements. Water pH averaged 6.2 for the season, and ranged from 6.0 to 6.4. Tidal influence was routinely seen during flood tides at the lower limit of spawning habitat, but salt water did not extend to the water chemistry station during spring measurements. Specific conductivity was similar to pH: consistently low over a narrow range.

Eel River. Water chemistry was measured at the south bank of the downstream face of the Rt. 3A bridge during each site visit in 1995. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 3.3, A.2). Dissolved oxygen was at or near saturation for all measurements. Water pH was slightly acidic, averaging 6.7 for the season. Tidal influence was observed at the water chemistry station on several occasions during flood tides. During May, several measurements found low salinity at the station, including one made at low tide. These observations indicate that as discharge declined later in spring the salt wedge moved farther up, pushing saline water into the marsh upstream of Rt. 3A. In the absence of saline water, the freshwater flow had low specific conductivity.

Stream Flow Discharge Measurements

Town Brook. Four discharge measurements were made in Town Brook during 1995 at a transect approximately 20 m downstream from the Rt. 3A bridge (Table 3.4). The water velocity and discharge were very consistent for these measurements. Mean water velocity ranged from 0.29 to 0.34 m/s and discharge ranged from 0.44 to 0.45 m^3/s. This unusually tight range is probably coincidental or reflects groundwater influence, as greater variation is expected with declining spring flows and the influence of precipitation. The spawning habitat was adequately covered during each measurement.

Eel River. Four discharge measurements were made in Eel River during 1995 at a transect located directly under the Rt. 3A bridge (Table 3.5). The constriction of the bridge creates high velocity flows at this transect. Mean water

Table 3.4 Stream discharge measurements made in Town Brook, Plymouth, 1995. Rainfall data are five day total precipitation at Plymouth-Kingston station (NOAA 1995).

Date	Width (m)	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Rainfall (cm)	Habitat Coverage
3/27/1995	4.95	0.27	0.338	0.452	0.23	adequate coverage
4/17/1995	4.95	0.27	0.332	0.444	1.14	adequate coverage
5/12/1995	5.35	0.29	0.285	0.442	0.28	adequate coverage
5/25/1995	4.95	0.27	0.326	0.436	0.81	adequate coverage

Table 3.5 Stream discharge measurements made in Eel River, Plymouth, 1995. Rainfall data are five day total precipitation at Plymouth-Kingston station (NOAA 1995).

Date	Width (m)	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Rainfall (cm)	Habitat Coverage
4/7/1995	4.60	0.20	0.654	0.602	0.51	adequate coverage
4/20/1995	4.60	0.23	0.903	0.955	1.17	adequate coverage
5/5/1995	4.60	0.21	0.729	0.704	1.30	adequate coverage
5/23/1995	4.60	0.22	0.707	0.715	0.86	adequate coverage

velocity ranged from 0.65 to 0.90 m/s. The combination of the stream gradient rise and water velocity at the higher end of this range may discourage smelt movements upstream of Rt. 3A. The discharges for these measurements ranged from 0.60 to 0.96 m^3/s. The spawning habitat was adequately covered during each measurement.

Other Diadromous Species

Town Brook. Low numbers of river herring were seen on several dates starting on April 20th in Town Brook during 1995. Unlike several other rivers on the South Shore, no observations of blueback egg deposition were made along the smelt spawning habitat. A few American eel elvers were observed, with the first caught in the smelt egg scoop on March 20th.

Eel River. Single adult river herring were seen in the Eel River on both May 16th and May 25th in 1995. Large numbers of American eel elvers were readily seen starting in mid-May. On May 18th, an illegally deployed elver trap was found and confiscated downstream of Rt. 3A. Several hundred elvers were in the trap.

Surveyed Tributaries

Five small coastal creeks were surveyed from the Plymouth/Kingston border down to the Cape Cod Canal and all possessed no or minimal smelt spawning habitat. An unnamed creek that flows from Stone Pond and Spooner Pond in North Plymouth had minor freshwater flow and lacked potential spawning riffles. Another unnamed creek that crossed Rt. 3A between Town Brook and Eel River had its channel obscured by *Phragmites* and minor freshwater flow resulting in no potential spawning riffles. Moving south of Eel River, Beaver Dam Brook flows through Bartlett Pond and discharges to White Horse Beach. This location was visited several times because the outlet presented the interesting potential of smelt spawning over the gravel outlet on White Horse Beach. No smelt eggs were found, and tidal conditions appear to limit the potential for smelt to use this outlet for spawning habitat. Bartlett Pond receives saltwater intrusion with most flood tides and maintains low salinity. At high tide, the channel of the beach outlet becomes obscured, resulting in limited or no freshwater riffle to attract spawning smelt. At low tide, the pond flow fans out over the beach as a delta with no clear channel. Next, Indian Brook was surveyed near Manomet Beach. This brook had minor freshwater flow and minimal potential spawning habitat. Lastly, an unnamed creek flowing from Savery Pond to Ellisville Harbor was surveyed near Rt. 3A and found to have minor freshwater flows and no potential spawning riffles.

DISCUSSION

The smelt runs in Town Brook and Eel River are of interest geographically because they are the southernmost smelt runs in the Gulf of Maine. No smelt runs have been known to occur on Cape Cod. Continuing south in Massachusetts, smelt runs are found again in Buzzards Bay. Both Town Brook and Eel River have relatively small smelt runs; furthermore, Town Brook had a very poor run in 1995 and was limited by several notable stressors. Town Brook was an anomaly in 1995 in that it showed little temporal synchrony with nearby smelt runs as has been typically seen. The spawning period, timing of onset, and timing of peak spawning in Town Brook was not well-matched to that found in Eel River to the south and the Jones River to the North. It is possible that smelt population, climatic or tidal conditions influenced the late-starting and brief spawning run in 1995.

The available spawning habitat in Town Brook observed in 1995 was limited in size and experienced significant habitat degradation due to sedimentation. The hydrology of Town Brook was altered with the colonial construction of a mill weir at Water Street. The stream bed from Rt. 3A to Water Street has become a depositional zone and received large amounts of road sand from downtown Plymouth. This same stretch received tidal influence as the height of flood tides rise over the weir. The combination of tidal influence, low velocity and sedimentation reduced the value of this stretch for smelt spawning habitat. Further upstream, there were additional locations with substrate degraded by sedimentation. Later in the spawning season, large growths of vascular freshwater plants fouled the river bed. Much of this growth occurred at the end of the smelt spawning season, although it may be indicative of excessive nutrients in the brook. In 2006, the Town of Plymouth completed a restoration project that lowered the weir to improve fish passage and enhance sediment transport and physically removed sediment upstream of the weir.

Eel River did not suffer from the obvious degradation seen in Town Brook. There were large stretches of fast-flowing riffles with relatively clean gravel and cobble substrate. The overall egg deposition observed in 1995 was well-below the capacity of these riffles, but the spawning period was typical for Massachusetts Bay with egg deposition greatly exceeding that seen in Town Brook. The only potential physical limitation noted in Eel River was the presence of sediment depositional areas in at several locations parallel to the road along Plymouth Harbor Beach. The accumulation of sand at small pools and shoals offers a less favorable substrate for smelt egg survival than the gravel and cobble riffles. It appears likely that some of this sedimentation is augmented by erosion from the seaward bank of Eel River along the beach.

RECOMMENDATIONS

Town Brook

1. Sedimentation Control in Downtown Plymouth. The Town of Plymouth has made progress reducing sediment loads from their drainage system in downtown Plymouth. This activity should be supported and continued in order to correct the significant sedimentation of smelt spawning riffles between Water Street and Pleasant Street.

Eel River

1. Erosion Control on Banks of Eel River. The bank of Eel River along Plymouth Harbor Beach could be stabilized to reduce the erosion of sand that degrades the spawning riffles along this stretch. We recommend that a program of stabilization with native plants be initiated by the Town of Plymouth and with local partners.

Large female smelt from the Parker River. M. Ayer

JONES RIVER

STUDY AREA

The Jones River is the primary freshwater drainage in the coastal embayment of Duxbury Bay, Kingston Bay and Plymouth Harbor. The two bays and harbor are semi-enclosed by Duxbury Beach and Plymouth Beach with the northwest portion of Cape Cod Bay seaward of the beaches. The drainage area from the mouth of the Jones River is 76.6 km^2, the second largest river next to the North/South River system in the South Shore Coastal Drainage Area (Wandle and Morgan 1984; Halliwell et al. 1982). Jones River flows originate from Silver Lake in Pembroke and freshwater swamps in Kingston and Plymouth. Silver Lake is a large reservoir (605 acres) that has been a water supply for the City of Brockton for decades. The threat of low stream flow to aquatic life in the Jones River is substantial. The MDEP 2001 water quality assessment for the South Coastal Basin listed two of the three Jones River segments as "impaired" for the designated use of Aquatic Life because of poor stream flow (MDEP 2006). The first passage impediment for smelt is the Elm Street Bridge located nearly a kilometer upstream of Rt. 3A in Kingston and above the tidal interface. The Jones River has one USGS stream flow gauge station located upstream of the Elm Street Dam which has operated since 1966 (#01105870; drainage area = 40.7 km^2). The monthly mean discharge values for the spring spawning period from 1966-2004 are: March–59.3 cfs; April–54.9 cfs; and May–39.9 cfs (USGS, http://waterdata.usgs.gov).

The Jones River is a known smelt run that historically was considered one of the largest smelt runs in Massachusetts (Reback and DiCarlo 1972; and Iwanowicz et al. 1974). The Jones River and the Parker River, Newbury, are the only rivers in the study area that had previous investigations on the spawning habitat and smelt populations. The smelt run in the Jones River was studied intensively during 1979-1981 as part of an assessment related to the Pilgrim Nuclear Power Plant (Lawton et al. 1990). This investigation described the size and location of spawning habitat, water chemistry in the Jones River, spawning period, age composition and population size. At the time of their study, there was a large run of smelt in the Jones River. Their estimate for the 1981 spawning run, based on egg production, was approximately 4,180,000 adult smelt. Age-2 was the primary age class in the spawning run, and age-2 and age-3 smelt comprised 83-99% of all fish sampled annually. This assessment remains a valuable reference of the Jones River smelt run. With this information available, only a single season of monitoring was conducted during 1995 with the Elm Street Dam as the spawning habitat monitoring station.

Four tributaries to the Jones River also contained known smelt spawning habitat. Halls Brook joins the Jones River estuary on the north side of the river slightly west of Rt. 3. Smelt Brook runs from Foundry Pond to join the Jones River estuary on the south side of the river east of Rt. 3A. Between Elm Street and Rt. 3A on the south side of the Jones River, First Brook and Second Brook (Laundry Brook) provide spawning habitat. All four of these tributaries were surveyed in 1994 and 1995 to confirm spawning and map spawning habitat. A monitoring station was established at Smelt Brook in 1995 because the extent of spawning habitat was uncertain.

RESULTS

Spawning Habitat

Jones River (main stem). Smelt eggs were found in 1995 over a kilometer of river length stretching from the intertidal zone downstream of Rt. 3A up to the passage barrier of the Elm Street Dam. The total river length of spawning habitat was 1,111 m and the substrate area was 10,813 m^2. This estimate of spawning habitat size compares well to the 1979-1981 estimate (1.2 km and 9,651 m^2) by Lawton et al. (1990). An additional 130 m^2 of spawning area was found at First and Second Brook (see below), raising the total for the Jones River to 10,943 m^2. The size of the Jones River spawning habitat ranks among the largest in the study area. The highest densities of deposited smelt eggs were found within 150 m of the Elm Street Dam. There were areas of egg crowding close to the dam where high mortality resulted from egg densities exceeding the substrate capacity. Egg densities were low and patchy over a long stretch (>500 m) upstream of Rt. 3A along mostly residential parcels. This stretch receives routine tidal influence and had pools that accumulated silt and sediment to render this stretch marginally suitable for spawning habitat. At high tides this whole stretch and the area downstream of Rt. 3A provided limited attraction for spawning adults. Egg densities increased immediately downstream of Rt. 3A due to the bridge constriction causing velocity and substrate particle size to increase. Light and patchy egg deposition was found below the Rt. 3A bridge for 120 m downstream where tidal influence typically exceeded 1 m in depth.

Smelt Brook. Smelt eggs were found during 1995 monitoring over 126 m of brook length that included 347 m^2 of brook substrate. This length was not continuous. There was a 105 m stretch upstream of a railroad bridge that contained silted pools with low velocity where no eggs were found. The majority of egg deposition occurred within 10 m of the downstream opening of the Rt. 3A culvert. Light egg deposition was found within the culvert and for 10 m upstream, but only during the peak of spawning activity around April 20th. The brook upstream of Rt. 3A quickly became overgrown with overhanging riparian brush that reduced velocity and limited fish passage. The railroad crossing had a similar effect of Rt. 3A on the main stem Jones River; the constriction created improved flow and substrate conditions to attract spawning smelt. In

1995, smelt eggs were found for 30 m downstream of the railroad crossing in the intertidal zone.

Halls Brook. Halls Brook (also called Stoney Brook) flows from Blackwater Pond through a Mill Pond to meet the main stem Jones River in the estuary west of Rt. 3. A dam at the Mill Pond prevents upstream passage. Smelt eggs were found from the base of the dam downstream for 66 m to the intertidal marsh. The substrate area of spawning habitat was 260 m^2. This stretch had suitable depth, flow and substrate for smelt spawning habitat, and moderate to high densities of smelt eggs were observed here in 1995. This brook was not monitored routinely; however, smelt eggs were seen during four visits from April 17th through May 18th at densities that exceeded those seen at Smelt Brook. Two discharge measurements were taken at Halls Brook: 0.274 m^3/s on May 2nd and 0.199 m^3/s on May 18th. Although the area of spawning habitat was less at Halls Brook than Smelt Brook, there was higher quality habitat, and the discharge was larger. A full season of monitoring would have been appropriate for this brook.

First and Second Brook. Two tributaries join the south bank of the Jones River adjacent to spawning habitat upstream of Route 3A. Because of their proximity to the main stem spawning habitat, these two brooks are not considered independent smelt runs and the spawning habitat area measurements are added to the Jones River main stem. Smelt eggs were found in Second Brook (Laundry Brook) on several occasions in April and May, 1995. Smelt eggs were found over a 78 m stretch from the culvert on Brook Street downstream. The average width of this small brook was slightly more than a meter and the substrate area of spawning habitat was 98 m^2. A raised culvert at Brook Street prevented upstream passage. Smelt eggs were found at First Brook, which crosses Brook Street downstream of Second Brook. Very low densities of smelt eggs were found in this tiny brook during a late-April visit in 1995. The length of brook receiving egg deposition was 43.5 m, and the substrate area was 32 m^2.

Spawning Period

Jones River. Smelt eggs were found in the Jones River on the third site visit early in March on the downstream face of the Rt. 3A bridge (Table 3.6). Egg deposition moved upstream with each site visit in March and on March 20th eggs were found immediately below the Elm Street Dam. Spawning activity increased sharply during the first three weeks in April. Very high egg densities were found in the 100 m of habitat below Elm Street Dam. High egg mortality was observed in the areas with dense egg deposition, apparently due to fungal growth where egg densities exceeded the substrate capacity. These conditions were similar to that reported by Lawton et al. (1990) for the spawning seasons of 1979-1981. The onset of spawning was determined to be between March 2nd and March 13th for 1979-1981. The observations of a progressive movement upstream in March and peak spawning period in April in 1995 were very similar to the previous study. Very light egg deposition was observed in May 1995; although all hatching was not complete until late in the month. The duration of the spawning period in 1995 was estimated at 81 days, one of the longest observed during this study.

Smelt Brook. The spawning period in Smelt Brook began later in March and was shorter in duration than the main stem Jones River (Table 3.6). The onset of smelt spawning was estimated as March 29th in Smelt Brook. The potential spawning habitat of this small creek was readily inspected with each site visit. Eggs were first found 30 m downstream of Rt. 3A. Peak spawning occurred during several waves in April. A sharp drop in the numbers of eggs found on the substrate occurred during mid-May, and only a few viable eggs were seen after this time.

Water Chemistry

Jones River. Water chemistry was measured at the USGS staff gauge on the north bank of the Jones River downstream of the Elm Street Bridge during 1995. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 3.7, A.3), with the exception of routine marginal violations of pH WQS. Dissolved oxygen was at or near saturation for all measurements. Water pH was consistently low, averaging 6.2 for the season, with the three lowest measurements of 5.9 in March. Tidal influence was not observed at the water chemistry station during the spawning season, and not commonly found until over 200 m downstream from Elm Street. Specific conductivity was consistently low over a narrow range. The 1979-1981 study found pH over a higher range (7.2-7.8) than seen in 1995 (5.9-6.5), and

Table 3.6 Smelt spawning period in the Jones River and Smelt Brook, Kingston,1995. The spawning period is an estimation based on observations of viable smelt eggs.

			Water Temperature (^oC)			
River	Spawning Period	Days	Start	End	Range	Mean
Jones River	March 5th - May 24th	81	2.4	18.5	1.8 - 18.6	9.5
Smelt Brook	March 29th - May 20th	53	9.0	16.4	6.4 - 19.1	11.6

included a reference to lower pH measurements (5.8-6.8) during the late 1980s (Lawton et al. 1990).

Smelt Brook. Water chemistry was measured at the north bank of the downstream face of the Rt. 3A bridge during 1995. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 3.7, A.4). Dissolved oxygen was at or near saturation for all measurements. Water pH was acidic, averaging 6.5 for the season. Tidal influence was observed at the water chemistry station on four occasions during above average amplitude flood tides and routinely observed only 10-20 m downstream of the Rt. 3A culvert during a wide range of tidal amplitude. Specific conductivity was moderately low over a narrow range.

Stream flow Discharge Measurements

Jones River. Four discharge measurements were made in Jones River during 1995 at a transect adjacent to the USGS staff gauge downstream of the Elm Street Dam (Table 3.8). The water velocity and discharge did not vary much for these measurements. Water depth was shallow at this transect: 15 to 18 cm. Mean water velocity ranged from 0.27 to 0.32 m/s, and discharge ranged from 0.48 to 0.65 m^3/s (17-23 cfs). These measurements did not coincide with recent rain events, and the discharges were well below monthly means for April and May in the Jones River. Overall, monthly mean discharges in 1995 were lower than the USGS 1967-2004 series for the Jones River (33-53% lower for March-May). The two measurements below 0.5 m^3/s corresponded with marginal coverage of spawning riffles below Elm Street. The dry 1995 spring does not appear to part of an ongoing trend of declining spring discharge in the Jones River. The USGS data series show much annual fluctuation but overall, no evidence of declining trends for monthly mean discharges for all spring months (Figures 3.2 and 3.3).

Smelt Brook. The Smelt Brook discharge was measured on four dates during 1995 at a transect located at the downstream mouth of the Rt. 3A culvert (Table 3.9). Similar to the Jones River, there was not much variation to these measurements during the dry spring of 1995. Mean water velocities ranged from 0.30 to 0.35 m/s and discharges from 0.10 to 0.12 m^3/s. The spawning habitat was adequately covered during each measurement.

Table 3.7 Water chemistry and weather summary for the Jones River and Smelt Brook spawning habitat stations, 1995. Data are averages (Tables A.3 - A.4) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Plymouth-Kingston station (NOAA 1995).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
Jones River								
March	9	3.8	7.6	4.5	0.0	6.1	12.7	0.124
April	8	7.6	6.6	10.0	0.0	6.2	11.0	0.136
May	8	12.6	6.1	14.4	0.0	6.3	9.9	0.142
Season	25	8.0	20.3	9.4	0.0	6.2	11.3	0.133
Smelt Brook								
March	9	3.8	7.6	6.3	0.0	6.5	11.6	0.218
April	8	7.6	6.6	10.6	0.0	6.6	10.3	0.231
May	8	12.6	6.1	14.9	0.0	6.5	9.2	0.244
Season	25	8.0	20.3	10.4	0.0	6.5	10.4	0.231

Table 3.8 Stream discharge measurements made in Jones River, Kingston, 1995. Rainfall data are five day total precipitation at Plymouth-Kingston station (NOAA 1995).

Date	Width (m)	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Rainfall (cm)	Habitat Coverage
4/7/1995	11.30	0.18	0.316	0.643	0.51	adequate coverage
4/25/1995	11.30	0.18	0.317	0.645	0.58	adequate coverage
5/12/1995	11.30	0.16	0.265	0.479	0.28	marginal coverage
5/25/1995	11.30	0.15	0.283	0.480	0.81	marginal coverage

Table 3.9 Stream discharge measurements made in Smelt Brook, Plymouth, 1995. Rainfall data are five day total precipitation at Plymouth-Kingston station (NOAA 1995).

Date	Width (m)	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Rainfall (cm)	Habitat Coverage
4/4/1995	1.50	0.23	0.351	0.121	0.41	adequate coverage
4/17/1995	1.50	0.22	0.300	0.099	1.14	adequate coverage
5/5/1995	1.50	0.22	0.330	0.109	1.30	adequate coverage
5/23/1995	1.50	0.22	0.309	0.102	0.86	adequate coverage

Other Diadromous Species

Jones River. Adult river herring were observed in modest numbers below the Elm Street Dam during the last three visits in late May. On May 25th and May 30th, blueback herring eggs were seen freshly deposited close to the dam. While checking the substrate for deposited eggs, American eel elvers were commonly seen resting in mats of green algae below the dam during May. An inspection for egg deposition on March 17, 2004 found a glass eel at the Rt. 3A bridge: one of the earliest observations of glass eels in the study area.

Smelt Brook. No observations of river herring were seen in Smelt Brook in 1995. This brook was not known to support a river herring run. A single American eel elver was observed below Rt. 3A on one date in May.

Surveyed Tributaries

In addition to the three tributaries surveyed with smelt spawning habitat (Halls, First and Second brooks), two other tributaries were surveyed. No potential spawning habitat was found at either brook. An unnamed creek on the south side of the Jones River's main stem between Elm Street and Second Brook was visited. Only a trickle of freshwater flow with no riffle habitat was found. Tussock Brook meets the intertidal marsh of Halls Brook close to Rt. 3 and the confluence with the Jones River estuary. There is a barrier to passage where the brook crosses the highway with salt marsh on the west side and brackish swamp on the east side.

DISCUSSION

The intensive smelt investigations of 1979-1981 found a very large population of smelt in the Jones River that were depositing eggs in densities that far exceeded the carrying capacity of the available substrate close to the Elm Street Dam (Lawton et al. 1990). Their investigation had little reason to express concern for this population. The only threat identified during 1979-1981 was egg mortality caused by fungal growth (*Saprolegnia sp.*) that commonly occurs following excessive egg densities. The restriction of the Elm Street Dam results in such egg crowding. However, these egg densities could only be created by a very large run of smelt that traveled over a kilometer of spawning habitat to reach the dam. Similar conditions have only been seen at the largest smelt runs in Massachusetts. With an estimate of 4.2 million adult smelt in the 1981 run, it is evident the Jones River was one of larger runs in the state. The 1995 monitoring found evidence of a large number of smelt spawning in the Jones River. Egg crowding was observed beginning on April 7th, and was followed by similar fungal infestation as observed during 1979-1981.

It is not possible to compare the population size of the run between the two periods. Unfortunately, the 1995 monitoring did not include population data as earlier. There are several pieces of information that point to a decline in the smelt run from the early 1980s to the 1990s. Observations of egg deposition and day-time schools of smelt below the dam indicate a smaller run occurred in 1995 when compared to similar observations recorded by Lawton et al. (1990). Further, Lawton et al. (1990) reported that visits to the Jones River consequent to the 1979-1981 period indicate that the population "declined markedly in the late 1980s". This trend has continued as visits to the Jones River since 1995 have found peak season egg deposition far less than that seen in 1995. Because of the strength of the spawning run in 1979-1981, there is little discussion that points to potential causes for the consequent decline. Observations from 1995 to present and discussions with authors from the earlier report indicate that the influences of sedimentation, eutrophication and water discharge may not have been favorable to the health of the spawning run since 1981.

Lawton et al. (1990) found evidence of sedimentation occurring in the spawning habitat called "Zone C" from their study, which was the approximately 400 m stretch above Rt. 3A adjacent to First and Second Brooks. This condition was observed again in 1995. The slower velocity caused by the pools in this stretch and the periodic tidal influence allow fine particles to settle in this stretch. Patchy egg deposition was found throughout this stretch; however, it was evident that the accumulation of sediment was reducing the suitability of the substrate for spawning. Authors from the earlier investigation, Robert Lawton and Phillips Brady (DMF Biologists, *pers. comm.*), believe that sedimentation has increased in the Jones River in the 1980s and 1990s. This concern resulted in the placement of a vortex style sedimentation trap on the bank of the Jones River shortly before the 1995 monitoring with the purpose of reducing sediment loads to the spawning habitat below Elm Street. The effectiveness of this trap is not known, but it is likely that the percentage removal from that location is small compared to all the point sources for sediment along the length of spawning habitat. Overall, the concern over sedimentation is appropriate, as chronic sedimentation appears to be degrading the overall area of suitable spawning riffles. The cause of sedimentation is not certain, but likely involves increased road sand contributions and riparian erosion in combination with seasonal water regulation. The role of municipal water manipulations of the Jones River headwaters is also unclear. Spring flows do not show obvious declining trends (Figure 3.2 and 3.3); however more investigation is needed to relate water use and annual climate patterns to spawning and nursery habitat requirements of anadromous fish.

A remarkable increase in the biomass of filamentous green algae, was observed through much of the spawning habitat within 100 m of the Elm Street Dam during the third and fourth week of April in 1995. The combination of this algal growth and infestation of fungus quickly caused a physical change to the spawning habitat and level of egg mortality not seen elsewhere during this study. It appeared that a very high percentage of all smelt eggs deposited during the first and second week of April were dead by the third and fourth week of the month. The growth of filamentous green algae and other periphyton of lesser biomass strongly indicate the influence of eutrophication in degrading the smelt spawning habitat. Authors from the earlier investigation (Robert Lawton and Phillips Brady (DMF Biologists, *pers. comm.*), do not recall any threat from algal growth during 1979-1981 but report the increasing presence of the algae in the 1990s. The species composition of periphyton in the Jones River in 1995 was clearly weighted more towards filamentous green algae as opposed to the gelatinous matrices of algae, diatoms and fungus seen in Smelt Brook and many other smelt runs in the study area.

The tributaries to the Jones River continue to attract spawning adult smelt. Halls Brook and Smelt Brook feed directly to the Jones River estuary and probably receive annual recruitment from smelt hatched in the main stem. Viewing the geography of the region, it is likely that all the smelt runs (including Island Creek, Town Brook, and Eel River) within the coastal embayment of Duxbury Bay, Kingston Bay and Plymouth Harbor receive recruitment from the main stem spawning habitat. Despite the small size of the Halls Brook, the spawning habitat is very suitable for smelt, and relatively large numbers of eggs were seen in 1995. Smelt Brook had far lower egg deposition than Halls Brook in 1995. Smelt Brook was stressed by low flows and degraded substrate that influenced higher than typical egg mortality. The substrate became fouled with periphyton starting in late-March. Gelatinous matrices of periphyton covered gravel and cobble downstream of Rt. 3A. The periphyton was nearly colored black; darker than seen at most smelt runs in the study area. Egg mortality was high on this substrate, and was enhanced by fungus that spread quickly over the eggs.

RECOMMENDATIONS

1. Sedimentation Reduction in the Jones River. Concern over the effects of sedimentation on Jones River spawning habitat was raised during the 1980s and 1990s. It is recommended that local authorities develop a management plan for addressing sediment containment along the roadway adjacent to the Jones River. This management plan can set priorities for seeking funding to correct stormwater conduits to the river with poor sediment containment/ removal. The plan can also discuss advanced strategies for sediment removal near prime spawning riffles.

2. Water Chemistry Investigations. Evidence from the present study in comparison with the earlier DMF study on the Jones River indicated that acidification and eutrophication are growing threats to the smelt run. It is recommended that further water chemistry investigations be conducted that relate high frequency sampling of pH and key nutrient parameters to climate and watershed attributes.

3. Water Withdrawal Investigations. The existing discharge data series does not indicate a negative trend in spring flows in the Jones River. However, dry springs can result in shallow depths at spawning riffles, and egg crowding at low discharge can result in high egg mortality. More information is needed on annual flow manipulations and the discharge requirements of anadromous fish in the Jones River. It is recommended that existing discharge records are analyzed in relation to municipal withdrawals, climate, and spawning habitat and nursery habitat requirements for anadromous fish in the Jones River.

4. Revisit Smelt Population Investigations. The 1979-1981 smelt population investigation provided valuable data on smelt in the Jones River. No such investigations have been conducted since for a species that is poorly described but apparently undergoing serious population decline. It may be difficult to match the detail of the earlier investigation. It is recommended that key population parameters (sex, size and age structure; spawning run CPUE) recorded earlier be revisited in the Jones River.

5. Halls Brook Riparian Buffer. The former mill property along the smelt spawning habitat in Halls Brook does not offer sufficient canopy or riparian buffer to provide shading and erosion protection. It is recommended that the riparian bank on that side of Hall Brook be landscaped to improve shading and erosion control along the spawning habitat.

Figure 3.2 Jones River average monthly discharge and trendline for March and April at Elm Street USGS gauge station, 1967-2004.

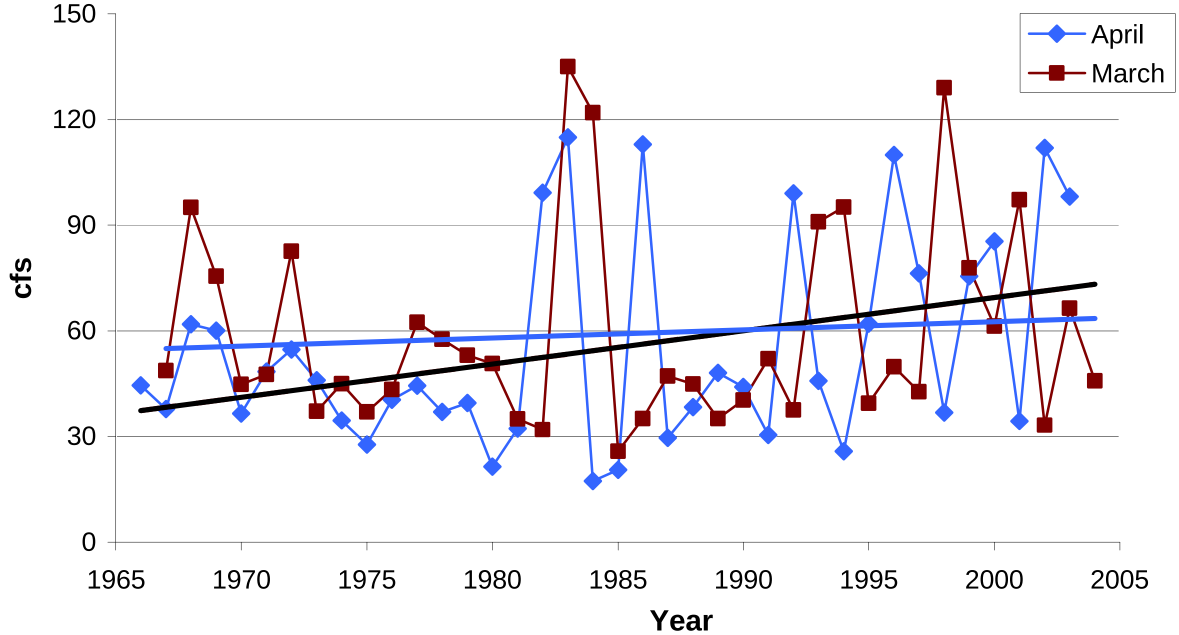
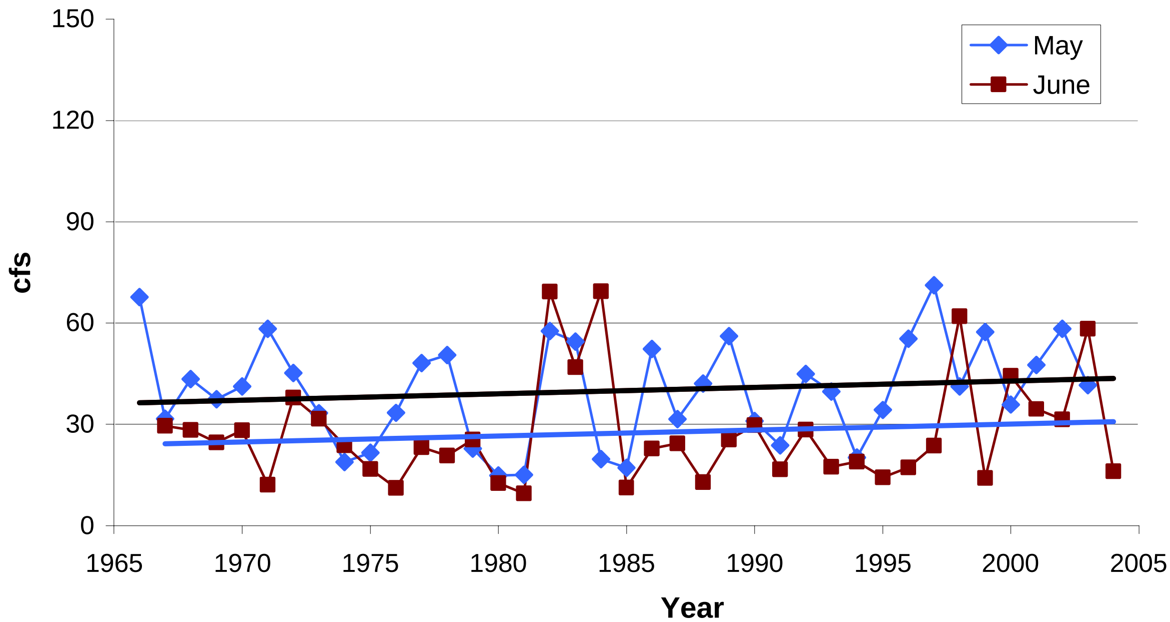


Figure 3.3 Jones River average monthly discharge and trendline for May and June at Elm Street USGS gauge station, 1967-2004.



ISLAND CREEK

STUDY AREA

Island Creek is located in the South Shore Coastal Drainage Area (Halliwell et al. 1982) in southern Duxbury. The primary source of freshwater flow is Island Creek Pond in Duxbury. Island Creek flows for about 2.5 km from Island Creek Pond through a small mill pond and empties into Kingston Bay. No estimate of drainage area size was found. Wandle and Morgan (1984) computed drainage areas only for South Shore streams that drained at least 7.8 km^2. No stream flow gauge stations are located on the creek.

Island Creek has been reported to support a smelt run (Reback and DiCarlo 1972; and Iwanowicz et al. 1974). No studies were found that specifically sampled marine or anadromous fish in Island Creek. Island Creek passes from the mill pond under Tremont Street in Duxbury and through a fishway for alewife (Belding 1921; and Reback and DiCarlo 1972). Downstream of the fishway, the creek runs for 0.5 km before reaching Kingston Bay. Much of this distance is through woodland and salt marsh. Shortly downstream of Tremont Street, the creek passes under a former railroad embankment. The stretch below the railroad embankment to the tidal zone was the likely region of smelt spawning habitat, and a sampling station was selected there for the 1994 and 1995 monitoring seasons. No other tributaries contribute to the Island Creek drainage. Several other tributaries in the northern Kingston Bay region were surveyed at this time and will be reported in this section.

RESULTS

Spawning Habitat

Smelt eggs were found in Island Creek in 1994 and 1995 below the railroad embankment near the upper limit of tidal influence. The entire stretch from the railroad embankment to the marsh (381 m) contained potential spawning riffles, although smelt eggs were only found from the marsh upstream for 304 m over 978 m^2 of creek substrate. Light densities of smelt eggs were found in both seasons. In 1994, nearly all egg deposition was located at the first riffle upstream of the marsh, and no eggs were found above the third riffle upstream of the marsh. In 1995, egg deposition was distributed over a wider range in the creek including upstream to within 77 m of the railroad embankment. The accumulation of wood debris blocked passage at the railroad embankment in 1994 and several fallen trees about 100 m below the railroad embankment also limited passage in 1994. These obstructions were cleared for the 1995 season to provide clear passage up to the fishway. The upper limit of observed egg deposition increased by over 100 m, but still no eggs were found near the railroad embankment or upstream to the fishway. Most of the creek from below the fishway to the railroad embankment was not suitable for spawning due to the deposition of fine sediments and lack of riffles.

Spawning Period. Smelt egg deposition was easily detected in shallow and narrow riffles upstream of tidal influence during both seasons. The onset of smelt spawning in Island Creek was consistent both seasons in terms of timing and location of initial egg deposition at the first riffle upstream of the marsh. Both spawning seasons began near the third week of March, and the spawning was concentrated in April (Table 3.10). Spawning activity faded quickly both seasons as few eggs were found in May. The spawning season in 1994 lasted longer than in 1995; although very few eggs were present after the first week in May.

Water Chemistry

Water chemistry was measured in the second to the last fishway pool below Tremont Street. For the parameters measured, water quality conditions were adequate to support aquatic life, with the exception of frequent violations of pH WQS (Table 3.11, A.5-A6). Dissolved oxygen was at or near saturation for all measurements. Water pH was routinely acidic in Island Creek and a serious concern for smelt egg survival. The higher rainfall of March 1994 influenced very acidic creek flows that averaged 5.4 for that month with a low value of 5.0. Tidal influence did not reach the water chemistry station, nor up to the railroad embankment at any time. Routine tidal influence was seen at the lower three riffles where smelt eggs were found, but the salt wedge did not reach this far upstream during spring conditions.

Stream flow Discharge Measurements

Eight discharge measurements were made at Island Creek during 1994 and 1995 (Table 3.12). All measurements were made in the fishway at the second pool below Tremont Street. This transect had suitable dimensions for measuring discharge, although the depth and water velocities are not directly comparable to the spawning riffles downstream. The average water depth at the transect ranged from 0.14 to 0.18 m. Water velocity ranged from 0.172 to 0.373 m/s. Discharge measurements ranged from 0.041 to 0.108 m^3/s (1.4 to 3.8 cfs). There was not a wide range to these measurements, and the lower discharges did not correspond with observations of large amounts of exposed spawning riffle downstream. This may have been more a coincidence of having some of the lower discharge measurements occur following rainfall. In the absence of late season rainfall, riffles in Island Creek were threatened by very low depth and flow coverage. Observations were made of spawning riffles with less than 10 cm of water depth coverage (common in latter half of 1995 season); however, these did not coincide with discharge measurements.

Other Diadromous Species

Alewives were reported in the past DMF surveys to spawn in Island Creek Pond (Belding 1921; and Reback and DiCarlo 1972). River herring (species not confirmed)

Table 3.10 Smelt spawning period at Island Creek, Kingston, 1994-1995.
The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (^oC) Start	End	Range	Mean
1994	March 22nd - May 21st	61	5.5	14.3	4.4 - 17.5	11.5
1995	March 18th - May 9th	53	6.4	13.3	5.8 - 15.3	10.4

Table 3.11 Water chemistry and weather summary for Island Creek spawning habitat station, 1994-1995. Data are averages (Tables A.5-A.6) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Plymouth-Kingston station (NOAA 1994 and 1995).

Sample Period	Station Visits (No.)	NOAA Air Temp. (^oC)	NOAA Rainfall (cm)	Water Temp. (^oC)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1994								
March	9	3.6	24.1	4.3	0.0	5.4	11.9	0.252
April	8	10.4	4.9	12.5	0.0	5.7	10.4	0.245
May	8	13.4	11.2	15.8	0.0	5.8	9.8	0.257
Season	25	9.1	40.2	10.6	0.0	5.6	10.7	0.251
1995								
March	9	3.8	7.6	4.9	0.0	5.8	13.0	0.183
April	8	7.6	6.6	11.1	0.0	6.3	11.3	0.207
May	8	12.6	6.1	15.5	0.0	6.2	9.7	0.218
Season	25	8.0	20.3	10.3	0.0	6.1	11.3	0.203

Table 3.12 Stream discharge measurements made in Island Creek, Kingston, 1994-1995.
Rainfall data are five day total precipitation at Plymouth-Kingston station (NOAA 1994 and 1995).

Date	Width (m)	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Rainfall (cm)	Habitat Coverage
4/6/1994	1.70	0.17	0.373	0.108	0.64	adequate coverage
4/21/1994	1.70	0.16	0.358	0.097	0.10	adequate coverage
5/16/1994	1.70	0.15	0.281	0.072	3.30	adequate coverage
5/31/1994	1.70	0.13	0.213	0.047	0.10	low flow; marginal coverage
3/20/1995	1.70	0.18	0.262	0.080	2.34	adequate coverage
4/13/1995	1.70	0.15	0.199	0.051	1.37	low flow; marginal coverage
5/2/1995	1.70	0.14	0.172	0.041	2.95	low flow; marginal coverage
5/18/1995	1.70	0.14	0.199	0.047	2.11	low flow; marginal coverage

were observed both seasons although less than 10 fish were seen each occasion. More river herring were seen in 1994 than 1995, as a few adults were seen on four occasions from April 19th to May 25th. Elver American eels were found both seasons while scooping for smelt eggs. The first observation was March 20th in 1995. A large adult American eel was seen on May 25th, 1995 in one of the fishway pools.

Surveyed Tributaries

Three freshwater drainages to Duxbury Bay between the South River and Island Creek were surveyed during 1994 and 1995. None of these possessed adequate base flows or potential smelt spawning substrate. The Green Harbor River flows primarily to Massachusetts Bay at Brant Rock. A tidegate on Route 139 at Brant Rock limits tidal flows and fish passage (MDEP 2006). Several April visits were made to the Green Harbor River at Webster Street near a golf course to look for evidence of smelt spawning. This location had fine sediments covering the substrate and not enough freshwater flow to support smelt spawning. Duck Hill River flows from an old mill pond under Tremont Street in Duxbury to the Duxbury Marsh. This drainage also had mucky sediments covering the substrate and minimal freshwater flows. A visit on May 26, 1994 found no freshwater flows coming out of the mill pond into Duck Hill River. The Bluefish River is located slightly south of Duck Hill River and also flows under Tremont Street to Duxbury Bay. Three spring visits were made to confirm that Bluefish River contained no potential spawning riffles. Tidal influence reaches a small man-made pond on the Bluefish River. Marsh habitat is found below the pond inlet, and passage into the pond is limited to higher tides.

DISCUSSION

The monitoring of 1994 and 1995 found Island Creek supporting a very small run of smelt. Smelt eggs were readily found at the first riffle upstream of the marsh, but the densities of eggs were always low, representing very few spawning adults. Island Creek is a small coastal creek that by limitation of habitat area and discharge would not likely support a very large run of smelt. However, the amount of egg deposition observed was well below the capacity of the available spawning habitat. Nearly 80 m of suitable riffle substrate below the railroad bridge did not receive egg deposition during the two seasons, and minor amounts of spawning habitat were available upstream of the railroad embankment. The creek possessed positive habitat features in terms of open passage to tidal flow and good riparian buffer. From Tremont Street to the marsh there was excellent tree canopy to provide shading and reduce periphyton growth. The two obviously negative features observed during monitoring were low pH and shallow depths over spawning riffles. Acidification is certainly a threat to the Island Creek smelt run. Water pH below 5.5 was measured each season and the pH averaged less than 6.0 for the entire 1994 season. Island Creek appears to have very low base flows: the eight discharge measurements were all less than 4 cfs. At the lower end of observed flows, the spawning riffles had minimal depths to provide coverage over deposited eggs during incubation.

RECOMMENDATIONS

1. Additional Water Quality Investigations. It is recommended that a more detailed evaluation be conducted on the status of low flow and low pH in Island Creek. More information on these two identified threats to the smelt run may provide mitigation options for local or state authorities.

2. Maintenance of Railroad Embankment Culvert. The culvert that conveys Island Creek flows under the former railroad embankment periodically can become partially blocked with wood debris. It is recommended that local interests or authorities inspect this location annually prior to spring spawning runs to clear passage for the migrations of diadromous fish.

3. Replacement of Railroad Embankment Culvert. The existing culvert under the railroad embankment is undersized although not a passage impediment if properly maintained. When discussions begin on culvert replacement at this location, it is recommended that fish passage requirements be considered when sizing a new culvert.

4. Maintain Riparian Buffer. The woodland surrounding Island Creek from the railroad embankment to the salt marsh offers very good vegetative canopy for the smelt spawning habitat. These conditions are not found in most smelt runs in Massachusetts. It is recommended that local officials recognize this valuable resource and actively protect the riparian buffer from development.

SOUTH RIVER

STUDY AREA

The South River originates from several small ponds and tributaries in northwest Duxbury and flows through Marshfield and along the Scituate border to discharge at the mouth of the North River estuary. Despite the connection to the mouth of the North River, the South River is not considered a tributary to the North River (Halliwell et al. 1982). For this reason, South River will be reported separately from the North River, although when discussing diadromous fish resources in this region it will be useful to associate the South River with the North River estuary. The drainage area of the South River at the North River confluence is 56.2 km^2 (Wandle and Morgan 1984). The first dam on the South River is located upstream of the junction of Rt. 3A and Rt. 139 in Marshfield Village. Slightly downstream of this junction is the upper limit of tidal influence during spring. From this point the river runs for 11.5 km through eastern Marshfield including large stretches of salt marsh to reach the North River confluence. There are no stream flow gauge stations located on the South River.

Smelt were known to spawn in the South River downstream of the dam in Marshfield Village (Reback and DiCarlo 1972). Reback and DiCarlo (1972) also noted that the South River was heavily stocked with smelt from 1918 to 1920. No passage upstream of this dam is possible for smelt. A single spawning habitat monitoring station was selected downstream of the junction of Rt. 3A and Rt. 139 for the 1994 and 1995 seasons. Three tributaries to the South River were also surveyed for potential spawning habitat during this period.

RESULTS

Spawning Habitat

Smelt eggs were readily found at the spawning habitat station downstream of Rt. 3A during both seasons. The upper limit of egg deposition was the dam at Marshfield Village. Despite the presence of suitable riffles upstream of the Rt. 3A bridge, very low egg densities were found from the bridge to the dam. Spawning was detected along a total river length of 229 m, covering 1,732 m^2 of substrate. The spawning habitat was not continuous. The lower limit of spawning occurred below the Willow Street Bridge. This location was exposed to the salt wedge and located in salt marsh. The constriction of the bridge increases water velocity, and it appears that cobble was introduced to stabilize the substrate, thereby creating a small stretch of spawning habitat. Poor egg survival was noted near the bridge. Upstream of the Willow Street bridge, no spawning occurs for several hundred meters as the river moves through a wide stretch of marsh with silty substrate and low water velocity. About 140 m below Rt. 3A the river narrows to create good spawning riffles. The upper end of this stretch near Rt. 3A is the limit of tidal influence and received the highest egg densities.

Spawning Period. Relatively high densities of smelt eggs were found during both 1994 and 1995, allowing the delineation of the spawning period (Table 3.13). In both years, the end date was not easily designated because of the onset of blueback herring spawning in mid-May. Smelt spawning began earlier in 1995, and the duration of the season was longer than typical. In both seasons, spawning peaked in early to mid-April and the runs appeared to be winding down by the end of April. Minimal smelt spawning continued during the first half of May when spawning period overlap with blueback herring was noted. Late-stage eyed smelt eggs were monitored from visit-to-visit and were found in low numbers by mid-May when freshly deposited blueback herring eggs began to appear. The difference in egg stage provided separation for smelt and blueback herring eggs during the onset of blueback spawning. Later in May, identification was more subjective as blueback eggs advanced to eyed stages. Eggs were collected for identification on May 23rd in both years. In 1994, all hatched larvae identified were blueback herring. In 1995, eggs collected from a large strand of green algae produced three species of fish with hatching starting on the 24th. Of 24 identified larvae, 18 were blueback herring, four were alewife and two were smelt.

Water Chemistry

Water chemistry was measured from the west bank of the river 10 m below the Rt. 3A bridge. This location coincided with the primary spawning riffle for smelt and the upper limit of tidal influence during the spring season. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 3.14, A.7-A.8), with the exception of pH which averaged below the 6.5 water quality criterion both seasons. Much higher precipitation in March 1994 than March 1995 corresponded to lower pH in 1994. Three pH measurements in the range of 5.1-5.3 during March, 1994 raise concerns over the influence of acidification on egg survival. Tidal influence was only detected at the water chemistry station on two occasions each season during above average high tides. No salinity was detected at this location. Specific conductivity was low (typically 0.2-0.3 mmho/cm) and higher in 1994 than 1995.

Stream flow Discharge Measurements

Eight discharge measurements were made at South River in 1994 and 1995 (Table 3.15). All measurements were made at the downstream face of the Rt. 3A bridge. South River flows displayed more consistency and less inclination to decline sharply in the absence of precipitation than other smelt runs associated with the North River estuary. Average water depths at the transect ranged from 0.21 to 0.33 meters. Average water velocity ranged from 0.288 to

Table 3.13 Smelt spawning period in South River, Marshfield, 1994-1995. The spawning period is an estimation based on observations of viable smelt eggs. The end dates (*) are based on the last observation of smelt eggs but uncertain because of the onset of blueback herring spawning.

Year	Spawning Period	Days	Water Temperature (^oC) Start	End	Range	Mean
1994	March 23rd - May 21st *	60	6.6	13.9	5.2 - 16.9	11.6
1995	March 13th - May 24th *	73	5.0	19.2	3.1 - 19.4	11.0

Table 3.14 Water chemistry and weather summary for South River spawning habitat station, 1994-1995. Data are averages (Tables A.7-A.8) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Plymouth-Kingston station (NOAA 1994 and 1995).

Sample Period	Station Visits (No.)	NOAA Air Temp. (^oC)	NOAA Rainfall (cm)	Water Temp. (^oC)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1994								
March	9	3.6	24.1	3.7	0.0	5.6	12.5	0.265
April	8	10.4	4.9	12.4	0.0	6.2	10.4	0.273
May	8	13.4	11.2	15.0	0.0	6.1	9.6	0.289
Season	25	9.1	40.2	10.1	0.0	5.9	10.8	0.276
1995								
March	9	3.8	7.6	5.1	0.0	6.1	12.5	0.188
April	8	7.6	6.6	10.8	0.0	6.6	11.3	0.210
May	8	12.6	6.1	15.3	0.0	6.5	9.9	0.217
Season	25	8.0	20.3	10.2	0.0	6.4	11.2	0.205

Table 3.15 Stream discharge measurements made in South River, Marshfield, 1994-1995. Rainfall data are five day total precipitation at Plymouth-Kingston station (NOAA 1994 and 1995).

Date	Width (m)	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Rainfall (cm)	Habitat Coverage
3/28/1994	7.9	0.33	0.508	1.324	2.39	high flow and depth
4/19/1994	7.9	0.26	0.373	0.766	1.63	adequate coverage
5/3/1994	7.9	0.20	0.288	0.455	0.38	low flow; marginal coverage
5/25/1994	7.9	0.23	0.380	0.690	0.97	adequate coverage
3/16/1995	7.9	0.25	0.380	0.751	0.05	adequate coverage
4/10/1995	7.9	0.22	0.279	0.485	1.65	low flow; marginal coverage
5/10/1995	7.9	0.23	0.278	0.505	0.00	low flow; marginal coverage
5/18/1995	7.9	0.21	0.288	0.478	2.11	low flow; marginal coverage

0.508 m/s. Discharge measurements ranged from 0.455 to 1.324 m^3/s (16.1 to 46.8 cfs). None of the eight discharge measurements corresponded with large exposure of spawning substrate. Water velocity along the flow transect was highest along the vertical stone wall on the east bank. The highest densities of smelt eggs observed in the South River were along this wall, where velocity was 30-40% higher than the transect average.

Other Diadromous Species

River herring were noted at the time of Belding's survey (1921) in the South River. No passage beyond the Marshfield Village Dam was possible at the time, and the herring were called "ditch herring" (assumed to be blueback herring) because they spawned in the river below. Reback and DiCarlo (1972) noted the presence of river herring and shad in the South River with limited passage occurring through a fishway at the Marshfield Village Dam. Relative to other rivers monitored in this study with river herring runs, the South River had large numbers of blueback herring observed in 1994 and 1995. No river herring were observed until May both seasons. High density blueback egg sets were seen between May 18th and May 25th both seasons. The overall deposition of blueback herring eggs greatly exceeded the observed smelt egg deposition in the South River, and large numbers of blueback eggs were seen upstream of Rt. 3A below the dam. Fishermen were observed both seasons fishing for trout and netting river herring. The hatched alewife eggs from 1995 indicate that alewife were also present. Elver eels were commonly seen at the smelt spawning habitat, often associated with the mats of green algae.

Surveyed Tributaries

Three tributaries of the South River were surveyed in 1994, and none possessed enough potential habitat to warrant routine monitoring. Macombers Creek joins the South River near the North River confluence in Marshfield. It crosses Damons Point Road and is tidal right up to Murdocks Pond. Tidal fluctuations greatly limit the formation of spawning habitat with the only potential attraction occurring a few meters below the pond at low tide. Littles Creek flows from Marshfield Center to meet the South River in salt marsh near the Sea View section of Marshfield. Littles Creek contained a small stretch of potential spawning habitat below Keenes Pond but was overgrown with vegetation and had minimal base flows. Subsequent visits during the spawning season found no smelt eggs in Little Creek. An unnamed creek on the north side of South River a few hundred meters downstream of the lower limit of egg deposition was also surveyed. This creek had minimal base flows and no riffle substrate.

DISCUSSION

The smelt spawning habitat in South River is similar in size to the three tributaries to the North River that support smelt runs. Other similarities include the threat of acidification found at all four smelt runs and the presence of enough smelt in these runs to readily allow the delineation of spawning habitat and period (except for the smaller run in Third Herring Brook). The South River provides a classic example of smelt spawning habitat where the peak spawning occurs at the first shallow riffle above average tidal influence. Light egg deposition was found throughout most of the 229 m of river length where eggs were found. Moderate to high egg densities were found in the 40 m below the Rt. 3A Bridge. The attraction of this location for spawning smelt may have been enhanced by the construction of the bridge and building of a retaining wall on the east side of the river. Water velocity increases on the wall side, apparently attracting the highest densities of smelt eggs that were found in South River.

The South River contained a viable smelt run during the monitoring seasons of 1994 and 1995 that could be considered of moderate size relative to other runs in the study area. The observed egg deposition was well-below the capacity of the available spawning habitat, and few eggs were found within the 32 m stretch upstream of Rt. 3A where suitable riffles were found below the Marshfield Village Dam. Acidification and eutrophication were identified threats to the smelt run observed in 1994 and 1995. Water pH in 1994 was especially acidic with a seasonal average of 5.9. In both seasons, pH increased as the season advanced. During a four day period in May 1994, the pH pulsed from 6.1 to 5.7 and back to 6.0 in response to 3.6 cm of rainfall. These episodic events could be damaging to an egg set in rivers such as the South River where base flows are routinely acidic.

Eutrophication was evident both seasons by dramatic growths of green periphytic algae in late April. This filamentous algal growth, continued in May resulting in complete coverage of the substrate in some locations. In 1994, a remarkable growth spike occurred from April 25th to April 29th. Unlike the gelatinous periphyton observed in First Herring Brook, this periphyton was not as damaging to smelt eggs. Smelt and blueback herring eggs were observed to attach readily and survive on these algae. However, eggs deposited prior to sharp growth peaks could be smothered. The concern of declining water flow was not identified as a direct physical threat to deposited smelt eggs as seen in First Herring Brook and Second Herring Brook. Discharges observed in 1994 and 1995 provided adequate coverage of smelt spawning substrate for most of the spawning period, and observations of lower flows resulted in only small patches of exposed habitat. There were indications at the end of May that stream flow coverage of the substrate may be a limiting factor for blueback herring egg incubation in some years.

The South River provides an interesting example of the overlap in spawning habitat use among species of anadromous fish. In most rivers where river herring and smelt were observed to spawn, there was minimal temporal overlap in spawning habitat use. In the South River, there was approximately two weeks in May when both species were spawning, and alewife eggs were found on the same periphyton as bluebacks and smelt on May 23, 1995. The frequent spawning events of blueback herring allowed for comparisons of smelt and blueback eggs that assisted the difficult process of separating the two species. Blueback eggs seen in the South River appeared more cloudy and smaller than smelt eggs when first deposited. After a few days, they would become clear and enlarge to appear very similar to smelt eggs. At this point, unless there were large developmental differences in the eggs observed (typical the first half of May but not later), hatching and larval identification were needed to separate the species.

RECOMMENDATIONS

1. Maintain Riparian Buffer. The South River had suitable canopy cover from Rt. 3A downstream to the marsh at the time of the study. Shading from this canopy is helpful to reduce growth of periphytic algae on spawning substrate. It is recommended that local authorities act to maintain and enhance this riparian buffer on the South River.

2. Prohibit Wading at Spawning Habitat. Fishermen were observed wading in areas of the South River to catch trout and river herring while smelt and blueback herring eggs were deposited in the substrate. At times, very high densities of blueback herring eggs were observed on the substrate near Rt. 3A. It is recommended that DMF prohibits wading in the South River for the length of the spawning habitat during the spring spawning seasons for smelt and blueback herring.

NORTH RIVER

STUDY AREA

The North River is formed by the joining of Indian Head River and Herring River at the Pembroke and Hanover border. It flows for 19.5 km through Hanover, Pembroke, Norwell, Marshfield and Scituate to discharge in Massachusetts Bay. The North River estuary is within the South Shore Coastal Drainage Area (Halliwell et al. 1982), with a total drainage area of 272 km^2 at the mouth of the estuary (Wandle and Morgan 1984). The North River estuary contains the largest area of salt marsh in Massachusetts Bay, estimated at 1,540 acres in 1966 (Fiske et al. 1966), and substantial tidal freshwater wetlands (Bowden et al. 1991) in the upper reaches of the estuary. Tidal flows exert a strong influence on river flows in the North River. Flow direction reverses with each flood tide well upstream of Rt. 3. The upper limit of salt water intrusion was documented at past Rt. 3 during spring and slightly past the Stone Arch Bridge in Hanover in the summer (Fiske et al. 1966). The first passage impediment in the North River estuary is the Elm Street Dam on the Indian Head River. The only main stem USGS stream flow gauge station is located at the Elm Street Dam in Hanover and has operated since 1966 (#01105730; drainage area-78.5 km^2). The gauge station is located well inland but only slightly above the upstream limit of tidal influence. The monthly mean discharge values for the spring spawning period from 1966-2003 were: March - 122 cfs; April - 101 cfs; and May - 66 cfs (USGS, http://waterdata.usgs.gov).

The North River system has a rich history of supporting anadromous fisheries (Fiske et al. 1966). Important fisheries for river herring and eels were known, and a shad run continues today in the Indian Head River that supports one of the few sportfisheries for shad in Massachusetts. Little information was available on the occurrence of smelt in the North River system. The DMF estuarine study of the North River in the 1960s did not catch smelt in seine or trawl sampling (Fiske et al. 1966). Reback and DiCarlo (1972) mentioned that smelt occur within the river system, but spawning areas were not known at the time. Monitoring stations for 1993-1995 were selected following the identification of known smelt spawning habitat in First Herring Brook and Second Herring Brook (Ken Reback, DMF, *pers. comm.*) and survey efforts that selected potential spawning locations in Third Herring Brook, Stoney Brook, Cove Brook, Robinson Creek, Indian Head River and the main stem North River (Figure 3.4). Greater details are next provided on the three North River tributaries with smelt spawning habitat.

First Herring Brook. First Herring Brook flows for approximately 11 km from South Swamp in Scituate to discharge to the North River 1.3 km from the mouth on the north side of the river. The brook flows through the First Herring Brook Reservoir and Old Oaken Bucket Pond, both water supplies for the town of Scituate. The size of the drainage area is not reported in Wandle and Morgan (1984), and no stream flow gauge stations are located on the brook. No references to a smelt run in First Herring Brook were found. Smelt were known to spawn in recent decades near the tidal zone below the Old Oaken Bucket Pond Dam in Scituate (Ken Reback, DMF, *pers. comm.*). A single spawning habitat station was selected downstream of the fishway at Old Oaken Bucket Pond and monitored during 1993 and 1994.

Second Herring Brook. Second Herring Brook flows from four small impoundments in Norwell to discharge to the North River 8.3 km from the mouth on the north side. The primary source of freshwater is Torrey Pond, located only 2.3 km from the confluence with the North River. The drainage area from Rt. 123 (about 1 km from the North River) is 8.2 km^2 (Wandle and Morgan 1984). No stream flow gauge stations are located on the brook. No references to a smelt run in Second Herring Brook were found. Downstream of Rt. 123, Second Herring Brook flows through Gordon Pond. Smelt were known to spawn below the dam at Gordon Pond near the tidal zone (Ken Reback, DMF, *pers. comm.*). A spawning habitat station was selected downstream of the Gordon Pond Dam and monitored during 1994 and 1995.

Third Herring Brook. Third Herring Brook flows from Jacobs Pond in Norwell for approximately 8.5 km before discharging to the North River at a distance of 16.5 km from Massachusetts Bay. It also receives flows from wetlands in Norwell and Hanover and three small impoundments downstream of Jacobs Pond. The drainage area from River Street on the Hanover and Norwell border is 25.3 km^2 (Wandle and Morgan 1984). The brook continues for approximately 1.0 km below River Street to meet the main stem North River. About half of this distance is under tidal influence and bordered by tidal freshwater marsh. No stream flow gauges are located on Third Herring Brook. No references to smelt on Third Herring Brook were found and it was not a known smelt run. A spawning habitat station was selected downstream of River Street near the upper limit of tidal influence and monitored during 1994 and 1995.

RESULTS

Spawning Habitat

First Herring Brook. Smelt eggs were found in First Herring Brook in 1993 and 1994 from the base of the fishway below Old Oaken Bucket Pond Dam downstream for 190 m to the tidal zone upstream of the New Drift Way Bridge. The substrate area where smelt eggs were found was 798 m^2. The elevation rise of the dam prevented passage farther upstream. Marginal spawning habitat was found for about 50 m below the downstream limit of observed egg deposition, although this stretch was subject

Figure 3.4 Smelt spawning habitat monitoring stations in the North River system. The downstream limit (green dots) and upstream limit (red dots) of smelt egg deposition are delineated. Monitoring stations where no eggs were found (yellow dots) and the ichthyoplankton station (blue dot) are also shown.

to reduced attraction flows at higher tides. The majority of egg deposition occurred in a moderate gradient riffle that begins at the downstream opening of the culvert under Country Way and continues for about 50 m until a sharp bend in the brook.

Second Herring Brook. Smelt eggs were found in Second Herring Brook in 1994 and 1995 from below the Gordon Pond Dam downstream for 205 m to a wood walk-bridge in the tidal zone. The substrate area where smelt eggs were found was 1,427 m^2. The Gordon Pond dam prevented passage farther upstream. Marginal spawning habitat was found for about 50 m below the downstream limit of observed egg deposition, although this stretch was subject to reduced attraction flows at higher tides. In addition, about 50% of the available spawning habitat received very little egg deposition because of the reduced attraction at high tides (increased depth and decreased water velocity). The locations with the highest densities of smelt eggs were shallow riffles on both sides of a wood bridge with corrugated pipe culverts. These riffles were vulnerable to shallow water depth as discharge declined later during the spawning season.

Third Herring Brook. Smelt eggs were found in Third Herring Brook in 1994 and 1995 below River Street near the upper limit of tidal influence. These are the first observations recorded of smelt in this brook and result in the designation of Third Herring Brook as a smelt run. The upper limit of smelt egg deposition was a riffle located 140 m downstream of River Street. There were no passage impediments preventing farther movements upstream, however, no eggs were found beyond this riffle. The highest densities of eggs were found only 20 m below this riffle at a separate riffle located about 75 m above the upper limit of tidal influence. Scattered egg deposition was found downstream as the brook transitioned from a woodland border to the tidal freshwater marsh. The entire length of

Table 3.16 Smelt spawning period in First Herring Brook, Norwell, 1993-1994. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (^oC) Start	End	Range	Mean
1993	March 30th - May 16th	48	3.4	16.4	2.9 - 20.5	11.9
1994	March 23th - May 24th	63	5.8	19.0	3.6 - 20.8	12.0

Table 3.17 Smelt spawning period in Second Herring Brook, Norwell, 1993-1994. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (^oC) Start	End	Range	Mean
1994	March 19th - May 28th	71	2.1	17.7	1.2 - 18.7	11.5
1995	March 8th - May 20th	74	1.9	16.7	1.7 - 18.5	9.9

Table 3.18 Smelt spawning period in Third Herring Brook, Hanover/Norwell, 1994-1995. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (^oC) Start	End	Range	Mean
1994	(not delineated) - May 21st			12.3		
1995	April 2nd - May 17th	46	7.5	12.8	6.6 - 14.0	10.7

Table 3.19 Water chemistry and weather summary for First Herring Brook spawning habitat station, 1993-1994. Data are averages (Tables A.9-A.10) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Plymouth-Kingston station (NOAA 1993 and 1994).

Sample Period	Station Visits (No.)	NOAA Air Temp. (^oC)	NOAA Rainfall (cm)	Water Temp. (^oC)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1993								
March	7	1.9	22.6	2.5	0.0	5.9	13.1	0.252
April	8	8.1	15.3	9.6	0.0	6.1	11.0	0.184
May	6	14.7	3.4	17.2	0.0	6.5	9.1	0.210
Season	21	8.2	41.3	9.4	0.0	6.2	10.9	0.210
1994								
March	9	3.6	24.1	3.8	0.0	5.8	12.7	0.313
April	8	10.4	4.9	11.7	0.0	6.2	10.3	0.329
May	8	13.4	11.2	15.9	0.0	6.2	9.3	0.321
Season	25	9.1	40.2	10.2	0.0	6.0	10.8	0.321

spawning habitat where eggs were observed was 345 m and the substrate area was 1,958 m^2. The physical appearance of spawning habitat in Third Herring Brook is close to optimal relative to all smelt runs visited for this study. There is excellent riparian buffer and canopy, no passage impediments, and the channel is natural with a series of high quality riffles and pools. The brook contained the largest amount of spawning habitat among North River locations. In addition to the spawning habitat where eggs were observed, there was a 200 m stretch of brook upstream with 1,170 m^2 of suitable spawning substrate.

Spawning Period

First Herring Brook. The onset of egg deposition occurred at the sharp bend below Country Way during 1993 and 1994 and the spawning period was well-defined during both seasons (Table 3.16). A harsh winter, including a Northeastern storm with a foot of snow on March 13th, may have delayed the onset of spawning in 1993 until the end of March. Spawning began earlier in 1994 and the spawning period lasted longer. Similar to other runs monitored or visited during the period of 1993-1995, the 1994 egg deposition greatly exceeded the other years. In both seasons, the bulk of spawning occurred in April and low densities of mostly eyed stages of eggs were present during the first half of May. Eggs were collected on April 12th in 1993 for confirmation as smelt eggs. Hatching began on April 20th and the larvae were identified as smelt.

Second Herring Brook. Smelt eggs were first found during 1994 and 1995 at the same riffle immediately downstream of the walk-bridge about 80 m below the Gordon Pond Dam. The start of the spawning period was well-defined both monitoring seasons and the end dates were subject to some uncertainty due to the presence of spawning river herring (Table 3.17). Spawning was first detected 11 days later in 1994 than in 1995; possibly due to cooler March water temperature in 1994. Spawning peaked in April, although the duration of the spawning period was relatively long, extending late into May both seasons. Second Herring Brook is one of the few rivers in this study that had overlap in the spawning period and spawning habitat use of smelt and river herring. The spawning run was stronger in 1994 than 1995. By mid-April in 1994 every riffle from Gordon Pond Dam down to the intertidal zone had moderate to high densities of smelt eggs.

Third Herring Brook. Smelt eggs were first found on April 25, 1994 at the first riffle above tidal influence downstream of River Street. It is possible that eggs were deposited before this date and not located. Although it is likely that little spawning occurred prior to April 25th because extensive monitoring efforts on April 15th and 19th found no eggs. In 1995, smelt eggs were found at the same riffle with an estimated start date of April 2nd (Table 3.18). The end dates of the spawning period were determined both years as occurring in the third week of May. However, the presence of river herring and newly deposited eggs during the third and fourth weeks of May each season made this determination difficult. Eggs collected on April 26th and May 11th in 1994 and on April 10th in 1995 were hatched at the laboratory and confirmed as smelt. On two occasions, newly deposited eggs were collected after the estimated end date of the smelt spawning season, but these did not survive to hatch. The temporal separation and difference in embryo development of observed smelt eggs and the late-May eggs suggest the likelihood that they were blueback herring eggs.

Water Chemistry

First Herring Brook. Water chemistry was measured 10 m below the downstream opening of the Country Way culvert at First Herring Brook. For the parameters measured, water quality conditions were adequate to support aquatic life, with the exception of consistent violations of the pH WQS (Table 3.19, A.9-A.10). March air and water temperatures were notably cooler in 1993 than 1994. Tidal influence was only detected at the water chemistry station on three occasions during above average high tides. The pH was routinely acidic in the range of 5.5 to 6.6. Low pH was a concern during both seasons, particularly in March and early April when the average pH was below 6.0. Specific conductivity was low (typically 0.2-0.3 mmho/cm), and higher in 1994 than 1993.

Second Herring Brook. Water chemistry was measured 2 m downstream of the wood bridge 80 m downstream of Gordon Pond Dam. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 3.20, A.11-A.12), with the exception of consistent violations of the pH WQS. Tidal influence was observed during each flood tide at the water chemistry station. The salt wedge was only detected once when 2.5 ppt salinity was measured during the height of an 11.1 ft. tide (these data are excluded from Table 3.20, but included in A.11). The acidity of water pH in 1994 was a concern for smelt egg survival. No measurements were above the 6.5 pH water quality standard. Two measurements in March 1994 were below 5.5, a level that is associated with increasing smelt egg mortality (Geffen 1990). The very low pH of 1994 was associated with higher rainfall in 1994 and was not repeated in 1995.

Third Herring Brook. Water chemistry was measured 10 m downstream of the River Street Bridge on the Hanover and Norwell border. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 3.21, A.13-A.14), with the exception of consistent violations of the pH WQS. Water temperature was uncommonly cold in March, 1994; not exceeding 1.0 °C until after March 17th. These conditions may have delayed the onset of smelt spawning in 1994. The 1994 season also had twice the precipitation as in 1995,

Table 3.20 Water chemistry and weather summary for Second Herring Brook spawning habitat station, 1994-1995. Data are averages (Tables A.11-A.12) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Plymouth-Kingston station (NOAA 1994 and 1995).

Sample Period	Station Visits (No.)	NOAA Air Temp. (^oC)	NOAA Rainfall (cm)	Water Temp. (^oC)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1994								
March	9	3.6	24.1	2.6	0.0	5.7	13.3	0.250
April	8	10.4	4.9	11.3	0.0	5.9	9.9	0.275
May	8	13.4	11.2	15.2	0.0	6.0	9.0	0.296
Season	25	9.1	40.2	9.3	0.0	5.8	10.7	0.274
1995								
March	9	3.8	7.6	4.3	0.0	6.2	12.5	0.194
April	8	7.6	6.6	11.0	0.0	6.2	10.7	0.213
May	8	12.6	6.1	15.2	0.0	6.3	9.2	0.247
Season	25	8.0	20.3	9.9	0.0	6.2	10.8	0.218

Table 3.21 Water chemistry and weather summary for Third Herring Brook spawning habitat station, 1994-1995. Data are averages (Tables A.13-A.14) except station visits and NOAA rainfall are total values Air temperature and rainfall data were recorded at Plymouth-Kingston station (NOAA 1994 and 1995).

Sample Period	Station Visits (No.)	NOAA Air Temp. (^oC)	NOAA Rainfall (cm)	Water Temp. (^oC)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1994								
March	9	3.6	24.1	2.7	0.0	5.3	12.8	0.365
April	8	10.4	4.9	10.6	0.0	5.8	10.4	0.377
May	8	13.4	11.2	13.3	0.0	6.0	9.5	0.375
Season	25	9.1	40.2	8.6	0.0	5.7	10.9	0.373
1995								
March	9	3.8	7.6	4.6	0.0	5.9	12.6	0.280
April	8	7.6	6.6	10.1	0.0	6.3	10.9	0.275
May	8	12.6	6.1	15.4	0.0	6.4	9.8	0.290
Season	25	8.0	20.3	9.8	0.0	6.2	11.1	0.282

Table 3.22 Stream discharge measurements made in First Herring Brook, Scituate, 1993-1994. Rainfall data are five day total precipitation at Plymouth-Kingston station (NOAA 1993 and 1994).

	Width (m)	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Rainfall (cm)	Habitat Coverage
4/27/1993	4.0	0.41	0.747	1.225	5.46	high flow and depth
5/19/1993	4.0	0.24	0.253	0.243	2.11	poor coverage; exposed habitat
3/14/1994	4.0	0.31	0.576	0.714	NA	adequate coverage
4/12/1994	4.0	0.28	0.324	0.363	1.04	poor coverage; exposed habitat
4/29/1994	4.0	0.20	0.114	0.091	0.20	poor coverage; exposed habitat
5/19/1994	4.0	0.33	0.371	0.490	4.09	low flow; marginal coverage

Table 3.23 Stream discharge measurements made in Second Herring Brook, 1994-1995. Rainfall data are five day total precipitation at Plymouth-Kingston station (NOAA 1994 and 1995). Discharge is the sum of flows through three 1.50 m diameter culverts.

Date	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Rainfall (cm)	Habitat Coverage
3/31/1994	0.25	1.188	1.033	4.19	adequate coverage
4/21/1994	0.15	0.637	0.333	0.10	low flow; marginal coverage
5/16/1994	0.17	0.716	0.422	3.30	low flow; marginal coverage
5/31/1994	0.12	0.351	0.149	0.10	poor coverage; exposed habitat
3/8/1995	0.25	0.944	0.829	1.40	adequate coverage
4/7/1995	0.12	0.467	0.200	0.51	poor coverage; exposed habitat
4/28/1995	0.11	0.403	0.154	1.47	poor coverage; exposed habitat
5/16/1995	0.14	0.474	0.230	1.02	poor coverage; exposed habitat

Table 3.24 Stream discharge measurements made in Third Herring Brook, 1994-1995. Rainfall data are five day total precipitation at Plymouth-Kingston station (NOAA 1994 and 1995).

Date	Width (m)	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Rainfall (cm)	Habitat Coverage
3/26/1994	4.40	0.82	0.534	1.927	3.33	high flow and depth
4/15/1994	4.30	0.56	0.374	0.901	1.22	adequate coverage
5/11/1994	4.30	0.61	0.245	0.643	0.76	adequate coverage
5/23/1994	4.30	0.62	0.184	0.491	0.28	adequate coverage
3/14/1995	4.25	0.58	0.257	0.634	0.05	adequate coverage
4/10/1995	4.25	0.47	0.128	0.256	1.65	low flow; marginal coverage
4/28/1995	4.25	0.46	0.097	0.190	1.47	low flow; marginal coverage
5/16/1995	4.25	0.48	0.128	0.261	1.02	low flow; marginal coverage

contributing to higher specific conductivity and lower pH in 1994. Spring pH levels are a serious concern for smelt egg survival in Third Herring Brook. The average March pH (5.3) in 1994 was the lowest measured for any river during this study. Two pH measurements of 4.9 in March 1994 would be expected to cause elevated smelt egg mortality (Geffen 1990).

Stream flow Discharge Measurements

First Herring Brook. Six discharge measurements were made at First Herring Brook in 1993 and 1994 (Table 3.22). All measurements were made at the downstream face of the County Way culvert. Average water depth ranged from 0.20 to 0.41 m at the transect. Water velocity ranged from 0.114 to 0.747 m/s. Discharge measurements ranged from 0.091 to 1.225 m^3/s (3.2 to 43.3 cfs). During three of the measurements (<0.4 m^3/s), some of the substrate in the spawning riffles was exposed to air from low flows. The May 19, 1994 measurement occurred when flows covered all spawning riffles but only by a slim margin. From these observations it is possible to describe 0.5 m^3/s as an approximate threshold for providing adequate coverage of spawning substrate, and discharges near 0.1 m^3/s (April 29, 1994) would clearly be a threat to egg survival.

Second Herring Brook. Eight discharge measurements were made at Second Herring Brook in 1994 and 1995 (Table 3.23). The measurements were made at the downstream face of the triple pipe culvert below Gordon Pond. Average water depth for the three culverts for each visit ranged from 0.11 to 0.25 meters. Average water velocity ranged from 0.351 to 1.188 m/s. The sum of the three discharge measurements for the three culverts ranged from 0.149 to 1.033 m^3/s (5.3 to 36.5 cfs). The spawning habitat below Gordon Pond was shallow at all discharge volumes. During half the measurements and during many visits in late-April and May there was inadequate flow coverage of the spawning habitat to prevent egg mortality due to air exposure. This exposure of spawning substrate and attached eggs was a severe problem in 1995 for smelt eggs and for blueback herring eggs during both seasons. The discharge observed on May 16, 1994 (0.42 m^3/s) was the third highest measured and did not result in exposed habitat; however it approximates the threshold for providing adequate substrate coverage.

Third Herring Brook. Eight discharge measurements were made at Third Herring Brook in 1994 and 1995 (Table 3.24). All measurements were made at the downstream face of the River Street culvert. Average water depth at the transect ranged from 0.46 to 0.82 meters. Water velocity ranged from 0.097 to 0.534 m/s. Discharge measurements ranged from 0.190 to 1.927 m^3/s (6.7 to 68 cfs). Much higher precipitation in 1994 than in 1995 influenced the higher discharges during the first season. Despite much lower discharge in April and May 1995, no exposed spawning substrate was observed. However, during this period the depth of water over the riffles was marginal, and water velocity was very low.

Other Diadromous Species

First Herring Brook. Alewives were reported as "numerous" in First Herring Brook previous to 1900 (Belding 1921), and an existing run was noted during the 1965 DMF North River estuary study (Fiske et al. 1966). The alewife run has apparently declined to low levels as they were observed only once during the two monitoring seasons, and I did not encounter any local anecdotes on their recent presence. Fewer than 10 river herring were seen in the Country Way culvert on April 21, 1994. Anecdotal reports were heard from locals on the presence of eels, but none were seen during monitoring.

Second Herring Brook. Historical accounts imply that a river herring run formerly occurred in Second Herring Brook but their presence was not reported at the time of the surveys of Belding (1921), Fiske et al. (1966), and Reback and DiCarlo (1972). River herring were seen starting in the second week of May in 1994 and 1995. Several river herring on two dates in 1994 were captured and examined internally to identify them as alewife. It is likely that both alewives and blueback herring were present. Elver American eels were found during both seasons while checking the substrate for smelt eggs, with the earliest observation on April 6th in 1994.

Third Herring Brook. Few references were found on anadromous fish in Third Herring Brook. Fisk et al. (1966) stated that a river herring run had occurred there previously. River herring were commonly seen in each monitoring season. They were first observed on April 29th in 1994 and mid-May in 1995. Because of the river habitat and presence of adhesive eggs in late-May it was assumed they were blueback herring. Three individuals were identified as alewives by internal inspection in May, 1995. It is likely that both species were present. More herring were seen in 1994; however, in both seasons schools with several hundred individual herring were observed. No observations of American eel were made. Three adult lamprey were observed on May 23rd and May 25th in 1995 building a nest and displaying courtship behavior.

Indian Head River. Indian Head River contains a small but popular American shad run that attracts sportfishing effort each spring (Reback and DiCarlo 1972). During the 1995 monitoring, river herring were seen in the three riffles and pools below Elm Street on several occasions and fishermen were seen snagging river herring while trout fishing. This location also attracted fishermen targeting American shad. Individual shad were observed at the first riffle below Elm Street on May 18th and May 25th, and several shad were seen there on May 23rd. In all cases they were small adult shad, about three pounds in weight.

Potential Spawning Habitat

Stoney Brook. Stoney Brook discharges to the North River between First Herring Brook and Second Herring Brook in Norwell. A water chemistry station was set at the crossing of Rt. 123 and this station was visited on 25 dates in 1994. Stoney Brook winds for 1.0 km from Rt. 123 to the North River of which about 0.7 km is salt marsh. Potential spawning habitat was found upstream of the salt marsh and tidal influence near the Rt. 123 station. No smelt eggs were found during 1994 monitoring or during two peak spawning season visits in 1995. Tidal influence was not detected at the Rt. 123 sampling station. Water chemistry was similar to other freshwater drainages in the North River system (Table A.15). The mean pH of 5.8 for the season indicates this brook suffers from acidification. Four spring discharge measurements were made in 1994 at the downstream face of the Rt. 123 culvert: the discharge ranged from 0.061 to 0.339 m^3/s, with an average of 0.186 m^3/s. Very high velocities (measured 1.7 and 1.9 m/s) occurred in this small culvert (1.2 m diameter) when flows were elevated.

Cove Brook. Cove Brook discharges to the south side of the North River in Marshfield, nearly opposite to the Stoney Brook confluence. A water chemistry station was set at the Highland Street crossing and was visited on 25 dates in 1994. Cove Brook winds for 2.0 km from Highland Street to the North River and nearly all this distance is through salt marsh. Suitable cobble and gravel riffles were found immediately downstream of street just before the brook reaches the marsh. No smelt eggs were found during the 1994 monitoring and one follow-up visit in 1995. Tidal influence was not detected at the street culvert, but was routinely observed 20-30 m downstream. Water chemistry was similar to other freshwater drainages in the North River system (Table A.16). The mean pH of 6.0 for the season indicates this brook is exposed to acidification. Four spring discharge measurements were made in 1994 downstream of the Highland Street culvert: the discharges ranged from 0.042 to 0.395 m^3/s and averaged 0.152 m^3/s.

Robinson Creek. Robinson Creek discharges to the south side of the North River in Pembroke between Rt. 3 and Third Herring Brook. A water chemistry station was set at the Water Street crossing and was visited on 25 dates in 1995. Robinson Creek winds for 1.1 km before reaching the North River and a majority of this distance is through salt marsh. A few isolated gravel riffles were found downstream of Water Street. No smelt eggs were found during 1995 monitoring or earlier spring surveys. Tidal influence was not detected at Water Street. Water chemistry was similar to other freshwater drainages in the North River system (Table A.17). Freshwater flows were slightly acidified (mean pH of 6.3) and were relatively cooler than other similar creeks. Four discharge measurements were made in 1995 at the downstream face of the Water Street culvert: the discharges ranged from 0.039 to 0.110 m^3/s with an average of 0.061 m^3/s. As discharge declined later in spring the creek appeared much less likely to support a smelt run. River herring had been reported previously in a side creek to Robinson Creek that leads to Howards Pond (Reback and DiCarlo 1972). No river herring were seen during monitoring visits and no potential smelt spawning habitat was found in the side creek.

North River (main stem). No records of smelt spawning in the main stem North River or upstream of Second Herring Brook were found. There are no impediments to fish passage from the estuary mouth to the Elm Street Dam, yet the width of the main stem and tidal range appear to discourage the development of spawning habitat. A main stem station was selected for monitoring at the historic Stone Arch Bridge on River Street in Hanover. The constriction of the bridge and rubble below appeared to offer some potential for attracting spawning smelt. This bridge is the approximate location of the upstream limit of saltwater intrusion during the summer (Fisk et al. 1966). The average tidal range at the bridge is approximately 0.5 m, compared to 2-3 m at the mouth of the estuary (Bowden et al. 1991). The wetlands upstream of the bridge are tidal freshwater and gradually shift to salt marsh downstream of the bridge.

No smelt eggs were found at the main stem station during one season of monitoring in 1994. During flood tides, flows were reversed at the bridge, effectively eliminating the potential spawning habitat seen at the bridge constriction in the absence of tidal influence. This dynamic limits the likelihood of smelt spawning anywhere on the main stem North River except where the river narrows below the Indian Head Dam. The water chemistry measured at this station was similar to that seen at the tributary stations (Table A.18). Mean pH in the main stem was 6.1 in spring 1994. On May 23rd and May 25th, thousands of river herring were seen milling around at the bridge station. The respiration of large numbers of fish presumably caused the water DO to lower to 5.8 mg/L on May 23rd and 5.2 mg/L on May 25th from 9.0 mg/L on May 19th. On May 31st, the last day of monitoring, an enormous egg set was seen on the substrate below the bridge. This observation indicates river herring spawning does occur at this main stem location.

Indian Head River (main stem). The main stem North River is called Indian Head River upstream of tidal influence. The first dam on the North River/Indian Head River system is the Elm Street Dam, located slightly upstream of Elm Street. A spawning habitat monitoring station was selected in 1995 below the Elm Street Bridge on the Hanover and Pembroke border. There are three major riffles starting at the Elm Street Bridge that could provide smelt spawning habitat. Below these riffles, the river enters tidal freshwater marsh and begins to meander through the marsh with reduced velocity and increased depth. No smelt eggs were found in 1995 at the three riffles below Elm Street. These riffles possessed suitable flow and substrate to attract spawning smelt; however, they are located a long distance from the estuary (>19 km). It is possible that during times of higher smelt abundance this habitat could have been used for spawning. Water chemistry was measured at the USGS gauge station in Hanover. Water chemistry measured at this station was similar to that seen at the tributary stations (Table A.19), although the pH was less acidic (mean = 6.7). Tidal influence was seen routinely reaching the lowest riffle at this station and could neutralize the riffle flow up to the second riffle. No tidal influence was seen reaching the gauge station.

Other Tributaries (surveyed)

Six other tributaries to the North River system were surveyed for potential spawning habitat and egg deposition during the spawning seasons of 1994 and 1995. Five of these were small brooks where no eggs were found and none possessed enough potential habitat to warrant the establishment of a monitoring station. An unnamed brook in Norwell on the north side of North River between Second and Third Herring brooks contained no suitable spawning substrate and minor base flows. Two small brooks in Hanover on the north side of North River contained minimal attraction flows and riffle habitat to attract spawning smelt: the Copeland Tannery Brook, which drains into Third Herring Brook below River Street, and Iron Mine Brook, which flows to Indian Head River below Elm Street. Two brooks in the upper estuary on the south side of North River were surveyed. Two Mile Brook in Pembroke had tidal flows up to Mounce Pond that limited the formation of spawning substrate. Pudding Brook, a tributary to Herring Brook in Pembroke, had passage impeded at Rt. 53 with low flow and swampy conditions below Rt. 53.

Herring River. Herring River in Pembroke had some potential spawning habitat downstream of Rt. 14 (Barker Street). Suitable spawning riffles were found for approximately 100 m below the river herring fishway on Barker Street. Attraction flows diminished as Herring Brook enters winding, freshwater tidal wetlands and travels 3.0 km to join the confluence of North River and Indian Head River. Four visits were made to this location during the 1994 and 1995 spawning seasons and no eggs were found. This location has potential smelt spawning habitat, but the long distance (3 km) from the main stem and location in

Table 3.25 Ichthyoplankton samples collected during 11 sample dates at the Bridge Street Bridge on the North River, Marshfield, 1994-1995. Sizes are average total length for larvae and diameter for eggs. The P-S group (*Paralichthys-Scopthalmus)* is most likely windowpane (*Scopthalmus aquosus*), and the L-L group (*Labridae-Limanda*) group is most likely cunner (*Tautogolabrus adspersus*).

Species		Type	FOC	Period	No.	Size (mm)	Ave. Density (No./100 m^3)
sand lance	*Ammodytes americanus*	larva	9	3/16 - 5/23	288	15.0	22.0
grubby	*Myoxocephalus aenaeus*	larva	6	3/16 - 5/23	61	8.3	4.7
radiated shanny	*Ulvaria subbifurcata*	larva	3	5/12 - 5/23	226	8.2	17.2
rock gunnel	*Pholis gunnellus*	larva	3	3/27 - 4/25	20	18.7	1.5
winter flounder	*Pseudopleuronectes americanus*	larva	3	4/25 - 5/23	56	5.0	4.3
seasnail	*Liparis atlanticus*	larva	2	5/12 - 5/23	16	3.3	1.2
Atlantic cod	*Gadus morhua*	larva	2	3/27 - 4/25	3	20.7	0.2
rainbow smelt	*Osmerus mordax*	larva	1	4/25	4	5.5	0.3
yellowtail flounder	*Limanda ferruginea*	larva	1	5/23	3	2.6	0.2
alligatorfish	*Aspidophoroides monopterygius*	larva	1	4/25	1	11.0	0.1
silver hake	*Merluccius bilinearis*	larva	1	4/8	1	9.1	0.1
white sucker	*Catostomus commersoni*	larva	1	5/23	1	10.0	0.1
L-L group	*Labridae-Limanda*	egg	2	4/25 - 5/12	8	0.9	0.6
American plaice	*Hippoglossoides platessoides*	egg	1	5/23	1	2.3	0.1
P-S group	*Paralichthys-Scopthalmus*	egg	1	5/12	1	1.1	0.1

the upper estuary reduces the likelihood of detection by spawning adult smelt. For this reason, it was not selected as a monitoring station.

Ichthyoplankton

Ichthyoplankton collections were made at the Bridge Street bridge on the Norwell and Marshfield border on 12 occasions during 1994 and 1995. Bridge Street is located 7 km from the mouth of the estuary and less than 2 km downstream from the Second Herring Brook confluence. The ichthyoplankton net was set early in the ebb tide because the current became too strong for the net as the outgoing tide progressed. Water depth at the downstream face of the bridge fluctuated much with tide and discharge changes (measured range of 3.5 to 7.5 m). Salinity also ranged widely at this point in the estuary. Surface salinity at low tide was often 0‰, and less than 5‰ for bottom measurements (Table A.20). Stratification was often evident near high tide, but the values fluctuated widely between 4–28‰ within an hour of high tide.

The ichthyoplankton catch at Bridge Street was the most diverse among all ichthyoplankton stations in this study, as 15 species were represented (Table 3.25). Relatively large numbers of fish larvae were caught in the density gradients that occur when the tide reverses current direction. Many of these samples contained a rich mix of fish larvae and high densities of zooplankton. Despite the high catches of larvae, smelt larvae were only caught once, as four yolk-sac larvae were caught on April 25th, 1994 (Appendix, Table B.1). Sand lance were caught most frequently (9 sets) and abundantly (22.0 per 100 m^3). Four species of flounder (winter, yellowtail, American plaice and windowpane) were caught at this location in the North River estuary.

DISCUSSION

Three tributaries of the North River were found to support smelt spawning during 1994-1995. Smelt do not appear to be spawning in the main stem North River. This is mostly because the reversal of tidal flow eliminates the potential for spawning riffles to form. The long distance from the estuary past the tidal interface makes this a difficult journey for adult smelt. There is some potential for main stem spawning to occur; below the Indian Head Dam (19.5 km from mouth) and at the Stone Arch Bridge (18.1 km from mouth). The constriction of the Stone Arch Bridge appears at low tide to be a likely candidate and is located only 2 km upstream the confluence with Third Herring Brook. However, no smelt eggs were found there in 1994, and reversed tidal flows reduced the attraction for spawning smelt. In earlier times of higher smelt abundance it is possible that main stem spawning occurred, although there are no locations on the Gulf of Maine coast of Massachusetts where smelt travel such distances to reach spawning habitat.

First Herring Brook. The smelt egg deposition observed in First Herring Brook was well below densities expected for a thriving population using the available spawning habitat. There is not a large amount of available spawning habitat in First Herring Brook, but the primary spawning riffle below the County Way culvert has very good physical features to support high densities of eggs for 50-75 m. There are several apparent stressors that could be negatively affecting spawning habitat and recruitment. Freshwater flows in First Herring Brook are tightly managed by the Town of Scituate. Typically, no flow spills out of Old Oaken Bucket Pond during July and August, and outflows in May and June will decline sharply with low precipitation (Gene Babin, Town of Scituate, *pers. comm.*). During 1994, low discharge was clearly impacting smelt spawning habitat and by the end of May there was nearly no flow coming over the dam. In that year, the growth of periphyton increased sharply by mid-April and by early May was a threat to smelt egg survival. The growth of periphyton was not as noticeable and delayed until May in 1993. The growth of algae is presumed to be a symptom of eutrophication and is probably exacerbated by flow manipulations that reduce spring discharge.

Lastly, low pH is a serious concern for First Herring Brook. Measurements were made each March at levels (5.5-5.6) that threaten smelt egg survival. The combination of low flows, eutrophication and water acidity maybe having a chronic effect on recruitment. Several site-specific conditions were also observed that if altered may improve the overall quality of the smelt spawning habitat. The invasive Japanese knotweed (*Polygonum cuspidatum*) was beginning to take over the riparian buffer along the south side of the First Herring Brook below County Way during 1993/1994. During recent visits, knotweed has been observed to have completely taken over this buffer. Across from the knotweed patch, a property was recently landscaped without leaving a suitable vegetated buffer to the brook. Both these riparian buffers could be improved with local restoration projects. The channel running under the Old Stockbridge Grist Mill can receive flows from Old Oaken Bucket Pond at the discretion of the Town of Scituate. This channel has poor water quality due to stagnation and received unknown flows from three small pipes coming out of the bank. The discharge from this channel flows directly to a primary smelt spawning riffle.

Second Herring Brook. A viable spawning run of smelt was found at Second Herring Brook in 1994 and 1995. The egg deposition observed during these seasons greatly exceeded that seen at other spawning locations in the North River system. This spawning habitat benefits from excellent shading and riparian buffer. Geographically, the brook is favorably located about mid-estuary and the spawning habitat is very close to the confluence with the North River. The egg deposition observed in 1994 was impressive and much higher than the following year. A similar trend was seen with far more river herring present in May 1994 than in 1995.

Despite the encouraging signs, the spawning habitat at Second Herring Brook was exposed to serious declines in discharge and water depth and also threatened with acidification. The three widely-spaced outlets at the dam at Gordon Pond cause the flows over the spawning habitat to spread widely over a poorly defined channel. A braided channel has developed over time and is now overgrown with trees and small earthen islands. When flows are high, much of the habitat below the dam is covered with water and will attract spawning smelt. As the season progresses flows can quickly drop resulting in desiccated eggs. This was observed in late April in 1994, and a major egg mortality event occurred on April 29th as many riffles in the braided channel became exposed. The declining flow occurred much earlier in 1995. Rapidly declining flows were noted during the first week of April and a modest egg mortality event occurred on April 7th. This is one of a few spawning habitats seen in this study where low water depth resulted in adult smelt mortality. Spawning smelt were observed stranded in braided channels with only a few centimeters of depth. The lower flows also corresponded with substrate degradation from increased growth of periphyton. There is potential to reconstruct portions of this habitat to improve the channel for spawning smelt and egg survival. Lastly, low pH is a serious concern for Second Herring Brook. The mean pH for spring 1994 was 5.8 and measurements were made in March 1994 (5.2-5.5) at levels that could reduce smelt egg survival.

Third Herring Brook. The spawning habitat in Third Herring Brook could be a textbook example of suitable smelt spawning habitat. With excellent gravel substrate, riparian buffer, canopy and no physical alterations, the stream channel is the most natural found among smelt runs in the study area. Very few rivers monitored for this study showed so little evidence of eutrophication. Including potential spawning habitat where no eggs were found, there is over a half kilometer of brook length and 3,000 m^2 of spawning substrate. This high quality habitat could support a much larger population than found by evidence of egg deposition in 1994 and 1995.

As a newly discovered spawning habitat, there is no previous information to compare with present conditions. The seclusion of this spawning run is part of the reason it escaped earlier detection. It is also possible that the brook did not previously support large numbers of smelt. It is likely that the distance of the brook from the mouth of the estuary acts as a natural limitation for this species. The brook is located 16.5 km from the mouth of the estuary, which is the farthest inland excursion of smelt in the study area. Secondly, the upper limit of the salt wedge during the spring is several kilometers downstream of Third Herring Brook's confluence with the North River. Attraction flows from Third Herring Brook may not provide a strong signal in the main stem freshwater flows. It is possible that smelt spawning in Third Herring Brook do not represent a discrete spawning stock of smelt, but belong to a North River stock that will use available spawning habitat upon detection. Under this scenario, the downstream tributaries would receive most spawning activity and Third Herring Brook spawning numbers would increase and fall with the size of spawning runs lower in the estuary. Another important consideration for the status of smelt in Third Herring Brook is water acidity. The mean pH of Third Herring Brook ranked among the lowest of all smelt runs in the study area. In the course of the spawning season, especially in March, pH levels occurred in a range that can increase smelt egg mortality. The DEP 2001 assessment of Third Herring Brook also found low pH (5.7-6.3 range) although considered the low pH a naturally occurring influence of groundwater resulting in an assessment of "support" for Aquatic Life based on water chemistry (MDEP 2006).

Third Herring Brook also provided interesting observations of reduced egg survival on clean gravel substrate versus eggs attached to aquatic moss growing in the same riffle. This condition has been routinely observed at other rivers, but often the gravel is fouled by periphyton. With remarkably little periphyton in Third Herring Brook, there must be other factors influencing the lower egg survival than seen on nearby moss. It is possible that the influence of scouring is higher on the clean gravel than on buoyant moss. Finally, Third Herring Brook is one of the few smelt runs on the Gulf of Maine coast where temporal overlap was found in spawning habitat use by several diadromous species. River herring eggs were found and lamprey were observed building a nest in May during both seasons in the same spawning riffles that contained late-stage smelt eggs.

RECOMMENDATIONS

Study of Three Tributaries

1. Watershed and Water Quality Analysis. The three tributaries that support smelt spawning in the North River offer contrasting conditions of water quality, habitat quality and status of smelt runs. The smelt runs are threatened by varying degrees of acidification, water supply management, eutrophication, and stormwater inputs. An investigation of these factors influencing the varied conditions among the three tributaries might produce insight on threats to anadromous fish spawning habitat and specific restoration options for the North River system.

First Herring Brook

1. Vegetative plantings. Japanese knotweed was colonizing the south bank of the First Herring Brook adjacent to the prime spawning riffle during the monitoring period. Presently, that bank is engulfed with the knotweed. It is recommended that consideration be given to removing the knotweed and planting more suitable vegetation for riparian buffering and shading. Also on the opposite bank to the knotweed patch, the buffer on a private property has been recently reduced. This bank should also be reviewed to evaluate the potential for improving the riparian buffer and shading.

2. Old Stockbridge Grist Mill channel. The channel running under the Old Stockbridge Grist Mill can receive flows from Old Oaken Bucket Pond at the discretion of the Town of Scituate. The channel empties directly to smelt spawning habitat less than 50 m downstream. Three additional pipes flow into this channel from adjacent properties. These pipes were observed flowing during dry weather in 1993/1994 and are active presently. The origin and composition of the flows are not known, however, the water quality of this channel appears compromised by discoloration and nutrient enrichment. It is recommended that local authorities investigate the potential that these discharges are negative influences on the water quality of First Herring Brook.

3. Town Management of Discharge. It is likely that the Town of Scituate's management practices for water withdrawal from First Herring Brook are having a negative influence on anadromous fish populations. It is recommended that local authorities review these management practices to evaluate the potential for keeping minimum flows in the brook during critical periods for anadromous fish. It is possible that minimal flows can be seasonally maintained without imposing on town water use.

Second Herring Brook

1. Triple Pipe Culvert Replacement. The three corrugated pipe culverts that serve a bridge leading to a private residence do not present a passage impediment under all but the lowest flows. The highest densities of smelt egg deposition are often found at the downstream opening of the culverts. It is recommended that an evaluation be conducted on replacing the three pipe culverts with a box culvert with natural substrate. A properly designed box culvert could eliminate low flow passage constraints, better distribute egg deposition, and create new spawning substrate inside the culvert.

2. Gordon Pond Dam. The dam at Gordon Pond has three spillways that distribute outflows to Second Herring Brook over a much wider width than would occur naturally. This condition has led to braided channels and very shallow depths in some locations. These features can result in high egg mortality as flows decline following egg deposition. It is recommended that an evaluation be made on altering the Gordon Pond Dam in order to consolidate flows to improve smelt spawning habitat and allow river herring passage. The options could range from dam removal to the installation of a fishway at a single outlet.

3. Channel Improvements below Gordon Pond. In the event that recommendation #2 proves unfeasible, some benefits could be gained for the smelt spawning habitat by simply grooming the cobble and boulders in the braided channel to steer spawning smelt to the deeper channels. It is recommended that this work be done either concurrently with recommendation #2 or independently as a second option.

4. Water Chemistry Analysis. Additional information on acidification in Second Herring Brook would be useful to determine if remediation options exist. Further sampling is recommended on the relationship of brook pH to precipitation and groundwater, followed by consideration on options for correcting the low pH problem.

Third Herring Brook

1. Water Chemistry Analysis. The same recommendation for Second Herring Brook should be applied to concerns over acidification in Third Herring Brook.

2. Riparian Buffer. Despite the excellent riparian buffer conditions observed in 1994 and 1995, follow-up visits in more recent years have observed increasing watershed development near the west bank of the brook coming from property development off Columbia Road. Because of the unique value of this habitat for diadromous fish, freshwater fish and other aquatic organisms it is recommended that authorities in Hanover consider this habitat as they review surrounding land developments.

Cove Brook

1. Smelt Population Restoration. Cove Brook was found to have a suitable stretch of gravel and cobble riffle that could serve as smelt spawning habitat. No smelt eggs were found during the monitoring. The brook is located favorably on the south side of the North River near mid-estuary upstream of Second Herring Brook. It is possible that during times of higher smelt population abundance that smelt used this habitat for spawning. Among all surveyed and monitored drainages in the South Coastal Basin where no smelt eggs were found, Cove Brook appears to have the highest potential to support a smelt run. If smelt population enhancement techniques can be successfully developed and suitable donor smelt runs are available, it is recommended that Cove Brook be considered a candidate location for smelt population enhancement.

SATUIT BROOK

STUDY AREA

Satuit Brook is located in the South Shore Coastal Drainage Area (Halliwell et al. 1982) in the town of Scituate. This small coastal creek flows for approximately 4 km from wetlands in Scituate to discharge into Scituate Harbor. No estimate of drainage area was found. Wandle and Morgan (1984) computed drainage areas only for South Shore streams that drained at least 7.8 km^2. No ponds or lakes contribute flows to Satuit Brook and no stream flow gauge stations are located on the brook. Despite its small size, Satuit Brook will be reported separately from Bound Brook to the north and North River to the south because it represents a distinct drainage and discreet smelt run. No previous references on smelt in Satuit Brook were found. A modest recreational smelt fishery has long occurred in Scituate Harbor from docks and piers in the fall and early winter, and locally, Satuit Brook was known as a smelt run. Satuit Brook was surveyed in 1992 and a single spawning habitat monitoring station was selected at the driveway crossing of Satuit Brook at the Scituate Senior Center off First Parish Road. Moving upstream from Scituate Harbor, Satuit Brook is first crossed by Front Street near the harbor and passes through a narrow salt marsh before meeting the second crossing at the Senior Center. No other tributaries contribute to the Satuit Brook drainage.

RESULTS

Spawning Habitat

Smelt eggs were found in Satuit Brook in 1993 and 1994 along a short stretch of habitat that started in the salt marsh upstream of Front Street and ended slightly upstream of the driveway to the Scituate Senior Center off First Parish Road. The length of the spawning habitat was only 55 m and the substrate area where eggs were found was 80 m^2. The average width of the brook along this stretch was 1.5 m. Most eggs were found on the downstream side of the culvert where 35 m of suitable spawning riffle is located. This reach receives tidal influence with each flood tide. Downstream of the lower limit of observed egg deposition there was about 20 m of potential spawning habitat, however, it is likely that tidal influence obscures the attraction of freshwater flows. Few eggs were found upstream of the driveway, and the upper limit of observed egg deposition was only 10 m beyond the culvert. Beyond this point riffles were absent as the brook widened causing water velocity to decrease.

Table 3.26 Smelt spawning period in Satuit Brook, Scituate, 1993-1994. The spawning period is an estimation based on observations of viable smelt eggs.

			Water Temperature (°C)			
Year	**Spawning Period**	**Days**	**Start**	**End**	**Range**	**Mean**
1993	April 18th - May 5th	18	11.5	17.2	7.5 - 18.6	12.1
1994	April 17th - May 8th	22	12.4	12.4	9.2 - 15.0	11.7

Table 3.27 Water chemistry and weather summary for Satuit Brook spawning habitat station, 1993-1994. Data are averages (Tables A.21-A.22) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Plymouth-Kingston station (NOAA 1993 and 1994).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1993								
March	8	1.9	22.6	2.3	0.0	6.5	11.9	0.342
April	8	8.1	15.3	9.2	0.0	6.6	10.1	0.268
May	6	14.7	3.4	15.8	0.0	7.0	10.0	0.324
Season	22	8.2	41.3	8.5	0.0	6.7	10.6	0.307
1994								
March	9	3.6	24.1	4.0	0.0	6.4	11.7	0.415
April	8	10.4	4.9	10.3	0.0	6.8	10.9	0.394
May	8	13.4	11.2	14.1	0.0	6.7	9.5	0.395
Season	25	9.1	40.2	9.2	0.0	6.6	10.7	0.401

Spawning Period. Smelt egg deposition was easily detected in the narrow, short stretch of riffle habitat in Satuit Brook allowing the determination of spawning period in 1993 and 1994 (Table 3.26). In both seasons, the spawning season was unusually late starting and of short duration. Smelt eggs were not found until after mid-April in both years and were present for only about three weeks. In 1993, very few individual smelt eggs were found. Several dozen smelt eggs were found at the start of the season. Smelt eggs from the initial spawning event were seen for about a week, and consequently, less than 10 eggs were found in early May. These observations imply that a very small number of adult smelt were involved in a spawning run that consisted of only a few nights of spawning. The spawning period in 1994 was nearly the same as 1993, although the amount of egg deposition increased. Once again, the season began with a mid-April spawning event and a second spawning event occurred in early May. These observations place Satuit Brook as one of the latest-starting and shortest duration smelt runs on the Gulf of Maine coast of Massachusetts.

Water Chemistry

Water chemistry was measured at the downstream face of the culvert under the driveway to the Scituate Senior Center. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 3.27, A.21-A.22). March air and water temperatures were notably cooler in 1993 than 1994 but no effect was seen on the onset of smelt spawning. Dissolved oxygen was at or near saturation for all measurements. Water pH was slightly acidic for most measurements. Tidal influence would cause freshwater flows to backup at the culvert sampling station during high tide although salinity was not detected during any visits.

Stream flow Discharge Measurements

Six discharge measurements were made at Satuit Brook 1993 and 1994 (Table 3.28). All measurements were made at the water chemistry station at the downstream face of the driveway culvert. Average water depths at the transect ranged from 0.28 to 0.41 meters. Water velocity ranged from 0.133 to 0.423 m/s. Discharge measurements ranged from 0.064 to 0.304 m^3/s (2.3 to 10.7 cfs). The spawning substrate was covered with adequate water depth during all measurements, even when discharge was very low. This is because the narrow brook channel maintained water depth at lower flows. The water velocity did decline to levels that provided poor attraction for spawning adult smelt at the lower discharges.

Other Diadromous Species (No others observed)

DISCUSSION

The smelt spawning habitat at Satuit Brook was adequately monitored during 1993 and 1994, and the spawning period was well-defined in both seasons. The small amount of spawning substrate allowed the monitoring to characterize this brook as a late-starting spawning run with low numbers of participants. The numbers of smelt eggs observed and limited habitat result in the ranking of Satuit Brook as one of the smallest smelt runs in the study area. Without previous references on smelt in Satuit Brook it is difficult to discuss population trends for this run. Anecdotally, smelt are reported to be presently caught in a Scituate Harbor smelt fishery that produced higher effort and catch several decades ago. The Satuit Brook smelt run may fall in the category of a small, coastal creek that depends on regional recruitment trends. These creeks can experience pulses of spawning adults that originated from strong cohorts in nearby smelt runs and otherwise produce barely detectable spawning runs from their own production. The potential of Satuit Brook to have had spawning production similar to nearby smelt runs (Bound Brook or First Herring Brook) is low. The brook upstream of the driveway culvert has only a small amount of spawning substrate (<20 m) that was not used in 1993/1994 and may have previously received more egg deposition. The brook widens upstream of the culvert and quickly loses riffle habitat and suitable water velocity.

RECOMMENDATIONS

No specific recommendations are currently made for the Satuit Brook smelt run. No water quality or passage problems were identified during the monitoring. The brook should be recognized as a smelt run by local authorities and receive protection from alterations.

Table 3.28 Stream discharge measurements made in Satuit Brook, Scituate, 1993-1994. Rainfall data are five day total precipitation at Plymouth-Kingston station (NOAA 1993 and 1994).

	Width (m)	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Rainfall (cm)	Habitat Coverage
4/16/1993	1.75	0.37	0.368	0.238	2.95	good flow and depth
5/11/1993	1.75	0.28	0.139	0.068	0.10	adequate coverage
3/14/1994	1.75	0.41	0.423	0.304	NA	good flow and depth
4/6/1994	1.63	0.32	0.195	0.102	0.64	adequate coverage
4/25/1994	1.65	0.29	0.133	0.064	0.05	adequate coverage
5/19/1994	1.64	0.35	0.266	0.153	4.09	adequate coverage

BOUND BROOK

STUDY AREA

Bound Brook is located in the South Shore Coastal Drainage Area (Halliwell et al. 1982) primarily in Cohasset and Scituate. Bound Brook is formed at the confluence of Aaron River and Herring Brook in Cohasset. These rivers receive flows from Aaron River Reservoir and Lily Pond which are both water supplies for the Town of Cohasset. Bound Brook runs through Hunters Pond before reaching the tidal waters of The Gulf which is a tidal tributary to Cohasset Harbor. The drainage area of Bound Brook above Hunters Pond Dam is approximately 29 km^2 (Wandle and Morgan 1984). No stream flow discharge stations are located on Bound Brook. A USGS stream flow gauge operated on the Aaron River (drainage area 12.6 km^2) during 1970-1971. Spring flows were only recorded in 1971 during which April had a daily mean flow of 11.9 cfs.

No previous references on smelt in Bound Brook were found. Alewives were known to pass a fishway at Hunters Pond Dam at the time of Reback and DiCarlo's survey (1972) although passage to their historical spawning location at Lily Pond was uncertain then and not likely earlier in the 20th century (Belding 1921). Bound Brook and five other freshwater creeks associated with Cohasset Harbor were surveyed in 1993. A smelt spawning habitat monitoring station was selected in Bound Brook downstream of the Hunters Pond Dam and was monitored during 1993 and 1994. A monitoring station was also established in 1993 at James Brook, which flows to Cohasset Cove near the confluence of The Gulf and Cohasset Harbor.

RESULTS

Spawning Habitat

Smelt eggs were readily found in the tidal zone below Hunters Pond Dam during 1993 and 1994. Smelt egg deposition reached the face of the dam and extended downstream for 166 m to the salt marsh where the brook widens and water velocity slows. Smelt eggs were found over a total substrate area of 912 m^2. A former mill located along Hunters Pond Dam contains a side spillway that also discharges flows from Hunters Pond. The stream channel from this spillway meets the main stem channel about 65 m below Hunters Pond Dam. Smelt eggs were found in the mill channel both seasons. The highest densities of eggs were found just upstream of the confluence of the two channels near the upper limit of tidal influence where high quality gravel and cobble riffles are enhanced with abundant growth of aquatic moss.

Spawning Period. The start of the spawning period in 1993 was not delineated, in part due to low egg deposition and the lack of previous knowledge on the spawning habitat in Bound Brook. Smelt eggs were not found in Bound Brook until April 13th in 1993. March air and water temperatures were colder in 1993 than 1994. It is likely that spawning began before April 13th, although extensive searches during previous visits found no eggs. The spawning period was well defined in 1994: occurring from March 19th until May 28th (Table 3.29). Most spawning occurred in April including several prominent egg deposition events, followed by sporadic and light spawning during the first half of May. Eggs from late-season spawning events (4/30/93 and 5/11/94) were collected, hatched, and identified as smelt to confirm they were not river herring. Low numbers of eyed eggs were found until late-May. Two episodes of higher than typical egg mortality were observed without certain indication of the cause in early-May 1993 and early-April 1994.

Water Chemistry

Water chemistry was measured 70 m downstream of the Hunters Pond Dam at a riffle that received routine egg deposition during both seasons. For the parameters measured, water quality conditions were adequate to support aquatic life, with the exception of routine violations of pH WQS (Table 3.30, A.23-A.24). March was notably cooler in 1993 than 1994 and may have delayed the onset of the spawning period. Dissolved oxygen was at or near saturation for all measurements. Specific conductivity was very low (mean = 0.16 mmho/cm) in 1993 and for unexplained reasons routinely higher in 1994 (mean = 0.25 mmho/cm). Water pH was chronically lower than most other smelt runs observed during this study and a concern for egg survival. All individual pH measurements (N = 43) were below the WQS for supporting aquatic life (6.5). The annual means for both seasons were below 6.0, and six individual measurements were below 5.5, a level of acidity found to cause increasing smelt egg mortality (Geffen 1990). Tidal influence was observed during each flood tide at the water chemistry station. The water flow would typically rise less than a half meter with the backing up of freshwater. On two occasions during 1993 coinciding with higher than average tidal amplitudes, low salinity (2-4 ppt) surface water was detected at this station (Table A.23).

Stream flow Discharge Measurements

Six discharge measurements were made at Bound Brook 1993 and 1994 (Table 3.31). All measurements were made at the water chemistry station when no tidal influence was present. Water depths across the riffle ranged from 0.25 to 0.37 m. Water velocity ranged from 0.357 to 0.750 m/s, all suitable to attract spawning adult smelt. Discharge measurements ranged from 0.311 to 1.388 m^3/s (11 to 49 cfs). Small amounts of spawning substrate were exposed in shallow riffle locations at the lowest observed discharges. Minor smelt egg mortality on exposed substrate was related to both gradually declining discharge during incubation and near-bank spawning at higher tides.

Table 3.29 Smelt spawning period in Bound Brook, Cohasset, 1993-1994.
The spawning period is an estimation based on observations of viable smelt eggs.

			Water Temperature (°C)			
Year	**Spawning Period**	**Days**	**Start**	**End**	**Range**	**Mean**
1993	(not delineated) - May 16th			15.1		
1994	March 19th - May 28th	71	3.0	18.4	2.4 - 20.6	11.2

Table 3.30 Water chemistry and weather summary for Bound Brook spawning habitat station, 1993-1994.
Data are averages (Tables A.23-A.24) except station visits and NOAA rainfall are total values. Chemistry data from 3/8/93 and 5/6/93 are excluded because of the presence of the salt wedge during high tide.
Air temperature and rainfall data were recorded at Logan Airport, Boston (NOAA 1993 and 1994).

Sample Period	**Station Visits** (No.)	**NOAA Air Temp.** (°C)	**NOAA Rainfall** (cm)	**Water Temp.** (°C)	**Water Salinity** (ppt)	**Water pH**	**Water D.O.** (mg/l)	**Water Sp. Cond.** (mmho/cm)
1993								
March	8	2.4	19.5	2.3	0.0	5.8	13.3	0.145
April	8	9.1	12.3	9.0	0.0	5.8	11.6	0.161
May	6	15.7	2.6	16.5	0.0	6.1	9.0	0.159
Season	22	9.1	34.4	8.6	0.0	5.8	11.4	0.155
1994								
March	9	3.4	19.0	3.5	0.0	5.5	13.2	0.227
April	8	10.8	5.7	11.1	0.0	5.8	10.5	0.244
May	8	14.7	13.6	15.0	0.0	5.8	9.4	0.269
Season	25	9.6	38.3	9.6	0.0	5.7	11.0	0.246

Table 3.31 Stream discharge measurements made in Bound Brook, Cohasset, 1993-1994.
Measurements were made at a transect 70 m downstream of Hunters Pond Dam. Rainfall are five day total precipitation at Logan Airport, Boston (NOAA 1993 and 1994).

Date	**Width** (m)	**Depth** Ave. (m)	**Velocity** Ave. m/sec	**Discharge** (m^3/sec)	**Rainfall** (cm)	**Habitat Coverage**
5/11/1993	3.8	0.29	0.444	0.489	0.20	minor exposure
5/28/1993	3.0	0.29	0.357	0.311	0.05	exposed substrate
3/21/1994	5.0	0.37	0.750	1.388	1.32	high flow and depth
4/8/1994	4.1	0.31	0.547	0.695	0.91	adequate coverage
4/25/1994	4.0	0.25	0.431	0.431	0.05	minor exposure
5/19/1994	4.0	0.32	0.551	0.705	3.94	adequate coverage

Other Diadromous Species

Local anecdotes were heard of the presence of a small river herring run, but none were observed during the 1993 and 1994 monitoring seasons. Large numbers of glass eels were seen during April in both seasons. The observations of glass eels relative to other river systems in this study indicate that Bound Brook may be a productive river system for eel. The first glass eel observed in 1993 was on April 1st, and on March 21st in 1994: one of the earlier observations of glass eel presence at the tidal interface in a Massachusetts Bay river during the study period.

James Brook

A spawning habitat and water chemistry station in James Brook was monitored in 1993 approximately 10 m downstream of Main Street, Cohasset, where upstream flows pass through an underground culvert. No smelt eggs were found during the 1993 season and no further monitoring was conducted because of the minimal amount of potential spawning habitat present. Before the brook goes underground, there was about 20-30 meters of marginal spawning riffles, degraded from sedimentation. Water chemistry was typical for South Coastal Basin creeks and supportive of aquatic life (A.25). Tidal influence reached this location during the highest tidal amplitudes, but no salt was detected. Elver American eels were observed at the station during several May visits.

Other Surveyed Tributaries

Four tributaries to Cohasset Harbor and the adjacent coast of Cohasset were surveyed in 1993. None of these possessed suitable characteristics of flow, passage and substrate to warrant monitoring for the spawning season. Each was checked at least twice during the spawning season and no smelt eggs were found. Richardson Brook flowing into Cohasset's Little Harbor has minor freshwater base flow and little suitable substrate. A second, unnamed creek flows into Little Harbor south of Richardson Brook contains mostly tidal flows and has little suitable substrate. An unnamed creek joins The Gulf slightly north of Bound Brook has potentially suitable spawning substrate but minor freshwater base flow and boulder passage impediments near the tidal zone. Furthest to the south, an unnamed creek that flows into Musquashcut Brook (tidal) under Hollett Street in North Scituate was tidally dominated and overgrown with reeds (*Phragmites*).

DISCUSSION

There is little anecdotal information available to compare the present status of the Bound Brook smelt run or smelt fishing in Cohasset Harbor. The smelt run was easily detected during 1993 and 1994 and low levels of catch and effort were reported for that period in a fall Cohasset Harbor smelt fishery. The peak of the spawning run in 1994 had much higher egg densities than seen in 1993 and the total egg deposition in 1994 was relatively high for the amount of available spawning habitat. The size of the Bound Brook spawning habitat is small and limited downstream by the tidal zone and upstream by Hunters Pond Dam. The prime spawning riffles were in good condition due to swift water velocity, clean cobble and the presence of aquatic moss. Higher densities of eggs were routinely observed attached to the moss as opposed to the gravel and cobble substrate. The spawning substrate in Bound Brook did not appear highly susceptible to the eutrophication impacts seen commonly throughout Massachusetts Bay.

Higher than expected egg mortality were observed during both seasons following specific spawning events. Because most egg deposition was limited to about a 50 m stretch of the spawning habitat, it was possible to monitoring the progress of individual spawning events. The highest rate of egg mortality occurred within days after the spawning event. In all cases, the numbers of surviving egg declined sharply, but some eggs survived to the last eyed stages before hatching. The cause of the egg mortality is not known, although the following three sources could be an influence: low pH, tidal dynamics, and declining brook discharge. The exposure of eggs to air from tidal dynamics and declining flows typically only effects eggs deposited at the shallowest depths. These influences on water depth certainly resulted in some egg mortality during the season. Much of this is related to the location of the Hunters Pond Dam relative to the interface of fresh and salt water. However, during several events, most notable on April 6, 1994 when thousands of eggs died quickly across the entire stream bed, mortality was not restricted to shallow depths (pH was 5.8 on the 6th and 5.5 the previous visit). These observations and low pH measurements raise concerns over the affect of acidification on smelt egg survival. The average and range of Bound Brook pH measurements were among the lowest observed for an active smelt run in the study area.

RECOMMENDATIONS

1. Bound Brook Water pH. The low pH found in Bound Brook is a threat to smelt egg survival. It is recommended that this condition be reviewed in greater detail in order to understand the causes of low pH and identify possible remedial options.

2. Bound Brook Discharge Measurements. Fluctuations in water depth appear to be contributing to elevated smelt egg mortality observed in Bound Brook. Part of the problem is the location of Hunters Pond Dam in relation to tidal influence. A stream flow gauge on Bound Brook would allow an evaluation of the influence of municipal water management on habitat changes. Because of the relatively small size of Bound Brook and high cost of gauge stations, this location may be a suitable candidate for a volunteer stream flow project that monitors a staff gauge on a seasonal basis. It is recommended that a stream flow gauge station be established in Bound Brook, and the available data evaluated in relation to the habitat requirements of smelt and other diadromous species.

3. Hunters Pond Dam. Hunters Pond Dam is a major influence on smelt spawning habitat in Bound Brook as the upstream boundary of spawning habitat and because of its proximity to the tidal zone. The removal of this dam could provide a substantial opportunity for increasing the amount of smelt spawning habitat and improve river herring passage. It is recommended that this restoration option for Bound Brook be evaluated.

4. Shading along Bound Brook Spawning Habitat. Since the monitoring was conducted in 1993 and 1994, a former mill property abutting the spawning habitat was converted to condominiums. The riparian zone directly along the spawning habitat has little vegetation to provide shading over the brook substrate. It is recommended that shading be enhanced along this stretch by planting appropriate vegetation.

Smelt spawning habitat in Bound Brook near tidal interface. B. Chase

CHAPTER 4. BOSTON HARBOR REGION

The Boston Harbor region included all coastal streams found within the embayments enclosed between Hull and Deer Island, Winthrop. A total of 35 specific locations were surveyed within the following river systems: Weir River, Town Brook (Hingham), Back River, Fore River, Town Brook (Quincy), Furnace Brook, Neponset River, Charles River, and Mystic River. From these surveyed locations, 14 stations were monitored as potential smelt spawning habitats between 1988 and 1993. Smelt spawning habitat was identified at 15 locations within the nine river systems (Figure 4.1 and Table 4.1).

The Fore, Charles and Neponset river systems contained the largest amount of available spawning habitat. The Back River was ranked 4th in spawning habitat size, although had less than half that found in the larger three rivers. Nine of the locations were small streams with low discharge (<0.5 m^3/s, April mean); some of which were found to contain very low densities of smelt eggs. The Weir River, Back River, Fore River and Mystic River had moderate spring discharges in the range of 1-2 m^3/s. Only the Charles River and Neponset River had large discharges (both about 17.5 m^3/s, April mean). In terms of qualitative observations of egg deposition, the Fore, Neponset and Back rivers contained the largest smelt spawning runs, not only in the region but for the entire study area. These three rivers are also associated with viable sportfisheries for smelt that occurred primarily in the fall. During the study period, the greatest amount of catch and effort on the Gulf of Maine coast in Massachusetts occurred within the Boston Harbor region.

The average starting date of the smelt spawning period in the Boston Harbor region was March 18th and the average ending date was May 22nd. The peak of the spawning period varied annually, but typically occurred between the third week of March and third week of April. The average duration of the spawning period was 69 days and the average starting water temperature was 4.4 °C. For all rivers combined, the total range of dates when smelt eggs was observed was March 3rd to May 27th.

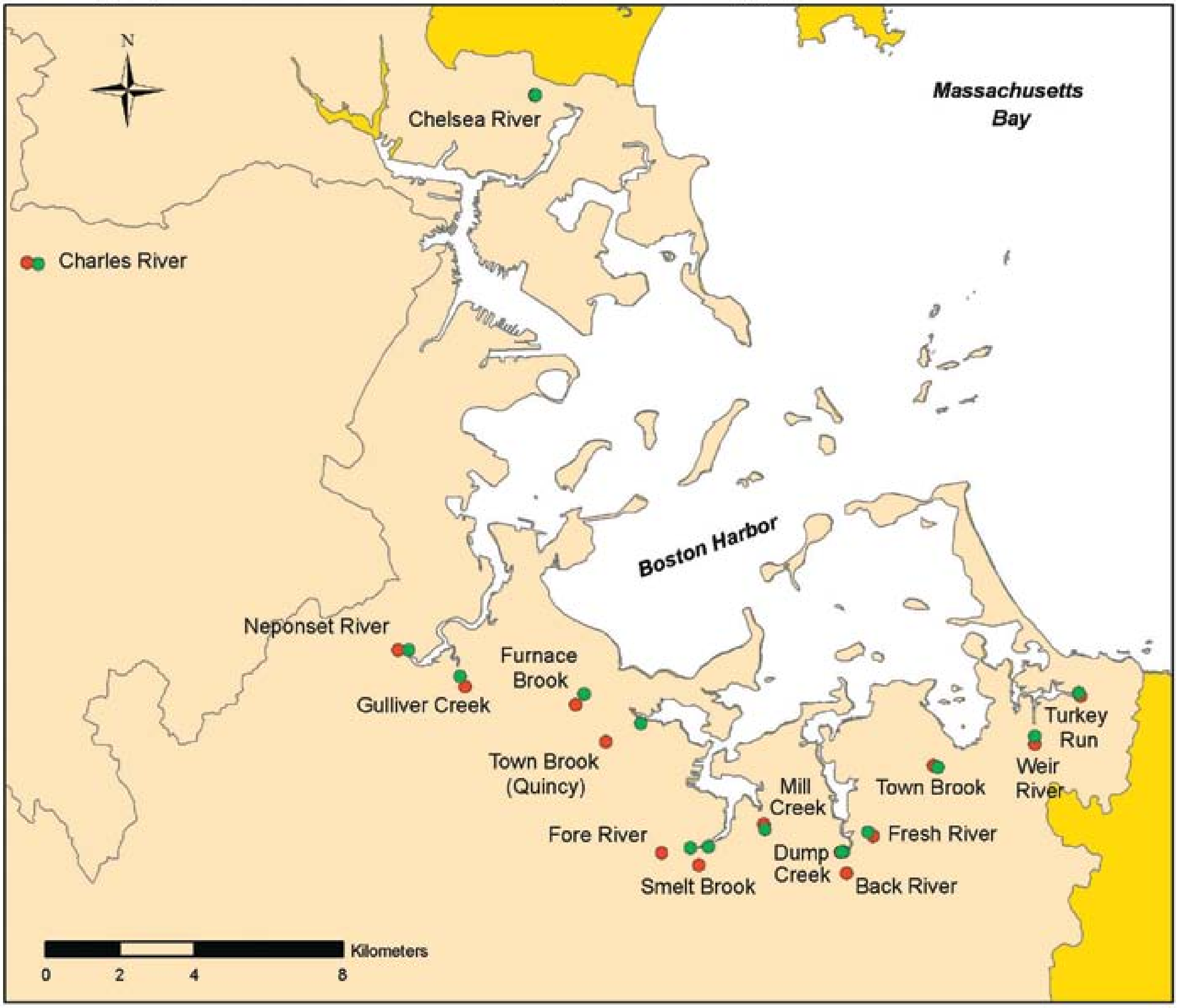
Water chemistry was monitored at all smelt spawning habitat stations and 10 additional locations, of which five were estuarine ichthyoplankton stations. The water chemistry sampled at the spawning habitat stations was adequate to support aquatic life considering the parameters measured. Dissolved oxygen was near saturation for most measurements during the spring spawning period. Water pH in this region appeared to be better buffered than other regions; ranging from slightly acidic to slightly alkaline in the nine river systems.

Ichthyoplankton collections were made at five sampling stations to record the downstream movement of smelt larvae. A total of 14 fish species were represented in 46 samples collected in the Weir River, Fore River, Town Brook (Quincy), Furnace Brook, and Neponset River. Smelt larvae were found at all sample stations and occurred at the highest frequency and density among fish species. Smelt larvae were caught within the period of April 14th to May 26th, with the highest densities (3.7-10.7 larvae/m^3) recorded in April. Atlantic tomcod was caught at the second highest frequency of occurrence, during the period of March 15th to April 19th.

Table 4.1 Smelt spawning habitat locations in the Boston Harbor region. The reported positions are the downstream and upstream limits of observed egg deposition recorded with a Garmin GPSmap 76.

Name	River System	Town	Downstream Latitude	Downstream Longitude	Upstream Latitude	Upstream Longitude	Length (m)	Area (m^2)
Mill Creek	Chelsea	Chelsea	42° 24.313'	71° 01.361'	42° 24.314'	71° 01.377'	33	127
Charles River	Charles	Watertown	42° 21.883'	71° 11.149'	42° 21.899'	71° 11.368'	311	9,896
Neponset River	Neponset	Milton	42° 16.246'	71° 03.909'	42° 16.244'	71° 04.126'	334	9,495
Gulliver Creek	Neponset	Milton	42° 15.853'	71° 02.910'	42° 15.708'	71° 02.812'	370	1,739
Furnace Brook	Furnace Brook	Quincy	42° 15.589'	71° 00.473'	42° 15.434'	71° 00.640'	485	1,623
Town Brook	Town Brook	Quincy	42° 15.160'	70° 59.374'	42° 14.887'	71° 00.057'	800	3,241
Fore River	Fore River	Braintree	42° 13.353'	70° 58.391'	42° 13.265'	70° 58.984'	1030	9,839
Smelt Brook	Fore River	Braintree	42° 13.354'	70° 58.062'	42° 13.078'	70° 58.249'	170	819
Mill Cove creek	Fore River	Weymouth	42° 13.674'	70° 56.977'	42° 13.600'	70° 56.955'	128	249
Back River	Back River	Weymouth	42° 13.267'	70° 55.405'	42° 12.952'	70° 55.359'	392	3,714
Dump Creek	Back River	Weymouth	42° 13.266'	70° 55.455'	42° 13.262'	70° 55.484'	73	174
Fresh River	Back River	Hingham	42° 13.546'	70° 54.936'	42° 13.485'	70° 54.831'	168	379
Town Brook	Town Brook	Hingham	42° 14.490'	70° 53.548'	42° 14.515'	70° 53.637'	115	200
Weir River	Weir River	Hingham	42° 14.930'	70° 51.650'	42° 14.813'	70° 51.650'	305	2,683
Turkey Run	Weir River	Hingham	42° 15.559'	70° 50.781'	42° 15.501'	70° 50.747'	149	319

Figure 4.1 Smelt spawning habitat in the Boston Harbor region. The green dots indicate the downstream limit of egg deposition and the red dots indicate the upstream limit of egg deposition.



WEIR RIVER

STUDY AREA

The Weir River is located in the Weymouth and Weir River Coastal Drainage Area (Halliwell et al. 1982) and flows for approximately 11 km to meet Hingham Bay in the eastern corner of Boston Harbor. The source of freshwater flow is several small ponds and swamps in the town of Hingham. Dams at several ponds in the Weir River system have altered flows and obstructed fish passage (Belding 1921). The dam closest to Hingham Bay is located at Foundry Pond. The drainage area of the Weir River at Foundry Pond is approximately 37.8 km^2 (Wandle 1984). The Foundry Pond dam was selected as a sampling station because it was a known smelt spawning location (Reback and DiCarlo 1972). Two small tributaries, Turkey Hill Run and Rattlesnake Run that enter tidal segments of the Weir River system were surveyed for potential spawning habitat. The Rockland Street Bridge was selected as an estuarine ichthyoplankton and water chemistry station.

No previous studies have been conducted on smelt in the Weir River, although the presence of a large spawning run has been noted (Reback and DiCarlo 1972; and Iwanowicz et al. 1973). A DMF study of the marine resources of Hingham Bay in 1970 found smelt to be the fourth most commonly caught fish by all gear types combined (Iwanowicz et al. 1973). This study also noted that the Weir River was one of the largest smelt runs in Massachusetts and had long contributed smelt eggs for DMF propagation transfers to other rivers. The drainage area of the Weir River has not experienced the extensive urban development seen in the neighboring Back and Fore Rivers. However, it appears the smelt population has severely declined since the earlier DMF studies. The increasing demand on the watershed aquifer for municipal water supplies is a growing concern for sustaining smelt and river herring populations in the Weir River.

RESULTS

The location of smelt spawning and the spawning period in the Weir River during 1992 and 1993 was readily delineated because the close proximity of tidal interface to Foundry Pond dam resulted in most egg deposition occurring directly below the dam. Smelt also spawned in Turkey Hill Run in 1992. No evidence of smelt spawning was found in Rattlesnake Run.

Spawning Habitat

Foundry Pond Dam. Smelt eggs were found in the Weir River from the basin below the Foundry Pond dam and continuing downstream in the river channel along the salt marsh. The spawning habitat measured 305 m in length and 2,683 m^2 in area of river substrate. Most egg deposition and the highest egg densities occurred within 50 m of the dam. The reach below the dam was irregular with several deeper channels bordered by boulders and small earthen islands, and the substrate included large gravel and cobble and abundant aquatic moss. This provided very suitable spawning habitat under conditions of ample freshwater flow. Below the dam basin, lower water velocity resulted in declining gravel and sediment size. The advancing tide would greatly reduce the attraction of these riffles for smelt spawning and consequently, egg deposition was sparse along the downstream 200 m of spawning habitat. The dam also contains a narrow sluiceway that attracted spawning smelt when the sluicegate was open. The spillway is about 50 m in length and 2 m wide. The sluice was designed for hydropower and is now used for pond level management.

Turkey Hill Run. Turkey Hill Run is a small freshwater creek that runs into the tidal segment of the Weir River and was a known smelt spawning run without documentation. Because of its small size, spawning habitat was easily delineated and monitoring was only conducted in 1992. Egg deposition was found along a 149 m reach that contained 319 m^2 of stream substrate. The highest egg densities were found within 20 m downstream of the Rockland Street culvert despite the exposure of this location to high salinity at high tides. Smelt passage was not prevented by the 25 m culvert that runs under Rockland Street, however upstream egg deposition was intermittent and sparse. Passage beyond the upstream limit of observed egg deposition was possible. Another 20 m (<50 m^2 substrate area) of potential spawning substrate was available upstream but not used in 1992.

Spawning Period. The commencement of egg deposition was accurately detected below the Foundry Pond dam in both 1992 and 1993, and at Turkey Hill Run in 1992 (Table 4.2). Spawning below the dam began about March 8th in 1992 when water temperature was about 5 °C. Spawning was delayed in 1993 until about March 24th, apparently due to a cool and wet season that included a blizzard on March 13th. Spawning began later in Turkey Hill Run in 1992 than the main stem. The end of the spawning period was similar for each observation in the Weir River and Turkey Hill Run, occurring near the third week in May.

Water Chemistry

Foundry Pond Dam. Water chemistry measurements were made 25 m downstream of the Foundry Pond Dam on the west bank of the river. The winter of 1993 was colder and had more precipitation than 1992, resulting in much colder March water temperatures in the Weir River in 1993 than 1992 (Table 4.3, A.26–A.27). The colder water and higher discharge were probable influences on the later start to 1993 spawning. For the parameters measured, water quality conditions were adequate to support aquatic life. Dissolved oxygen concentrations were at or near saturation and pH was near neutral for base flow conditions. Lower pH was recorded in 1993 due to the higher precipitation, including frequent measurements below 6.5 during March

Table 4.2 Smelt spawning period in the Weir River and Turkey Hill Run, 1992-1993. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (^oC) Start	End	Range	Mean
Weir River						
1992	March 8th - May 23rd	77	5.4	15.5	2.0 - 18.2	9.4
1993	March 24th - May 22nd	60	3.2	16.6	2.8 - 19.4	10.7
Turkey Hill						
1992	March 22th - May 18th	58	3.7	18.6	3.0 - 18.6	11.2

Table 4.3 Water chemistry and weather summary for the Weir River spawning habitat station, 1992-1993. Data are averages (Tables A.26-A.27) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Logan Airport, Boston (NOAA 1992 and 1993).

Sample Period	Station Visits (No.)	NOAA Air Temp. (^oC)	NOAA Rainfall (cm)	Water Temp. (^oC)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1992								
March	8	1.9	9.1	3.8	0.0	7.1	13.1	0.255
April	7	8.0	5.9	9.6	0.0	6.8	11.3	0.223
May	8	13.1	3.6	14.5	0.0	7.0	10.0	0.237
Season	23	7.7	18.6	9.3	0.0	7.0	11.5	0.239
1993								
March	8	2.4	19.5	1.6	0.0	6.4	13.5	0.276
April	8	9.1	12.3	9.2	0.0	6.3	11.0	0.200
May	6	15.7	2.6	16.4	0.0	6.8	9.1	0.251
Season	22	9.1	34.4	8.4	0.0	6.5	11.2	0.238

and April. Despite routine tidal influence at the dam spillway during high tides, no salinity was measured at the sampling station. The observed rise in water elevation was freshwater flow backed up by the tide.

Turkey Hill Run. Water chemistry was measured at the Turkey Hill Run at the downstream opening of the Rockland Street culvert only in 1992. Water chemistry at this location was influenced by tide stage and the 1.2 m diameter culvert. Because of the effect of tidal influence, mean values do not characterize the freshwater flow and raw data are reported in the Appendix (Table A.28). Water chemistry at higher tide stages were characterized by a bottom layer of saline water (20-28 ppt) that would extend into the 25 m culvert. Surface flows contained only freshwater except during conditions of the highest tidal amplitude or very low discharge. Measurements of pH and DO indicated that water quality conditions were adequate to support aquatic life.

Rockland Street Bridge. Surface and bottom water chemistry measurements were made at the Rockland Street Bridge ichthyoplankton station during each sampling trip in 1992 and only during ichthyoplankton samples in 1993 (Table A.29). Depth at this station ranged between less than 0.5 m at low tide to 2.5 m during high tide. Tide stages closer to low tide had little or no salinity on the surface and bottom. Tide stages closer to high tide showed stronger stratification with traces of salinity (0-5 ppt) in surface flow and saline bottom flow (17-29 ppt). One exception to this pattern occurred during an 11.1 ft. high tide on March 20, 1992 when 26 ppt was found in both surface and bottom measurements.

Stream Flow Discharge Measurements

No stream flow stations were located on the Weir River during the study period. No discharge measurements were made during this study in the Weir River because suitable flow transects were not available in the irregular spillway channel below Foundry Pond. Three stream discharge measurements were made at Turkey Run during low tide 10 m upstream of the Rockland Street culvert. The mean discharge of these measurements, 0.150 m^3/s, provides an indication of the small size of this creek. These measurements were 0.037 m^3/s (5/21/92, ave. depth 0.14 m), 0.332 m^3/s (4/27/93, ave. depth 0.39 m), and 0.082 m^3/s (5/19/93, 0.20 m).

Ichthyoplankton

Ichthyoplankton samples were collected from surface flow during ebb tide at the Rockland St. Bridge. Five species of fish were collected during eight sets (Table 4.4, Appendix B.2). Smelt was the most common fish larvae caught, occurring in 50% of the net sets. Smelt larvae were caught from May 4th to May 26th. The density of smelt larvae captured ranged from 1-43/100 m^3. All smelt larvae were recently hatched, yolk-sac larvae (6-7 mm TL), except for one 16 mm larva caught on May 26th. Atlantic tomcod and rock gunnel larvae were the second most common larvae in the catch, occurring in 38% of the net sets.

Other Diadromous Species

Historical records indicate the Weir River once contained an alewife run that supported a public fishery (Belding 1921). Belding (1921) also reported that by the early 20th century only an occasional alwife was caught in the lower Weir River, and pointed to the construction of dams as the principle cause of the decline. Previous studies by DMF reported that alewives pass fishways at Foundry Pond and Triphammer Pond to spawn in Triphammer Pond (Reback and DiCarlo 1972; and Iwanowicz et al. 1973). Recent observations of river herring in the Weir River have been sparse and imply the presence of a small spawning population. Several individual river herring were observed in the fish ladder at the Foundry Pond Dam on one occasion in May, 1992. Moderate numbers of recently deposited demersal eggs were found below the dam on May 26, 1992 and May 25, 1993. Eggs were hatched and all larvae were identified as blueback herring.

Other Surveyed Tributaries

Rattlesnake Run was surveyed on three spring dates (1992-1994) for potential spawning habitat and the presence of smelt eggs. Rattlesnake Run flows into the eastern end of Straits Pond in Cohasset. No eggs were found and the existing habitat was marginal for adult smelt attraction and egg survival. Freshwater flow was minimal during dry weather and an elevation rise at a stone wall near the tidal zone prevents smelt passage under typical spring flow conditions. It is likely that smelt entering the Weir River estuary would have difficulty detecting this small stream within the tidal Straits Pond, and would be initially attracted to Weir River and Turkey Run discharges.

DISCUSSION

The smelt egg deposition observed in the Weir River followed the same pattern of a stronger spawning run in 1993 than 1992 as seen elsewhere in Massachusetts Bay. Egg deposition during 1993 peaked in late April, resulting in high densities of eggs below Foundry Pond dam. The monitoring in 1992 and 1993 also provided a good example of climatic influence on the spawning period of smelt. This monitoring program has shown that smelt spawning in larger Massachusetts Bay rivers begins during the first half of March, and often during the first week. This was the case during 1992 when spawning began on about March 8th. The winter of 1993 was harsh and included a blizzard on March 13th. These conditions resulted in a large, cold freshet that presumably delayed the onset of spawning until about March 24th.

Periodic visits to check on smelt egg deposition and habitat quality have been made to the Weir River smelt spawning habitat since monitoring was completed in 1993. Smelt eggs have been found with each visit during the spawning period. However, relative to the larger contemporary smelt runs in Massachusetts Bay (Neponset River, Fore River, Back River), the Weir River has a modest spawning run, and no longer ranks as one of the largest runs in the state. The cause for this 20-30 year decline is not known. The common threat of stormwater pollution is less of a concern because of the large amount of undeveloped, vegetated land in the Weir River drainage. The chronic impact of water withdrawals for municipal uses on smelt spawning habitat and egg survival is a primary concern. Monitoring observations and anecdotal information

Table 4.4 Ichthyoplankton samples collected during 8 sample dates at the Rockland Street bridge on Weir River, 1992-1993. Sizes are average total length for larvae and diameter for eggs. Density data are the absolute density collected in total sample volume (928.2 m^3).

Species		Type	FOC	Period	No.	Size (mm)	Density (No./100 m^3)
rainbow smelt	*Osmerus mordax*	larva	4	5/4 - 5/26	70	6.5	7.5
rock gunnel	*Pholis gunnellus*	larva	3	3/18 - 5/4	16	14.5	1.7
Atlantic tomcod	*Microgadus tomcod*	larva	3	3/18 - 4/15	15	9.4	1.6
Atlantic silverside	*Menidia menidia*	larva	1	5/26	8	6.2	0.9
grubby	*Myoxocephalus aenaeus*	larva	1	3/18	6	10.4	0.6
rainbow smelt	*Osmerus mordax*	egg	2	4/16 - 5/4	7	1.1	0.8

indicates that April and May base flows may be declining and suboptimal for smelt spawning. However, with the absence of discharge data this concern is not assessed. A more recent and obvious concern was the direct damage to smelt spawning habitat that occurred with the rebuilding of the Foundry Pond Dam in 1997 and 1998.

The Town of Hingham conducted emergency repairs on the Foundry Pond Dam in 1997/1998. Because regulations governing emergency dam repairs allow relief from state environmental review the repair was made without precautions made for fishery resources. The repair included widening the basin below the dam and clearing out boulders and small earthen islands below the dam, and cutting trees on the bank. The removal of these large materials and widening of the basin resulted in a homogenous substrate of smaller sized gravel and cobble, loss of aquatic moss, reduction of shading from trees on the bank, shallower depths, and lower water velocity. These conditions represent a severe degradation of the quality of this habitat to support egg survival. Subsequent visits to the Weir River after the dam repair found a direct impact of the changes on smelt egg survival

Low flow conditions were observed in 1999 and 2000 that resulted in shallow depths and weak water velocity below the basin. These conditions resulted in observations of high smelt egg mortality. In 2001, the timing of peak spawning and flow changes resulted in significant egg loss. On April 26, 2001, millions of dead eggs were observed in the Foundry Pond Dam basin. Water flow was only coming through the fishway and sluicegate in the spillway. No flow was coming over the dam. Apparently, a large spawning event occurred earlier in April when flows were coming over the dam, and these eggs did not survive when flows were later diverted through the spillway. Given these observations, it is possible that the changes to the basin below the dam combined with chronically depressed base flows will further reduce the capacity of the Weir River run to rebound from the late 20th century trend of a declining spawning stock.

RECOMMENDATIONS

1. Weir River Discharge Station. No continuous river flow records are available for the Weir River. Annual discharge data on freshwater flows are essential to manage and sustain valuable aquatic resources. We recommend that a USGS discharge gauge station be installed and continuously operated in the Weir River.

2. Management of Foundry Pond Discharge. Excessive smelt egg mortality has been related in recent years to the operation of the spillway floodgate that releases water from Foundry Pond. Egg mortality has occurred in both the side sluiceway (egg crowding and declining water depth/velocity) and below the dam (declining water depth/velocity as water is diverted from dam crest to sluiceway). We recommend that the Town of Hingham adopt a management plan for spillway use that minimizes discharges of Foundry Pond water into the spillway from March 1st to May 30th, and considers the presence of large egg sets before any sluicegate operation.

3. Restore Spawning Habitat at Foundry Pond Basin. The 1997/1998 repairs to Foundry Pond Dam degraded the smelt spawning habitat in the basin below the dam. We recommend that this habitat be restored by modifying the basin to improve the spawning channels, add stone to increase the heterogeneity of spawning substrate, and decrease the width of the basin. Shading can also be restored by planting trees along the river bank.

HINGHAM HARBOR

STUDY AREA

Three small creeks that run into Hingham Harbor were surveyed for potential smelt spawning habitat in the early 1990s. Hingham Harbor is located in the Weymouth and Weir River Coastal Drainage Area (Halliwell et al. 1982). Broad Cove is a tidal basin located on the western side of the harbor that contains a creek that was previously noted as a smelt run (Reback and DiCarlo 1972; and Iwanowicz et al. 1973). Town Brook is a small freshwater tributary that runs through the business district of Hingham and empties to the harbor at a seawall outlet. Located next to Town Brook is an outlet for Home Meadows, a large intertidal marsh with minor freshwater inputs. Separate tidegates control flows for both Home Meadows and Town Brook. The sources of freshwater for these creeks are a series of freshwater wetlands located between the Back and Weir River drainages. No discharge records are available for these creeks.

These small creeks have been significantly altered during the development of Hingham Harbor. The alterations to Town Brook and Home Meadows have been dramatic; involving tideland filling, railroad construction in the 19th century and flood control in the latter half of the 20th century. While investigating local knowledge of smelt in Hingham Harbor, I learned that Town Brook contained a smelt run and was considered a strong run prior to the underground piping of Town Brook in the 1950s and 1960s. Broad Cove and Home Meadows were not known by locals to support smelt runs. Hingham Harbor had a popular winter smelt fishery as recently as 25-30 years ago that has faded to present conditions of very low catch and effort. All three creeks were surveyed in 1992 and 1993, and no potential spawning habitat was found in Broad Cove or Home Meadows. A single sampling station in Town Brook was selected for monitoring in 1993.

RESULTS

Spawning Habitat

Town Brook. From the outlet at Hingham Harbor, Town Brook is piped approximately 800 m in 1.2-1.5 m concrete pipe until it daylights parallel to the Penn Central railroad track near the junction of South Street and Central Street in the business district of Hingham (MDPW 1970). The pipe opens to a narrow (0.9 m) stone channel that runs upstream for 12.5 m where the channel widens (1-2 m) for nearly 200 m before entering a pipe again. Smelts eggs were found in 1993 in the daylighted section of Town Brook for 115 m beginning at the pipe opening in the stone channel. The total area of spawning substrate was approximately 200 m^2. Nearly all eggs were found in the stone channel where increased water velocity provided attraction for adult smelt and swept sediment from the substrate. Very few eggs were found in the 60 m reach upstream of the stone channel where fine sediments dominated and the substrate was poorly suited for spawning habitat. A 40 m reach upstream of the previous reach had improved habitat with limited gravel riffle; however, only a single smelt egg was found there. No smelt eggs were found along the remaining 84 m of open channel before the brook entered a pipe again. It is not known if any spawning occurred within the underground sections of Town Brook.

Spawning Period. Smelt eggs were not found in Town Brook until late April in 1993, which is later than typical for smelt runs in Massachusetts Bay. The estimated starting date of spawning was April 21st and the end date was May 26th (Table 4.5). Peak spawning appeared to occur in late April. On April 30th about 100 adult smelt were observed schooling within the stone channel. Given the small amount of available spawning habitat, it is not likely that earlier spawning was overlooked during monitoring. It is possible that spawning occurred earlier in the piped sections of Town Brook or that the downstream tidegate impeded access to spawning habitat thereby causing a later onset of the spawning season.

Water Chemistry

Town Brook. Water chemistry was measured within the stone channel where Town Brook daylights and where most smelt eggs were found. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 4.6, A.30). However, there were signs of degraded water quality in this small creek, mostly related to stormwater flows. Rain events caused water pH to pulse down the low 6.0s. Turbidity increased greatly with stormwater inputs and large amounts of fine sediments were transported through the brook. Specific conductivity was relatively high during base flows, typically in the range of 0.6-0.8 mmho/cm. No evidence of tidal influence was observed upstream of the stone channel opening. Prior to repairing the tidegate in the late 1970s, effects of the flood tide could be seen in the open channel (MDPW 1970).

Stream Flow Discharge Measurements

Four discharge measurements were made in Town Brook during 1993, revealing very low base flows and marginal velocity to support spawning habitat (Table 4.7). The mean velocity for the measurements was 0.35 m/s, and mean discharge was only 0.08 m^3/s. The base stream flow observed in 1993 provided spawning habitat only in the narrow stone channel. As the stream channel widened upstream of the stone channel the velocity became too low to induce smelt spawning during base flows.

Other Diadromous Species

No evidence of other diadromous fish species was found in Town Brook or the other Hingham Harbor creeks during monitoring. Nor have previous documents noted existing fish runs in Hingham Harbor other than smelt.

Table 4.5 Smelt spawning period in the Town Brook, Hingham, 1993.
The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (^oC) Start	End	Range	Mean
1993	April 21st - May 26th	36	11.6	15.0	7.6 - 16.9	12.7

Table 4.6 Water chemistry and weather summary for the Town Brook, Hingham, spawning habitat station, 1993. Data are averages (Table A.30) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Logan Airport, Boston (NOAA 1993).

Sample Period	Station Visits (No.)	NOAA Air Temp. (^oC)	NOAA Rainfall (cm)	Water Temp. (^oC)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1993								
March	7	2.4	19.5	4.7	0.0	6.5	11.4	0.727
April	8	9.1	12.3	9.3	0.0	6.5	10.5	0.520
May	7	15.7	2.6	14.2	0.0	6.9	10.1	0.717
Season	22	9.1	34.4	9.4	0.0	6.6	10.6	0.641

Table 4.7 Stream discharge measurements made in Town Brook, Hingham, 1993. Three depth/velocity cells were measured in the stone channel 4 m upstream of the pipe opening. Rainfall data are five day total precipitation at Hingham station (NOAA 1993).

Date	Width (m)	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Rainfall (cm)	Habitat Coverage
4/1/1993	0.90	0.39	0.645	0.226	5.5	good; high flow
4/16/1993	0.90	0.16	0.352	0.051	3.0	adequate coverage
5/4/1993	0.90	0.15	0.234	0.032	<0.1	adequate coverage
5/13/1993	0.90	0.13	0.171	0.020	0.2	poor; low velocity

The catadromous American eel was not observed, but it is possible that eels visit these creeks for foraging.

Other Surveyed Tributaries

Survey visits to Home Meadows and Broad Cove found no habitat with potential to attract spawning adult smelt or support survival of deposited eggs. Home Meadows is brackish throughout the marsh and lacks freshwater tributaries that could host a smelt run. Broad Cove has two inlets that may have provided freshwater spawning habitat in previous decades. A tidal creek that crosses Rt. 3A on the north side of Broad Cove is severely silted and choked with *Phragmites*. A remnant of a creek is found on the south side in the form of a wide channel leading from a very small pond to Broad Cove. Both creeks presently offer minimal attractant flows and no spawning substrate.

DISCUSSION

Substantial alterations to Town Brook have resulted in a difficult migration path for adults and very little remaining spawning habitat. As a result, this smelt run has been reduced to one of the smallest and most threatened in Massachusetts Bay. Physical changes by the railroad in the 19th century and early flood control projects are not well documented. It is presumed that these changes at least included channelization and moving the brook to suit the railroad track. In 1946 work began to reduce flooding in the Hingham business district (MDPW 1970). The streambed was moved and about 800 m of concrete pipe were installed to direct flows out to Hingham Harbor. The brook pipe, along with a tidegate were buried underground until opening to a stone channel near the junctions of South and Central Street. The tidegate was designed to close during flood tides, and open again when Town Brook elevations were higher than water in the harbor.

The continued existence of a smelt run in Town Brook is remarkable when considering all the challenges facing a successful spawning run. Adult smelt need to find the attraction of a very small volume of discharge coming out of the Town Brook outlet on a seawall in Hingham Harbor. They enter the outlet and encounter a tidegate that is closed during flood tides, the tidal period when they seek to move upstream. They have to pass 800 m of underground pipe before coming out to open stream channel. This challenging passage to spawning habitat is unique among smelt runs in Massachusetts. It is a conventional belief in New England and the Canadian Provinces that smelt will not pass long distances in underground pipes and culverts. There are few examples in Massachusetts of smelt passing through 100 m of underground pipe or culvert and the next longest passage is over 300 m in Smelt Brook, Weymouth (Chase and Childs 2001). Once reaching the open stream channel in Town Brook there is very little substrate remaining that is not severely degraded by sedimentation.

Discussions with locals and a reference in Iwanowicz et al. (1973) indicate that a substantial winter smelt fishery existed in Hingham Harbor as recently as 25-30 years ago. Locals also noted a period in the late 1970s and early 1980s when large numbers of smelt were observed running up Town Brook. Observations on the spawning run diminished sharply in the 1980s and many believed the run was eliminated by the 1990s. Some identified the repair of the poorly operating tidegate in the late 1970s as principal cause of the failure of the Town Brook smelt run. Apparently, the original tidegate became stuck partially open and the repair restored the original operation of the tidegate to close during flood tides. It is likely a combination of the stream piping, tidegate operations and habitat degradation has resulted in a chronic reduction in recruitment for smelt in Town Brook. Presently, the affects of stormwater are a serious concern for the brook as water quality declines dramatically with each rain event.

It is not certain exactly where smelt formerly spawned in Broad Cove. There is no remaining stream substrate that has potential for providing smelt spawning habitat. It is possible that 40 years of development and changes to drainage patterns have drastically altered the two brackish creeks in Broad Cove. No potential was identified for spawning habitat restoration in Broad Cove or Home Meadows, although improved tidal flushing could benefit the marsh ecology and foraging habitat for smelt and eels.

RECOMMENDATIONS

1. Town Brook Management Plan. It is recommended that DMF assists the Town of Hingham to develop a management plan for improving the smelt run in Town Brook. A key component would be the annual cleaning of local catch basins and clearing of debris at the trash racks on the brook. Secondly, operation of the tidegate should consider smelt passage during the spawning season.

2. Spawning Habitat Improvement. Remarkably, smelt continue to pass through the piped segments of Town Brook. Most spawning occurs where the pipe daylights to a narrow stone channel. This stone channel acts as a raceway to increase flow velocity and depth. It is recommended that DMF work with the Town of Hingham to construct similar riffle habitat upstream of the stone channel by making simple modifications to stream substrate and dimensions.

3. Town Brook Daylighting. The existing flood control piping in Town Brook is reaching an age when planning for repair or replacement of some sections will be necessary. There are also ongoing flooding concerns and interest in returning the railroad to service. Discussions on modifications to Town Brook should include an evaluation of daylighting sections now piped in order to improve smelt spawning habitat. A modest stretch of 100 m of daylighted brook with restored substrate could substantially enhance this smelt run, without compromising flood control interests.

4. Tidegate Improvement. The existing tidegate in Town Brook is approximately 20 years old, and will soon require consideration for repair or replacement. When this time comes, DMF recommends that a self-regulated tidegate be installed that will allow average flood tides to advance and operate in a flood control mode during rain events and higher elevation tides. Tidegate technology has improved to allow spring time fish passage and flood control functions to co-occur.

Note: Recommendations 2-4 were adopted during the permitting process for the Massachusetts Bay Transportation Authority (MBTA) Greenbush train project and were enacted in 2006.

BACK RIVER

STUDY AREA

The Weymouth-Back River (Back River) is located in the Weymouth and Weir River Coastal Drainage Area (Halliwell et al. 1982). Freshwater flows in the Back River originate from two large ponds in Weymouth. The Mill River connects Great Pond (300 acres) in western Weymouth to Whitmans Pond (188 acres), and the Back River flows from Whitmans Pond for approximately 5 km to Hingham Bay. Great Pond serves as a municipal water supply for Weymouth. The drainage area of the Back River at the outlet of Whitmans Pond is 32.6 km^2 (Wandle 1984). Smelt were known to spawn below a fishway that is downstream of the Whitman Pond outlet (Reback and DiCarlo 1972). This location was selected as a sampling station for smelt spawning habitat in 1992 and 1993. Four tributaries that entered the intertidal marsh in the Back River were surveyed for potential spawning habitat. Fresh River and an unnamed creek in Beal Cove were surveyed on the Hingham side of Back River. Spring Brook and an unnamed creek that crosses Wharf Street were surveyed on the Weymouth side. Fresh River was monitored both seasons and the Wharf Street creek was monitored only in 1992. Ichthyoplankton was not collected because a suitable sampling station was not present.

No previous studies have been conducted on smelt in the Back River. The Hingham Bay region (Figure 4.2) has long been recognized as supporting large smelt runs, including the Back River (Kendall 1926; Reback and DiCarlo 1972; Iwanowicz et al. 1973). Reback and DiCarlo (1972) called the Back River "an excellent smelt run" that was "probably a significant contributor to the sport fishery in the Boston Harbor area". The Back River is known for having a substantial alewife run that pass through five fishways into Whitmans Pond (Reback and DiCarlo 1972; and Iwanowicz et al. 1973). Extensive flood control construction occurred during the last half of the 20th century in order to facilitate drainage into the Back River. These changes probably caused major alterations to smelt spawning habitat in the Back River. Impacts due to water withdrawals are uncertain. River discharge data were not available in the Back River system during the study period.

RESULTS

The amount of smelt egg deposition and available spawning habitat found during 1992 and 1993 indicated that the Back River remains one to the larger smelt runs in the study area. The total area of substrate in the Back River system where smelt eggs was found was approximately 4,267 m^2. Smelt eggs were readily found in the Fresh River and the creek at Wharf Street. A few smelt eggs were found at the Beal Cove creek during one visit during 1993.

Spawning Habitat

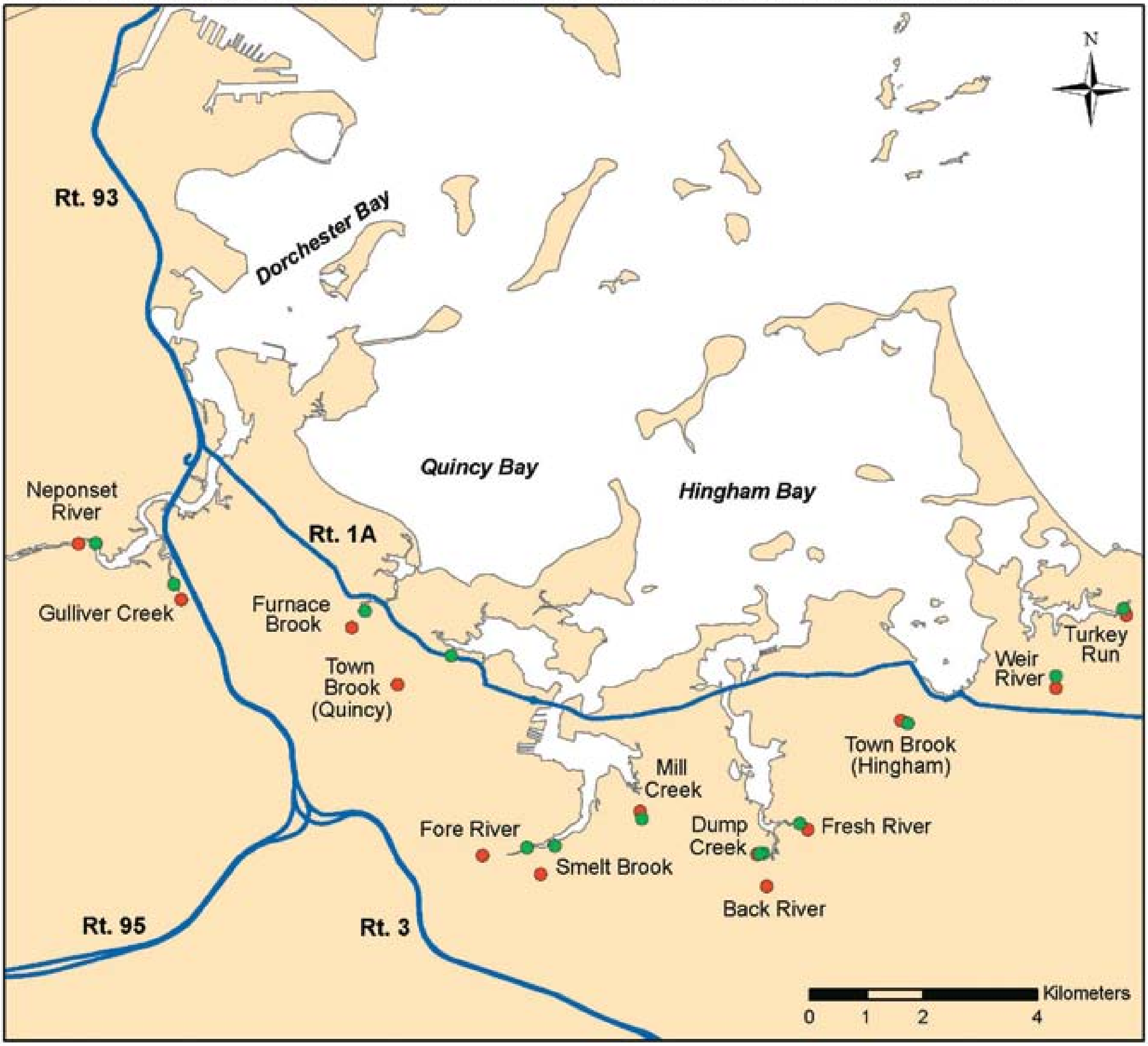
Back River (main stem). The main stem of the Back River leading up to the Jackson Square fishway is channelized and subject to tidal influence. Smelt use the flood tide to rise into the swift flow below the fishway. The highest concentration of smelt eggs was found at the base of the fishway and for 75 m downstream. The upstream limit of spawning was tide and discharge dependent, but typically in the first 3-6 steps of the fishway as the elevation increases and prevents further passage. Spawning continued within the concrete-lined flood control channel and the earthen banked flood control ditch for 227 m downstream to a large embankment of the former Old Colony Railroad track. A large majority of spawning activity in the Back River system occurred within approximately 150 m downstream of the fishway. Two large culverts (1.8 m diameter) pass through the railroad embankment and lead out to less altered intertidal marsh habitat. Light egg deposition was found for 165 m downstream of the embankment. The total river length of the main stem spawning habitat was 392 m and the total area of substrate was 3,714 m^2.

Egg deposition was not continuous throughout the 392 m length of spawning habitat. There were several locations close to the railroad embankment, both upstream and downstream, that had poor attraction for spawning adults due to lower water velocity and silty substrate. Overall the spawning habitat in the main stem appeared to be highly degraded. Water quality degraded rapidly with stormwater inputs; in addition there was no aquatic moss, poor shading, excessive periphyton growth, and substantial sedimentation with visible accumulation of metal residues.

Fresh River. The Fresh River drains swamps and small ponds in Hingham near the Weymouth border, and enters the upper Back River estuary. The drainage area is 2.4 km^2 (Wandle 1984). Smelt egg deposition was found over a 168 m stretch of Fresh River that began just upstream of the Commercial Street culvert and ended 80 m into intertidal marsh habitat. The area of river substrate where eggs were found was 379 m^2. Very few eggs were found upstream of the Commercial Street culvert, despite open passage under the street. Most eggs were found within 100 m downstream of the culvert, where the spawning habitat contained suitable riffles. Adequate water velocity occurred below the culvert and the substrate contained moderately clean gravel and cobble and aquatic moss. The amount of egg deposition observed in Fresh River during 1993 greatly exceeded that seen in 1992. The habitat quality and egg production observed in this small tributary to the Back River during 1993 surpassed many larger smelt runs in Massachusetts Bay.

Wharf Street creek. This small unnamed creek (called "Dump Creek" locally) with a drainage area of only 1.0 km^2 (Wandle 1984) flows under a commercial building on the upland side of Wharf Street and empties through

Figure 4.2 Smelt spawning habitat in the southern Boston Harbor region. The green dots indicate the downstream limit of egg deposition and the red dots indicate the upstream limit of egg deposition.



a culvert to intertidal habitat in close proximity to main stem Back River spawning habitat. Elevation increases at the culvert mouth below Wharf Street and in the bedrock channel can limit adult passage during average tides. When passage was possible, smelt spawning was concentrated at the culvert opening. Smelt egg deposition was found along 73 m of creek substrate downstream of the culvert, over an area of 174 m^2. No eggs were found in the Wharf Street culvert, although passage appeared possible at the highest tidal amplitudes. Spawning was found during both seasons, although egg deposition was intermittent and probably resulted from a few adults that broke off from larger schools in the main stem. The substrate was degraded from road sedimentation and water depth was influenced by tide stage.

Beal Cove creek. This small creek on the Hingham side of the estuary was not selected for routine monitoring during 1992 and 1993 because of the minimal presence of freshwater flow and suitable spawning habitat. It was visited several times during 1992 and 1993 and again in 1999 and no smelt eggs were found, except for May 6, 1993 when less than 50 smelt eggs were found above the upstream opening of the culvert that drains the creek into the marsh. Smelts eggs were found over a 10 m stretch that was only 1 m wide (area = 10 m^2) and 10 cm deep. This creek may offer occasional attraction for a few smelt that break away from schools in the main stem Back River. It is not considered a separate spawning location because of its proximity to the main stem Back River and the likelihood that this tiny discharge is not visited annually by a smelt run.

Spawning Period. The flood control alterations to Back River cause the crowding of spawning adults which allowed the accurate delineation of spawning period in the main stem during both seasons. The spawning periods in the main stem Back River and Fresh River were consistent during both seasons, despite the occurrence of much higher egg deposition at both locations in 1993 than seen in 1992. Spawning began in the Back River main stem near mid-March in both seasons and concluded near mid-May (Table 4.8). In both seasons, Fresh River spawning began later in March (March 26th –1992 and March 28th –1993) and hatching concluded a few days later than the main stem during the fourth week of May.

Water Chemistry

Back River (main stem). Water chemistry was measured 165 m downstream of the Back River fishway in Jackson Square at the border of the sloped, cement channel wall and the earthen bank. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 4.9, A.31-A.32). Unlike the Weir River in 1993, the harsh winter and March blizzard did not appear to strongly depress water temperatures or delay the start of the spawning season. Dissolved oxygen was at or near saturation for all measurements, except on 5/28/92 (Table A.31) when the respiration of densely crowded alewives depressed bottom DO concentrations. Water pH was slightly less than neutral for base flow conditions. The higher precipitation in 1993 resulted in a lower season mean pH than found in 1992. Typical spring flows at the sample station contained no salinity. Flood tides routinely increased the water elevation and the salt wedge was detected on a few occasions during higher tidal amplitudes and lower discharge.

Fresh River. Water chemistry was measured 5 m from the downstream opening of the Commercial Street culvert during 1992 and 1993. For the parameter measured, water quality conditions were adequate to support aquatic life (Tables A.33-A.34). Water temperatures were slightly warmer than the main stem Back River in 1992 and colder in 1993 because the shallow stream responded quickly to changes in air temperature. Otherwise, the water chemistry measured was very similar to that found in the main stem.

Wharf Street creek. Water chemistry measurements were made 3 m downstream of the Wharf Street culvert only during 1992 (Table A.35). For the parameters measured, water quality conditions were adequate to support aquatic life and found in similar ranges as at the other stations in this river system. Average water temperature in March was noticeably warmer in this creek (8.1 °C) than the main stem (4.4 °C) and ambient air temperature (1.9 °C). The cause of this warming was not identified. Because of the creek confluence in the Back River estuary, tidal action had a strong influence on water depth and fish passage. Thirty meters downstream of the culvert a steep drop in the bedrock required higher tide stages for smelt to pass. Eggs deposited below this drop were exposed to saline water at high tide.

Stream Flow Discharge Measurements

Water discharge measurements were made on six occasions during low tide at the main stem Back River within the flood control channel below the fishway (Table 4.10). The spawning substrate had adequate coverage of water under the wide range of flows measured, except during dry periods in the latter half of May. The mean velocity was 0.42 m/s and the mean discharge was 1.63 m^3/s. Water discharge measurements were made on two occasions in the Fresh River downstream of the Commercial Street culvert (Table 4.10). The mean velocity was 0.36 m/s and the mean discharge was 0.12 m^3/s. The Fresh River spawning habitat received adequate coverage during these observations.

Other Diadromous Species

The Back River alewife run has improved greatly (Reback and DiCarlo 1972; and Iwanowicz et al. 1973) since the early 20th century when passage into Whitmans Pond was not possible (Belding 1921). Based on visits to the Back River the 1990s, I would rank the alewife run as one

Table 4.8 Smelt spawning period in the Back River, Weymouth, 1992-1993. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (°C) Start	End	Range	Mean
1992	March 15th - May 20th	67	4.4	17.0	3.1 - 17.9	10.4
1993	March 17th - May 16th	61	2.9	16.9	2.2 - 18.0	9.8

Table 4.9 Water chemistry and weather summary for the Back River spawning habitat station, 1992-1993. Data are averages (Tables A.31-A.32) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Logan Airport, Boston (NOAA 1992 and 1993). Specific conductivity data in 1992 exclude four measurements with salt wedge influence (Table A.31).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1992								
March	8	1.9	9.1	4.4	0.0	7.0	13.2	0.241
April	7	8.0	5.9	10.7	0.0	6.8	11.0	0.252
May	8	13.1	3.6	15.0	0.0	6.7	9.1	0.240
Season	23	7.7	18.6	10.0	0.0	6.8	11.1	0.244
1993								
March	8	2.4	19.5	3.6	0.0	6.5	13.1	0.299
April	8	9.1	12.3	9.7	0.0	6.4	10.9	0.212
May	7	15.7	2.6	17.1	0.0	6.7	8.4	0.315
Season	23	9.1	34.4	9.8	0.0	6.5	10.7	0.271

Table 4.10 River discharge measurements made at Back River smelt spawning habitat, 1992-1993. Ten depth/velocity cells were measured at a transect 135 m downstream of the fishway in the Back River. Four depth/velocity cells were sampled 5 m downstream of Commercial Street in the Fresh River. Rainfall data are five precipitation totals at the Hingham weather station (NOAA 1992 and 1993).

River	Date	Width (m)	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Rainfall (cm)	Habitat Coverage
Back River	4/1/1992	7.3	0.42	0.360	1.104	2.1	adequate coverage
Back River	5/18/1992	7.3	0.28	0.138	0.282	0.1	poor; low velocity
Back River	3/29/1993	7.3	0.69	1.000	5.037	NA	adequate coverage
Back River	4/13/1993	7.3	0.53	0.662	2.561	3.9	adequate coverage
Back River	5/6/1993	7.3	0.34	0.255	0.633	0.0	adequate coverage
Back River	5/28/1993	7.3	0.25	0.092	0.168	0.0	poor; exposed cobble
Fresh River	4/30/1993	1.65	0.20	0.403	0.133	3.5	adequate coverage
Fresh River	5/6/1993	1.61	0.19	0.324	0.099	0.0	adequate coverage

of the largest in Massachusetts Bay. In 1992 and 1993, there was clear overlap of the timing of the alewife and smelt runs. Alewives were first seen on April 21st in 1992 and April 20th in 1993, and were still running strong at the end of May during both seasons. For both years, Weymouth herring wardens considered April 18th the start of the herring run. Blueback herring are also found within the Back River system: late season eggs found in the Fresh River on May 25, 1993 were hatched and identified as blueback herring. American eel elvers were commonly found while scooping gravel to look for smelt eggs, beginning in early April. While visiting the Back River in May, 1998, one dead adult white perch was found near the confluence of Wharf Street Creek and the main stem.

Other Surveyed Tributaries

Spring Brook on the Weymouth side of the Back River estuary was surveyed for potential spawning habitat. No smelt eggs and very little potential for spawning habitat were found. Spring Brook runs through Cushman Meadow and the Great Esker Park before meeting the Back River. The exposed brook receives tidal flooding with each high tide and fine sediments cover most of the brook substrate. These conditions and the minor freshwater attraction limit the suitability of this brook for smelt spawning habitat.

DISCUSSION

The Back River was considered "an excellent smelt run" thirty years ago (Reback and DiCarlo 1972) and continued to be a productive smelt run as evident from 1992 and 1993 monitoring. In the early 1990s, I considered the Back River, the Fore River and Neponset River as the three largest smelt runs on the Gulf of Maine coast of Massachusetts. The size of the Back River smelt run resulted in DMF using the run as a smelt egg donor for restoration projects in the 1990s. Eggs were transferred from the Back River to the Jones River, Plymouth, during 1994-1996 (Bob Lawton, DMF, *pers. comm.*), and approximately 2.7 million smelt eggs were transferred to the Crane River, Danvers, during 1995-1997 (Chase et al. *In Prep.*).

The smelt egg collection efforts in these years allowed for continued observations on the general status of the Back River smelt run. Egg production declined sharply after the 1995 season. Fluctuations in spawning run size are common in smelt populations; however, egg production has been notably low in the Back River since 1995 while other Massachusetts Bay smelt runs have shown periodic improvement. This was most evident in 2000 when the neighboring Fore River and Neponset River had large spawning runs and Back River egg production was again low. Overall, observations since 1995 would not allow the ranking of Back River in the same category as the Fore River and Neponset River. The cause for the declining trend in Back River's smelt run is not certain, although I suspect that state-wide concerns over spawning habitat degradation are a factor. Concern over the impact of egg transfers has been raised. The potential for such impacts should be low considering the relatively small number of eggs taken. For example, all transfers to the Crane River during three seasons would only represent the fecundity of less than 100 female adult smelt. Therefore, the loss in Back River recruitment from the transfers would be minor.

The chronic degradation of spawning habitat from stormwater inputs may be depressing smelt recruitment in recent decades. The substrate below the fishway appears severely degraded relative to other smelt runs in Massachusetts Bay. Coarse road sand is deposited directly below the fishway and finer materials have settled in the flood control ditch above the railroad tracks. A large stormwater pipe discharges directly over spawning habitat through the channel wall 60 m below the fishway. The cobble substrate below the pipe is discolored with metal residues. The influence of eutrophication on periphyton growth is another concern. Large blooms of green algae were observed in late March in the main stem and Fresh River. Eggs deposited on these algae at the onset of growth were engulfed and suffer high mortality.

RECOMMENDATIONS

1. Stormwater Treatment. It is probable that sedimentation from stormwater flow is impacting smelt spawning habitat in the Back River. We recommend that an evaluation be conducted of the origin of stormwater flows running through Jackson Square and treatment options are developed to reduce pollutant loads discharged directly to smelt spawning habitat.

2. Shading Improvement. The Back River main stem from the fishway to the railroad embankment needs more vegetation to improve shading of the spawning substrate. Periphyton growth is presently enhanced by the open access to sunlight. Tree cover may also benefit migrating adult smelt and river herring from the large numbers of gulls and cormorants that prey on fish in the shallow flood control channel.

3. Fresh River Vegetation. The spawning habitat in the Fresh River is burdened by overgrowth of vegetation at two locations, one above and one below Commercial Street. It is possible this instream growth could limit smelt and river herring passage, which locals reported continued far beyond Commercial Street several decades ago. We recommend that a vegetation clearing plan is developed and executed in cooperation with the Hingham Conservation Commission.

4.River Discharge Station and Minimum Flows. Efforts are ongoing by the USGS and City of Weymouth to measure river discharge in the Back River system. This effort should receive ample financial support to ensure that discharge data can be recorded annually. Discharge data should be subsequently evaluated in order to establish minimum flows for anadromous fish passage and spawning habitat requirements in the Back River.

Note: In regard to Recommendation #4, a USGS stream flow gauge (#01105608) was established at the Whitmans Pond fishway in East Weymouth in 2002.

FORE RIVER

STUDY AREA

The Weymouth-Fore River (Fore River) is located in the Weymouth and Weir River Coastal Drainage Area (Halliwell et al. 1982), approximately 16 km south of Boston. The Fore River refers to the tidal portion of this river system, and flows into Hingham Bay. Upstream of tidal influence to the confluence of its tributaries it is called the Monatiquot River. The primary source of freshwater flow is Great Pond in Randolph and Braintree. Smaller water bodies and freshwater swamps in Randolph, Braintree, and Weymouth also contribute to the Fore River discharge. The drainage area of both tidal and freshwater portions of this river system (at Rt. 3A) is 93.5 km^2 (Wandle 1984). The Fore River also receives freshwater from Smelt Brook that flows for about 2 km from Pond Meadow Lake in Braintree before joining the Fore River at Weymouth Landing. The drainage area of Smelt Brook is 5.4 km^2 (Wandle 1984). Great Pond and Pond Meadow Lake are both reservoirs altered for municipal water supplies. No river discharge station was present in the Fore River system and discharge measurements were not made during the study period. Recent Fore River discharge measurements resulted in averages for spring smelt spawning period of 0.93 m^3/s (33 cfs) for 2002 and 2.24 m^3/s (86 cfs) in 2003 (B.Chase, unpublished DMF data).

The shoreline of the Fore River estuary has undergone numerous changes since the colonial period to improve the land for transportation, commerce and residential use. These developments may have negatively influenced the Fore River smelt population by altering stream channels, restricting passage, and increasing stormwater pollutants. More recently, concern is growing over the potential for municipal water management to impact anadromous fish spawning and nursery habitat. The Old Colony railroad ran a passenger service from 1848 to 1959 and freight service continued until 1983. The railroad corridor includes two crossings at important stretches of smelt spawning habitat in Smelt Brook and the Monatiquot River. The Edgar Station operated near Rt. 3A in Weymouth as a coal-fired, electricity generating plant from 1925 until its retirement in 1978. The Edgar Station depended on Fore River water for cooling and was permitted to withdraw about 523 million gallons per day. Smelt Brook has undergone extensive modifications during the 20th century to increase available land and reduce flooding. Most recently, in 1975, a flood relief conduit was added to the Smelt Brook under Weymouth Landing as part of a large flood control project (ACOE 1976). Although most raw sewage discharges to the Fore River have been eliminated, a sewer overflow adjacent to Smelt Brook spawning habitat continues to discharge raw sewage periodically.

The Fore River has traditionally supported a large sportfishery for smelt (Kendall 1926). A 1916 report by the Massachusetts Commissioners of Fisheries and Game noted the poor condition of smelt fisheries in the state and considered the Back and Fore rivers to contain the only remaining natural breeding grounds of importance (MCFG 1917). The Fore River remains one of the larger smelt runs in the study area today; and supports a viable sportfishery. The Fore River smelt run has been recognized historically and during DMF surveys (Reback and DiCarlo 1972; and Iwanowicz et al. 1973); however, no specific information was available on this large smelt run. Sampling stations were selected at known spawning habitat in the Fore River and Smelt Brook to monitor egg deposition and water chemistry. Four additional creeks were surveyed for potential habitat, and a main stem ichthyoplankton station was also selected near Rt. 53 at the Braintree Yacht Club. Three years of monitoring (1988-1990) were conducted in the Fore River due to the large size of the smelt run and spawning habitat.

RESULTS

Spawning Habitat

Smelt egg deposition was readily monitored in the Fore River during each sampling season. A majority of smelt spawning during 1988-1990 occurred upstream of Rt. 53 in the Monatiquot River. Minor egg deposition was found in Smelt Brook during 1989 and 1990. Overall, smelt spawning occurred over nearly a kilometer of river length and 10,000 m^2 of river substrate. These observations place the Fore River system as one of the largest smelt runs in the study area. Consequent observations of egg deposition extend the spawning habitat delineation in the Fore River and are reported in the Discussion section.

Monatiquot River. Smelt eggs were deposited in the Monatiquot River from the Shaw Street Bridge upstream to the McCusker Drive overpass. Smelt egg deposition was observed over a river length of 1030 m and 9839 m^2 in area during monitoring. Early season smelt eggs were first found in the stretch from Shaw Street to the Old Colony railroad bridge embankment that is the transition zone from tidal to freshwater habitat. The embankment narrows the river width to 7 m where boulders create an elevation rise that can inhibit smelt passage during lower tides. Upstream of the railroad embayment the river takes on a lotic environment with shallow riffles and several deeper pools. The substrate was primarily gravel and native shale, with minor patches of sand and silt associated with lower water velocity. Egg deposition was observed at most suitable riffles up until McCusker Drive. The concrete lip of the sluiceway below McCusker Drive created a modest vertical rise (15-25 cm depending on flow) that prevented upstream passage during the study period.

Smelt Brook. The spawning habitat observed in Smelt Brook has been greatly modified by flood control efforts. These modifications and stormwater inputs have reduced the quality of this brook for smelt spawning habitat. Smelt Brook empties through two round culverts into a stone lined channel that runs for over 200 m before meeting the Fore River across from the Braintree Yacht Club. The channel drains to a shallow freshwater flow at ebb tide and fills with 2 m of seawater at flood tide. The highest smelt egg densities were found at the smaller culvert opening (1.83 m diameter). Smelt continued spawning inside the smaller culvert for an undetermined distance. It was presumed that no spawning occurred above the upstream opening of the culverts where a steep spillway precluded passage on the upstream side of Rt. 53. Light and intermittent egg deposition was observed at the opening of the larger culvert (2.44 m diameter) and for 160 m downstream of the culverts. The substrate below the culverts was degraded by sedimentation and various articles of trash. The downstream limit of egg deposition was intertidal and not typical smelt spawning habitat: barnacles, soft-shell clams, and rockweed were present. For 1989 and 1990, egg deposition was found over a stretch of Smelt Brook that measured 170 m in length and 819 m^2 in area.

Spawning Period. During 1988-1990, smelt spawning began during the first or second week of March and viable eggs were found as late as the third or fourth week in May (Table 4.11). Episodes of high spawning activity and egg deposition primarily occurred from late March to early May. The spawning period duration and density of egg deposition in 1989 exceeded that observed in 1988 and 1990. Spawning began at least a week earlier in 1989 than the other two seasons and coincided with considerably colder water temperature. In late-April, 1989, heavy egg deposition and day-time schools of thousands of adult smelt were observed downstream of the McCusker Drive sluiceway. The spawning period in Smelt Brook followed a similar pattern as the main stem but the delineation of start and end dates was incomplete during the two years of monitoring (1989 and 1990).

Water Chemistry

Monatiquot River. Water chemistry measurements were made at a sampling station under the railroad bridge upstream of Shaw Street. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 4.12, A.36-A.38). Dissolved oxygen measurements were near saturation and pH measurements exceeded neutral under normal conditions. Tidal influence was observed at this location within two hours of high tide at most tidal amplitudes. However, no measurements detected salinity during the spawning period, indicating the observed tidal influence was the backing up of freshwater flow.

Smelt Brook. Water chemistry measurements were made during 1989 and 1990 at the downstream opening of the 1.83 m culvert (Tables A.39-A.40). Water temperature, dissolved oxygen, and pH were similar to those at the Monatiquot River station and were within a suitable range for smelt spawning and egg survival. The salinity measurements indicate the substantial influence of tidal intrusion over the spawning habitat. Low salinity (1-4 ppt) was often detected in surface waters, although varied greatly depending on tidal stage, amplitude, and rainfall patterns. At higher tide stages, the bottom water was consistently in the 25-30 ppt range. Egg exposure to salinity in this high range is not typical for most smelt spawning habitats in the study area.

Braintree Yacht Club. Water chemistry measurements were made from the yacht club float that extended furthest into the river channel (Tables A.41-A.43). High salinity and modest thermal stratification were recorded at all tidal stages. The salt wedge dominated bottom water chemistry at all tidal stages. Bottom salinity averaged 29 ppt in 1988/1990 and 30 ppt in 1989, and displayed little variation to tidal or rainfall conditions. Surface flow was most influenced by river discharge. Surface salinity averaged between 3 and 5 ppt during the three spring seasons and did not exceed 9 ppt. Depth measurements made at the sampling station ranged between 2 to 5 m from low to high tide. This ichthyoplankton station was one of the few in the study area to display routine estuarine characteristics of stratified freshwater and saltwater flow.

Ichthyoplankton

Ichthyoplankton samples from surface flows were collected on 19 dates from the Braintree Yacht Club station (Figure 4.2). At least seven species of fish were collected. Smelt was the most common fish larvae caught, occurring in 58% of the net sets (Table 4.13, B.3). All smelt larvae were caught from April 14th - May 26th. Atlantic tomcod were the second most common fish larvae, occurring in 37% of the net sets. All tomcod were caught from March 15th - April 19th. A large majority of smelt larvae were yolk-sac larvae (mean TL = 7.0 mm). The highest densities of yolk-sac smelt were collected during April (10.7/m^3 on 4/14/88 and 5.6/m^3 on 4/28/89), and were among the highest densities of smelt larvae observed in the study area.

Other Anadromous and Catadromous Fish

Previous studies that have discussed anadromous fish in Hingham Bay did not report on the existence of a spawning run of river herring in the Fore River at the time of their surveys (Belding 1921; Reback and DeCarlo 1972; and Iwanowicz et al. 1973). We observed small schools (<100 fish) of river herring downstream of the McCusker Drive spillway in late April and May during both 1989 and 1990. In recent years, additional observations have been made, and both alewife and blueback herring were identified from the schools (B.Chase, DMF pers. observation). American eel were commonly observed each sampling season. Glass eels entered the Monatiquot River during late March or early April in large numbers, and by May most elvers observed had developed darker pigmentation.

Table 4.11 Smelt spawning period estimates for the Fore River, 1988-1990. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (°C) Start	End	Range	Mean
1988	March 15th - May 15th	62	4.0	14.0	2.0 - 16.0	9.6
1989	March 4th - May 25th	83	1.0	17.0	0.0 - 18.0	8.4
1990	March 11th - May 27th	78	4.0	17.8	0.0 - 19.0	10.2

Table 4.12 Water chemistry and weather summary for the Fore River smelt spawning station, 1988-1990. Data are averages (Tables A.36-A.38) except station visits and NOAA rainfall data are total values. Air temperature and rainfall data were recorded at Hingham, Massachusetts (NOAA 1988-1990).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)
1988							
March	9	3.8	10.4	5.8	0.0	7.4	
April	8	7.6	4.8	9.6	0.0	7.4	
May	7	13.7	9.4	14.2	0.0	7.6	
Season	24	8.4	24.6	9.5	0.0	7.5	
1989							
March	10	2.3	9.6	3.7	0.0	7.5	13.6
April	6	7.1	11.2	10.5	0.0	7.5	11.3
May	4	13.5	13.2	15.5	0.0	7.3	10.3
Season	20	7.6	34.0	8.1	0.0	7.5	12.2
1990							
March	8	4.4	5.1	4.0	0.0	7.4	13.5
April	8	8.6	13.5	9.2	0.0	7.3	11.7
May	8	12.3	19.3	14.9	0.0	7.4	10.5
Season	24	8.4	37.9	9.4	0.0	7.4	11.9

Table 4.13 Ichthyoplankton samples collected during 19 sample dates at the Braintree Yacht Club station on the Fore River, 1988-1990. Sizes are average total length for larvae and diameter for eggs. The P-S group (*Paralichthys-Scopthalmus)* is most likely windowpane (*Scopthalmus aquosus*).

Species		Type	FOC	Period	No.	Size (mm)	Ave. Density (No./100 m^3)
rainbow smelt	*Osmerus mordax*	larva	11	4/14 - 5/26	688	7.0	78.9
Atlantic tomcod	*Microgadus tomcod*	larva	7	3/15 - 4/19	78	7.3	8.9
radiated shanny	*Ulvaria subbifurcata*	larva	2	3/15 - 4/14	2	7.1	0.2
winter flounder	*Pleuronectes americanus*	larva	1	4/14	3	7.8	0.3
striped seasnail	*Liparis liparis*	larva	1	4/19	1	5.7	0.1
Atlantic silverside	*Menidia menidia*	larva	1	6/9	4	6.3	0.5
Atlantic silverside	*Menidia menidia*	egg	3	4/14 - 5/12	10	1.1	1.1
P-S group	*Paralichthys-Scopthalmus*	egg	2	4/25 - 5/23	6	1.1	0.7

Other Surveyed Tributaries

Four small, tidal creeks that run into the Fore River were surveyed for potential smelt spawning habitat. On the west side, Hayward Creek is a small freshwater stream that flows from Hayward Pond in Braintree near the Quincy border. The creek was altered in 1977/1978 as part of an ACOE flood control project. Upstream of Rt. 53 it enters an underground culvert and runs for 850 m before meeting the Fore River at the former Quincy Shipyard. On the upstream side of the culvert there are a few meters of gravel substrate and then a small fishway with steps too steep for smelt to pass. The target species for the fishway is not certain. The streambed and culvert have been designed to accommodate higher stormwater flows. Two spring surveys of Hayward Creek found glass eels but no smelt eggs below the fishway. It appeared unlikely that smelt spawn in this small stream or would pass the long underground culvert, although it was not possible to inspect inside the culvert. It is quite possible that smelt spawning occurred here prior to shipyard and flood control alterations.

Three unnamed tidal creeks run into the Fore River on the east side (Weymouth). One creek runs into Mill Cove has a prohibitive elevation rise in the tidal zone. Two creeks cross under the railroad tracks on either side of Idlewell in Weymouth and are both choked with *Phragmites*. All three creeks were found to have minor freshwater discharge and minimal or no spawning substrate. No smelt eggs were found at these three creeks during the study period.

DISCUSSION

The monitoring efforts of 1988-1990 result in the conclusion that the spawning run of smelt in the Fore River is one of the largest in the study area. This finding is based on the amount of available spawning habitat and observed egg deposition, both relatively large compared to other smelt runs in Massachusetts. The spawning stock from the Fore River supports sportfisheries for smelt in the Boston Harbor region, one of the few regions left in Massachusetts with viable smelt fisheries. Greater detail on the 1988-1990 Fore River monitoring is available in a previous DMF report (Chase and Childs 2001).

The relatively high abundance of smelt in the Fore River has been recognized by previous ecological surveys. A 1970 DMF study on the marine resources of Hingham Bay found smelt to be the third most numerically dominant fish caught at intertidal seine stations (Iwanowicz et al. 1973). Recently, studies related to proposals for constructing a new power plant at Edgar Station provide evidence of a large spawning run of smelt and the importance of Fore River as nursery habitat for smelt. During ichthyoplankton, trawl and seine catches near Edgar Station in 1989-1992 and 1998-1999, smelt were among the top three numerically dominant fish for each method (UEC 1992; and MRI 1999). Most of the smelt caught by trawl and seine were young-of-the-year smelt captured during the fall season in the lower estuary. An adult smelt biomass estimate was also made in 1999 to assist evaluations of the potential effects of power plant operations on the local smelt population (MRI 1999). The egg production method was used, wherein egg deposition and drift were estimated and used to back-calculate adult smelt equivalency. The estimate for the Monatiquot River and Smelt Brook spawning habitat in 1999 was 312,505 adult smelt (109,000-489,000 smelt, 95% CI). The investigations were discontinued following 1999, in part due to an agreement to adopt air-cooled condensers for the power plant. The decision to not use river water in an open-cycle cooling system eliminates concerns related to the entrainment, impingement, and thermal influences from the power plant on smelt.

Observations since 1990

I have visited the Fore River smelt spawning habitat each season since 1990 to obtain a sense of the status of annual spawning runs. Most visits were made during the peak spawning season to observe egg deposition. One or two visits during mid-April are made most years. In 1997, 2000, and 2001, numerous visits were made. In 1997, smelt eggs were transferred (<100,000) from the Monatiquot River to the Crane River, Danvers, during a DMF smelt restoration project (Chase et al. *In prep.*). Weekly visits were made during the 2001 spawning season to monitor the smelt run in relation to a proposal to reinstate the Old Colony train line. From these visits it was discovered that the earlier delineation of Smelt Brook and tributary spawning habitat was incomplete. These observations also contribute to better understanding of the dynamics of smelt spawning habitat use and of Fore River smelt population trends.

Population Trends. Substantial annual variation was observed in the size of spawning runs, amount of egg deposition and catches in local sportfisheries during the period of 1988-2001. Overall, we have seen no clear relationship between observations of egg deposition and subsequent recruitment to the Fore River spawning stock or local sportfisheries for smelt. The egg deposition observed in 1989 stands out as the highest densities observed in the Fore River by this project during 1988-2001. The spawning seasons in 1994, 1995 and 2000 were notable for egg deposition well above average densities. Very low egg densities were observed during 1990-1992 and again during 1996-1998. The participation and catch in the 1994 fall/winter sportfishery for smelt in this region was probably the highest during 1988-2001, while 1993, 1995, and 2000 showed better than average catches. These years with relatively higher catches show little synchrony with expected recruitment from years with higher egg deposition. Caution should be used when considering these qualitative observations: no population or fisheries indices of abundance are conducted for smelt in Massachusetts. Only one Fore River smelt population assessment was made in 1999 (MRI 1999), and the egg deposition that produced the estimate of over 300,000 adults could be qualitatively classified as average for the time period.

The variability seen in Fore River smelt spawning runs has been noted in other New England smelt populations (Kendall 1926; and Rupp 1959). We have observed some consistency in the annual strength of Massachusetts' smelt runs among the larger populations. When high or low egg densities are observed in the Fore River, similar trends are often observed in the Back River or Neponset River. Overall, the Fore River and these larger Boston Harbor smelt runs have varied widely in year class strength since 1988 and continue to support modest sportfisheries in the region. Substantial concerns exist over apparent declines in most smelt runs in the study area over the past 20-30 years. The Fore River population appears to have declined during this period, although possibly not as severely as most coastal river systems.

Smelt Brook. My understanding of smelt passage in Smelt Brook as of 1990 was that smelt could enter and spawn in the culverts below the railroad bed in Smelt Brook, but could not pass above the grated spillway found on the upstream side of Rt. 53. The area of substrate where smelt eggs were observed was recorded and it was recognized there was uncertainty over the distance smelt would pass and spawn in the culverts. Since then, I've learned that smelt passage above the grated spillway was incorporated into the US ACOE flood control project constructed during the mid-1970s (ACOE 1976). A 0.6 by 1.2 m sluicegate was constructed near the grated spillway of the 2.44 m culvert that can be operated to allow smelt passage from the 1.83 m culvert. The two culverts are separate for the entire length (347 m for 2.44 m culvert). The smaller culvert is not continuous: box culverts, stone channels, and a smaller round culvert makes up some of the distance to the sluicegate. The Operation and Maintenance Manual for the project stipulates that the sluicegate should be opened from March 1st to May 31st each year to allow smelt passage at the discretion of the Weymouth-Braintree Regional Recreational-Conservation District (ACOE 1976). Therefore, upstream smelt passage is possible via spring flows that are directed through the smaller culvert.

Through discussions with the Recreational-Conservation District (J. Paul Toner, *pers. comm.*, 2000) I learned that smelt passage above the sluice gate was observed in recent years. In addition to the substrate within the 1.83 culvert, smelt have access to spawn in over 200 m of channelized streambed (>400 m^2) from the sluice gate upstream until a perched culvert prevents further passage. I made weekly visits to the upstream reach during the 2001 spawning season and did not find smelt eggs or evidence of smelt passage, and consequent visits have not found smelt eggs. A more formal effort commissioned by the MBTA in 2001 also did not find evidence of smelt spawning above the sluice gate (MRI 2001). The MBTA study did find minor evidence of spawning upstream of the 1.83 m culvert opening, adjacent to a Weymouth Landing pub where that culvert is briefly daylighted.

The realization that more smelt spawning habitat is available in Smelt Brook is encouraging, although it is also apparent that the complexity of the flood control structures presents a serious challenge to upstream passage. There are few examples in Massachusetts of smelt persisting in river systems with similar elevation changes and culverts that exceed 100 m. The spawning habitat above the sluicegate is suitable, however most spawning occurs below the sluicegate where the habitat is severely degraded by sewage and stormwater inputs, and is subject to saline flood tides. High egg mortality has been consistently observed below the culvert opening in the tidal zone. The continued presence of smelt in Smelt Brook reflects their resilient spawning habits, and possibly annual subsidy from egg production in the main stem Fore River.

Main Stem Spawning Habitat. Additional spawning habitat area in the main stem Fore River has been recorded since that delineated from the 1988-1990 monitoring (Chase and Childs 2001). The upstream limit of egg deposition was extended from McCusker Drive to a natural fall 42 m upstream (332 m^2). This was done by adding cobble to the stream bed below the lip of the sluiceway at McCusker Drive (M. Ricardi, *pers. comm.*) The cobble was added downstream of the eastern chamber of the sluiceway to reduce the elevation drop. Following this change, smelt adults and smelt eggs have been observed in the upstream reach. The downstream limit of egg deposition was also extended with observations of smelt eggs downstream of Shaw Street. Viable eggs have been found up to 50 m below the Shaw Street bridge in recent years. It is suspected that the downstream limit is not a static boundary but can change annually in response to dynamics between the salt wedge and river discharge. It was previously assumed that the constriction of ledge at Shaw Street Bridge was the downstream limit of egg deposition. It is more likely that this limit extends upstream during low discharge years and extends further downstream in higher discharge years. The extension of the boundaries of smelt spawning habitat in the Fore River results in an increase in know spawning habitat of 1,372 m^2 from previously reported (Chase and Childs 2001), and provides interesting information for consideration of smelt spawning behavior and habitat selection.

Tributary Spawning Habitat. The four creeks where no smelt eggs were found during earlier surveys were also visited periodically without evidence of smelt spawning until late-March 2006 when smelt eggs were found in the unnamed creek in Weymouth Heights. Carl Pawlowski (Fore River Watershed Association, *pers. comm.*) informed me that over 100 smelt were present in the unnamed creek in Weymouth Heights on the eastern side of Idlewood. At the same time he also had seen a few adult smelt in Haywood Creek just below the fishway, and another observation was reported of adult smelt in the unnamed creek on the other side of Idlewood (M. Ricardi, *pers. comm.*). I made three visits to these creeks during April/May 2006 and observed adult smelt and found smelt eggs only in the creek east of Idlewood over a 128 m stretch (249 m^2 area). Finding smelt spawning here was unexpected given the poor passage (overgrown vegetation), small discharge (<1 cfs) and limited spawning riffles. Over the creek stretch where eggs were found, the eggs were concentrated at seven short riffles where flow was briefly constricted. The conditions observed during the spring of 2006 at this creek may represent the extreme case observed during this project of smelt spawning at marginally suitable habitat. The 2006 observations result in the designation of the creek as smelt spawning habitat.

The observation of smelt upstream of the Haywood Creek culvert is significant to our understanding of smelt spawning migrations. The fact that smelt would orientate to the very low discharge of this creek and run up 850 m of underground culvert is enlightening on the capacity of smelt in urban settings. This location presently offers little potential for spawning smelt. During the observed low flows, smelt could not pass the vertical rise of the fishway and the flow resulted in less than 5 m^2 of potential spawning habitat directly below the fishway before the creek enters underground culvert. Spawning in the culvert under these conditions is not likely since the wide diameter of the culvert causes insufficient water velocity to induce spawning. Many elver eels were seen during my visits in late-April and early-May: possible evidence of the purpose of the fishway. The lack of smelt egg observations after numerous peak-season visits prevents the designation of this creek as a spawning run; however, spawning habitat use prior to the culvert construction is likely and a daylighting restoration project may create suitable spawning habitat. The suitability of spawning habitat at the other unnamed creek on the west side of Idlewood may be less than the latter two creeks. It is remarkable that smelt would cue to this choked drainage with no riffle habitat. Collectively, these observations in these three creeks reinforce the notion that a relatively large run in a main stem river can contribute spawning run recruitment to very small discharges in the region on an intermittent basis. It is possible that a late-March rain pulse in 2006 following a dry winter caused smelt in the upper estuary to respond to the stormwater flush in these creeks. Two days following the rain, there was little that resembled smelt spawning habitat in these creeks.

Ongoing Concerns

The cause and effect of recent declines in smelt populations in Massachusetts is not well quantified. However, it is not difficult to visualize the threats confronting populations of fish when their adapted spawning locations have become centers of human development. Smelt spawning habitat in Massachusetts Bay is typically located in coastal rivers that were historically developed for water power, commerce and transportation, and more recently, for residency and flood control. These activities have resulted in a variety of impacts to spawning runs of smelt, including passage impediments, streambed alterations, acute pollution discharges, and chronic stormwater inputs. The Fore River watershed contains over 170,000 people in the three coastal cities (Quincy, Braintree, and Weymouth), is highly urbanized (MBP 1997) and contains all the above challenges to smelt. The following paragraphs summarize observations related to major concerns to the Fore River smelt population.

Adult Smelt Passage. Spawning smelt in the Monatiquot River have access to a relatively large amount of spawning habitat. No major impediment to adult passage or evidence of habitat limitations on egg deposition was observed in the main stem. The rapids below the railroad bridge can act as a temporary impediment to smelt movements until the flood tide reduces the turbulence and elevation rise caused by a pile of boulders. The degree to which this reduces passage depends on the timing of smelt movements relative to river flow and tide stage. Smelt will spawn at this junction but poor egg survival has been observed here and I suspect large numbers of eggs die after being swept downstream. The lip of the McCusker Drive sluiceway remains an impediment to open passage under most flow conditions. The conditions in Smelt Brook are not favorable to upstream passage. Smelt must pass through about 300 m of culvert before reaching a small sluice gate. The grade increase from the culvert face to the sluice gate opening combined with strong spring flows creates difficult passage for smelt.

Stormwater Inputs. Stormwater dynamics in the watershed may be impacting the smelt spawning habitat by the contribution of pollutants and reductions in base flows. Sediments, nutrients, and toxins are carried from the watershed to the Fore River via stormwater flows. Reductions in pervious surfaces can result in the concentration of some pollutants at sensitive habitats. Increased development near Rt. 93 in recent years may exacerbate this concern. Relative to other Massachusetts Bay smelt runs, the Fore River still possesses stretches with strong flows, and adequate shading and riparian buffering, all which help reduce the negative influences of stormwater inputs. However, I suspect that alterations to watershed stormwater dynamics have resulted in specific local changes to streambed sedimentation, nutrient concentrations and freshwater discharge. These stormwater related concerns are difficult to quantify but are suspected to have an influence on water and habitat quality in the Fore River.

Freshwater Discharge. Concern exists over the sustainability of adequate base flows to provide suitable conditions for egg deposition and survival during the spring spawning period. In recent years, I have observed large gravel banks in prime spawning riffles that become exposed to air as the season progresses and water levels decline. Eggs deposited in late-March or early April are susceptible to exposure during their long incubation period. High egg mortality in has been observed in some years due to this problem. However, without discharge data from a stream gauge station on the Fore River it has not been possible to know if this problem is related to reductions in base flows. It is possible that climatic trends, changes in river hydrology or changes in municipal water withdrawal practices may influence the exposure of the gravel banks in recent years. Losses of pervious surfaces in the watershed may contribute to the problem by reducing the retention and participation of stormwater in base flows.

Nutrient Inputs. Concern exists on the potential for higher nutrient concentrations to degrade smelt spawning habitat by increasing periphyton growth rates and altering natural algal communities. Sharp increases in periphyton growth have been observed in the Fore River, typically beginning during late-March or early-April, but with substantial annual variability in timing and intensity. The periods of high periphyton growth can coincide with large events of egg deposition, resulting in high egg mortality. The growth of periphyton presumably is not optimal for egg respiration and metabolism during this period when incubation lasts 2-3 weeks. The Fore River also has unique nutrient concerns related to the sewage discharge at the Smelt Brook sewer overflow.

RECOMMENDATIONS

1. Stream flow gauge station. Annual discharge data on freshwater flows in the Fore River will be essential for aquatic resource management in this valuable river system. A gauge station should be installed and continuously operated on the Monatiquot River.

2. Adult smelt passage improvement (Monatiquot River). Minor physical alterations to the sluiceway lip at McCusker Drive and the railroad bridge boulder pile could assist adult smelt passage. These options should be evaluated when resource restoration funds become available for the region. It is also recommended that local interests monitor the accumulation of debris at the McCusker Driver sluiceway each spring season and remove the debris when necessary.

3. Adult smelt passage improvement (Smelt Brook). Improvements to adult smelt in Smelt Brook will be a greater challenge because of the complexity of the existing flood control structures. Structural changes to flood conduits will be costly. The present operational requirements for the flood control system should be evaluated by all concerned parties and structural and operational methods to improve smelt passage should be identified.

4. Riverbank protection. Locations with stable river banks, adequate vegetative shading and buffering and clear passage for migrating fish should be protected. River reaches that are lacking suitable conditions should be considered for local restoration projects.

5. Stormwater Inputs. Local, state and federal authorities should consider the importance of smelt spawning habitat during planning and construction for projects that contain stormwater conveyances to the Fore River. We recommend that all such projects should strive to comply with Best Management Practices and seek advanced stormwater treatment and sediment retention when in close proximity to sensitive habitats.

6. Sewer Overflow. The sanitary sewer overflow located at Smelt Brook should be eliminated. Given the proximity to smelt spawning habitat, soft-shell clam beds, and other natural resources in the upper estuary of the Fore River, raw discharges should not be permitted at this location.

Note: In regards to Recommendation #1, a USGS stream flow gauge (#01105583) was established at Commercial Street on the Monatiquot River in 2006.

Smelt spawning riffle in the Fore River.

TOWN BROOK

STUDY AREA

Town Brook is located in the Weymouth and Weir River Coastal Drainage Area (Halliwell et al. 1982) on the south side of Boston Harbor. Town Brook originates from freshwater wetlands in the Blue Hill Reservation and flows into the Old Quincy Reservoir in Braintree. From the Old Quincy Reservoir, Town Brook flows for about 4 km to reach the tidal zone, where it is known as Town River. Town River flows into Town River Bay which meets the Fore River close to the confluence with Hingham Bay. The drainage area of Town Brook is approximately 11 km^2 (Wandle 1984) and is highly developed for much of its path. Town Brook crosses Rt. 128 before reaching Old Quincy Reservoir and near the Quincy border crosses under the junction of the Rt. 93 and Rt. 3. Town Brook receives stormwater drainage from a large area of roadways and retail complexes that have proliferated near the highways. In Quincy, Town Brook runs through dense residential areas and the downtown business district before reaching Town River (Figure 4.3). Much of the brook's path in Quincy has been altered in attempts to reduce flooding. Most recently, a large and complex flood control project resulted in major alternations to the streambed and hydrology of Town Brook in the late 1990s. The project sought to reduce Town Brook flooding by increasing storage capacity at the Old Quincy Reservoir, improving drainage by enlarging culverts at key junctions and bypassing flood waters away from downtown and through a deep rock tunnel with an outlet to the Town River marsh (ACOE 1980).

Several references note the presence of a smelt spawning run in Town Brook during the 1970s (Reback and DiCarlo 1972; Iwanowicz et al. 1973; and Dupee and Manhard 1974). Dupee and Manhard (1974) recorded observations of large smelt spawning events occurring in the intertidal zone at the Rt. 3A bridge. A USGS stream flow station (#01105585) was installed in Town Brook in 1972 and has recorded data in most years since. The mean discharge in April at this station for 1973-1986 was 0.32 m^3/s or 11.3 cfs (USGS, http://waterdata.usgs.gov). Four sample stations were selected for monitoring in 1988 and 1989. The Rt. 3A overpass was selected as both a spawning habitat and ichthyoplankton station. In the freshwater zone, the crossings at Washington Street and Revere Road, and the USGS station off Miller Stiles Road were selected as spawning habitat stations. No additional tributaries are found in the Town River basin. The monitoring of smelt spawning habitat preceded construction of the flood control project. This chapter will present findings from 1988 and 1989 and discuss changes that have occurred since then.

RESULTS

Spawning Habitat

Smelt eggs were readily found at all four sampling stations during 1988 and 1989. Early in the season, smelt eggs were first found in the cobble spillway downstream of Rt. 3A (Figure 4.3). Immediately upstream of Rt. 3A, Town River widened as it passed through salt marsh. This depositional zone received little spawning activity because of low velocities, tidal influence and fine sediments. As the river narrowed a few hundred meters into the salt marsh, intermittent egg deposition was found on patches of gravel. Before reaching Elm Street, the salt marsh ends and the river bank becomes channelized with stone blocks. This stretch was degraded by sedimentation and debris and received minor egg deposition on isolated riffles. Upstream of Elm Street, the channelized river crosses Washington Street and goes into an underground culvert for approximately 125 m before daylighting upstream of Bigelow Street. Egg deposition increased between Elm Street and Washington Street as tidal influence declined and riffle habitat increased. However, the entire tidal zone from Rt. 3A to Washington Street received much less egg deposition than upstream locations and possessed degraded substrate and marginally suitable riffle habitat.

Upstream of Bigelow Street, Town Brook runs through a granite-wall channel that declines in width to 3-4 m, and contains higher water velocity to sustain riffle habitat and attract spawning smelt. The bulk of spawning in Town Brook occurs from Bigelow Street upstream to the Revere Road sampling station. The highest quality riffles were found downstream of Miller Stiles Road within 50 m of the USGS gauge station along the Quincy Chamber of Commerce. The upstream limit of egg deposition in 1988 was the Revere Road downstream culvert opening. Upstream of Revere Road the brook goes underground for about 100 m before briefly opening (10 m length) in a retail parking lot below Cottage Street. A small amount of smelt eggs were found at this opening in 1989. Upstream of this brief opening the brook goes into an underground culvert for over 600 m through downtown Quincy. No eggs were found at the upstream opening and passage was not anticipated; however, a school of 200-300 adult smelt were observed there on one occasion, May 16, 1989 (Abby Childs, DMF, *pers. observation*). Despite underground culverts, long stretches of degraded habitat, and low discharge, the Town Brook provided a large amount of spawning habitat. The brook length where eggs were found in 1988 and 1989 was 800 m and the area of spawning habitat was 3241 m^2. Town Brook has undergone major alterations and a reduction in available spawning habitat since this monitoring. Refer to the Discussion for a description of changes resulting from flood control construction.

Figure 4.3 Smelt spawning habitat in Town Brook, Quincy, with the downstream limit (green dot) and upstream limit (red dot) of observed smelt egg deposition displayed.

USGS gauge station in Town Brook 1998. B.Chase

Spawning Period. Smelt spawning in 1988 and 1989 began later in Town Brook than other smelt runs monitored in the Boston Harbor region. Smelt spawning began on about March 22nd in 1988 and March 30th in 1989 (Table 4.14). Water temperatures were not particularly cold during early March in these years. For unknown reasons, the run appeared to start late and continue later in May than typical. The end of the spawning period was estimated to be May 25th in 1988. The end date of the spawning period in 1989 was not isolated, although viable smelt eggs and adult smelt were observed on May 25th, indicating that the spawning period likely continued until near the end of May. No eggs were found during several June visits in 1989. The spawning activity and egg deposition in 1989 greatly exceeded that observed in 1988. After observing late and minimal spawning in March, a large spawning event occurred on April 6th, and from this point until the third week in May there was evidence of a strong spawning run in Town Brook. During three station visits from May 5th to May 18th, thousands of adult smelt were observed crowded in the channel below Revere Road and egg deposition greatly exceeded the habitat capacity at the Revere Road and USGS stations. At several riffles containing very high egg densities, the substrate was covered throughout the channel with white smelt eggs that died from crowding.

Water Chemistry

Spawning Habitat Stations. Water chemistry measurements were made during 1988 and 1989 at the USGS discharge station off Miller Stiles Road (Table 4.15, A.44-A.45) and the downstream culvert openings at Revere Road for both years (A.46-A.47) and at Washington Street for 1988 (Table A.48). For the parameters measured, water quality conditions were adequate to support aquatic life. Dissolved oxygen measurements were at or near saturation and pH measurements slightly exceeded neutral during base flows. Seasonal averages for dissolved oxygen and pH were nearly identical for the Revere Road and USGS stations. Tidal influence was not detected at either station. Tidal influence was routinely observed downstream of the Washington St. culvert, although no traces of salinity were measured. It appeared that the backing up of freshwater observed at Washington St. during high tides dissipates in the underground stretch between Washington and Bigelow Street. Rain events were quickly followed by degraded water quality at these stations, as evident by the presence of trash, oil residues, and high turbidity.

Route 3A. Water chemistry measurements were made at the downstream opening of the culvert under Rt. 3A (Tables A.49-A.50). Water chemistry at this station was driven by tide stage. Near low tide, water depth was less than 0.5 m and no salinity was detected. Near high tide, water depth exceeded 2 m and the bottom water was highly saline. Within two hours of high tide, all bottom salinity measurements were in the range of 26-34 ppt. Surface waters near high tide were slightly saline, but variable and dependent on freshwater discharge and tidal amplitude. The elevation rise and constriction of the Rt. 3A bridge apparently induce some smelt to spawn during ebb tide. Few locations in Massachusetts have smelt spawning and egg survival occurring with exposure to such high salinity.

Discharge Measurements. Stream discharge measurements have been made at the USGS gauge station during most years since 1973. Provisional data are available for 1988, but unfortunately, no data were recorded in 1989. For the period of March-May 1988, the minimum flow was 0.20 m^3/s (7.2 cfs) and the maximum discharge was 1.56 m^3/s (55.0 cfs). The monthly mean discharge for March-May 1988 were slightly higher than the series averages for this station (Table 4.16). Five discharge measurements were made at the Revere Road station during 1992 and 1993 (Table 4.17). These measurements at a shallow spawning riffle below Revere Road had a mean depth of 24 cm and mean water velocity of 0.464 m/s.

Ichthyoplankton

Ichthyoplankton samples were collected from surface flow during ebb tide on seven dates at the Rt. 3A overpass of Town River. Relative to other sample stations, very few ichthyoplankton were caught. Only four samples contained fish eggs or larvae (Table B.4). Smelt larvae were caught on two dates, a large catch on April 28, 1988, and a single larva on May 26, 1988. A high density of yolk-sac smelt larvae were caught on April 28th (371/100 m^3, mean length = 6.1 mm TL). The only other identified ichthyoplankton caught were smelt eggs (dead or detrital) on two dates in April (120 and 150/100 m^3), and a single Atlantic tomcod larva caught on March 24, 1989.

Table 4.14 Smelt spawning period in Town Brook, Quincy, 1988-1989. Viable eggs were observed on May 25th, 1989; however, the end date was not accurately delineated. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (°C) Start	End	Range	Mean
1988	March 22nd - May 25th	65	8.0	13.0	7.0 - 13.5	10.6
1989	March 30th - (not delineated)		7.0	-	-	-

Table 4.15 Water chemistry and weather summary for the Town Brook spawning habitat station at Miller Stiles Road, 1988-1989. Data are averages (Tables A.44-A.45) except station visits and and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Hingham, Massachusetts (NOAA 1988 and 1989).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)
1988							
March	6	3.8	10.4	8.0	0.0	7.0	-
April	8	7.6	4.8	10.0	0.0	7.1	-
May	7	13.7	9.4	12.5	0.0	7.2	-
Season	21	8.4	24.6	10.0	0.0	7.1	-
1989							
March	10	2.3	9.7	5.5	0.0	7.5	12.4
April	6	7.1	11.2	10.0	0.0	7.1	11.3
May	4	13.5	13.2	14.0	0.0	7.1	9.9
Season	20	7.6	34.1	8.5	0.0	7.3	11.5

Table 4.17 River discharge measurements made at Town Brook, Quincy, 1992-1993. Five depth/velocity cells were measured at a transect 10 m downstream of Revere Road. Rainfall data are five day precipitation totals at the Hingham weather station (NOAA 1992 and 1993).

Date	Width (m)	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Rainfall (cm)	Habitat Coverage
3/24/1992	2.5	0.22	0.374	0.206	1.02	adequate coverage
5/12/1992	2.5	0.22	0.420	0.231	0.74	adequate coverage
4/8/1993	2.5	0.27	0.609	0.411	0.05	good flow over substrate
5/4/1993	2.5	0.26	0.494	0.321	0.03	adequate coverage
5/28/1993	2.5	0.21	0.424	0.223	0.00	adequate coverage

Table 4.16 Town Brook discharge records for 1973-2004 from the US Geological Survey gauge station (#01105585), Miller Stiles Road, Quincy. Discharge data are cubic feet per second (cfs) provided by the USGS Water Resources Division, Marlboro, Massachusetts. Data from 1973-1986 are final data and 1987 to 2004 are provisional data. Rain data are departure from normal monthly total precipitation (inches) at Logan Airport, Boston. The flood control tunnel was constructed in1997 and operating in 1998.

	March				***April***				***May***			
Year	**Min.**	**Max.**	**Mean**	**Rain**	**Min.**	**Max.**	**Mean**	**Rain**	**Min.**	**Max.**	**Mean**	**Rain**
1973	4.2	13.0	6.1	-1.70	2.9	37.0	12.5	2.09	2.8	27.0	9.2	0.53
1974	4.4	77.0	14.5	0.11	7.4	45.0	15.0	0.40	4.9	16.0	7.0	-0.36
1975	6.0	32.0	9.8	-1.16	3.6	58.0	9.4	-1.16	3.6	43.0	9.1	-1.45
1976	4.7	16.0	8.3	-1.48	1.7	20.0	5.5	-1.56	3.4	24.0	5.3	-1.25
1977	12.0	57.0	19.0	0.86	1.3	40.0	8.1	0.51	1.1	52.0	7.5	0.29
1978	2.2	55.0	16.5	-1.44	3.2	23.0	7.5	-1.77	2.8	55.0	11.5	1.27
1979	8.7	60.0	18.6	-0.87	2.4	32.0	6.7	-0.37	1.3	31.0	7.6	1.01
1980	1.5	37.0	8.2	1.47	4.5	66.0	11.6	0.80	1.6	9.4	4.3	-0.93
1981	2.4	20.0	9.4	-3.28	2.4	15.0	5.6	-0.42	2.0	13.0	5.1	-2.06
1982	5.5	12.0	7.7	-1.73	5.4	30.0	14.0	-0.14	2.6	11.0	5.9	-0.65
1983	15.0	124.0	33.8	5.82	13.0	87.0	26.5	3.30	2.1	24.0	11.2	-0.29
1984	10.0	120.0	27.4	2.92	14.0	61.0	24.9	0.87	8.6	120.0	18.9	5.54
1985	2.9	24.0	8.1	-1.63	2.9	15.0	4.9	-1.94	2.4	31.0	5.6	0.13
1986	3.9	28.0	8.5	-0.48	3.6	12.0	6.4	-1.97	2.0	9.1	4.7	-1.92
1987												
1988	10.0	55.0	21.8	-0.38	8.5	31.0	15.7	-2.09	7.2	39.0	12.7	-0.37
1989												
1990	13.0	32.0	16.7	-2.19	12.0	81.0	24.6	2.38	16.0	56.0	26.1	3.30
1991									13.0	24.0	15.7	-2.31
1992	9.4	40.0	17.4	-0.31	15.0	36.0	18.6	-1.22	14.0	25.0	15.6	-1.83
1993	6.5	71.0	18.4	3.77	12.0	81.0	24.4	1.30	5.6	21.0	14.1	-2.19
1994	8.2	107.0	23.1	3.59	10.0	20.0	12.6	-1.31	8.6	37.0	12.2	2.12
1995	9.3	31.0	13.1	-1.70	3.7	19.0	7.9	-2.16	2.3	12.0	4.0	-1.41
1996	4.3	19.0	10.0	-1.54	3.8	60.0	14.7	0.81	9.0	23.0	13.1	-0.50
1997	4.6	30.0	8.6	0.78	0.8	35.0	15.6	-0.10	2.9	15.0	6.8	-0.60
1998	0.9	51.0	5.6	0.25	1.2	14.0	7.0	0.02	4.6	58.0	12.6	3.61
1999	7.6	17.0	10.3	0.67	2.4	7.7	5.1	-2.73	2.2	21.0	5.3	-0.53
2000	4.5	26.0	8.9	-0.31	4.1	25.0	7.7	1.46	3.6	17.0	6.3	-0.35
2001	2.7	63.0	13.7	3.67	1.9	13.0	6.1	-2.68	1.8	10.0	3.1	-2.00
2002	2.8	19.0	7.3	-0.38	3.2	24.0	6.7	-0.92	2.7	30.0	8.8	1.25
2003	4.4	35.0	8.2	0.15	5.1	31.0	9.2	0.40	3.3	27.0	6.4	0.88
2004	2.4	16.0	4.4	-0.65	4.5	52.0	10.3	5.75	2.5	12.0	4.5	-0.28
Mean												
1973-1997	6.8	48.2	14.8	-0.03	6.1	41.1	13.3	-0.17	5.2	31.2	10.1	-0.17
1998-2004	3.6	32.4	8.3	0.49	3.2	23.8	7.4	0.19	3.0	25.0	6.7	0.37

Other Diadromous Species

No other anadromous fish were observed in Town Brook during 1988 and 1989 and there are no previous records of anadromous fish other than smelt. The catadromous American eel was observed on several occasion in Town Brook. Elvers were observed swimming upstream at the Rt. 3A culvert and two dead adult eels were observed at upstream spawning stations.

DISCUSSION

Monitoring of Town Brook smelt spawning habitat in 1988 and 1989 portrayed a viable smelt run existing in a small, highly altered brook. The density of egg deposition observed in 1989 exceeded the capacity of the prime riffle habitat and indicated the presence of a large run relative to other smelt runs of similar size (available habitat and discharge) in the study area. Previous references of Town Brook smelt spawning habitat identified only the tidal zone near Rt. 3A as spawning habitat (Reback and DiCarlo 1972; and Dupee and Manhard 1974). Presumably, these studies observed the upstream culverts and degraded habitats and expected that smelt would not pass further upstream. The late 1980s monitoring and subsequent visits to Town Brook in the 1990s have provided some insight on the continued viability of the smelt run in a degraded urban river system. I suspect the combination of recruitment from the Fore River spawning habitat and stretches of suitable spawning habitat in the Town Brook are sustaining the smelt run. The proximity of the main stem Fore River may allow schools of smelt that hatched in the Fore River to detect the attraction of Town Brook flows. And despite the lengthy stretches of poor spawning habitat, the brook from Bigelow Street to Revere Road has physical characteristics (width, depth, velocity and substrate) that create a raceway effect that is well suited for spawning smelt.

Six visits were made to Town Brook during 1992 and 1993 to observe egg deposition during the peak spawning season and to measure discharge at the Revere Road station. The stream bed below the Revere Road culvert has been modified, resulting in a rise in the stream bed slope and a cement-lined substrate. This location can attract large numbers of spawning smelt, mostly during years of an above average spawning run. The water chemistry measurements found higher than average specific conductivity for smelt runs in the study area (N =5; range = 0.62-0.88 mmho/cm; and mean = 0.72 mmho/cm). Also noted during these site visits was the growth of algae on the substrate and poor egg survival of eggs deposited on the algae. Brown periphyton were observed throughout the spawning habitat and growths of green algae were observed at Revere Road.

Town Brook Flood Control Projects

Since the 1988/1989 monitoring, alterations to Town Brook smelt spawning habitat have occurred as a result of the completion of several components of a large and complex flood control project. The project was designed by the US ACOE with participation from the MDC in the 1970s to address flooding problems in the downtown Quincy district, and received interagency review in the 1980s to avoid impacting natural resources, including the smelt run. Most components of the project were constructed in the 1990s. The following paragraphs summarize major components of this project and describe impacts to smelt spawning habitat that have been identified since 1997. Specific details on the project design are not located in one document. An Environmental Impact Review was not required for this project. Refer to the ACOE's feasibility report (1980), the Notice of Intent (DEQE 1987) and Water Quality Certificate (DEQE 1989) for more details on the project.

Route 3A Culverts. Three large box culverts (16 ft. x 7 ft.) replaced a smaller culvert that ran under the Rt. 3A bridge. The larger culverts enhanced the movement of the salt wedge into the basin upstream of Rt. 3A. The improved flushing may benefit the ecology of the basin; however, by removing the constriction at the Rt. 3A bridge the attraction for smelt spawning has been minimized. A few dead smelt eggs have been found since construction of the new culverts downstream of Rt. 3A. Presumably, the wider opening and grade reduction eliminates spawning riffles during ebb tides and encourages upstream passage. This relatively small loss of spawning habitat (about 171 m^2) was not anticipated by the flood control project design.

Town River marsh upstream of Rt. 3A. The Town River channel upstream of Rt. 3A was widened to accommodate releases of flood waters from the deep rock tunnel, and portions of the stream bed and bank were lined with gabion mattress to stabilize underlying sediments. This construction removed salt marsh vegetation and resulted in losses of smelt spawning habitat. Prior to the widening, there were small patches of gravel riffles where spawning occurred. Since construction, a few dead eggs have been found on gabion wire near the deep rock tunnel outlet where the basin width decreases. The widening has decreased water velocity and lowered water depth (<10 cm at low tide) causing poor spawning attraction and egg survival. Habitat losses here were similar in area to Rt. 3A and not anticipated by the flood control project design.

Deep Rock Tunnel. A principal component of the overall flood control project was the construction of a 4,100 ft. tunnel (12 ft. diameter) that would travel to depths exceeding 100 ft. under the downtown district of Quincy for bypassing stormwater flows. The tunnel was constructed primarily during 1996 and 1997 and began operation in early 1998. The tunnel inlet is located off School Street and includes a sediment trap and weir to divert Town Brook flows. If properly maintained, the trap and weir can reduce sedimentation at downstream spawning habitat. The inlet is designed to divert flows in excess of 100 cfs into the tunnel. The outlet is located downstream of Elm Street in the former salt marsh. The construction of the tunnel resulted in direct mortality to smelt eggs during the 1997 spawning run (Chase 1998). Discharge records and observations since 1998 indicate that the tunnel is diverting Town Brook water at much lower levels than 100 cfs and this condition is chronically degrading the smelt spawning habitat upstream of the tunnel outlet.

Old Quincy Reservoir. The Old Quincy Reservoir in Braintree was reconstructed to improve the storage capacity of the reservoir. This project was recently completely in 2002. The installation of a regulated discharge gate at the reservoir provides to mechanism to assist the smelt run, by augmenting Town Brook flows during the smelt spawning period. This operational feature has potential to be a valuable safeguard for the Town Brook smelt run.

Urban Drainage Improvement. Included in this large flood control project were several smaller projects designed to improve local drainage, primarily through the construction of new culverts and relief conduits along the urban path of Town Brook. Culverts were completed in Braintree and Quincy near Rt. 93 and a major relief conduit was constructed from Centre Street to School Street along the existing Burgin Parkway. A Town Brook channel improvement project (Bigelow Street component) further downstream in Quincy has not been constructed as of 2005. The junction structure at Centre Street was designed to divert Town Brook flood flows into the Burgin Parkway relief conduit which empties to the inlet for the deep rock tunnel. This critical junction is diverting brook flows well below the design specifications. Furthermore, the diversion of dry weather flows is also occurring at Centre Street due to the periodic backwater influence from sediment, debris, and plant growth. Finally, flows from a tributary at Crown Colony that once contributed to Town Brook now run directly to the Burgin Parkway conduit. These routine diversions are having a negative impact on the smelt run by reducing the supply of Town Brook water to downstream spawning habitat. The negative impacts have been seen since the tunnel was constructed in 1997 both in the form of acute affects on egg mortality from low water and the affects of sedimentation and periphyton growth on spawning substrate from chronic lower flows.

Smelt Egg Mortality, 1997

During April, 1997, while working instream related to the deep rock tunnel construction, contractors for ACOE diverted water from Town Brook into the tunnel inlet. Town Brook discharge records indicate the diversion began on April 23rd. The USGS gauge recorded stream discharges of 0.8-0.9 cfs for April 24th-27th, representing a 90-95% reduction in stream flow from April 22nd. On April 26th, DMF staff inspected Town Brook spawning habitat and found a large majority of the streambed exposed to air and that a major smelt egg mortality event had occurred. Upon notification of the egg mortality, the contractors began to disassemble the diversion on April 28th and by April 30th, stream flow had been restored to the spawning habitat (Figure 4.4).

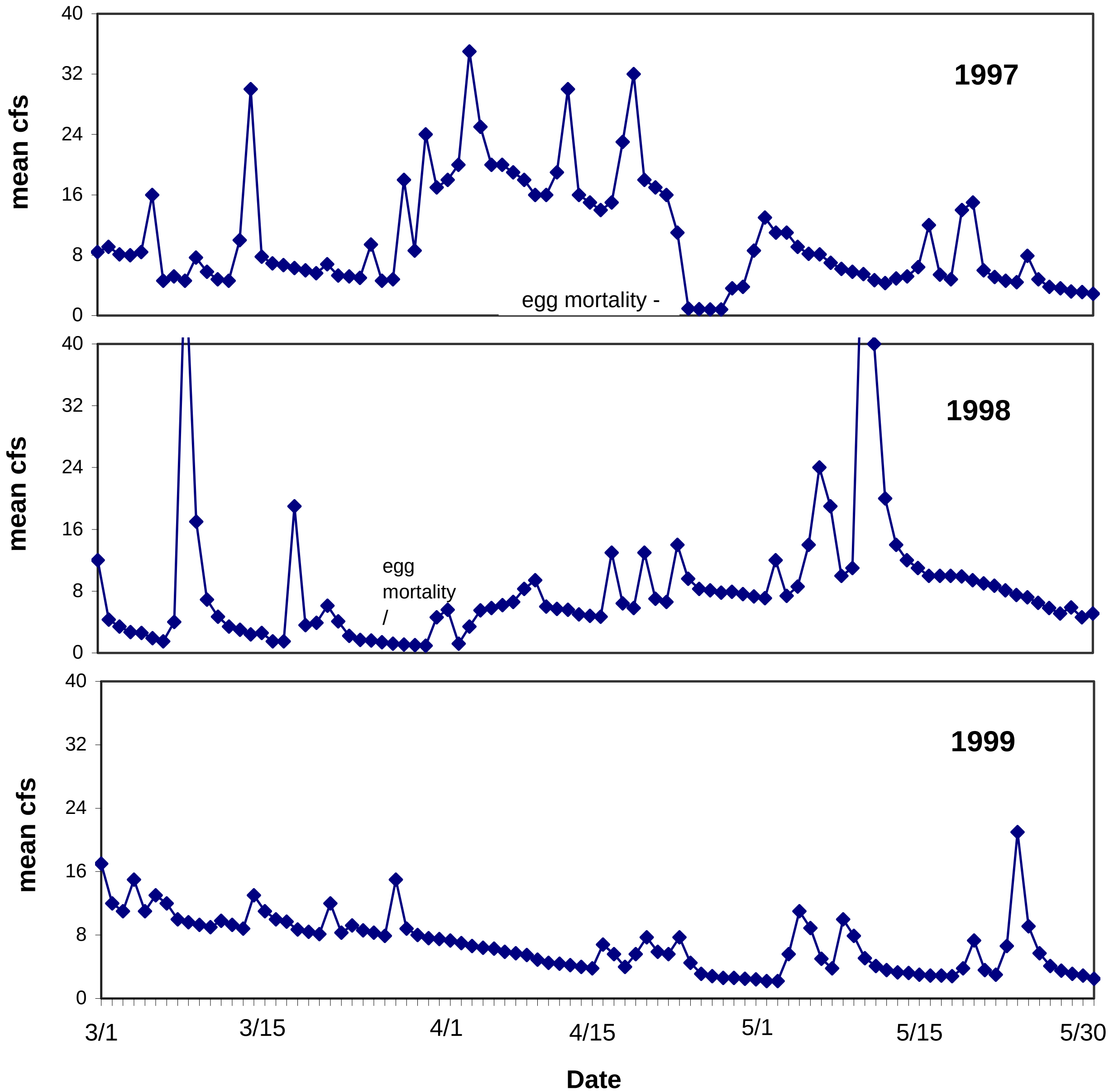
A smelt egg mortality assessment was conducted by DMF following the egg mortality event (Chase 1998). Estimates of smelt egg densities were applied to the Equivalent Adult Method (Boreman 1997) to forecast the losses of age-2 smelt due to the egg mortality event. The estimated losses for age-2 adult smelt were approximately 14,000 – 21,000 for the medium egg density estimate (15.5 eggs/cm^2). The diversion of water from Town Brook and resulting smelt egg mortality was determined by the Commonwealth's Attorney General to be an impact from tunnel construction that violated the project's order of conditions under the Wetlands Protection Act (G.L. c. 131, section 40). The smelt egg mortality was also determined to be a violation of the Massachusetts Inland Fish Kill statute (G.L. c. 131, section 42). A settlement was reached with the ACOE contractors to pay a civil penalty of $50,000 to the Commonwealth and pay $75,000 to the Natural Resources Damages Trust Fund for future smelt restoration efforts in Town Brook.

Smelt Egg Mortality, 1998

On March 25th, 1998, a second smelt egg mortality event was observed by DMF staff at Town Brook. Similar to 1997, a majority of the stream bed was exposed and a high percentage of deposited smelt eggs were dead. An evaluation of the USGS stream discharge records indicated that flows had been depressed since the deep rock tunnel became operational in January, 1998. During January-March, the discharge at the USGS station increased with rain, followed by steady decline to a range of 1-2 cfs. The cause of the diversion was not apparent at first. By early April it was discovered that debris and sediment build-up downstream of the Centre Street junction box was causing brook water to back up and spill into the Burgin Parkway conduit which fed directly to the tunnel inlet. This was corrected on April 3rd and discharge responded by rising to about 8 cfs. Apparently, smelt had entered the spawning habitat while flows were elevated by rain around the third week in March. Their deposited eggs were then exposed as discharge declined during the last week of March to a low of 0.9 cfs (Figure 4.4).

The project's environmental permits did not contain operational requirements for providing minimum flows in Town Brook, and therefore, DEP determined no violations had occurred during the 1998 smelt egg mortality. The timing of smelt spawning was unfortunately matched with the flow blockage at the Centre Street junction box. The egg mortality did raise important questions on the loss of Town Brook flows through the Burgin Parkway conduit and over the maintenance of the flood control project. No assessment was conducted on smelt egg mortality and

Figure 4.4 Spring discharge (daily mean cfs) at Town Brook USGS gauge station, 1997-1999. The discharges associated with 1997 and 1998 smelt egg mortality events are noted on graphs.



resulting losses of equivalent adult smelt.The egg mortality was judged to have occurred prior to peak smelt spawning season and to have involved lower egg densities than the 1997 event.

Town Brook Discharge Measurements

The USGS gauge station on Town Brook has provided a valuable time series of discharge measurements that has improved the understanding of smelt spawning habitat requirements and the performance of flood control structures.A summary of discharge records from 1973-2003 during the spring spawning season display a wide range of discharge with periodic lows near one cfs and occasional storm flows over 100 cfs (Table 4.16). This variability reflects the influence of the flood control structures and precipitation on a small, channelized stream in an urban setting. Rainfall results in sharp pulses in discharge and during dry periods the flow steadily decline to very low levels (Figure 4.4).

The discharge records can be associated with field observations to develop a range of flows needed for smelt spawning and egg survival requirements in Town Brook. In 30 years of records, the two lowest monthly minimum flows in the spawning period resulted in substantial smelt egg mortality (April-1997 and March-1998).These data indicate that discharges less than 1.0 cfs will expose large

Smelt egg mortality following 1998 low flows. B. Chase

amounts of spawning substrate. Additional observations at discharges below 2.0 cfs indicate that reduced egg survival will result by exposing parts of spawning riffles to air and lower water velocity. Comparisons of discharge records before and after the deep rock tunnel was opened (1998) indicate that the operation of the flood control structures is depressing Town Brook discharge flowing over spawning habitat. The mean April discharge during 1998-2004 was 7.4 cfs, compared to 13.3 for 1972-1997. The lowest monthly mean discharges on record for March and May, and second lowest for April, have occurred since the tunnel opened. More annual observations and analyses that include precipitation data are needed to define Town Brook discharge relationships. However, observations of the spawning habitat before and after the tunnel construction are clearly demonstrating an impact is occurring. In addition to egg mortality events, lower water velocity, sediment accumulation, and periphyton growth are related to chronic low base flow and degrading spawning riffles.

Town Brook Smelt Conservation Team

The ACOE Section 10/404 permit for the Bigelow Street component of this flood control project contained a requirement for MDC to establish and coordinate a multi-jurisdiction "Town Brook Smelt Conservation Team" for the purpose of resolving project impacts to smelt (ACOE 1998). The team met once or twice a year during 1998-2002, and was typically comprised of staff from MDC, DMF, ACOE, NMFS, City of Quincy, and local participants. Recommendations from the Team were required to be incorporated into the Operation and Maintenance manual for the Bigelow Street project; however, the project has been permitted but not constructed to date. Therefore the team's work is ongoing and final recommendations have not been reported. The team has been successful in linking components of this complex project to smelt impacts and have developed proposals for solving specific problems. The team has identified key brook junctions that need to be inspected and routinely cleaned of sediment (Rt. 93 culvert, Centre St. culvert, and tunnel inlet sediment basin). The team developed a process to use outlet flows at the Quincy Reservoir to augment Town Brook flows when gauge station discharges fall below a 2 cfs threshold. The process includes a low-flow alarm at the gauge station to prompt inspections by Quincy's Department of Public Works. The low-flow augmentation process will be included in the Old Quincy Reservoir O&M plan, and should be a valuable mechanism to protect the smelt run.

The low-flow augmentation provides a process to respond to low water levels during the smelt spawning season. A long-term goal of the team is to avoid water level problems at the spawning habitat by recapturing Town Brook flow losses into the Burgin Parkway conduit at the Centre Street junction. These flows bypass the spawning habitat by going into the deep rock tunnel and contribute to chronically depressed spring flows over the smelt spawning habitat. This issue has not been resolved to date. The source of the diversion involves a combination of maintenance and design concerns at the Centre Street junction, and direct losses of stream flow from Crown Colony to the Burgin Parkway conduit. Further evaluations are needed on the design of Centre Street junction structures and on retrieving dry weather flow losses.

Minimum Flow Requirements

An important component of the effort to sustain a smelt spawning run in Town Brook is the determination and maintenance of water flow levels that meet minimum requirements for adult smelt attraction and smelt egg survival. When this project was under review in the 1980s, the project was designed to not release dry weather flows into the deep rock tunnel and maintain flows less than 100 cfs in Town Brook (ACOE 1980; and DEQE 1989). These conditions have not been met, and consequently the smelt run has suffered acute impacts (egg mortality) and chronic impacts (reduced spawning habitat; and sedimentation and periphyton accumulation in the presence of lower flows) since tunnel construction. The interagency evaluation of the project design for the deep rock tunnel accepted the 100 cfs diversion target as adequate for smelt requirements. By the time that the Bigelow Street component was under review in the late 1990s concerns over minimum flow in Town Brook were apparent. As a result, the Bigelow Street component permits (ACOE Section 10/404 and DEP Water Quality Certificate) contain a monthly mean stream flow of 8 cfs and daily minimum stream flow of 4 cfs for the months of March, April and May (ACOE 1998; and MDEP 1998). Unfortunately, the depressed flows in Town Brook have resulted in these specifications being exceeded in most years since the tunnel became operational (Table 4.16). However, these criteria are only requirements for the Bigelow Street component, which has not been constructed.

The Smelt Brook Conservation Team developed the low-flow augmentation protocol to use Quincy Reservoir outflow to enhance discharge over the spawning habitat when measurements drop below 2 cfs. This is a positive safeguard against major resource losses, but the action level is approaching a discharge where acute impacts may occur and chronic impacts are probably already occurring. It is likely that the 4-8 cfs range that was adopted during the Bigelow Street permit review is better suited for smelt spawning requirements in Smelt Brook. Additional work is needed to both retrieve dry weather losses in the deep rock tunnel and relate the function of flood control structures to smelt spawning habitat requirements.

RECOMMENDATIONS

1. Remediation Work Plan. Following the 1998 egg mortality event, Secretary of EOEA requested that the ACOE's Lt. Colonel for the New England District develop a work plan with other agencies to remediate the flood control project impacts on the Town Brook smelt run. This effort has not been completed. It is recommended that the remediation plan be developed.

2. Sedimentation Maintenance. The accumulation of debris and sediment at the Centre Street junction structure had a major role in the smelt egg mortality event in 1998. Responsibility for maintaining sediment basins has been passed from the ACOE to MDC to the city of Quincy and is documented in the O&M plan. It is essential that sediment and debris are removed from Centre Street junction structures, the Rt. 93 sediment basin and the tunnel inlet basin each year prior to the spring smelt spawning season. Consideration should also be given to an in-stream sump downstream of the Centre Street Junction Box to capture sediment loads and facilitate cleaning.

3. Chronic Low Discharge. The USGS gauge station has documented depressed Town Brook discharges during the smelt spawning season since the deep rock tunnel became operational in 1998. This chronic condition is having a negative impact on the quality of smelt spawning habitat and the survival of smelt eggs. Two identified sources of lower flows were the reconstruction of Quincy Reservoir and diversions at the Centre Street junction structure. With the completion of the Quincy Reservoir in 2002, there may be more stability to spring flows and augmentation is now possible. However, the long-term solution is to recapture flow losses that are diverted at the Centre Street junction and run through the Burgin Parkway conduit into the tunnel. Routine annual maintenance of this structure is part of the solution. It is also recommended that the ACOE evaluate and correct dry weather diversions by using their program authorities for project modifications.

4. Stream Discharge Data. The USGS stream discharge station has provided useful data that improved our understanding of hydrological dynamics between Town Brook and the flood control project. It is recommended that this valuable data series (1973 to present) be continued. It is also recommended that analyses are conducted relating the operation of the flood control project to Town Brook discharges with consideration for precipitation.

5. Minimum Flow Requirements. The original flood control project did not contain requirements for sustaining minimum stream flows during the smelt spawning season. The Bigelow Street channel modification component (permitted but not constructed) does include requirements for maintaining stream flows during the spawning period. Project permits (ACOE 1998; and MDEP 1998) requires a monthly mean flow of 8 cfs, and a daily minimum of 4 cfs during March-May. It is recommended that future efforts to remediate the present impacts in Town Brook revisit the issue of minimum flows and provide updated criteria. The evaluation of existing DEP requirements, USGS stream gauge data and discharge records for the Old Quincy Reservoir can assist this process.

6. Revere Road Brook Substrate Modification. It is recommended that a spawning habitat restoration project be conducted along the Revere Road streambed. The flow regime at this location is suitable for smelt attraction but the elevation rise and smooth cement channel floor are not optimal for egg survival. Better egg survival could be achieved by removing the cement floor and replacing it with large cracked stone and reducing the stream elevation to prevent egg crowding.

FURNACE BROOK

STUDY AREA

Furnace Brook is located in the Weymouth and Weir River Coastal Drainage Area (Halliwell et al. 1982), about 15 km south of Boston. Furnace Brook originates in the Blue Hill Reservation west of Quincy, crosses Rt. 93, and flows for a total of 6.5 km to the Blacks Creek Estuary. The Black Creek Estuary enters Quincy Bay through tide gates under Quincy Shore Drive. The only significant tributary to Furnace Brook is Cunningham Brook, which drains a small region of Milton. The overall drainage area of Furnace Brook is 9.9 km^2 (Socolow et al. 1998). The drainage area west of Rt. 93 is relatively undeveloped compared to the dense residential and mixed industrial development east of the highway. This extensive development contributes to stormwater flooding along Furnace Brook (MHD 1999). The Massachusetts Highway Department is currently considering structural changes in Furnace Brook to reduce stormwater flooding.

No previous studies have been conducted on smelt in Furnace Brook, but the presence of a resident smelt population has been known for many years (Reback and DeCarlo 1972). The contribution of the Furnace Brook smelt run to Quincy Bay fisheries is uncertain, although probably minor given the small size of the run. A USGS stream flow gauge station was maintained at the Hancock Street Bridge from 1973-1980. The mean monthly discharge for April during this period was 0.23 m^3/s (8.1 cfs). Two sample locations were selected after surveying the brook in 1991 and were monitored in 1992 and 1993. The Hancock Street Bridge was used as a water chemistry station and central point for monitoring egg deposition. The tide gates on Quincy Shore Drive were used as a marine water chemistry and ichthyoplankton collection station. Greater details of the Furnace Brook monitoring are provided in a previous DMF report (Chase 2000).

RESULTS

Spawning Habitat

Few smelt eggs were found in 1992, partly due to low egg densities and incomplete knowledge on Furnace Brook spawning habitat. Greater numbers of smelt eggs were found in 1993, allowing the delineation of the spawning habitat and season. Spawning occurred along approximately 993 m^2 of river substrate in a 295 m stretch in the Furnace Brook. This entire stretch ran along the former National Armory (now National Guard property) with Hancock Street as the upstream limit. Egg deposition was sparse within this stretch. The highest densities observed occurred during 1993 at riffles within 100 m downstream of Hancock Street. No eggs were found upstream of Hancock Street during 1992 and 1993, despite the lack of an impediment to passage at the Hancock Street Bridge. A few smelt eggs were found during consequent site visits over the 190 m stretch of habitat (area 630 m^2) from Hancock Street to the Newport Street Bridge. This additional stretch increases the Furnace Brook spawning habitat to 485 m in length and 1,623 m^2 in area.

Spawning Season. Smelt eggs were found in Furnace Brook in 1992 from April 10th through May 12th. Egg deposition was light compared to that found in 1993 and only occurred in shallow riffles downstream of Hancock Street. It is likely that spawning began before April 10th in 1992 and was not detected. The spawning period was better delineated in 1993 and occurred from March 24th to May 16th (Table 4.18). Egg deposition in 1993 primarily occurred during the last week of March and first two weeks of April. Very few viable eggs were found during the first half of May.

Water Chemistry

Furnace Brook. Water chemistry measurements were made at the staff gauge of the discontinued USGS gauge station 5 m upstream of Hancock Street. Spawning commenced in 1993 when water temperatures were about 4 °C. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 4.19, A.51-A.52). Dissolved oxygen concentrations were at or near saturation and pH was near neutral for most conditions. No salinity or tidal influence was detected at the Hancock St. water chemistry station. Tidal influence was routinely observed during high tide at the lower end of spawning habitat as the advancing tide backed up freshwater flow.

Blacks Creek Tide Gates. Water chemistry measurements were taken on only five occasions during ichthyoplantkon sampling because water flow at the tidegates was too swift during most of the tide cycle to deploy water quality instruments. The five measurements were taken soon after slack high tide and showed the ebb flow out of Blacks Creek was dominated by the marine water with a slight depression of salinity due to Furnace Brook freshwater (mean = 27.6 ppt). The surface and bottom measurements confirmed that the water column was completely mixed at the tidegates.

Stream Discharge

Eight discharge measurements were made during the two spawning seasons (Table 4.20). Excluding one measurement taken during flood conditions (78 cfs, 4/1/93), the depth ranged between 0.2 - 0.4 m for discharges of 0.11 - 0.66 m^3/sec (4 - 23 cfs). The upper end of these ranges provided adequate coverage of spawning substrate and the lower ends resulted in low velocities (≤ 0.2 m/sec) and exposed habitat. A summary of discharge measurements taken at the USGS gauge station near Hancock Street during 1973-1980 displayed annual spring maximum flows usually in the range of 0.5-1.0 m^2/s (20-40 cfs) and annual spring minimum flows in the range of 0.05- 0.15 m^2/s (2-5 cfs). The lower discharges represent conditions that may impact

Table 4.18 Smelt spawning period in Furnace Brook, Quincy, 1992-1993. Smelt eggs were present from April 10th to May 12th in 1992, but the start and end dates were not clearly defined. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (^oC) Start	End	Range	Mean
1992	*incomplete delineation*					
1993	March 24th - May 16th	54	4.4	13.2	4.1 - 13.9	9.6

Table 4.19 Water chemistry and weather summary for the Furnace Brook spawning habitat station, 1992-1993. Data are averages (Table A.51-A.52) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Logan Airport, Boston (NOAA 1992 and 1993).

Sample Period	Station Visits (No.)	NOAA Air Temp. (^oC)	NOAA Rainfall (cm)	Water Temp. (^oC)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1992								
March	8	2.0	9.1	5.2	0.0	7.2	13.6	0.515
April	7	8.0	5.9	9.7	0.0	7.1	12.2	0.428
May	8	13.1	3.6	13.0	0.0	7.2	11.2	0.451
Season	23	7.7	18.6	9.3	0.0	7.2	12.3	0.466
1993								
March	8	2.4	19.5	4.3	0.0	7.0	12.9	0.528
April	8	9.1	12.3	8.7	0.0	6.9	11.2	0.417
May	7	15.7	2.6	13.3	0.0	7.0	10.0	0.482
Season	23	9.1	34.4	8.6	0.0	6.9	11.3	0.470

Table 4.20 Stream discharge measurements made at Furnace Brook smelt spawning habitat, 1992-1993. The sample transect was located upstream of the Hancock Street bridge at the former USGS gauge station. Rainfall data are five day total precipitation from Logan Airport (NOAA 1992 and 1993).

Date	Width (m)	Depth Ave. (m)	Velocity Ave. m/sec	Discharge (m^3/sec)	Staff Gauge	Rainfall (cm)	Habitat Coverage
3/27/1992	3.65	0.31	0.375	0.424	2.12	1.91	adequate coverage
5/12/1992	3.65	0.19	0.206	0.142	N/A	0.71	poor; exposed substrate
3/26/1993	3.70	0.39	0.458	0.660	2.40	N/A	adequate, high flows
4/1/1993	3.70	0.67	0.894	2.217	3.30	N/A	adequate, flood flows
4/20/1993	3.70	0.32	0.311	0.367	2.19	2.16	adequate coverage
4/30/1993	3.70	0.29	0.238	0.255	2.08	2.79	adequate coverage
5/13/1993	3.60	0.23	0.156	0.129	1.88	0.20	poor; exposed substrate
5/25/1993	3.65	0.23	0.131	0.110	1.83	0.00	poor; exposed substrate

smelt spawning habitat and routinely occurred during April and May for each year of this series

Ichthyoplankton

Ichthyoplankton samples were collected at the tide gates on Quincy Shore Drive. Samples could only be collected shortly after slack high tide because of the high velocity of ebb flow through the tide gates (>1 m/s). These conditions limited successful sampling to only three dates. Smelt larvae were collected on 5/14/92 and 4/30/93. Most of these were yolk-sac larvae, indicating that these larvae moved out of Blacks Creek and into Quincy Bay shortly after hatching. Seven other species of finfish were represented in the ichthyoplankton samples (Table B.5). Sand lance (*Ammodytes sp.*) was the only species besides smelt that occurred in more than one sample.

Other Diadromous Species

No observations were made of other anadromous fish or the catadromous American eel (*Anguilla rostrata*) in 1992 or 1993. This finding was expected for river herring because Furnace Brook was not previously known to contain a river herring run (Reback and DeCarlo 1972). The presence of eels may have simply been overlooked during the monitoring for smelt eggs, although observations of elver eels were readily made at most river systems that support smelt in Massachusetts.

Other Surveyed Tributaries

Two unnamed creeks on the western side of Blacks Creek were surveyed for potential smelt spawning habitat. One creek crosses Fenno Street in Merrymount and the other crosses Fenno Street near Rt. 3A. Water in both creeks originated from tidal and stormwater flows. No potential spawning habitat or dry weather freshwater flow was found in either creek.

DISCUSSION

The low densities of smelt eggs observed in 1992 and 1993 relative to the available spawning habitat in Furnace Brook raise concerns over the health of this spawning run. The monitoring of other smelt runs in the region provides a frame of reference for expected egg deposition for the habitat conditions found in Furnace Brook. For example, the egg deposition in Town River, Quincy, greatly exceeded that in Furnace Brook during 1992 and 1993. Town Brook is located less than 2 km away from Furnace Brook and contains a similar amount of spawning area and discharge. With only two years of monitoring in Furnace Brook it is difficult to determine the reasons for the poor spawning runs. Monitoring observations suggest that the degraded condition of the spawning substrate is probably a contributing factor to the health of this population.

The assessment of the Furnace Brook smelt spawning habitat may have been influenced by two very different weather patterns for the Boston area during 1992 and 1993. The winter in 1992 was relatively calm and January-May precipitation was 50% below normal (NOAA 1992). The winter in 1993 had much snow and January-May precipitation was 14% above normal (NOAA 1993). Snow and rain storms in March and April in 1993 resulted in a wet spawning period with high stream flows. Overall, the March-May precipitation in 1993 was nearly double the amount in 1992 (Table 4.19). These weather conditions had a strong effect on the physical appearance of the spawning habitat for these two years.

Stream flow was low for most of the spawning period in 1992. The average staff gauge height for the season was 1.88 (Table A.51). The USGS gauge station was discontinued therefore the staff gauge height cannot be converted to discharge, although the heights can be compared for 1992 and 1993. Gauge heights less than 1.80 corresponded to flows that exposed portions of spawning riffles. These low flow conditions contributed to the settling of fine sediments and the proliferation of periphyton that quickly degraded the substrate for egg survival. Enhanced growth of periphyton was observed as early as March 10th, 1992. By mid-April, spawning substrates were severely degraded by matrices of colonial and filamentous periphyton. Very poor egg survival was observed for eggs attached to the periphyton.

In contrast, 1993 spring flows were much higher, driven by high precipitation in March and April. The gauge height averaged 2.18 for the season and fell below 1.80 only once, on May 28th. High flows contained potentially poor water quality from stormwater loads, but the scouring effect on the substrate was beneficial. When flows diminished in early May the substrate below Hancock Street was remarkably free of fine sediments and periphyton. The scouring of the earlier stormwater flows removed the fine sediment and algae that had degraded the bottom in 1992. The settlement of larger sediment further downstream degraded the spawning substrate near the lower limit of egg deposition. Despite the clean substrate observed in early May, by the end of May, periphyton growth had increased substantially, although did not reach the abundance seen in 1992.

Stream Discharge

Adequate water flow is essential to provide attraction to mature adults during the spawning run and for the survival of deposited eggs. A comparison of stream flow measurements and observations in 1992 and 1993 to previous flow records can provide useful information on the needed stream flow and depth for smelt during the spring spawning season. Stream flow measurements of 0.13 and 0.11 m^3/s during May of 1993 corresponded with observations of minor exposure of portions of the spawning riffles (Table 4.20). These flow measurements corresponded to staff gauge readings of 1.88 and 1.83, respectively. For both measurements the average depth of the transect was 0.23 m. No exposed habitat was noted for stream flows over 0.15 m^3/s or gauge heights over 1.90. It is likely that stream flow less than 0.10 m^3/s results in the exposure of substantial amounts of spawning substrate. The depth at the flow transect when the threat of egg exposure becomes significant is probably near 0.20 m. Such a depth at the narrow transect would correspond to an average depth of less than 15 cm with some exposed substrate at wider riffles downstream of Hancock Street where most egg deposition occurred.

The records from 1973–1980 indicate that the average of monthly mean discharges during March and April exceed 0.20 m^3/s, but not by a large margin. The mean May stream flow for this period was less than 0.20 m^3/s during all but two years. Most minimum stream flows observed during April and May for these years were close to the 0.10 m^3/s level that results in exposed substrate. It appears the threat of egg exposure could be an annual event given the relatively low base flows. This would certainly be the case for deposited eggs in late April or early May during a dry spring. Overall, the stream flow data portray a system where stormwater quickly pulses through the narrow width stream bed and several days after precipitation spring flows settle down below 0.30 m^3/s. During the smelt spawning season, base flows appear to range between 0.10 m^3/s and 0.30 m^3/s (3.5 - 10.5 cfs) , which may provide little buffer for deposited smelt eggs during dry seasons.

Blacks Creek Tidegates

While degraded spawning substrates appear to have a negative influence on egg survival, it is likely that other factors also contribute to the depressed state of the Furnace Brook smelt run. Most Massachusetts Bay smelt runs suffer from habitat degradation due to sedimentation and algae growth. Yet the egg densities observed at Furnace Brook are extremely low compared to that observed in smelt runs with similar spawning habitat area and conditions of flow and substrate. It is possible that the construction and operation of tide gates at Quincy Shore Drive has diminished the freshwater attraction to adult smelt seeking upstream spawning habitat. The constriction of the tide gates provides a narrow spatial zone for smelt to pass and mixes the water column thoroughly with each tidal exchange. Under this condition it is possible that the larger river systems nearby (Neponset, Fore, Back river) provide much greater attraction to adult smelt. Secondly, the altered flushing of the Blacks Creek Estuary due to the tidegate operations in the 1980s and 1990s may have degraded the quality of the estuary as nursery habitat for larval and juvenile smelt.

RECOMMENDATIONS

1. Stormwater Impacts on Spawning Habitat. The smelt spawning habitat in Furnace Brook appears to be degraded from nutrient and sediment contributions from stormwater flows in the urban watershed. It is recommended that an evaluation of the source and impact of stormwater pollutants in this watershed be investigated and new projects that seek to alter the drainage area of Furnace Brook should consider these concerns and make efforts to improve and not exacerbate existing conditions.

2. Sedimentation Remediation. In relation to recommendation number one, this evaluation should consider options for reducing the sediment load to spawning habitat in Furnace Brook. There is potential for an instream sediment sump to annually collect sediment upstream of Hancock Street. This and other sediment remediation options should be evaluated.

3. Low Base Flows. The smelt habitat monitoring provided evidence that base flows in Furnace Brook may typically be less than optimal for adult smelt attraction and egg survival. More information is needed on discharge conditions and their relation to spawning habitat. This concern is closely related to stormwater dynamics. Similar to recommendation number one, it is recommended that an evaluation of chronic low base flows be conducted and new projects that seek to alter the drainage area of Furnace Brook should consider these concerns and make efforts to improve and not exacerbate existing conditions.

4. Tide Gates at Quincy Shore Drive. The tide gates that regulate flows in and out of Blacks Creek may limit the attraction of adult smelt to Furnace Brook flows and restrict their opportunity to move upstream to spawning habitat. It is recommended that the City of Quincy review the operations of these tide gates and develop operational guidelines for the spring anadromous fish run. An evaluation of the tide gate influence on tidal hydrology in Furnace Brook and Blacks Creek may also identify tide gate modifications that will improve the overall ecology of the estuary.

NEPONSET RIVER

STUDY AREA

The Neponset River is one of six rivers flowing through the Boston Harbor Drainage System (Halliwell et al. 1982) into Massachusetts Bay. The headwaters of the Neponset River is the Neponset Reservoir in Foxborough. The river flows for 47.5 km from the reservoir to Dorchester Bay. The Neponset River watershed basin includes 14 towns and drains 303 km^2 (Wandle 1984). The Neponset River estuary and adjacent main stem are located in the metropolitan Boston area and have been exposed to urban development for decades. The river has been a major source of water for municipal supplies and hydro-power; there are currently 12 dams, and 19 MDEP permits for water withdrawals (Kennedy et al. 1995). The Neponset River estuary contains the largest salt marsh in Boston Harbor, providing habitat for many marine organisms. The Neponset River estuary was designated an Area of Critical Environmental Concern by EOEA in 1995, in order to improve the conservation of valuable natural resources in the estuary (Delaney and Wiggins 1995).

No previous studies have been conducted on smelt in the Neponset River, although the presence of a smelt population has been known for many years. The main spawning location for smelt in the Neponset River is found below the dam at Lower Mills (or Baker Dam) on the border of Dorchester and Milton (Reback and DeCarlo 1972). The dam is the first obstruction to fish passage in the river and tidal influence routinely approaches the habitat below the dam due to the proximity of the estuary. Smelt were also known to spawn in one tributary to the Neponset River, Gulliver Creek, in Milton (J. DeCarlo, DMF, *pers. comm.*). The 1967-68 DMF study on Dorchester Bay marine resources found smelt to be the fifth most common fish captured by all sampling gear combined (Chesmore et al. 1971). This study also mentioned a popular smelt sportfishery, noting that one marina operator estimated that 3,000 anglers fished from his floats during September, 1967. The fishery continues today, although catch and effort have declined significantly from the levels observed 30-40 years ago.

Four sample locations were selected within the Neponset River Basin for this study (Figure 4.5). The following two locations were monitored for egg deposition and sampled for water chemistry during both 1989 and 1990: the Lower Mills spawning habitat near the Adams Street bridge, and the MBTA train bridge immediately downstream of the former mill complex. The Gulliver Creek spawning habitat was monitored in 1989, and the Granite Avenue Bridge was selected as an ichthyoplankton sampling location for 1989 and 1990. During monitoring, the closest stream flow gauge station in Canton was too distant (70.5 km^2 drainage area) to provide comparisons to the sample station at Lower Mills. In 1996, the USGS established a new gauge station at Lower Mills (#011055566; drainage area = 262 km^2) (Socolow et al. 1998).

RESULTS

A large amount of spawning habitat is available to smelt in the Neponset River system. Based on the delineation of spawning habitat and observed egg deposition below the Lower Mills dam in 1989 and 1990, the Neponset River ranks as one of the largest smelt runs in the study area. The total area of spawning habitat available in both the Lower Mills and Gulliver Creek was estimated at 11,234 m^2. Greater details on the Neponset River monitoring are provided in a previous DMF report (Chase 1996).

Spawning Habitat

Lower Mills (main stem). Smelt egg deposition was routinely observed at Lower Mills in 1989 and 1990, allowing the delineation of spawning habitat area. An estimated 9,495 m^2 (Mass. GIS, 1990 data) of river substrate served as smelt spawning habitat at Lower Mills. The upstream limit of egg deposition was the Lower Mills Dam, and the downstream limit was the MBTA commuter rail bridge, approximately 334 m below the dam. A large majority of egg deposition was concentrated in the 100 m stretch below the dam. Few eggs were found near the train bridge, and none were found downstream of the bridge. High egg mortality was observed at the bridge, presumably due to the exposure of saline water at high tides.

Gulliver Creek. Spawning was found in 1989 over a straight and narrow (ave. width of 4.7 m) stretch of Gulliver Creek mostly upstream of the salt marsh. Approximately 1,739 m^2 of stream substrate was used by spawning smelt. The upper limit of smelt spawning was the culvert at the intersection of Christopher Drive and Squantum Street. The lower limit was approximately 370 m downstream of the culvert where the creek begins to meander into a dense patch of *Phragmites*. The creek bottom shifts from hard substrate to a silty marsh substrate about 50 m above this meander. A majority of eggs were found within 100 m of the culvert. A few eggs were found over the culvert lip, but no eggs were found more than one meter inside the culvert. No eggs were found upstream of Squantum Street where the creek comes out of the culvert, although suitable spawning habitat was present. The creek was sampled only in 1989 because of the relatively easy delineation of spawning habitat. Two station visits were made in 1990, finding lower egg densities than seen in 1989 and no eggs deposited upstream of the street culvert.

Spawning Period. The spawning period at Lower Mills was determined to begin in early March and end in late May for both seasons (Table 4.21). Spawning commenced during the first week in March during 1990 despite water temperatures close to zero. Peak spawning occurred in April both seasons, although heavy egg deposition was observed in 1989 from late March until early May. Estimates of egg

Figure 4.5 Smelt spawning habitat in the Neponset River system, with the downstream limit (green dot) and upstream limit (red dot) of smelt egg deposition displayed.

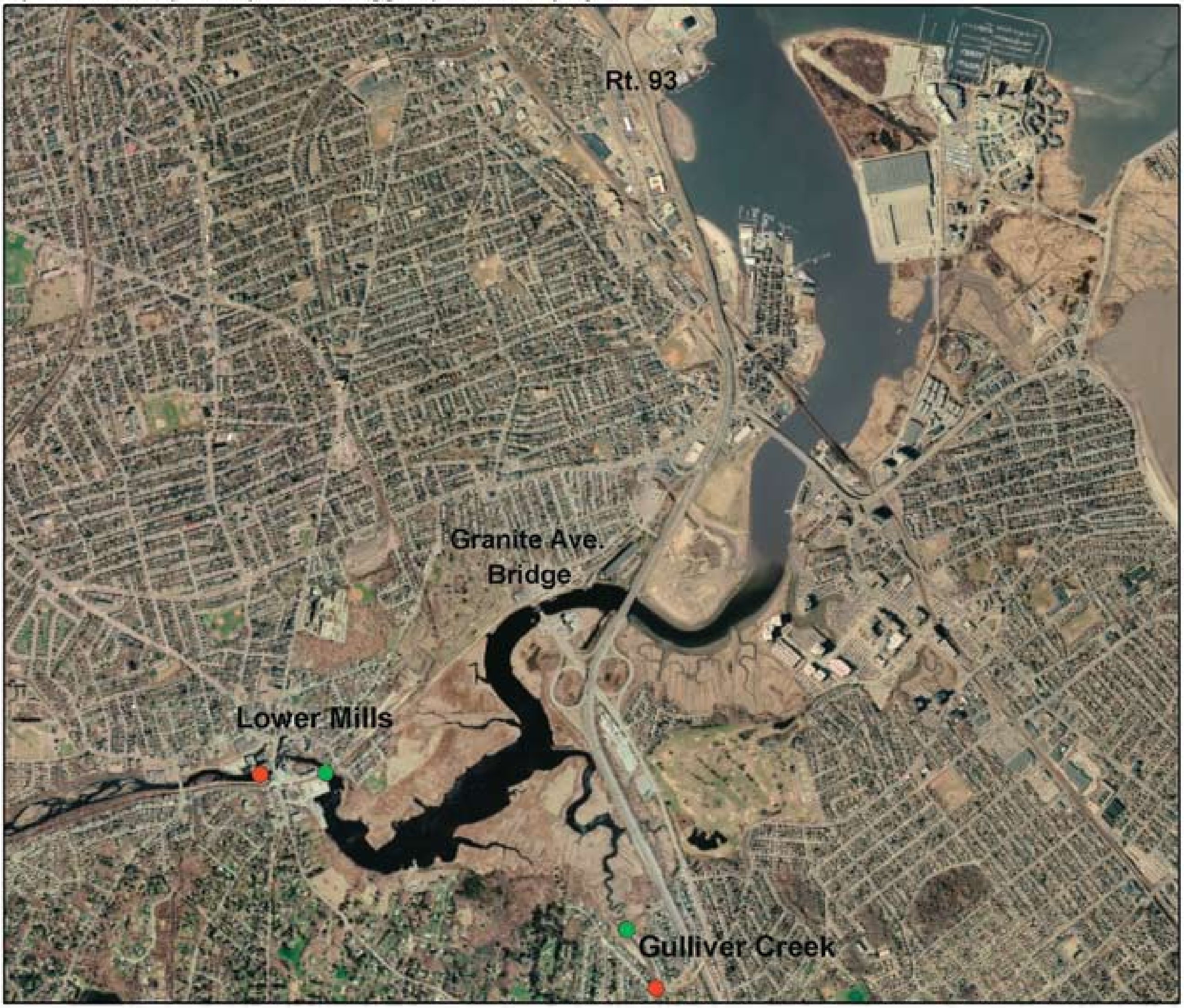


Table 4.21 Smelt spawning period at Lower Mills in the Neponset River, 1989-1990. The spawning period is an estimation based on observations of viable smelt eggs.

			Water Temperature (°C)			
Year	**Spawning Period**	**Days**	**Start**	**End**	**Range**	**Mean**
1989	March 12th - May 22th	72	3.0	19.0	3.0 - 19.0	10.2
1990	March 3rd - May 26th	85	1.0	14.0	0.0 - 18.0	9.4

production were not made, but it was obvious that egg production in 1989 greatly exceeded that in 1990. Adult smelt were commonly seen schooling below the Adams Street Bridge during the daytime for over two months in 1989, and very few were observed during 1990. The spawning period for Gulliver Creek occurred within the limits of the Lower Mills spawning period in 1989, beginning slightly later and ending slightly earlier.

Water Chemistry

Lower Mills. Water chemistry measurements were made downstream of Adams Street next to the walk-bridge to the former Ware Mill. For the parameters measured, water quality was suitable to support aquatic life (Table 4.22, A.53-A.54). Water pH averaged 7.3 for both seasons, indicating a capacity to provide buffering from acidic precipitation. All dissolved oxygen measurements were near saturation, providing adequate oxygen for aquatic respiration. Tidal influence was observed at the sample station during all high tides. The salt wedge commonly caused freshwater to back up and reduce the rapid flow below Adams Street. Tidal influence diminished upstream of Adam Street due to the large volume of freshwater coming over the dam, and its presence at the spillway was difficult to perceive during spring flows. It appears that spring flow conditions cause the salt wedge to taper off just below the bend in the river at the water chemistry station. Low salinity (1-2 ‰) was detected once on the surface and twice sub-surface in 1989 at this station, but not at all in 1990.

Neponset River Estuary. The surface flows at the MBTA bridge were freshwater dominated and consistently 0-3‰ for all measurements (Tables A.55-A.56). Bottom salinity showed more variation and averaged 16‰ in 1989 and 21‰ in 1990. Barnacles were commonly attached to the substrate below the bridge and the depths ranged from approximately 1.5 - 4 m. The stratification of estuarine waters was also evident lower in the estuary. Surface and bottom water measurements at the Granite Avenue station showed low salinity on the surface during most tide stages (averaged 10‰ in 1989 and 3‰ in 1990. and bottom salinity was higher and more consistent (averaged 23‰ in 1989 and 21‰ in 1990, Tables A.57-A.58). The water depth at the Granite Avenue station typically ranged between 3-6 m with the tides.

Gulliver Creek. Water chemistry measurements were made at the downstream face of the Christopher Driver culvert (Table A.59). These measurements were similar to water chemistry collected at Lower Mills in 1989. Tidal influence was routinely observed at the culvert within approximately two hours of high tide. The presence of tidal influence lowered water velocity and contributed to sediment deposition below the culvert.

River Discharge

The relationships between Neponset River flows and spawning habitat requirements are not well understood. This is an important resource management issue for the river because of the large number of water withdrawal permits and the expectation of increased water demand in the future. The USGS has recorded flow data at gauges upstream of Lower Mills for over 40 years but given the dynamic hydrology between river locations, the flows between upstream gauges and Lower Mills are poorly correlated (Kennedy et al. 1995). In 1994, USGS conducted discharge measurements to establish a water flow rating curve and installed a wire-weight gauge on the upstream side of the Adams Street bridge. The Neponset River Watershed Association set up a volunteer program to record both flow measurements from the Lower Mills gauge and observations of habitat conditions (Chase et al. 1997). This effort led to the installation of a continuous stream flow gauge station by USGS downstream of the Baker Dam in the fall of 1996. The monthly mean discharge values for the spring from 1997-2001 were: March - 658 cfs; April - 626 cfs; and May- 349 cfs. The lowest monthly mean discharge recorded during the smelt spawning period for 1995-2001 were 95 cfs in May 1995 and 140 cfs in May 2001. These lower flows did result in minor exposure of spawning substrate. Smelt spawning habitat was considered during a 1995 MDEP review of water withdrawal permits in the Neponset River. A minimum streamflow of 95 cfs for March-May was recommended to provide roughly 1 ft. of water depth for spawning smelt at Lower Mills (Kennedy et al. 1995).

Ichthyoplankton

Seven species of fish were collected in nine ichthyoplankton samples taken from the GraniteAvenue Bridge during 1989 and 1990 (Table 4.23, B.6). Smelt larvae were caught on two occasions and were found in the highest density, 1.6 larvae/100 m^3, among the seven species. Overall, the abundance of larvae in ichthyoplankton samples was low relative to other large estuary stations in the study area. Atlantic cod larvae were caught most frequently among ichthyoplankton (N = 3). An exploratory bottom net set on May 5th, 1989, caught a high density of dead smelt eggs (222/100 m^3), possibly an indication of a high rate of egg flushing from the upstream spawning habitat due to the dynamics of tidal influence below the dam.

Other Diadromous Fish

Historical records show that American shad and river herring were found in large numbers in the Neponset River prior to the advent of riverside industry and construction of dams in the 1700s (Chesmore et al. 1971). Belding's (1921) survey of anadromous fish reported that no shad or alewives existed in the Neponset River at the time due to industrial pollution and obstructions. The DMF survey in the 1960s confirmed the status of no shad or alewives due to pollution and obstructions, and stated that poor water quality prevents the restoration of these species (Reback and DeCarlo 1972). No mention was made in either report on the occurrence of blueback herring. The DMF survey of

Table 4.22 Water chemistry and weather summary for the Neponset River, Lower Mills, 1989-1990. Data are averages (Tables A.53-A.54) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Logan Airport, Boston (NOAA 1989 and 1990).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)
1989							
March	11	2.9	7.9	4.4	0.0	7.4	13.6
April	6	7.7	9.1	11.6	0.0	7.2	11.2
May	4	15.2	8.9	16.6	0.5	7.4	11.1
Season	21	8.6	25.9	8.8	0.0	7.3	12.3
1990							
March	8	4.5	4.3	4.5	0.0	7.4	12.9
April	8	8.7	15.0	9.4	0.0	7.3	11.6
May	7	12.7	16.5	14.6	0.0	7.4	10.6
Season	23	8.6	35.8	9.3	0.0	7.3	11.8

Table 4.23 Ichthyoplankton samples collected during 10 sample dates at the Granite Avenue Bridge station on the Neponset River, 1989-1990. Sizes are average total length for larvae and diameter for eggs. Larvae density is the absolute density collected in total sample volume.

Species		Type	FOC	Period	No.	Size (mm)	Density (No./100 m^3)
rainbow smelt	*Osmerus mordax*	larva	2	4/17 - 5/5	12	6.9	1.6
Atlantic cod	*Gadus morhua*	larva	3	3/10 - 4/21	4	11.0	0.5
grubby	*Myoxocephalus aenaeus*	larva	2	3/10 - 4/07	3	10.4	0.4
rock gunnel	*Pholis gunnellus*	larva	1	4/3	2	22.0	0.3
Atlantic silverside	*Menidia menidia*	larva	1	5/22	1	5.3	0.1
winter flounder	*Pleuronectes americanus*	larva	1	4/3	1	8.2	0.1
radiated shanny	*Ulvaria subbifurcata*	larva	1	5/5	1	5.5	0.1

Dorchester Bay of 1967-68 found relatively low numbers of adult alewives and bluebacks near the Neponset River mouth (Chesmore et al. 1971).

Blueback herring were observed on several occasions in 1989 while smelt were dipnetted at Lower Mills. Schools were observed with hundreds of individual fish. Identification was confirmed by catching a few individuals and examining the body cavity. On one occasion in May, 1989, several American shad were observed schooling with bluebacks just upstream of the Adams Street bridge. Smelt were schooling below the larger fish, allowing for the observation of all three species at once. The size of the schools and presence of suitable spawning habitat for bluebacks below the dam indicates a viable population of blueback herring exists in the Neponset River. The status of shad is not certain. DMF biologists have reported infrequent observations of a single or few individual shad in the Neponset River (K.Reback, DMF, *pers. comm.*). No other anadromous species were seen in Gulliver Creek. American eels were observed as live juveniles and dead adults at both Gulliver Creek and Lower Mills.

Other Surveyed Tributaries

Two creeks were surveyed on the north side of Neponset River for potential spawning habitat and were found to lack suitable substrate and freshwater flow for smelt spawning. Downstream of Rt. 93 an unnamed creek at the former drive-in theater (current DCR park) contained silty substrate and minor base flows. Upstream of Rt. 93 near the Cedar Grove Cemetery another unnamed creek had silty substrate and was primarily a tidal creek with little freshwater discharge. The Sagamore Creek on the south side of the Neponset River was also surveyed and found lacking suitable substrate and freshwater flow for smelt spawning.

Adult Smelt Composition

Adult smelt were collected by dipnet on six occasions in 1989 for the purpose of collecting size data on the Neponset River smelt run. Adult smelt were observed schooling in the daytime in pools at Lower Mills from mid-March to mid-May in 1989. Two daytime dipnet collections were made in March and four in April. One of the April collections was made at the Gulliver Creek spawning habitat. Smelt were measured to the nearest mm (N = 354) and sex was identified. The Neponset River length composition was compared to the length and age composition of smelt sampled from the Parker River during 1974-1975 (Murawski and Cole 1978), and the Jones River in the 1970s (Lawton et al. 1990) to estimate age structure. Scale ageing of Neponset River smelt was beyond the scope of this project and it was expected that distinct length modes would be comparable to the estimates of mean length at age from previous studies.

The length composition of Neponset River smelt displays two obvious age modes (Figure 4.6). The first mode, centered around 130 mm, represents age-1 smelt. The second mode, centered at 170-180 mm, represents age-2 smelt. Very few smelt were in the size range of age-3 Parker River smelt. All age-1 smelt were males, and the smallest female was 167 mm. Less than 1% of the males were possibly age-3: the largest male was 202 mm. The sex ratio was about 8:1, males to female, the same as that found in 1975 during the Parker River spawning run (Murawski and Cole 1978), and similar to the 9:1 ratio found in 1979 and 1981 in the Jones River (Lawton et al. 1990).

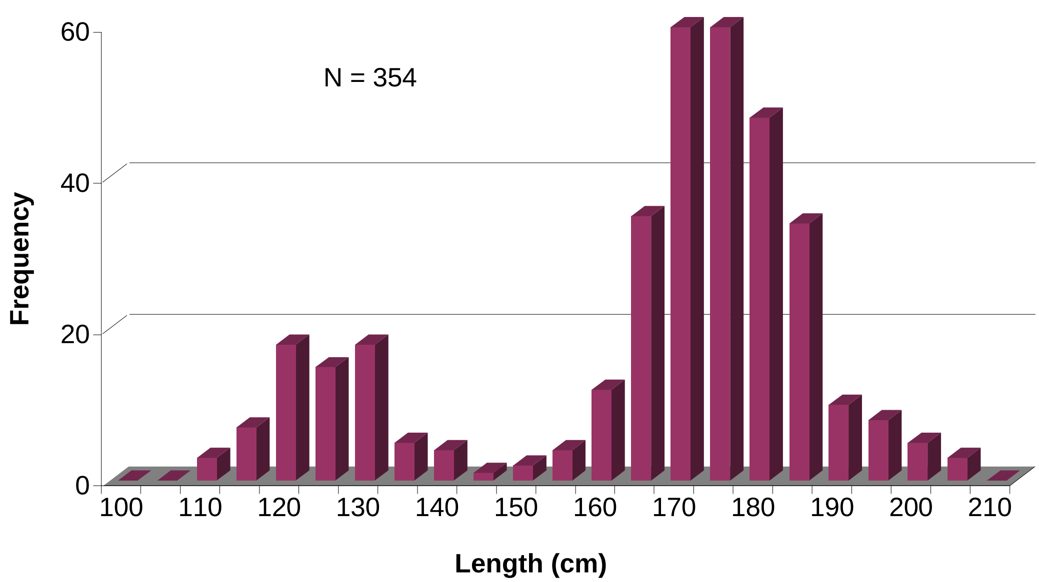
DISCUSSION

Based upon the observations made during monitoring, it is reasonable to conclude that the Neponset River contains one of the largest smelt runs in Massachusetts. This conclusion applies in terms of spawning habitat size, egg production and size of the local fishery. Two of the other larger smelt runs, Fore River and Back River, also flow into Boston Harbor. Along with the Neponset River, these three rivers probably account for much of the smelt production that sustains the smelt fishery in Boston Harbor, the only region on the Gulf of Maine coast of Massachusetts that continues to have an annual fishery that attract large numbers of anglers.

Similar to other smelt runs in the study area, information on the Neponset River smelt population is limited and population or fishery indices are not available. The general declining trend seen in smelt runs and fisheries in the study area appears to apply to the Neponset River, however, the Neponset River appears to have maintained a population that is relatively strong compared to most runs in the region. During the study period of 1988-1995, high densities of egg deposition were observed in the Neponset River during 1989, 1994 and 1995. The other years had much lower egg deposition and low densities relative to available habitat. The Boston Harbor smelt fishery during the 1994/1995 fall and winter was notable for higher catches than any other season in over a decade. This fishery was driven by the 1992 year class (age-2 smelt), which coincided with very low egg deposition observed in the Neponset River and other Boston Harbor smelt runs.

The viability of the Neponset River smelt run may be related to improving water quality and a large amount of available spawning habitat. It is possible that improving water quality since the time of Belding's report (1921) has been beneficial to anadromous fish populations and perhaps has allowed river herring to colonize the Lower Mills spawning habitat. Despite the relatively favorable condition of smelt in the Neponset River, the following

Figure 4.6 Length frequency of smelt collected with dip net at Lower Mills in the Neponset River, from March 24th - April 28th, 1989. Data are arranged in 5-cm bins.



indicators of potential negative impacts were observed and should be addressed.

Eutrophication. Excessive algal growth on smelt spawning habitat was observed at Lower Mills beginning in late-March. The algae grew as the water temperature warmed, resulting in a slimy, dark green or brown covering on most substrates. The algal growth could outpace the hatching of smelt eggs (8-15 days) and smother the eggs. By comparing egg survival on algae covered substrates to nearby patches clean substrate (due to shading), it was apparent that eggs deposited on early stage algae could suffer high mortalities. It is suspected that growth rates are enhanced by nutrient loadings in the river system. The MDEP Neponset River Watershed Assessment Report (Kennedy et al. 1995) conducted nutrient testing in the Neponset River and found that most locations have ammonia-nitrogen concentrations below the "conservative NH3-N criteria" of 0.21 mg/l. Additional information is needed on the influence of eutrophication on the survival of smelt eggs in the Neponset River.

Stormwater Pollution. Stormwater and nonpoint source discharges are recognized as contributors to water quality problems in the Neponset River basin (Leo et al. 1995). The MDEP Neponset River Watershed Report provides an assessment of stormwater and nonpoint source status and impacts (Kennedy et al. 1995). Direct impacts to smelt spawning habitat were observed in both Gulliver Creek and Lower Mills as street drains delivered sand and petroleum residues over natural substrates. Sand deposits from the Gulliver Creek culvert storm drain clearly reduced surface area of the spawning substrate, contributing to egg crowding and fungal growth.

Stream Flow. The MDEP Neponset River Watershed Report extensively evaluated water use in the Neponset River and recognized smelt spawning as the instream use most threatened by low flow conditions (Kennedy et al. 1995). The interaction between river flow conditions and smelt population spawning success is complex. While additional water withdrawals may take volumes of river water that are insignificant in relation to the total flow, it is the cumulative effect of many withdrawals that may impact anadromous fish. More information is needed to determine how declining discharges impact the habitat where eggs are deposited. These data will contribute to a quantitative approach for determining minimum flows requirements for spawning runs of anadromous fish.

Tidal Influence. Spawning activity from the previous night could easily be detected by the presence of viable eggs exposed on rocks by the receding tide. The resulting smelt egg mortality due to air exposure during ebb tide is an unfortunate problem that has probably existed since the dam was built. It is common in many other river systems, and in some cases may be considered a source of natural mortality. This problem is relatively severe in the Neponset River because the estuary is so close to the dam and a large volume of water is backed up with each high tide.

RECOMMENDATIONS

1. Watershed Nutrient Reductions. Elevated concentrations of nutrients have been identified in the Neponset River and are believed to foster the excessive growth of periphyton that degrades smelt spawning habitat. It is recommended that all municipalities in the Neponset River watershed adopt policies that reduce the consumption and transport of nutrients used in domestic and municipal applications.

2. Stormwater Treatment. Stormwater impacts to smelt spawning habitat is an ongoing concern in the Neponset River. It is recommended that all storm drains in the vicinity of anadromous fish spawning habitat be maintained and evaluated for performance, and that new construction along the river should use the best available technology for catch basins and stormwater control.

3. River Discharge Evaluations. More information is needed on the relationship between river discharge and anadromous fish spawning habitat in order to develop minimum flow requirements for in the Neponset River. It is recommended that investigations be conducted on the spawning requirements of anadromous fish in the Neponset River and that an interagency evaluation is made on incorporating these requirements into water withdrawal permits.

4. Gulliver Creek Culvert. The downstream face of the culverts that convene Gulliver Creek under Squantum Street create an obstruction to smelt passage further upstream. At higher tides, smelt can pass into the culvert. However, it appears that smelt crowd up to the culvert face, depositing large numbers of eggs in the 10 m below the culvert. In 1989, very high mortality of smelt eggs was observed as fungus spread through the crowded eggs. This location also suffers from sedimentation as road sand settles below the culvert and excessive predation mortality. It is recommended that the culvert face is modified to by lowering the vertical invert so smelt can easily pass upstream. Cobble can be added to the substrate below the modified culvert face to improve the suitability for smelt egg survival.

5. Smelt Population Enhancement. Very few smelt runs in Massachusetts produce enough egg deposition to allow removals for enhancement efforts of either egg transfers or hatchery enhancement. The Neponset River is one of the few with such potential and is favorable because of the opportunity to reduce the high egg mortality that occurs from air exposure during ebb tide. It is recommended that the Neponset River be considered a potential location for locating a smelt hatchery if feasible culture technology becomes available.

CHARLES RIVER

STUDY AREA

The Charles River is located within the extensive Charles River watershed basin (Halliwell et al. 1982) that includes 24 cities and towns. The river originates at Echo Lake in Hopkinton and flows for approximately 127 km to Boston Harbor (Reback and DiCarlo 1972). The lower Charles River flows through highly developed, urban areas of metropolitan Boston. The drainage area of the entire watershed is 805.5 km^2 (Wandle 1984). Many dams have been constructed along the Charles River for industrial hydropower. Of this type, the Watertown Dam is the furthest downstream, located about 13 km from Boston Harbor. A large dam was built at the mouth of the Charles River in 1910 to address the problem of sanitation pollution in the lower Charles River (CDM 1976). This structure drastically altered the hydrology and ecology of the Charles River by changing the lower river from an estuary to a freshwater basin. The Charles River dam was reconstructed in the late 1970s to replace the existing dam, improve flood control features and reduce saltwater intrusion into the lower Charles (CDM 1976).

Early in the 20th century, anadromous fish runs (alewife and shad) were thought to be eliminated in the Charles River due to passage impediments and severe industrial and sanitary pollution (Belding 1921). Reback and DiCarlo (1972) stated that a minor alewife run was found in the Charles River and smelt spawning was known to occur below the Watertown Dam in the 1960s. This area was visited on seven occasions in 1989 to confirm smelt spawning and roughly delineate spawning habitat. The Charles River was routinely monitored in 1991 with a spawning habitat station at the Watertown Dam and a water chemistry station at Rt. 20 (Beacon St. Bridge). Several USGS streamflow gauge stations are located on the Charles River. The closest gauges to smelt sampling stations are upstream of the Watertown Dam (#01104615, established 1999, drainage area = 694 km^2) and in Waltham downstream of the Moody St. Dam (#01104500, established 1931, drainage area = 650 km^2) (USGS, http://waterdata.usgs.gov).

RESULTS

Spawning Habitat

Smelt eggs were readily found in the riffle habitat below the Watertown Dam during seven visits in 1989. Smelt eggs were first found on March 15th, and high densities of eggs were observed during March visits. Egg deposition occurred throughout the area below the dam for 150 m downstream, and scattered eggs were observed for the next 100 m downstream towards the Rt.16 bridge. The Watertown Dam station was routinely monitored in 1991 and no smelt eggs were found during 21 visits. Once it was apparent that spawning was delayed or absent, efforts were increased to locate smelt eggs. From late March to early May, the substrate at prime spawning riffles was inspected for 20-45 minutes twice each week without finding a single egg. In contrast, in 1989 a single rock in the prime spawning riffles could have dozens to several hundred attached smelt eggs. The Watertown Dam station was visited during the peak spawning season from 1992-1996. During each season, a small number of smelt eggs (1-50) were found with similar effort as during 1991 visits. Collectively, these efforts allowed the delineation of smelt spawning habitat in the Charles River. The spawning habitat covered a river length of 311 m from the Watertown Dam to the Rt. 16 bridge (Figure 4.7). Most egg deposition occurred within 150 m of the dam, and few eggs are found within 100 m of the Rt. 16 bridge where depth increases and velocity decreases. The area of spawning habitat from the dam to the bridge was estimated as 9,896 m^2 (1:25,000 hydrography, Mass. GIS). The Charles River widens downstream of Rt. 16, resulting in decreased velocity, increasing depth and increased sediment deposition. These factors minimize the potential for attracting smelt spawning at downstream locations.

Spawning Period. Observations of egg deposition were not adequate to delineate the start and end of the spawning season in 1989 or any other year. Smelt eggs were found on the first visit (March 15th) and last visit (May 12th) in 1989. This time period is similar to the spawning period of large smelt runs in Massachusetts Bay. No smelt eggs were seen during routine monitoring in 1991 and the isolated observations of low densities of smelt eggs during 1992-1996 imply that limited spawning was occurring over a truncated season.

Water Chemistry

Watertown Dam. Water chemistry was measured 60 m downstream of the Watertown Dam on the south bank of the Charles River upstream of Laundry Brook. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 4.24, A.60). Dissolved oxygen was elevated by aeration as flows spilled over the dam, and most measurements were at or near saturation. Water pH averaged higher than neutral and during dry weather exceeded 7.5. Prior to the construction of the new Charles River Dam in the late 1970s, the salt wedge could reach the Watertown Dam during dry summers (CDM 1976). Presently, saltwater intrusion is limited to the lower Basin (Breault et al. 2000) and no tidal influence reaches the Watertown Dam.

Route 20 Bridge. Surface and bottom water chemistry measurements were made from the Rt. 20 bridge (Beacon St. Bridge) on nine occasions starting March 1st, 1991 (Table A.61). No additional measurements were made after the Hydrolab cable failed on April 15th. This location was selected to check water column stratification and to serve as a base for locating downstream spawning habitat. For the

Figure 4.7 Smelt spawning habitat in the Charles River, with the downstream limit (green dot) and upstream limit (red dot) of smelt egg deposition displayed.

Table 4.24 Water chemistry and weather summary for the Charles River, Watertown Dam, spawning habitat station, 1991. Data are averages (Tables A.60) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Logan Airport, Boston (NOAA 1991).

Sample Period	**Station Visits** (No.)	**NOAA Air Temp.** (°C)	**NOAA Rainfall** (cm)	**Water Temp.** (°C)	**Water Salinity** (ppt)	**Water pH**	**Water D.O.** (mg/l)	**Water Sp. Cond.** (mmho/cm)
1991								
March	9	5.3	11.0	6.1	0.0	7.1	12.7	0.304
April	8	10.7	12.3	12.6	0.0	7.4	11.5	0.308
May	4	17.4	2.3	21.0	0.0	7.5	8.6	-
Season	21	11.1	25.6	11.4	0.0	7.3	11.5	0.305

period sampled, there was little difference in the parameter values measured at the Watertown Dam station. There was no salinity measured or elevated conductivity. The average depth was 2.5 m and there was no evidence of stratification during this period.

River Discharge.

The USGS streamflow gauge station downstream of the Moody Street Dam in Waltham provides an excellent record of Charles River discharges. The monthly mean discharge values for the spring spawning period from 1932-2001 are: March- 627 cfs; April – 610 cfs; and May – 363 cfs. The flow data displays much variation in mean spring flows with no clear series trend (Figure 4.8). March and April flows peak at over 1,000 cfs and April and May lows occasionally decline below 200 cfs. Mean discharges in the springs of 1989 and 1991 were similar to the series means for March, April and May. The Watertown Dam gauge station began operation in the fall, 1999. The spring mean discharge values in 2000 were 20-30% higher at the Watertown Dam station than the Moody Street Dam station upstream. Water velocity measurements were made at two transects (at Laundry Brook and 100 m downstream) across the spawning riffles below the dam on three dates in 1991. Very swift flow was found at the upstream transect and along the north bank at both transects (>1.0 m/s). The mean velocity of all transect measurements ranged from 0.55 to 1.11 m/sec.

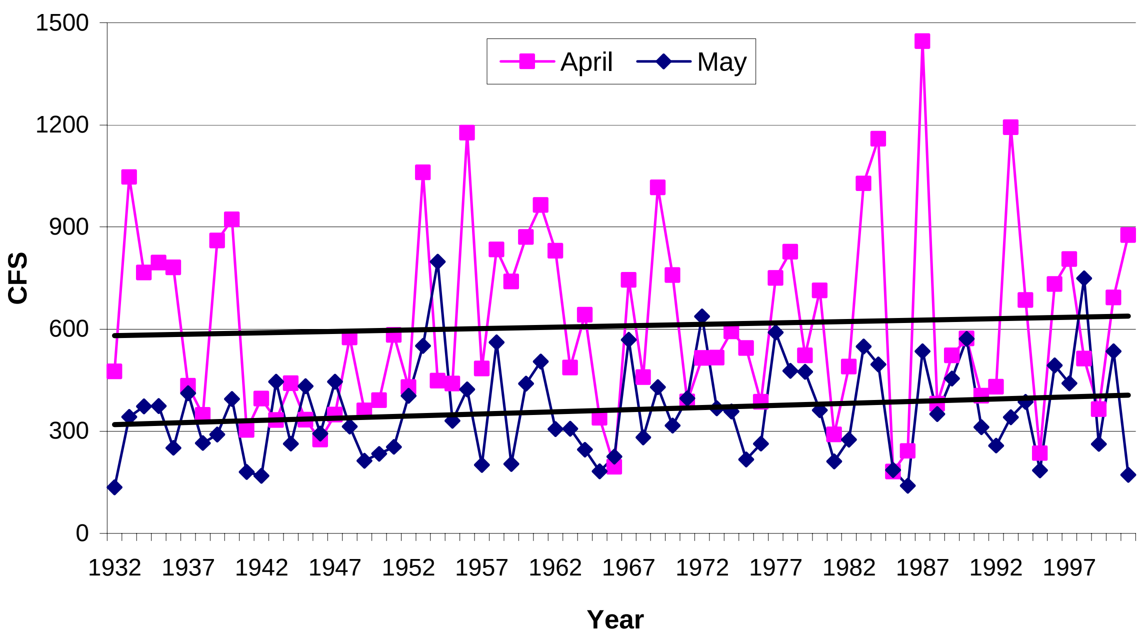
Other Diadromous Species

The river herring population in the Charles River during the 1990s appears to have improved from the absence reported at the turn of the 20th century (Belding 1921) and low levels in the 1960s (Reback and DiCarlo 1972). Large numbers of river herring (primarily blueback herring) run up the Charles River each spring, and DMF uses this run as the main source for stocking blueback herring in other systems (Phil Brady, DMF, *pers. comm.*). While routinely checking for smelt eggs during 1989, 1991, and 2002, spawning events with heavy egg deposition occurred below Watertown Dam between May 9th and May 15th. Eggs were collected on each occasion and identified as blueback herring after hatching. American shad were stocked in the Charles River during the 1970s and 1980s, and some returns were documented by the occasional capture of an adult shad while collecting bluebacks at the Watertown Dam (Phil Brady, DMF, *pers. comm.*). White perch have been reported in the Charles River by local fishermen and a single dead adult white perch was found in April, 1989 at the Watertown Dam. American eels are thought locally to be common but declining in the Charles River. Glass eels were seen at the Watertown Dam while monitoring for smelt eggs. An uncommon occurrence of gizzard shad (*Dorosoma cepedianum*) was documented in June 2000, when I identified an adult gizzard shad caught by a fisherman at the Watertown Dam.

Other Surveyed Tributaries

No other tributaries to the Charles River were identified as having potential to support smelt spawning habitat. The Watertown Dam is the upper limit to smelt passage in the Charles River. Laundry Brook is located about 50 m downstream of Watertown Dam and some smelt eggs have been found at the confluence of Laundry Brook and

Figure 4.8 Charles River monthly mean discharge in April and May at the Waltham USGS Station (#01104500), 1932-2001.



Charles River. The brook goes into an underground culvert shortly after the confluence and passage is obstructed by an elevated spillway. A small amount of habitat adjacent to the main spawning riffle below the Watertown Dam can receive egg deposition. For this reason, the spawning habitat was considered part of the main stem river. The Muddy River was also surveyed where it meets the south side of the Charles River at Back Bay. No potential spawning habitat was found in this highly altered and degraded drainage.

DISCUSSION

The monitoring of smelt spawning habitat in the Charles River confirmed an existing smelt run and documented general characteristics of the spawning run. However, the description of this spawning run leaves some questions unanswered. High densities of smelt eggs were found in 1989 over a large area of spawning habitat. These observations suggested that the size of the Charles River smelt run ranked highly among all river systems monitored in this program. Yet, no smelt eggs were found in 1991 with routine monitoring. In most years since then very low numbers of smelt eggs have been found below the Watertown Dam. I suspect that smelt in the Charles River are challenged by impediments to passage at the Charles River Dam and habitat degradation related to water quality. These factors may be chronically reducing recruitment success over the last few decades, resulting in the observations of low spawning activity in the 1990s.

The smelt spawning habitat in the Charles River is unlike any other smelt run in Massachusetts. Smelt must first pass the locks at a river mouth dam that was built to keep saltwater out and not designed with consideration for their spawning migration. The riffle habitat below Watertown Dam is 13 km upstream from the locks, with wide stretches of freshwater habitat over much of that distance. For every other smelt run in the study area, smelt use the flood tide to aid their migration to freshwater riffles slightly upstream of the salt wedge. Once reaching the Watertown Dam riffles, smelt find suitable depth, velocity and gravel/cobble substrata, although excessive periphyton growth raises concerns over egg survival.

Fish Passage at the Charles River Dam. Little information is available on the Charles River smelt run prior to the construction of the replacement dam in 1978. Anecdotes from local fisheries indicate it was traditionally a large spawning run. The construction of the dams certainly limited smelt passage by eliminating the movement of the flood tides into the lower Charles River. The 1978 dam included a large boat lock, two small boat locks and a vertical slot fishway that was designed to primarily pass alewife and shad. The fishway operates both by gravity flow and pumping depending on tide stage. The fishway has never performed as planned, due to a combination of poor design, pump failure and insufficient maintenance. The fishway location may be the primary reason for poor function. The fishway is located on the north side of the dam at the harbor entrance, well removed from the locks and main channel. On either side of the fishway are sluiceways designed to move water out of the basin. During typical spring conditions these sluiceways are operating frequently, discharging large amounts of high velocity water that obscures the much smaller fishway discharge. Under these conditions, very few fish enter the fishway.

River herring may have actually prospered in the Charles River in the latter half of the 20th century. There are no indices of abundance for anadromous fish populations or fisheries in the Charles River. However, reports from local fisheries and observations from DMF activities clearly suggest that river herring runs have remained strong in the 1980s and 1990s while the smelt run has sharply declined. River herring appear to benefit from the increase in boating activity that coincides with their spawning migration later in the spring than the smelt run. Unlike smelt, river herring will also seek to move upstream in the day and the lock operators will routinely lock through schools of herring upon sighting. Smelt are seeking to move upstream in February and March and encounter few lock openings and a poorly located fishway that is often obscured by sluice flow.

Concerns over declining smelt runs prompted DMF to contact MDC in 1989 to discuss fish passage problems at the Charles River Dam. A letter was sent out that year and each year since requesting that lock openings are conducted to facilitate smelt passage past the dam. Recent letters have requested openings from February 15th to April 30th and have sought an interagency review of fish passage issues at that dam (Letter from P. Diodati, DMF Director, 2001). Outstanding questions remain over the impact of the dam on fish passage, the affect of locking to date, the optimal locking protocol, and the status of the smelt population.

Water and Habitat Quality. Water quality in the Charles River has suffered greatly because the highly develop watershed has depended on the Charles as a conduit to transport stormwater and wastewater. As recently as the 1970s, wet weather discharges of raw sewage were common from CSOs in the Charles River (CDM 1976). Substantial water quality improvement has been achieved in the 1980s and 1990s through reduction of wastewater discharges, although stormwater remains a primary concern. Currently, the Charles River is the focus of an extensive initiative to restore the Charles River Basin to fishable and swimmable conditions by 2005 (EPA 2002). Water quality monitoring in the lower Charles River has identified high levels of nutrients, particularly phosphorus, as evidence of eutrophication (CDM 1976; Fiorentino et al. 2000; EPA 2002). The 1997 MDEP assessment of the Charles River found the benthic community near Watertown Dam was degraded in response to nutrient enrichment (Fiorentino et al. 2000). Observations from the DMF smelt monitoring and recent investigations (B.Chase, unpublished data, DMF) indicate that the periphyton growth at the spawning riffles below Watertown Dam is high relative to other smelt runs in the study area and the substrate is not favorable to high survival of attached smelt eggs.

Other Concerns. The construction of the dam at the mouth of the Charles River has possibly caused negative impacts on the smelt population other than those related to adult smelt passage. Upon hatching, smelt larvae move passively along freshwater flow into the estuary where they are retained by the ebb and flow of the tide in a highly productive environment to forage on marine zooplankton. In most smelt runs this movement into the estuaries occurs very quickly. In the Charles River, this process has been greatly altered by the elimination of tidal flow, and there may be suboptimal foraging opportunities for larval smelt as they slowly move downstream in the freshwater basin.

There are also concerns of increased predation pressure on smelt in the Charles River. Observations of aggregations of seals, gulls and cormorants on the harbor side of the dam in March suggest that the impediment of the dam may improve foraging opportunities for wildlife feeding on smelt. Also the long journey within the freshwater basin may expose schools of smelt to greater predation than in most river systems. I have observed largemouth bass and bullheads (1-2 kg) and striped bass (5-10 kg) feeding on river herring in May in the shallow riffles where smelt spawn below Watertown Dam. And the Watertown Dam contains large numbers of resident freshwater fish (white sucker and yellow perch are common) not usually seen at typical smelt spawning riffles. Although direct feeding on smelt has not been observed, the obstruction of the dam and prolonged period in freshwater may expose smelt to predation not experienced elsewhere, in Massachusetts.

RECOMMENDATIONS

1. Charles River Dam passage. The issue of anadromous fish passage at the Charles River Dam should be revisited with a high level of interagency review. Fish passage protocols for smelt and other anadromous species should be refined and included in the dam's Operation and Maintenance Manual.

2. Smelt Habitat Monitoring. The smelt spawning habitat in the Charles River should be monitored extensively for two years to determine the present status of the smelt run and assist efforts to improve passage operations at the Charles River Dam. The monitoring should use the methods previously deployed with inclusion of periphyton and nutrient monitoring.

3. Smelt Habitat Enhancement. An investigation should be made to determine if additional smelt spawning habitat can be created downstream of Watertown Dam, to increase available spawning habitat and reduce the distance smelt must travel. It may be possible to add suitable substrate at downstream constrictions (primarily bridges) where velocities could be increased and depth could be decreased without impacting navigation.

MYSTIC RIVER BASIN

STUDY AREA

The Mystic River watershed basin includes the Mystic, Malden, Chelsea and Aberjona rivers and several lakes, ponds and smaller tributaries (Halliwell et al. 1982). Mystic River flow originates in the Aberjona River, which runs into the Upper and Lower Mystic Lakes in Arlington and Medford. The Mystic River flows from the Lower Mystic Lake for 11 km to the inner harbor of Boston. The Amelia Earhart Dam is located in tidal portion of the Mystic River, just downstream of the Malden River's confluence with the Mystic River. The dam contains locks for boat traffic, but upstream tidal movement is prevented, resulting in a freshwater environment above the dam. The drainage area of the Mystic River at the Amelia Earhart Dam is 162.4 km^2 (Wandle 1984). A USGS stream flow gauge station has operated on the Aberjona River since 1939 (Socolow et al. 1998).

The Mystic River was not known as a smelt run at the time of monitoring. The Mystic River and Lower Mystic Lake received tidal influence until the construction of the Craddock Dam in downtown Medford in 1908 (MDC 1994). Belding (1921) noted the presence of the dam in Medford that obstructed river herring passage and tidal flow. By the time of Reback and DiCarlo's survey (1972), the Craddock dam was down, the Amelia Earhart Dam was constructed (1966), and the river herring run to the Mystic Lakes appeared to have improved since Belding's report. Both these reports do not mention smelt in the Mystic River. However, local anecdotes imply a smelt run may have occurred in the Mystic River in the 1960s and early 1970s, and a DFW fish survey in the Lower Mystic Lake caught 111 adult smelt (15-25 cm) in April, 1977 (Lindenberg 1977).

The following locations were surveyed for potential smelt spawning habitat in 1990: Lower Mystic River Lake, Mill Brook (Arlington), Alewife Brook (Arlington), Malden River, and Mill Creek (tributary to Chelsea River). No locations possessed likely spawning habitat and it was clear that the Amelia Earhart Dam was a substantial obstruction to upstream passage for all locations except Chelsea River. Mill Brook and the base of the dam at the Mystic lakes were selected as monitoring stations for 1991 as they were the only locations with riffle habitat. A water chemistry station was also selected at the Rt. 16 Mystic River bridge.

RESULTS

No smelt eggs or adult smelt were found at the Mystic Lake and Mill Brook monitoring stations during 22 visits in 1991. The spillway below the Mystic lakes dam provided marginal conditions of depth, velocity and substrate for smelt spawning, and Mill Brook contained a short stretch of irregular cobble substrate that could possibly serve as spawning habitat. Both locations possessed only a few 100 m^2 of substrate that had potential as smelt spawning habitat.

Water Chemistry

The spring water chemistry for the parameters measured at the two stations appeared adequate to support aquatic life (Table 4.25, A.62). Mean dissolved oxygen, pH and specific conductivity were similar for the two stations. The water coming from Upper Mystic Lake in the spring was slighter cooler and more alkaline than water in Mill Brook (Table A.63). Water chemistry was measured on eight dates at the Rt. 16 bridge in the Mystic River in order to detect tidal influence or stratification (Table A.64). The wide river channel contributed to very low water velocity at this location. Depths ranged from 1.7 m to 2.8 m in the mid-channel below the bridge. No salinity was detected and the water column was fully mixed.

River Discharge.

A USGS streamflow gauge station (#01102500, http://waterdata.usgs.gov).) is located 0.8 km upstream of the Upper Mystic Lake in Winchester, covering a drainage area of 62.4 km^2. The river flow at this location is influenced by diversions for industrial uses and municipal supplies for Winchester and Woburn. The monthly mean discharges for the period of 1939-2001 were 65.6 cfs for March, 54.2 cfs for April, and 33.4 cfs for May. The discharge records for 1991 (43.5 cfs for March, 40.0 cfs for April, and 28.2 cfs for May) indicate the flows were lower than average during that year.

Table 4.25 Water chemistry summary for sample stations in the Mystic River Basin, 1991. Data are averages for March - May (Tables A.62-A.63) except station visits and NOAA are total values. Air temperature and rainfall data were recorded at Logan Airport, Boston (NOAA 1991).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
Mystic Lake Dam	22	11.1	25.6	9.4	0.0	7.5	11.5	0.527
Mill Brook	22	11.1	25.6	10.7	0.0	7.2	11.5	0.593

Other Diadromous Species

A large alewife population is known to spawn in the Lower Mystic Lake (93 acres). This population presently ranks highly among alewife runs in Massachusetts north of Cape Cod. The run is known to contain a mix of blueback herring as well as alewife. It was known to be a large run during Reback and DiCarlo's survey (1972), but was described as having few fish by Belding (1921) in the early 20th century. A dam (1.8 m spillway height) connecting the Lower and Upper Mystic lakes (166 acres) presently prevents passage into the Upper Mystic Lake. Alewives are also known to run into Alewife Brook which occurs below the Mystic lakes and Mill Brook, a tributary running into Lower Mystic Lake. The first sign of alewives in the Lower Mystic Lake in 1991 was observed on April 8th. Few fish were seen below the Mystic lakes dam until early May. On May 15th, the numbers seen increased dramatically, as tens of thousands of alewives were crowded into the flow at spillway. Substantial scale loss and some mortality were observed as fish pushed up against the dam. Several fishermen were observed each trip in May collecting alewives for bait or roe. A few dozen alewives were observed in Mill Brook, but only on two dates in late May.

Other Surveyed Tributaries

Malden River. No potential smelt spawning habitat was found in the Malden River. The Malden River is located upstream of the Amelia Earhart Dam, therefore smelt passage into the Malden River is obstructed. The main stem Malden River leads into a culvert which runs underground beneath downtown Malden. The river runs underground for over 1.5 km before daylighting. No spawning riffles were found, little base flow occurs during dry weather and stormwater quality is highly degraded. Similar conditions were found at two Malden River tributaries also surveyed on the Medford/Malden border and in Everett along Rt. 16.

Alewife Brook. No potential smelt spawning habitat was found in Alewife Brook. The substrate was primarily covered with fine sediments and water velocities were too low to create riffle habitat. The water quality appears degraded due to the low flow and urban stormwater influences.

Chelsea River (Mill Creek). Mill Creek was surveyed in 1990 and 1991 and was not selected for routine monitoring because of the absence of suitable spawning riffles. The creek was significantly altered by construction related to the Rt. 1 ramp and upstream channelization. Downstream of Rt. 1 the creek runs through salt marsh and receives saline water during flood tides. The substrate along the marsh is primarily lined with fine sediments. The creek passes under Rt. 1 in wide culverts designed to facilitate stormwater drainage and is convened in an open, concrete-lined bed upstream of Rt. 1. No potential spawning habitat was found upstream of Rt. 1 and flows were primarily tidal ebb and stormwater. Little dry weather discharge was detected in Mill Creek.

In response to reports of smelt runs in the Chelsea River within the last 30 years (Peter Santini, Fishing Finatics, Everett, *pers. comm.*), I revisited the Chelsea River in the late 1990s. Single visits were made from 1998-2001 during the peak spawning period to survey Mill Creek on both sides of Rt. 1. Smelt eggs were found in 1998 (4) and 1999 (5) at the same creek bend in the marsh below Rt. 1. Only two eggs were viable, and no eggs were found in 2000 and 2001. The creek bend abuts a parking lot and has received dumped gravel and trash. The bend and irregular substrate apparently creates enough turbulence to attract a few adult smelt. On both sides of the bend, the substrate contains fine sediments and water flow velocities are low. The habitat where eggs were located was measured at 33 m in length and containing 127 m^2 of potential spawning substrate at low tide. This habitat receives saline water during flood tide; as evident by the presence of attached barnacles and marine macrophytes. Based on these egg observations, Chelsea River is designated as a smelt run.

DISCUSSION

Observations in 1991 gave little reason to expect the existence of a smelt run within the Mystic River Basin. The presence of the Amelia Earhart Dam appears to fully obstruct smelt passage upstream and has eliminated the Mystic River estuary which may have formerly contained spawning riffles for smelt near the interface of tidal flow and freshwater from downtown Medford to the inlet at Lower Mystic Lake. Presumably, spawning habitat in Mill Creek was degraded by the Rt. 1 ramp construction and flood control structures, however, evidence of either a remnant smelt run or a few adults colonizing from a nearby population was recently found.

The only confirmed record of smelt in the Mystic River Basin is the DFW survey that caught smelt in Lower Mystic Lake in 1977 (Lindenberg 1977). Despite sparse documentation of a former smelt run in the Mystic River, anecdotal reports support the likelihood that a smelt run occurred in the Mystic River prior to the completion of the Amelia Earhart Dam in 1966. A dam operator at the Amelia Earhart dam reported that during his first year working at the dam in 1967 he observed large numbers of smelt milling about the harbor side of the locks (Mark Connolly, MDC, *pers. comm.*, 2002). These observations continued for a few years, then quickly faded in the early 1970s. During 1991 monitoring, I questioned five freshwater bass fishermen with at least 25 years of experience on the Mystic Lakes about the local occurrence of smelt. Two of the five had heard of smelt in the Lower Lake about 30 years ago, and the others were not aware of smelt in the basin.

It appears likely that a smelt run did formerly occur in the Mystic River and the construction of the dam presented an immediate obstacle to the spring spawning runs of smelt. Large numbers of adult smelt returned for a few years and it is possible that some smelt moved upstream of the dam via lock openings for early season boat traffic. Unfortunately, it appears that the blockage of tidal fluctuations and the raising of the basin elevation with freshwater eliminated upstream spawning riffles. The combination of the passage obstruction and loss of habitat resulted in the rapid elimination of the smelt population. This situation is similar to the Charles River, where the dam has greatly limited smelt passage. However, the Charles River smelt spawning habitat is far enough upstream that no changes were made to the riffle habitat. With this difference, the Charles River smelt run still occurs after 30 years (at very low levels) and the Mystic River run is gone.

The influence of changes in water quality in the Mystic River basin on anadromous fish populations is not known. Belding (1921) referred to severe water pollution problems in the Mystic River basin related to factory discharges. Anaerobic conditions have occurred in bottom waters of the Mystic Lower Lake since the Craddock Dam was constructed due to the trapping of saline waters in two deep holes (Process Research 1974). The extent of the anoxic bottom layer has been since reduced by a pumping project and natural flushing (DiPietro 1994). Sewage discharges have been greatly reduced in the basin and industrial pollution sources have been largely eliminated, although contaminated sediments are still a concern (Aurilio et al. 1994). Stormwater impacts and eutrophication are a growing concern in the basin. The increase in the size of the alewife run from Belding's era to the 1960s is an encouraging sign that benefits from improved water quality may have occurred.

The current status of smelt in the Chelsea River is uncertain and no documentation was found on a former run in that river. It appears that a few adult smelt have spawned in Mill Creek in recent years. These smelt could be remnants to a viable population that was impacted by the flood control changes made to Mill Creek, or strays from a nearby run that encountered the small amount of spawning habitat in the marsh. This habitat in its present state cannot sustain a large run of smelt. The potential smelt spawning habitat is limited further by extremely low freshwater base flows that have resulted from the alterations to Mill Creek drainage.

RECOMMENDATIONS

1. Mystic River Spawning Habitat. An evaluation should be conducted to determine if alterations could be made to the river bed in the Mystic River to create smelt spawning habitat. It is possible that riffle habitat could be constructed in Medford locations where the river channel is narrow but velocities and substrate are not suitable. If a feasible location is identified, a Mystic River smelt restoration project could be developed that included habitat restoration, locking protocols at the dam, and smelt population enhancement.

2. Amelia Earhart Dam Locking Protocols. The 1991 monitoring did not identify suitable spawning habitat for smelt in the Mystic River basin. If habitat can be created, it may be possible to restore smelt to the river by initiating a locking protocol for smelt to facilitate their passage prior to the late spring increase in boating traffic. This protocol should be developed under the authority of DMF and close coordination with DCR.

3. Evaluate Restoration of Tidal Flushing. The construction of the Amelia Earhart Dam has impacted the smelt population and certainly degraded estuarine habitat upstream of the dam for numerous species. An evaluation should be conducted to determine if the locking system can be operated to allow limited tidal flushing in a manner that is compatible with existing flood control operations. The exposure just a small portion of the lower Mystic River to tidal influence could restore a large acreage of subtidal habitat.

4. Mill Brook Culvert Cleaning. The culvert at the confluence of Mill Brook and the Lower Mystic Lake is prone to blockage by debris each spring and this has been observed to restricted river herring movements into Mill Brook. It is recommended that local authorities routinely clean this culvert prior to each season's spawning run.

5. Chelsea River Restoration. The Chelsea River does not currently possess suitable conditions to make this system a high priority for smelt restoration. However, the presence of low numbers of smelt should be noted by local and state authorities. If large-scale drainage or highway projects are proposed adjacent to Mill Creek, an evaluation should be conducted on improving flow conditions and spawning habitat for smelt.

CHAPTER 5. NORTH SHORE REGION

The North Shore region surveyed for this study included all coastal streams found within embayments from Broad Sound to Essex Bay. The North Shore Coastal Drainage Area is designated as a specific drainage area based on hydrologic features (Halliwell et al. 1982). A total of 55 specific locations were surveyed within the following river systems or geographical areas: Saugus River, Salem Harbor, Danvers River, Manchester Bay, Cape Ann, and Essex River. From these surveyed locations, 19 stations were monitored as potential smelt spawning habitats between 1988 and 1991. Smelt spawning habitat was identified at 12 locations within the six river systems/areas (Figure 5.1 and Table 5.1).

Most of these smelt runs were relatively small; containing less than 500 m^2 of suitable substrate for spawning habitat. The Saugus River, North River and Essex River contained the largest amounts of spawning habitat where egg deposition was observed. All other spawning habitats were found to have egg deposition at less than 900 m^2 of substrate.

Nine of the locations where smelt eggs occurred were small streams with minor discharge (<0.5 m^3/s, mean April discharge). Four of the spawning habitats were not designated as spawning runs during the monitoring period. Two small creeks in Cape Ann (Sawmill Brook and Mill Brook) were overlooked during monitoring and may or may not represent discrete annual smelt runs. The North River appears to have had smelt recently colonize the spawning habitat after decades of severe water and habitat degradation. The North River presently has a very small smelt run, although nearly 6,000 m^2 of potential spawning habitat is available. The Crane River now has a small run of smelt after a DMF restoration project provided smelt access to 2,000 m^2 of spawning habitat and transferred smelt eggs during 1995-1997 (Chase et al. *In prep.*).

The average starting date of the smelt spawning period in the North Coastal Basin was March 25th and the average ending date was May 17th. Peak spawning typically occurred from the end of March through the first three weeks of April. The average duration of the spawning period was 52 days and the average starting water temperature was 6.3 °C. For all rivers combined, the total range of dates when smelt eggs was observed was March 11rd to May 27th. The onset of spawning in several drainages (Shute Brook and Manchester Bay creeks) began at the end of March or early April, in contrast to a mid-March start for most runs in Massachusetts.

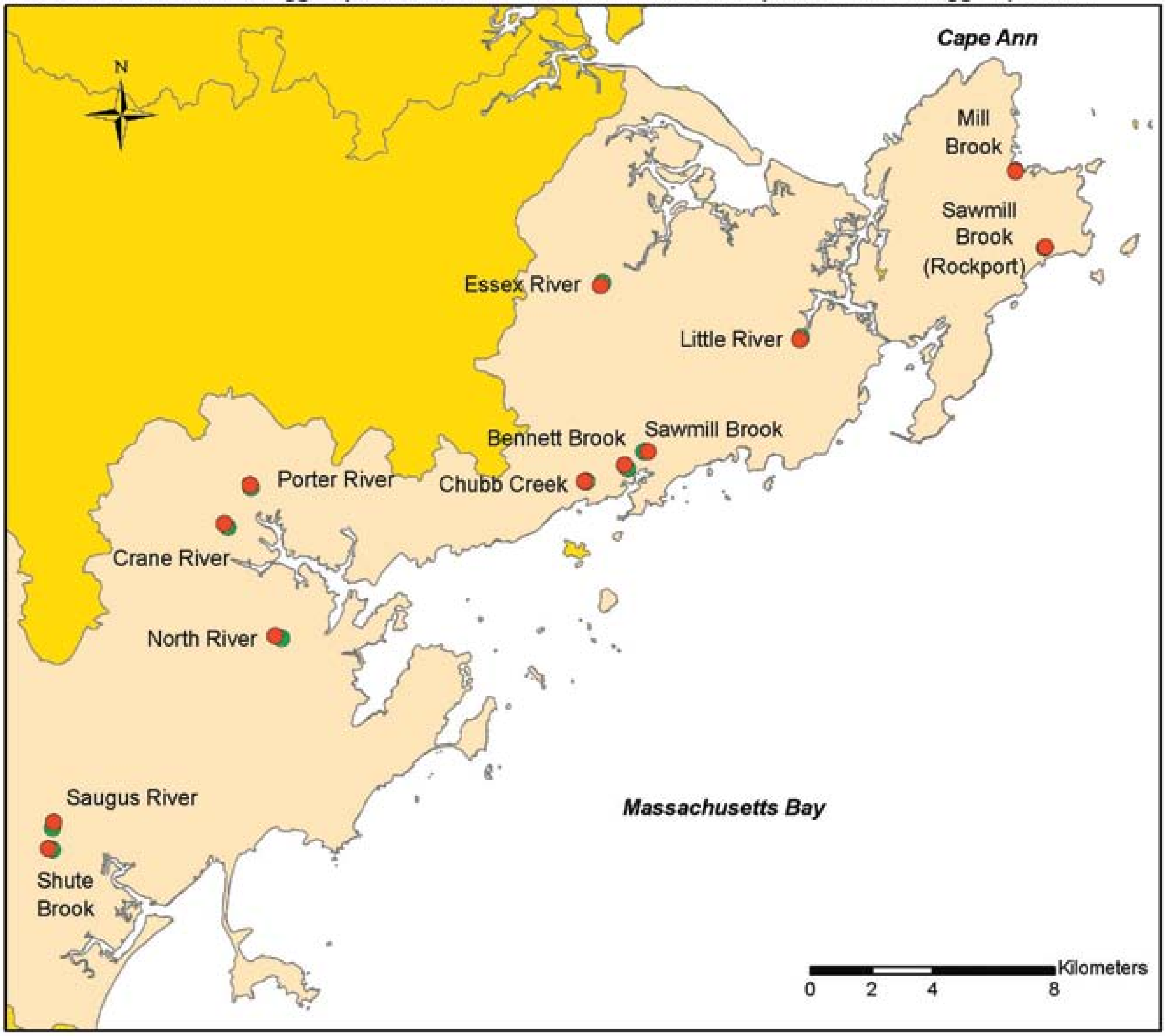
Water chemistry was monitored at all smelt spawning habitat stations and 11 additional marine/ichthyoplankton stations. The water chemistry at the spawning habitat stations was adequate to support aquatic life considering the parameters measured. Dissolved oxygen was near saturation for most measurements during the spring spawning period. Water pH at some rivers in this region was subject to depressions below 6.5 following precipitation, especially at the creeks overlaying bedrock in Cape Ann and Manchester Bay.

Ichthyoplankton collections were made at nine stations where suitable sampling could be conducted to record the downstream movement of smelt larvae. A total of 24 fish species were represented in 108 samples collected at all stations. Sand lance larvae were found at the highest frequency of occurrence among fish species (26%), followed by smelt larvae (25%) which were caught within the period of April 20th to June 6th.

Table 5.1 Smelt spawning habitat locations in the North Shore Coastal Drainage. The reported positions are the downstream and upstream limits of observed egg deposition recorded with a Garmin GPSmap 76.

Name	River System/ Region	Town	Downstream Latitude	Downstream Longitude	Upstream Latitude	Upstream Longitude	Length (m)	Area (m^2)
Saugus River	Saugus River	Saugus	42° 28.097'	71° 00.457'	42° 28.198'	71° 00.434'	175	1,215
Shutes Brook	Saugus River	Saugus	42° 27.714'	71° 00.459'	42° 27.729'	71° 00.561'	147	810
North River	Danvers River	Salem	42° 31.427'	70° 54.959'	42° 31.465'	70° 55.104'	195	1,209
Crane River	Danvers River	Danvers	42° 33.392'	70° 56.225'	42° 33.455'	70° 56.301'	120	513
Porter River	Danvers River	Danvers	42° 34.094'	70° 55.662'	42° 34.140'	70° 55.680'	80	350
Chubb Creek	Manchester Bay	Manchester	42° 34.154'	70° 47.639'	42° 34.154'	70° 47.676'	58	71
Bennett Brook	Manchester Bay	Manchester	42° 34.376'	70° 46.651'	42° 34.439'	70° 46.725'	172	296
Sawmill Brook	Manchester Bay	Manchester	42° 34.674'	70° 46.263'	42° 34.673'	70° 46.164'	98	339
Little River	Cape Ann	Gloucester	42° 36.672'	70° 42.471'	42° 36.628'	70° 42.506'	88	192
Sawmill Brook	Cape Ann	Rockport	42° 38.206'	70° 36.612'	42° 38.216'	70° 36.608'	28	35
Mill Brook	Cape Ann	Rockport	42° 39.575'	70° 37.301'	42° 39.571'	70° 37.300'	16	16
Essex River	Essex River	Essex	42° 37.661'	70° 47.211'	42° 37.607'	70° 47.259'	123	921

Figure 5.1. Smelt spawning habitat in the North Shore Coastal Drainage Area. The green dots indicate the downstream limit of egg deposition and the red dots indicate the upstream limit of egg deposition.



SAUGUS RIVER

STUDY AREA

The Saugus River is located in the North Shore Coastal Drainage (Halliwell et al. 1982), between Boston Harbor and the Danvers River estuary. The Saugus River originates from Lake Quannapowitt, Wakefield, and meanders for 21 km before discharging into Broad Sound. The drainage area of the Saugus River at the mouth is 125 km^2 (Wandle 1984). The Pines River is a major tributary to the Saugus River estuary and is tidal for most of its 5 km length (ACOE 1989). Much of the watershed is urbanized and has a long history of industrial development close to the river. Two major highways, Rt. 1 and Rt. 128 cross the Saugus River, and Rt. 1 also cross the Pines River near the tidal zone. The Saugus River and related impoundments are the sources for the municipal water supply of the City of Lynn.

The Saugus River is naturally a slow-moving river due to low gradient and numerous small lakes and marshlands found along its path (ACOE 1989). The river has been stressed in the 20th century by water withdrawals and restrictions at highway culverts and the Boston and Maine Railroad embankment that crosses the freshwater Reedy Meadows. No stream flow gauges were present on the Saugus River at the time of monitoring. A USGS stream flow gauge (Station #01102345) was installed at the Saugus River Iron Works in 1994. The Saugus River Iron Works location is slightly upstream of the fresh and salt water interface. The drainage area of the Saugus River watershed at this location is 53.9 km^2.

The Saugus River smelt run traditionally supported a modest shoreline fishery that peaked in October and November. Local fishermen report that the catch and effort of smelt fishing declined markedly in the 1980s. No previous studies of smelt in the Saugus River have been conducted. There have been several environmental baseline studies in the Saugus River that include data on fishery resources (Chesmore et al. 1971; MRI 1987; ACOE 1989; and Tashiro et al. 1991). Incidental records of smelt presence in the estuary were noted but no information was found in these reports or anecdotally on the location of smelt spawning habitat in the Saugus River. Following initial surveys, monitoring was conducted during 1988-1990 at four stations selected as potential spawning habitat: Hamilton Street Bridge and Saugus River Iron Works, Saugus River; Shute Brook, and Pines River, Revere. The Lincoln Avenue Bridge on the Saugus/Lynn border of the Saugus River was selected as an ichthyoplankton sampling station.

RESULTS

Smelt eggs were found at two locations in the Saugus River estuary; Shute Brook, and in the main stem Saugus River at the Saugus River Iron Works. Both locations were not known smelt spawning habitats prior to this monitoring. The combined area of spawning habitat was approximately 2,000 m^2 for the two locations. The preliminary results of this monitoring were previously reported by DMF in greater detail (Chase 1992).

Spawning Habitat

Saugus River Iron Works. A majority of the smelt egg deposition observed and available spawning habitat in the Saugus River was found at the Saugus River Iron Works, a National Historic Site managed by the National Park Service. Smelt eggs were first found in April 1988, during informal surveys and the location was routinely monitored in 1989 and 1990. Egg deposition was found over a river length of 175 m that began in salt marsh and ended near the rubble of a former dam at the Iron Works. The river substrate area where eggs occurred was 1,215 m^2. The upper limit of egg deposition was caused by a rise in stream gradient at the rubble of the former dam. The highest densities of deposited eggs were found in a short stretch of habitat below the rubble. No eggs were found at the Hamilton Street bridge station during a single season of monitoring. The bridge is located a few hundred meters downstream of the lower limit of egg deposition at the Iron Works station and exposed to nearly two meters of tidal fluctuations. The stream bed for 50 m downstream of Hamilton Street appears suitable for smelt spawning at low tide, although the riffles are negated with each high tide.

Shute Brook. Shute Brook is a small freshwater tributary that originates in wetlands of western Saugus and moves easterly to join the Saugus River estuary between Hamilton Street and Lincoln Avenue. The upper limit of spawning was the culvert under Central Street. The culvert did not physically impede further upstream movements, but few eggs were found more than several meters inside the downstream side of the culvert. Egg deposition was found for 147 m downstream over approximately 810 m^2 of substrate. The highest egg deposition occurred within 20 m of the Central Street culvert.

Spawning Period. The spawning period at the Saugus River Iron Works was accurately delineated only in 1989, when eggs were present from about mid-March to mid-May (Table 5.2). Without previous knowledge of smelt spawning in the Saugus River, 1988 monitoring was more exploratory and eggs were not found until April. In 1990, there was sparse egg deposition throughout the North Coastal Basin. Smelt eggs were first found at the Iron Works on March 30th in 1990, although earlier spawning is likely. Smelt eggs were readily found in Shute Brook, resulting in the delineation of spawning period for all three seasons (Table 5.3). Spawning in Shute Brook consistently began in late-March and early-April, which is later than observed in most smelt runs in the study area.

Table 5.2 Smelt spawning period in the Saugus River, at the Saugus River Iron Works, 1989-1990. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (°C) Start	End	Range	Mean
1989	March 12th - May 16th	66	5.0	13.5	5.0 - 16.5	10.8
1990	(not delineated) - May 19th			12.0		

Table 5.3 Smelt spawning period in Shute Brook, 1988-1990. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (°C) Start	End	Range	Mean
1988	March 26th - May 20th	56	10.0	13.5	8.0 - 16.0	10.9
1989	April 1st - May 20th	50	10.0	12.0	8.0 - 16.0	12.1
1990	April 2nd - May 19th	48	7.0	11.5	6.0 - 16.0	11.7

Table 5.4 Water chemistry and weather summary for the Saugus River Iron Works spawning habitat station, 1989-1990. Data are averages (Tables A.65-A.66) except station visits and NOAA Rainfall data are total values. Air temperature and rainfall data were recorded at Marblehead, Massachusetts (NOAA 1989 and 1990).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)
1989							
March	8	2.3	9.4	5.6	0.0	7.7	13.7
April	8	6.8	10.4	11.4	0.0	7.6	11.2
May	4	14.4	11.7	14.0	0.0	7.3	10.1
Season	20	7.8	31.5	9.6	0.0	7.6	12.0
1990							
March	8	3.8	5.1	5.6	0.0	7.5	13.3
April	7	8.1	15.5	10.7	0.0	7.5	11.9
May	9	12.0	16.5	14.5	0.0	7.6	10.8
Season	24	8.0	37.1	10.4	0.0	7.5	12.0

Water Chemistry

Saugus River Iron Works. Water chemistry measurements were made in 1989 and 1990 1 m upstream of the wood walk bridge at the Iron Works. Dissolved oxygen and pH values were adequate to support aquatic life (Table 5.4, A.65-A.66). The pH values were more alkaline than measured at most Massachusetts Bay smelt runs. No measurements detected salinity at this station. The backing up of freshwater at flood tide was observed on three occasions. A previous study on flood control in the Saugus River (USACE 1989) determined that the Saugus River Iron Works was the upstream limit of the salt wedge (0.5 ‰ salinity). The movement of the salt wedge to this point probably occurs during seasonal low flow periods. Low salinity was measured at the Hamilton Street station during May in 1988 (Table A.67).

Shute Brook. Water chemistry measurements were made during 1988-1990 5 m downstream of the Shute Brook culvert face at Central Street. Water chemistry values were similar to the main stem Saugus River and adequate to support aquatic life (Table 5.5, A.68-A.70). The pH values were more alkaline than measured at most Massachusetts Bay smelt runs. Salinity was not detected at this station, although tidal influence was observed backing up freshwater flow on three occasions. Shute Brook flow was strongly influenced by stormwater, quickly becoming turbid following precipitation.

Lincoln Avenue Bridge. This station was sampled for water chemistry and ichthyoplankton collections during 1988-1990 (Tables A.71-A.73). Evidence of stratification was found at this point in the estuary. Water depth (0.5-3.0 m) and salinity were dependent on tide stage and precipitation. Salinity was typically 20-26‰ on the bottom with less saline and more variable surface flows, ranging from 0-25‰.

Stream Flow Discharge Measurements

No streamflow gauges were present in the Saugus River during smelt habitat monitoring. Three spring discharge measurements were made at the Shute Brook and Saugus River Iron Works habitat stations in 1991 (Chase 1992). The mean velocity was 0.451 m/s and the mean discharge was 0.115 m^3/s at the Shute Brook water chemistry station. The mean velocity was 0.629 m/s and the mean discharge was 1.223 m^3/s at the Saugus River Iron Works. Discharges of 0.060 m^3/s at Shute Brook and 0.432 m^3/s at the Iron Works on May 17, 1991 were noted as providing poor coverage of spawning habitat. The USGS installed a streamflow gauge at the Saugus River Iron Works in 1994. Monthly mean discharge for the spring months during 1994-2002 were: March - 1.82 m^3/s (64.1 cfs), April - 1.48 m^3/s (52.4 cfs), and May - 0.86 m^3/s (30.3 cfs).

Ichthyoplankton

Ichthyoplankton samples were collected from surface flow during ebb tide on 18 dates at the Lincoln Street Bridge on the Saugus River, 1988-1990 (Tables B.7-B.8). Eleven species of fish were collected (Table 5.6). Smelt was the most common fish larvae caught, occurring in 39% of the net sets and had the highest total density among fish (12/100 m^3). Smelt larvae were caught from April 20th to May 16th. Atlantic herring (33%) and sand lance (22%) ranked second and third for frequency of occurrence. The Saugus River was the only ichthyoplankton station in the study area that consistently caught Atlantic herring. Atlantic herring post-larvae were caught each season in March and early April.

Other Diadromous Species

Previous references indicate the presence of a small river herring run in the Saugus River during the 20th century and larger runs in the 19th century. Belding (1921) reported a moderate spawning run of alewives occurred into Prankers Pond and Reback and DeCarlo's survey (1972) noted the presence of this run. The DMF study of the marine resources of Lynn-Saugus Harbor caught several adult alewives and blueback herring in the Saugus River estuary during the spring of 1969 (Chesmore et al. 1972). No river herring were observed in the Saugus River during the study period. However, spawning adult alewives were observed in Camp Nihan Pond in the 1990s during occasional spring visits to check on the smelt spawning run. American eel elvers were commonly seen during monitoring at the two smelt spawning locations in April and May, with relatively large numbers of glass eels observed at the Iron Works.

Other Surveyed Tributaries

The Pines River was monitored during the spring of 1988 with no observations of deposited smelt eggs or adult smelt. The tide advanced past tide gates at the Rt. 1 monitoring station where the Pines River becomes channelized and is known as Town Line Brook. Town Line Brook drains a large and highly urbanized area north of Boston. Upstream of Rt. 1, the channelization continues for over 3 km and the combination of wide channel width, tidal influence and minor freshwater base flow results in the absence of potential spawning riffles Because of these conditions, this station was not monitored after 1988. A creek known as Strawberry Brook drains an urban section of Lynn and flows through a culvert at Summer Street and discharges to the Saugus River estuary was surveyed in 1989. High salinity tidal flow enters the outfall of this creek. The creek remains underground for several hundred meters and no potential spawning substrate was found upstream or downstream of the underground pipe.

Table 5.5 Water chemistry and weather summary for the Shute Brook spawning habitat station, 1988-1990. Data are averages (Tables A.68-A.70) except station visits and NOAA Rainfall data are total values. Air temperature and rainfall data were recorded at Marblehead, Massachusetts (NOAA 1988 and 1990).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)
1988							
March	8	3.3	10.9	7.8		7.5	
April	8	7.7	5.6	10.2		7.8	
May	8	13.4	11.9	13.0	0.0	7.6	
Season	24	8.1	28.4	10.3		7.6	
1989							
March	8	2.3	9.4	6.6	0.0	7.6	13.7
April	8	6.8	10.4	11.6	0.0	7.6	11.5
May	4	14.4	11.7	13.3	0.0	7.3	10.5
Season	20	7.8	31.5	9.9	0.0	7.6	12.2
1990							
March	8	3.8	5.1	6.4	0.0	7.5	13.8
April	7	8.1	15.5	10.5	0.0	7.5	12.4
May	9	12.0	16.5	13.2	0.0	7.5	11.2
Season	24	8.0	37.1	10.2	0.0	7.5	12.4

Table 5.6 Ichthyoplankton samples collected during 18 sample dates at the Lincoln Street Bridge station on the Saugus River, 1988-1990. Sizes are average total length for larvae and diameter for eggs. Larvae density is the absolute density collected in total sample volume (1688 m^3).

Species		Type	FOC	Period	No.	Size (mm)	Density (No./100 m^3)
rainbow smelt	*Osmerus mordax*	larva	7	4/20 - 5/16	206	6.9	12.2
Atlantic herring	*Clupea harangus*	larva	6	3/03 - 4/13	7	38.0	0.4
sand lance	*Ammodytes americanus*	larva	4	3/7 - 4/4	19	8.5	1.1
grubby	*Myoxocephalus aenaeus*	larva	3	3/7 - 4/13	8	5.6	0.5
Atlantic tomcod	*Microgadus tomcod*	larva	2	3/7 - 3/10	10	5.6	0.6
Atlantic silverside	*Menidia menidia*	larva	2	6/2 - 6/6	30	4.7	1.8
seasnail	*Liparis atlanticus*	larva	1	4/20	1	3.5	0.1
fourspine stickleback	*Apeltes quadracus*	juvenile	1	6/2	1	19.3	0.1
ninespine stickleback	*Pungitius pungitius*	juvenile	1	6/6	1	28.5	0.1
L-L group	*Labridae-Limanda*	egg	3	5/16 - 6/6	9	1.0	0.5
P-S group	*Paralichthys-Scopthalmus*	egg	2	5/16 - 6/2	16	1.1	1.0

DISCUSSION

The smelt run at the Saugus River Iron Works is one of the few active runs in the North Coastal Basin with greater than 1,000 m^2 of spawning habitat. Similar to other smelt runs monitored during this period, 1989 egg deposition at the Iron Works habitat was substantially higher than observed in 1988 and 1990. The sparse egg deposition observed in 1988 and 1990 was surprising given the amount of spawning habitat available and the general appearance of suitable riffles at the interface of saltwater and freshwater flow. Although not quantified, the amount of egg deposition seen for those years at the Iron Works was similar to that seen at Shute Brook, a much smaller tributary.

Subsequent visits to check on smelt spawning activity in the Saugus River during the 1990s have found very low densities of smelt eggs. Overall, the observations of poor egg deposition relative to available spawning habitat and anecdotes of the local smelt sportfishery slowly fading away raises concerns for the health of the Saugus River smelt population. The causal factors for the apparent declining smelt population are not certain. The following sources, some common throughout Massachusetts Bay and some specific to the river, are probably contributing factors.

Stormwater Pollution. The densely developed watershed and high-traffic corridor of Rt. 1 contribute to the delivery of large amounts stormwater pollution with each rainfall to the spawning habitats in both Shute Brook and the Iron Works. The low discharge at Shute Brook appeared especially susceptible to rapid degradation following precipitation. The relationship between stormwater pollutants and the quality of smelt spawning habitat is largely unassessed, although the monitoring did document physical degradation in the form of sedimentation and excessive periphyton growth at both locations.

Discharges of Contaminants. Several discharges of petroleum and chemical pollutants were observed upstream of both spawning locations during the 1988-1990 monitoring (Chase 1992). Given the urban development of the watershed, it is likely that these events occurred at a potentially threatening frequency during the 20th century. The source associated with a pollution discharge observed in 1988-1990 was identified and abated (Chase 1992). The concern of mortality associated with toxic contaminants may be diminished with the maturity of the CWA, but could have exerted a negative influence on smelt recruitment that continues to limit the population.

Water Withdrawals. The principal local authority that withdraws water from the Saugus River for municipal use is the Lynn Water and Sewer Commission (LWSC). They have been given wide statutory authority to withdraw water. In dry years, contributions from the Commission's reservoirs to the Saugus River main stem can be minimal. Impacts to smelt spawning habitat (low depths and velocity) were not apparent during March and April monitoring. Declining habitat quality was seen during low flow episodes in May. The direct impact of water withdrawals to smelt spawning habitat and other anadromous species in the Saugus River is not known, although concerns over the ecological health of the river system should be considered. The preliminary report on the Saugus River smelt run (Chase 1992) raised this issue and recommendations from that report and the Saugus River Watershed Council (SRWC) led to the installation of a USGS gauge in 1994. The continued review of streamflow data and recent collaborative efforts by the SRWC and LWSC on resource and habitat requirements for streamflow should help identify problems and solutions.

Entrainment and Thermal Impacts on Larvae. Concerns have been raised over the entrainment of smelt larvae at two facilities located in the Saugus River that withdraw water for cooling purposes (Chase 1992). Both the RESCO and General Electric plants, located downstream of Rt. 107 are authorized by NPDES permits to routinely withdraw tidal water in the Saugus River. The concern was raised by a biological monitoring program at RESCO that found a high ratio of entrained smelt larvae at their river intake to those sampled at a mid-river boat station (15:1 in 1987 and 48:1 in 1989) (MRI 1989). These data indicate that the location of the river bank intake coincides with concentrations of smelt larvae. Subsequent attempts to assess this concern at both RESCO and General Electric were unsuccessful because so few smelt larvae were caught. The location of two water intakes along the river banks remains a concern for smelt mortality. The locations of these intakes may be important nursery habitats for smelt larvae that are known to benefit from estuarine retention at favorable foraging locations (Ouellet and Dodson 1985). The concern has also been raised but not resolved on potential thermal impacts from the heated water discharge from both these facilities.

RECOMMENDATIONS

1. Shute Brook Habitat Restoration. The spawning habitat at Shute Brook has been degraded by both physical changes to the substrate at the street culvert and chronic sedimentation and trash accumulation from run-off. It may be possible to enhance the quality of the spawning habitat here with modest substrate improvements at the culvert opening accompanied by routine maintenance. This location should be considered as a potential smelt spawning habitat restoration project.

2. Saugus River Iron Works Habitat Restoration. Smelt are currently limited to spawning below of the rubble of the former dam upstream of the Iron Works property. The elevation rise and turbulent flow prevents smelt from passing upstream to suitable habitat. It is recommended that an evaluation be made of making modest structural changes to this section of the river bed to improve smelt passage and increase the amount of potential spawning habitat.

3. River Water Withdrawals. It is recommended that all concerned resource agencies work with the LWSC and SRWC to evaluate existing river flows and habitat requirements and develop minimum flow requirements for anadromous fish in the Saugus River.

4. Smelt Larvae Mortality. It is recommended that concerns over ichthyoplankton entrainment at the General Electric and RESCO facilities are evaluated during the next reauthorization of their NPDES permits. Structural and/or operational changes to the water intakes may be possible to reduce larval entrainment. Thermal impacts from cooling water discharges at these facilities should also be evaluated.

5. Stormwater Remediation. It is recommended that local authorities routinely maintain stormwater retention basins in the vicinity of the Shute Brook and Iron Works spawning habitats. When possible, resources should be devoted to the installing the best treatment technologies for drains next to these valuable habitats.

Saugus River spawning habitat. B. Chase

SALEM HARBOR

STUDY AREA

Salem Harbor is located in the North Shore Coastal Drainage (Halliwell et al. 1982), between Boston Harbor and Cape Ann. The primary drainages in Salem Harbor are the South River and Forest River. South River freshwater flows originate from wetlands in southern Salem and freshwater flow in the Forest River originates from Thompsons Meadows and associated wetlands. No smelt runs were known to occur in Salem Harbor and only the Forest River contained potential spawning habitat. Forest River flows into Salem Harbor at the boundary between Salem and Marblehead. Tidal influence occurs for approximately 1.5 km upstream of the confluence with Salem Harbor. Near the upper limit of tidal influence the river bank transitions quickly from salt marsh to dense *Phragmites* to upland woods.

Few studies of any kind have been conducted in the Forest River, and the hydrology has not been described. The freshwater discharge has not been documented, but it is apparent that freshwater is a small portion of the total water volume found in the estuary relative to the tidal exchange during most weather conditions and tide stages. The mouth of Forest River is known locally as the "Lead Mills". A lead mill operated there for about 100 years, beginning in 1826 (Essex Institute 1971). Tidegates have been in operation for over 70 years on Rt. 114 upstream of the Lead Mills. Moore and Delpapa (1992) presented DO sampling and discussed the potential ecological impacts of the Forest River tide gates located near the river mouth. The tide gates have been managed by the City of Salem for flood control and during the summer to retain water in an upstream wading pond. No streamflow gauge stations were located on the Forest River during the study period.

The Forest River was selected for monitoring after a 1988 survey found a small stretch of potential spawning habitat upstream of the tidal marsh. No previous studies have documented smelt spawning in the Forest River. Adult smelt were caught in the Forest River in the early 1970s by DMF biologists using hoop nets upstream of Rt. 1A, but no evidence of smelt spawning has been reported (C.O. Anderson, DMF, *pers. comm*.). Three sites were selected for sampling during 1989 and 1990. The former railroad trestle at the mouth of Forest River on Salem Harbor was selected for water chemistry and ichthyoplankton sampling. A second water chemistry site was selected at the Rt. 1A intersection with the river. A third site was selected for water chemistry and spawning habitat sampling above the fresh and saltwater interface. This site was 130 m upstream of the wood walk bridge in the marsh near the Salem State South Campus. The South River and two creeks in Marblehead were surveyed in 1988 and 1989 but not selected for monitoring because of the absence of suitable spawning habitat.

RESULTS

Conclusive evidence of smelt spawning in the Forest River was not found during 1989 and 1990 monitoring, or during subsequent visits to the Forest River and other drainages in Salem Harbor. Potential spawning habitat in the Forest River was degraded low freshwater flow and by alterations from invasive *Phragmites*. Based on these findings, the Forest River is not classified as a smelt run. More details are provided in a previous DMF report on the Forest River (Chase and Roderick 1994).

Potential Spawning Habitat

A small stretch of the Forest River at the fresh and salt water interface was found to have minor potential for supporting smelt spawning habitat. The stretch was only 50 m in length and contained 75 m^2 of potential spawning substrate. The habitat was poorly suited for smelt spawning because of very low freshwater discharge, sedimentation and high densities of *Phragmites* in the stream channel. No conclusive evidence of smelt spawning in the Forest River was found during 44 sample visits in 1989 and 1990. Two demersal eggs were found on April 4, 1989 adhered to a rock at this habitat. The eggs were approximately 1 mm in diameter, and had the general appearance of smelt eggs. The eggs were not brought back to the laboratory for identification because it was assumed more would be collected in subsequent visits. The two eggs were no longer attached to the rock a few days later and no other eggs were found during enhanced efforts for the remainder of the 1989 season and in 1990. No observations of adult smelt were made in the Forest River estuary during the two seasons.

Water Chemistry

Potential Spawning Habitat Stations. Surface water chemistry measurements of temperature, salinity, pH, and dissolved oxygen were supportive of aquatic life at the tidal interface sampling station (Table 5.7, A.74-A.75). Dissolved oxygen levels were at or near saturation for all measurements. Measurements of pH did not reflect acidic conditions as seen at numerous drainages in the study area; averaging 7.6 in 1989 and 7.5 in 1990. Tidal influence was observed at the highest tidal amplitudes at this station, although salinity was not detected during spring discharges. The sampling station at Rt. 1A was only sampled in 1989 because of the lack of spawning habitat potential and water chemistry measurements were highly dependent on tide stage (Table A.76).

Railroad Trestle Station. The Forest River passes through the narrow opening at the railroad trestle to meet Salem Harbor. Water salinity was dependent of tide stage and river discharge (Tables A.77-A.78). At lower tide stages, the water column was well-mixed with salinities typically in the 5-10‰ range. At higher tide stages, modest stratification could occur with highly saline water on the bottom (27-33‰) with slightly fresher water on the surface.

Table 5.7 Water chemistry and weather summary for the Forest River spawning habitat station, 1989-1990. Data are averages (Tables A.74-A.75) except station visits and NOAA Rainfall data are total values. Air temperature and rainfall data were recorded at Peabody, Massachusetts (NOAA 1989 and 1990).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)
1989							
March	8	2.8	7.6	5.7	0.0	7.6	13.1
April	8	7.2	10.9	11.4	0.0	7.7	11.1
May	4	15.0	10.2	15.0	0.0	7.5	10.0
Season	20	8.3	28.7	9.8	0.0	7.6	11.7
1990							
March	8	3.7	4.8	6.4	0.0	7.5	13.1
April	8	8.8	15.8	10.9	0.0	7.5	11.7
May	7	12.2	16.5	15.9	0.0	7.6	9.8
Season	23	8.2	37.1	10.8	0.0	7.5	11.6

Table 5.8 Ichthyoplankton samples collected during nine sample dates at the Forest River railroad trestle (Rt. 114), 1989-1990. Sizes are average total length for larvae and diameter for eggs. Larvae density is the absolute density collected in total sample volume (774.5 m^3).

Species		Type	FOC	Period	No.	Size (mm)	Density (No./100 m^3)
sand lance	*Ammodytes americanus*	larva	4	3/15 - 4/20	86	9.3	11.1
grubby	*Myoxocephalus aenaeus*	larva	3	3/15 - 4/20	7	4.6	0.9
radiated shanny	*Ulvaria subbifurcata*	larva	1	5/24	3	8.0	0.4
threespine stickleback	*Gasterosteus aculeatus*	juvenile	1	5/16	1	41.0	0.1
Atlantic silverside	*Menidia menidia*	larva	1	5/24	1	5.1	0.1
yellowtail flounder	*Limanda ferruginea*	larva	1	4/20	1	5.0	0.1
seasnail	*Liparis atlanticus*	larva	1	4/18	2	4.3	0.3
P-S group	*Paralichthys-Scopthalmus*	egg	1	5/16	53	1.0	6.8

Ichthyoplankton

Nine ichthyoplankton samples taken at the railroad trestle station produced eight species of fish, but no smelt larvae (Tables 5.8, B.9). Sand lance were the most common fish larvae caught for the March-May sampling period, in terms of frequency of occurrence (44%) and relative abundance. Grubby occurred second most frequently (33%).

Other Diadromous Species

No anadromous species were observed in the Forest River during monitoring, and no records were found documenting previous spawning runs. American eel elvers were observed on several occasions at the potential spawning habitat station.

Other Surveyed Tributaries

South River. The South River enters a culvert near downtown Salem and runs underground for over 1.5 km before opening again. The streambed upstream of the culvert opening had no riffle habitat and suffered from sedimentation. The upstream discharge is dominated by stormwater flows. During dry seasons the streambed upstream of the culvert opening has been observed to be dry and vegetated as early as May. No anecdotal information was found on former anadromous fish runs in the South River and no potential was seen for supporting a smelt run in 1988 and 1989. The mouth of South River at Salem Harbor is a known location where fall smelt fishing occurs.

Marblehead Creeks. Two unnamed freshwater creeks were surveyed on the Salem Harbor shore of Marblehead. Both creeks had very minor freshwater discharge and minimal amounts of substrate that could support smelt runs. These creeks have not been known to support anadromous fish runs and subsequent visits found no evidence of smelt and limited potential.

Forest River Tributary. An unnamed tributary flows from a pond near Legg Hill to meet the Forest River in the marsh downstream of Rt. 1A. The pond was enlarged by groundwater manipulations in the 20th century and a drain pipe was installed to maintain desired pond elevations. Drainage from the pipe has created a man-made stream that flows down the hill to the Forest River. The stream is not indicated on topographical maps and was not known during the 1989/1990 monitoring. The stream contains minor patches of gravel and cobble (< 100 m^2) that could be colonized by smelt for spawning habitat. *Phragmites* encroachment creates an impediment to smelt passage at the junction with Forest River, although not to the extent found upstream in the main stem. No smelt eggs have been found during recent visits to the stream. It is similar in size and discharge to the upstream Forest River station and the Waters River in the Danvers River estuary, and is also considered to have minor potential to support smelt spawning habitat.

DISCUSSION

It is reasonable to conclude that a smelt run was not present in the Forest River during the 1989 and 1990 seasons. The two eggs observed but not identified in April of 1989 could have been the following: smelt eggs from a stray of a near-by run (Saugus River or Danvers River), smelt eggs from remnants of a dwindling Forest River population, or eggs from another species. No other eggs were found during extensive searches over the small amount of potential habitat (75 m^2). The Forest River may have once supported a smelt population, but historical documentation is lacking. The present encroachment of reeds in the stream channel and related reduction of freshwater flow velocity offers little attraction for spawning smelt and may prevent upstream passage.

It is likely that the operation of the tide gates has contributed to the encroachment of *Phragmites* and the degraded substrate conditions at the interface of saltwater and freshwater. Moore and DelPapa (1992) hypothesized that increased tide gate operations have denied the upland border of the marsh periodic saltwater flushing and this has resulted in the *Phragmites* invasion. They also note that the *Phragmites* stand near the upland border has been increasing over the 25 years prior to their study. Their comments are consistent with my observations of increasing *Phragmites* densities 50 m above and below the wood walk bridge since 1990. In the late 1990s the City of Salem acted to reduce the closures of the tidegates in order to improve tidal flushing in the Forest River estuary. It is possible that proactive management of the tidegates may improve the ecological health of the Forest River.

Observations Since 1990. The Forest River was visited several times during the springs of 1994 to look for smelt egg deposition and in 1997 related to water sampling of Salem Sound tributaries (Chase et al. 2002). No evidence of smelt spawning was found during these visits. Stream flow measurements during these visits illustrate the small size of the Forest River. The average of six discharge measurements made throughout the year was 0.044 m^3/s (1.6 cfs) and for two May measurements was 0.071 m^3/s (2.5 cfs). The range and densities of *Phragmites* near the tidal interface had increased markedly since the 1990 monitoring. By 1997, no passage of adult smelt was possible through the dense reeds. In addition, the *Phragmites* has caused a widening and reduced definition of the stream channel upstream of the walkbridge. The *Phragmites* roots in this stretch are trapping sediment and detritus, resulting in reduced water velocity. This stretch of habitat had clearly degraded from 1990 to 1997, further reducing the likelihood of supporting a smelt run.

RECOMMENDATIONS

1. Tidegate Flushing. No recommendations are offered specifically for smelt in Salem Harbor due to the existing habitat degradation and minor available freshwater discharge and potential spawning habitat. It is recommended that the tidegates near the mouth of Forest River are operated to maximize tidal flushing in order to benefit the ecology of the Forest River.

DANVERS RIVER

STUDY AREA

The Danvers River is located in the North Shore Coastal Drainage (Halliwell et al. 1982), between Boston Harbor and Cape Ann. Freshwater flow in the Danvers River does not originate from large water bodies, but primarily from wetlands in Peabody and Danvers. Five major tributaries contribute freshwater to the Danvers River estuary. The Porter, Crane and Waters Rivers all meet the Danvers River in the vicinity of Danversport. The Danvers River then flows for 2.6 km to the mouth at Beverly Harbor. The Bass River flows through Beverly and the North River flows through Peabody and Salem to join the Danvers River upstream of Beverly Harbor. The Danvers River is described as a relatively shallow estuary with a large intertidal area and high flushing potential: approximately 70% of the total water volume is exchanged with each tide cycle (MDPW 1991). No streamflow monitoring stations were present in the Danvers River, and no documentation was found on estimates of total freshwater flow from the five tributaries.

A fall and early winter smelt fishery traditionally occurred in the Danvers River at several location were shoreline access was available. Presently, the fishery has diminished to the point that very few anglers participate in dock fishing from Salem and Marblehead harbors and the public docks seaward of the Beverly-Salem Bridge. Local fishermen who still fish at these docks report that the abundance of smelt has declined sharply in the past two decades. No previous studies of smelt in the Danvers River have been conducted. The DMF Beverly-Salem Harbor study found smelt to be the second most abundant species at the Danvers River beach seine station in 1965 (Jerome et al. 1967). Reback and DeCarlo (1972) did not record a Danvers River smelt run in their anadromous fish survey. Smelt have been known to spawn in only one location in the Danvers River, at the tidal interface in the Porter River (H.R. Iwanowicz, DMF, *pers. comm.*). Anecdotes received from fishermen with experience prior to the 1960s indicate that smelt fishing formerly occurred at the mouths of the Crane, North and Bass rivers.

All freshwater tributaries to the Danvers River were surveyed in 1988 to select sample sites for potential spawning habitat. The Waters River was not selected because it lacked suitable flow and substrate conditions. The Bass River was not selected because of obstructions to passage into the freshwater zone. The North River (29.8 km^2 drainage area) was monitored only in 1988 because no evidence of spawning was found and the substrate was severely degraded from chronic pollution. The Crane River (14.8 km^2 drainage area) and Porter River (11.4 km^2 drainage area) were monitored from 1988 to 1990. Spawning habitat stations were located below the Purchase Street culvert in the Crane River and upstream of Rt. 62 in the Porter River. Ichthyoplankton samples were collected at estuarine stations in both Crane River and Porter River.

RESULTS

Evidence of smelt spawning within the Danvers River system was found only at a small stretch of the Porter River. No evidence of smelt spawning was found during 1988 in the North River and three years of monitoring in the Crane River. The results of this monitoring were reported in greater detail in an earlier DMF report (Chase 1993). Subsequent to the completion of field monitoring for this project, smelt eggs were found in the Crane and North Rivers, resulting in the present classification of these tributaries as smelt runs.

Spawning Habitat

Porter River. During each year the Porter River (freshwater zone is also known as Frost Fish Brook) was monitored, smelt eggs were readily found over an 80 m reach upstream of Rt. 62. Spawning began at a cobble riffle 12 m upstream of the Rt. 62 culvert and eggs were found no further upstream than a shallow, gravel riffle approximately 90 m above the culvert. Smelt passage beyond the riffle was not impeded, however, despite three seasons of extensive efforts, no eggs were found at suitable upstream riffles. The area where egg deposition was recorded was 350 m^2 and an additional 400 m^2 of potential spawning habitat was found above the upper limit of observed egg deposition.

Spawning Period. The spawning period was accurately delineated in 1989 and 1990 (Table 5.9). Smelt eggs were not found until March 30th in 1988 because of sparse

Table 5.9 Smelt spawning period in the Porter River, Danvers, 1988-1990. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (°C) Start	End	Range	Mean
1988	(not delineated) - May 5th			11.0		
1989	March 11st - May 27th	78	1.0	15.0	1.0 - 17.0	9.5
1990	March 27th - May 9th	44	6.0	14.5	5.0 - 19.0	10.5

deposition and unfamiliarity with this run. The densities of egg deposition observed in 1989 greatly exceeded that seen in 1988 and 1990, and the spawning period extended to 78 days, over a month longer than the other two seasons. In all three seasons, peak egg deposition occurred in April and was concentrated at two riffles near the center of the 80 m reach.

Water Chemistry

Porter River. Water chemistry measurements were made at the first riffle 30 m above the Rt. 62 culvert. The water temperatures at the onset of spawning period varied between seasons. Air temperature in early March, 1989, was unusually cold, yet spawning began on March 11th with a water temperature of 1.0 °C: a much earlier onset than seen in 1990. Dissolved oxygen and pH values were adequate to support aquatic life (Table 5.10, A.79-A.81). The pH values were stable and alkaline during the study period (mean = 7.6). The clay lined stream bed may provide buffering from acidification. Increased water depth at the spawning habitat due to tidal influence was observed on four occasions. On March 18, 1988, during an 11.2 ft high tide, water depth reached 1 m and salinities of 1‰ (top) and 21‰ (bottom) were measured at the sample site. For average high tides, the salt wedge did not extend to smelt spawning habitat.

Crane River. Water chemistry measurements were made 10 m downstream of the culvert on Purchase Street. Tidal influence was not observed at the sample station during the three seasons, although the backing-up of freshwater at flood tide was routinely observed 50 m downstream while searching for smelt eggs. Dissolved oxygen and pH values were similar to the Porter River and adequate to support aquatic life (Table 5.11, A.82-A.84).

North River. Water chemistry measurements were made at the downstream opening of the Rt. 114 culvert in Salem on the North River only during 1988 (Table A.85). This location received high salinity bottom water with each flood tide and surface salinity depended greatly on freshwater discharge. At low tide, the entire river upstream of the sample station was freshwater. North River water and substrate quality was clearly degraded from chronic pollution inputs throughout the river stretch monitored for egg deposition (Rt. 114 to Howley Street, Peabody). North River (also known as Proctor Brook in the freshwater zone) water was often discolored from high stormwater turbidity, oil sheens and unknown pollutants.

Stream Flow Discharge Measurements

Stream discharges in the tributaries to the Danvers River have not been well-described by any source, and during the study, there were no stream flow monitoring stations in the river system. Following the monitoring period, discharges were measured on four dates in the Porter River, and two dates in the Crane River. Discharge in the Porter River ranged from 0.128-0.283 m^3/s. A small amount of substrate was exposed on 4-17-91, when the discharge was 0.128 m^3/s. Adequate water coverage of the substrate where eggs were deposited was found for the other three measurements, which averaged 0.258 m^3/s (9 cfs). Discharge measurements were made during a 1997 DMF investigation in the Crane, Porter and North Rivers on four dates within the smelt spawning season (Chase et al. 2002). The combined measurements are presented in Table 5.12 to provide an approximation of spring discharges in these tributaries. The 1997 DMF study estimated annual mean discharge for the five tributaries to the Danvers River. The sum of the five annual mean discharges was 0.56 m^3/s (~20 cfs); a relatively small contribution of freshwater to the Danvers River estuary.

Ichthyoplankton

Porter River. Nineteen ichthyoplankton samples were collected in the Porter River (Table 5.13, B.10). Samples were collected at Popes Landing in 1988 and the Rt. 128 Bridge in 1989 and 1990. Smelt larvae were the second most frequently caught fish larvae (21%) and occurred from May 10th to June 7th. Twelve species of fish were represented by the eggs and larvae collected. Sand lance was caught most frequently (32%) and at the highest average density (1.3/100 m^3). Labridae-Limanda group eggs (most likely cunner) were caught most frequently (21%) among fish eggs.

Crane River. Nineteen ichthyoplankton samples were collected in the Crane River at the abandoned railroad bridge upstream of Rt. 35 (Table 5.14, B.11). The presence of smelt larvae in the samples raised questions over the existence of a Crane River smelt run. Smelt larvae were the most frequently caught larvae (26%) and occurred from April 27th to May 17th. Seven species of fish were represented by the eggs and larvae collected. Sand lance and grubby were the next most frequently caught larvae (21%). Two of the ten smelt larvae caught in the Crane River were yolk-sac larvae (mean length = 5.6 mm). The others were larger larvae with no yolk-sac remaining (mean length = 7.7 mm).

Other Diadromous Species

River Herring were not known to spawn within the Danvers River system at the time of smelt monitoring. Both Belding (1921) and Reback and DiCarlo (1972) noted that an alewife run to Mill Pond was formerly know in the Crane River. Minor evidence of river herring spawning runs were found in both the Crane River and Porter River. A 46 mm juvenile blueback herring was caught in a Porter River ichthyoplankton net set on 5-20-88. A school of eight river herring were observed in the pool below the Purchase Street sluiceway in the Crane River on 5-13-88, and a similar school was seen at that location during a discharge measurement in May, 1991. These observations provide evidence of a river herring run in the Danvers

Table 5.10 Water chemistry and weather summary for the Porter River spawning habitat station, 1988-1990. Data are averages (Tables A.79-A.81) except station visits and NOAA Rainfall data are total values. Air temperature and rainfall data were recorded at Peabody, Massachusetts (NOAA 1988-1990).

Sample Period	Station Visits (No.)	NOAA Air Temp. (^oC)	NOAA Rainfall (cm)	Water Temp. (^oC)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)
1988							
March	9	3.6	9.4	4.2	0.0	7.5	
April	9	7.8	7.4	9.4	0.0	7.7	
May	8	14.0	11.2	13.8	0.0	7.7	
Season	26	8.5	28.0	9.0	0.0	7.6	
1989							
March	9	2.8	7.6	4.1	0.0	7.6	13.7
April	8	7.2	10.9	9.6	0.0	7.5	12.0
May	6	15.0	10.2	13.8	0.0	7.7	10.9
Season	23	8.3	28.7	8.5	0.0	7.5	12.4
1990							

Table 5.11 Water chemistry and weather summary for the Crane River sampling station, 1988-1990. Data are averages (Tables A.82-A.84) except station visits and NOAA Rainfall data are total values. Air temperature and rainfall data were recorded at Peabody, Massachusetts (NOAA 1988-1990).

Sample Period	Station Visits (No.)	NOAA Air Temp. (^oC)	NOAA Rainfall (cm)	Water Temp. (^oC)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)
1988							
March	9	3.6	9.4	4.1	0.0	7.3	
April	9	7.8	7.4	10.1	0.0	7.5	
May	8	14.0	11.2	15.6	0.0	7.7	
Season	26	8.5	28.0	9.7	0.0	7.5	
1989							
March	9	2.8	7.6	4.9	0.0	7.5	12.6
April	8	7.2	10.9	9.6	0.0	7.4	11.7
May	6	15.0	10.2	14.4	0.0	7.5	10.4
Season	23	8.3	28.7	9.0	0.0	7.5	11.7
1990							
March	8	3.7	4.8	5.5	0.0	7.5	13.8
April	9	8.8	15.8	10.7	0.0	7.5	12.1
May	7	12.2	16.5	14.1	0.0	7.5	10.6
Season	24	8.2	37.1	10.2	0.0	7.5	12.2

Table 5.12 River discharge measurements made at tributaries to the Danvers River, 1991-1997. The available measurements for March-May were averaged from post-monitoring sampling during 1991-1993 and four spring measurements from Chase et al. (2002).

River	Sample (No.)	Depth (Ave.m)	Velocity (Ave.m/sec)	Discharge (Ave. m^3/sec)	Min. Disc. (m^3/sec)	Max. Disc. (m^3/sec)	Discharge Range w/ Exposed Substrate
Porter	8	0.16	0.406	0.211	0.097	0.494	0.097 - 0.128
Crane	6	0.27	0.446	0.541	0.220	1.147	not observed
North	4	0.47	0.275	0.680	0.302	1.109	not observed

Table 5.13 Ichthyoplankton samples collected during 19 sample dates at the Porter River, Danvers, 1988-1990. Sizes are average total length for larvae and diameter for eggs. Larvae density is the absolute density collected in total sample volume (1266 m^3).

Species		Type	FOC	Period	No.	Size (mm)	Density (No./100 m^3)
sand lance	*Ammodytes americanus*	larva	6	3/15 - 4/29	16	13.4	1.3
rainbow smelt	*Osmerus mordax*	larva	4	5/10 - 6/7	12	11.8	1.0
grubby	*Myoxocephalus aenaeus*	larva	2	3/20 - 3/23	5	6.3	0.4
Atlantic silverside	*Menidia menidia*	larva	2	5/20 - 5/24	2	5.3	0.2
radiated shanny	*Ulvaria subbifurcata*	larva	1	5/11	2	8.9	0.2
winter flounder	*Pleuronectes americanus*	larva	1	6/7	1	5.6	0.1
Atlantic herring	*Clupea harangus*	juvenile	1	3/15	1	28.0	0.1
blueback herring	*Alosa aestivalis*	juvenile	1	5/20	1	46.0	0.1
mummichog	*Fundulus heteroclitus*	juvenile	1	5/24	1	31.0	0.1
rock gunnel	*Pholis gunnellus*	larva	1	3/20	1	12.3	0.1
L-L group	*Labridae-Limanda*	egg	4	5/24 - 6/8	362	1.0	28.5
P-S group	*Paralichthys-Scopthalmus*	egg	1	5/10	3	1.1	0.2
rainbow smelt	*Osmerus mordax*	egg	1	5/1	2	1.1	0.2

Table 5.14 Ichthyoplankton samples collected during 19 sample dates at the Crane River, Danvers, 1988-1990. Sizes are average total length for larvae and diameter for eggs. Larvae density is the absolute density collected in total sample volume (1351 m^3).

Species		Type	FOC	Period	No.	Size (mm)	Density (No./100 m^3)
grubby	*Myoxocephalus aenaeus*	larva	4	3/15 - 3/26	12	6.6	0.9
sand lance	*Ammodytes americanus*	larva	4	3/15 - 6/8	11	9.7	0.8
rainbow smelt	*Osmerus mordax*	larva	5	4/27 - 5/17	10	7.3	0.7
Atlantic silverside	*Menidia menidia*	larva	3	5/24 - 6/8	8	4.5	0.6
winter flounder	*Pleuronectes americanus*	larva	3	5/11 - 6/7	6	5.9	0.4
L-L group	*Labridae-Limanda*	egg	3	5/24 - 6/7	32	1.0	2.4
P-S group	*Paralichthys-Scopthalmus*	egg	1	6/7	3	0.9	0.2

River, comprised of remnants of earlier noted spawning runs or intermittent colonization from other runs on the North Shore. American eel elvers were routinely observed each year in the Porter River, beginning in mid-April, and less frequent elver observations were also made in the North and Crane Rivers.

Potential Spawning Habitat

Crane River. Three seasons of monitoring in the Crane River produced no observations of deposited smelt eggs or adult smelt despite the appearance of suitable spawning habitat near the tidal interface. A passage impediment was identified at the sluiceway to a former tannery pump house on Purchase Street. The elevation rise at the sluiceway slot was less than 0.5 m, but enough to prevent upstream passage by smelt. The combination of flow and tide conditions that allowed upstream passage at the sluiceway occurred infrequently during spring, and was only observed once in the three year study period (5-8-89, 12.2 ft. high tide, during low flow period). Upstream of the sluiceway there was nearly 2,000 m^2 of potential spawning habitat that included reaches along the Walnut Grove Cemetery with suitable depth, velocity and substrate for spawning. A small area of potential spawning habitat was found well downstream of the sampling station at the constriction of the Rt. 128 bridge. This location appeared to have suitable water velocity and substrate at low tide but is situated in the estuary and covered by nearly two meters of depth at high tide.

Despite the lack of smelt egg deposition, the status of Crane River as a smelt run was not certain after two seasons of monitoring. At the start of monitoring, it was expected that smelt eggs might be located in the Crane River. Local fishermen reported that the confluence of the Crane and Danvers Rivers was a known smelt fishing location in the 1950s and 1960s. Smelt larvae were caught at the Crane River railroad bridge during ichthyoplankton sampling during each season. However, given the negative observations at the upstream monitoring station and proximity of the Porter River spawning habitat, it is likely that the larvae originated in the Porter River and entered the Crane River during a flood tide. After 73 site visits during three seasons of monitoring it was concluded that Crane River did not have a smelt run, with the chief limiting factor being the activity of the former tannery including the passage barrier at the pump house (Chase 1993).

North River. The North River was monitored only in 1988 and water and substrate quality was found to be highly degraded from pollution inputs. The river has long been used as a conduit for waste disposal, going back to intensive use by the historic tannery industry. Tidal influence extends into Peabody in the North River, and has been observed as far as Howley Street, although the salt wedge probably does not extend much past Goodhue Street, Salem. It is

Potential spawning habitat in the Crane River. B. Chase

easy to imagine that the North River once supported a smelt run. There is ample freshwater flow with no current impediments to passage. There are several shallow water riffles that have gravel substrate. If there was once a smelt run, decades of pollution discharges and sedimentation probably rendered the habitat unfit to sustain a population. The remnants of a tide gate at the Rt. 114 culvert was present in 1988 and may have limited fish passage during earlier decades.

With each visit to the North River in 1988 oil and/or brightly colored chemical residues were seen in surface flows and on intertidal substrata. Dead *Nereis* seaworms were routinely observed and several dead juvenile American eels were seen. Between Goodhue Street and Howley Street, the river length is approximately 775 m, and the wet area is over 5,600 m^2. Several thousand square meters of this area has some potential to attract spawning smelt. Above Howley Street, there is a similar amount of shallow riffles that could be used for spawning by smelt. No evidence of smelt spawning was found that season and the river was not further monitored because of the severely degraded habitat. The North River was visited each year from 1989-1993 during the peak smelt spawning season to look for signs of smelt spawning and no evidence was found.

Bass River. The Bass River, Beverly, was surveyed in 1988 but not monitored because of the absence of potential spawning habitat. Tidal flow in the Bass River runs under Rt. 62 and through an underground pipe to a low head dam at the cooling pond of the former United Shoe Company. Freshwater flows in the Bass River are regulated by water withdrawals at an upstream golf course, the dam at Shoe Pond and at the entrance to the coolant pond. Upstream passage beyond the tidal zone is limited by the coolant pond dam. These conditions result in a saline environment below the coolant pond and the absence of spawning riffles. Local anecdotes were reported by fishermen who caught smelt at the Rt. 62 culvert in the 1950s.

Waters River. The Waters River, Danvers, was surveyed in 1988 but not monitored because of the poor substrate quality and minimal potential spawning habitat. Three creeks contribute freshwater to the tidal Waters River. A creek running under Endicott Street joins a creek running under Sylvan Street at the upper limit of salt marsh behind Endicott Street. The junction of this creek has small patches of gravel and coarse sand that possibly could attract spawning smelt. A third creek comes from a wooded area at the Rt. 114/Rt. 128 junction and meets the Waters River in the salt marsh upstream of Rt. 128. All three of these creeks have little freshwater baseflow and are subject to polluted stormwater flows from the high density of impervious surfaces found at the surrounding roadways and malls. The substrata at all creeks suffered from sedimentation. No passage impediments occurred and all creeks had small patches of gravel that could serve as spawning habitat. No evidence of smelt spawning was found in 1988 and at subsequent visits in the 1990s during the peak of spawning season.

DISCUSSION

It is likely that anadromous fish spawning runs in the Danvers River have diminished greatly from the status of pre-industrial times. The monitoring of existing conditions and anecdotal accounts indicate that smelt may have previously spawned in the North, Crane and Bass Rivers.

A small smelt run was found in the Porter River during 1988-1990. Given the name of the brook leading into Porter River, Frost Fish Brook, it is likely that a larger smelt population occurred formerly and the run continued well above the habitat now used. River herring may also have been more abundant in the Crane and Bass Rivers. The size of the river herring run in the Crane River is so small that its detection nearly eluded three years of monitoring.

The causal factors for the decline of anadromous fish in the Danvers River are not known for certain, but there are some conditions in the tributaries that clearly have had local impacts. The construction of the cooling ponds for the United Shoe Company on the Bass River blocked passage of anadromous fish to upstream freshwater locations. The dam in the Crane River cut off a run of alewives that formerly spawned in Mill Pond (Reback and DeCarlo 1972). And the pump house sluiceway in the Crane River is an example of a physical obstruction that severely limits the amount of spawning habitat available to smelt.

Negative impacts to anadromous fish runs may have also resulted from degradation of spawning substrate and water quality. The North River is the most obvious example of chronic pollution degrading spawning habitat. Sediment testing in the North River found very high levels of chromium and lead (MDPW 1991), common constituents used in the tanning industry that prospered on the North River during the last century. To an unknown degree, land and water use practices have degraded the quality of habitat for aquatic organisms throughout the Danvers River estuary. The proliferation of retail complexes along Rt. 128 has greatly increased the amount of impervious surfaces and creates a substantial stormwater load to the upper estuary. The accumulation of sediment and the excessive growth of periphyton near potential spawning riffles are two forms of habitat degradation observed during the monitoring period.

With no time series information available, it is difficult to say to what extent sedimentation has affected substrate conditions. The appearance of a large shoal of clean, coarse sand was observed in the Porter River in 1989. The sand shoal settled over soft-shell clam habitat between the 1988 and 1989 seasons, directly upstream of Rt. 128. The source of the sand is not known: sand coming from the highway would be expected to settle downstream of the bridge. Recent sedimentation events were seen on several occasions at the Porter River spawning habitat, reducing the attraction of riffles for spawning smelt and reducing the quality of substrate for egg survival. The impact of nutrient loading is not as obvious as sedimentation. Observations were made each monitoring season of excessive periphyton growth degrading riffle habitat. The periphyton growth was highest in the Crane and North rivers, and noticeably lower in the Porter River.

Two other potential sources of habitat degradation identified in the preliminary Danvers River report were sewer discharges and boating operations (Chase 1993). During monitoring, there were eight combined sewer discharges (CSOs) active in the Danvers River (SESD 1991). Raw sewage discharges were observed in the Porter River during each monitoring season. Most CSOs in the Danvers River have been since eliminated, and the frequency of raw sewage discharges is now greatly reduced. Recreational boating in the region has been popular for decades and is probably increasing. High densities of boats are berthed in the Danvers River: in 1997, Danvers report 810 boat berths in the tributaries to the Danvers River associated with six marinas/yacht clubs (Chase et al. 2002). Several marinas are located in the upper estuary. This concentration of boating activity has likely contributed to the degradation of the Danvers River estuary through pollution inputs and reduction of salt marsh for boating infrastructure.

In summary, it appears that the cumulative impacts of stream obstructions, industrial discharges, sedimentation, nutrient loading, and tideland development have degraded the ecological health of the Danvers River. These conditions have certainly contributed to the decline in local smelt runs. Despite these substantial obstacles to anadromous fish populations, there has been some success in recent years to reduce sewage discharges and toxic pollution loads in the Danvers River/Salem Sound region. The benefits of the Clean Water Act may be occurring in this region, as evident from improving water quality during dry weather flows (Chase et al. 2002). These improvements may be related to more recent observations of smelt eggs in the both the Crane and North rivers.

Observations in the Crane River since 1990. The Crane River was earlier identified as a having potential for smelt population spawning habitat restoration (Chase 1990 and 1993). With nearly 2,000 m^2 of suitable spawning substrate upstream of the Purchase Street sluiceway, it was selected as a priority location in Massachusetts Bay for smelt population enhancement and habitat restoration. A restoration project was conducted during 1995-1997 to transfer smelt eggs from donor rivers to the Crane River (Chase et al. *In prep.*). This project was unique for rainbow smelt in that the egg transfers were quantified (both numbers transferred and egg survival) and accompanied with habitat restoration (elimination of the passage impediment) and an evaluation of the project methods and success. Approximately three million smelt eggs were transferred to the Crane River during 1995-1997 and the habitat was monitored for smelt egg deposition during 1997-2001. Smelt eggs were located in the Crane River during 1997, the first year of potential recruitment from transferred eggs. The monitoring during 1997-2001 found smelt eggs during each year except 1999. The project appears to have successfully introduced smelt to the Crane River, although the evaluation found the method to be inefficient due to the low survival of transferred eggs and the poor availability of donor populations in Massachusetts (Chase et al. *In prep.*).

Observations in the North River since 1990. The North River was recognized in 1988 as having no impediments to passage and suitable physical conditions to support a smelt run. Unfortunately, water and substrate quality was severely degraded from decades of chronic industrial pollution. Water quality in the North River was sampling on 18 dates in 1997 during a DMF study on marine resources in Salem Sound (Chase et al. 2002). The water quality during dry weather flows was noted to be supportive of aquatic life and the substrate quality had substantially improved from that observed in 1988. Renewed visits to find smelt eggs in the North River were conducted in 1997-1999, and routine monitoring was conducted in 2000 and 2001. On March 29, 2001, less than 50 smelt eggs were found 100 m downstream of Howley Street. In the spring of 2002, a collaborative smelt habitat restoration project received a grant from NOAA Restoration Center and Fish America to improve the spawning substrate for smelt upstream of the tidal interface. Two seasons of monitoring have found few smelt eggs in the North River. The amounts of smelt eggs found (<50 eggs/hour of effort) are similar to that found in the Crane River and represent a very small spawning run.

It appears that smelt have colonized the North River on their own after decades of chronically degraded water and habitat quality. In the nearby Crane River, the egg transfer project resulted with modest success of continued spawning after the end of egg transfers. It is not known if there is any relationship between Crane River egg stocking and the colonizing of the North River spawning habitat. These recent events are encouraging. The available spawning habitat in both the two tributaries exceeds 2,000 m^2, which would represent the largest smelt spawning habitats on the North Shore. It should be recognized that these runs are very small at this time. The amount of eggs found in the North or Crane River during an entire season of monitoring can be found on a single rock in prime spawning riffles during the peak of the large Boston Harbor smelt runs.

Observations in the Porter River since 1990. Periodic visits during the peak spawning season have been made to the Porter River spawning habitat since the monitoring period. Smelt eggs have been found each year, although very low densities have been observed. The relatively high egg densities found in 1989 have not been observed since. In 1995, the spawning habitat was altered by instream bulldozer activity upstream of Rt. 62. The natural riffles were widened and stream sinuosity was reduced. The footprint of the work coincided with the length of the spawning habitat. Inquiries to neighbors and the Danvers Department of Public Works were inconclusive. The work was alleged to have been done privately without permits to reduce flooding at neighboring properties. The spawning habitat has experience some modest natural reclamation since then as scouring effects have improved the damaged riffle habitat.

RECOMMENDATIONS

1. Porter River Habitat Improvement. The spawning habitat at Porter River may benefit from physical improvements to repair the damage done to riffles above Rt. 62. An evaluation should be made on improving the stream bank and riffle habitat along this reach.

2. Porter River Junction with Route 62. The junction of Rt. 62 and the Porter River contains a narrow culvert and is a source of sediment loading to the Porter River. This location should be considered a candidate for culvert improvement and enhanced stormwater treatment and sediment controls when opportunities arise. Existing catch basins should be annually cleaned at this location.

3. Crane River Monitoring and Assessment. It is encouraging that smelt egg deposition continues in the Crane River after egg transfers were ended in 1997. However, spawning activity continues to be scant relative to the available habitat. The smelt run in the Crane

River should be monitored for spawning activity and recommendations should be developed for improving water quality in the Crane River.

4. North River Monitoring and Assessment. Similar to the Crane River, minor egg deposition is now found relative to the available spawning habitat. Efforts should continue to monitor this smelt run and identify means for improving water and substrate quality. An evaluation should be made on the potential for enhancing the recent restoration project with additional structural improvements to further improve riffle habitat.

5. North River Sediment Remediation. The North River has over 700 m of river length that contain potentially suitable spawning riffles near downtown Peabody. These riffles are susceptible to sedimentation impacts from high stormwater sediment loads. This region is also prone to flooding and the focus of planning efforts to reduce flood damage. It is recommended that planning to improve the drainage infrastructure in the North River include structural and operational goals for sediment remediation.

6. Population Enhancement. The next practical step following the egg transfer project is to enhance smelt populations using hatchery methods to improve egg survival. This may provide benefits if a quantitative mark and recapture approach is taken in concert with water and habitat quality improvements. If hatchery enhancement is attempted in Massachusetts Bay, the North River and Crane River should be considered candidates to receive contributions of larvae.

7. Protection of River Shading. Recent observations have been made of clearing river bank vegetation in the Porter, Crane and North rivers. A vegetation canopy provides the benefits of reducing warming and algal growth in eutrophied rivers. In some cases, this clearing must receive approval through the Wetlands Protection Act. It is recommended that the Conservation Commissions of each municipality develop by-laws to protect shading along river habitats.

8. Crane River Stormwater Improvement. A stormwater culvert drains the parking areas of a large retail complex to a location on Crane River just downstream of the lower limit of smelt egg deposition. An evaluation should be conducted on the efficiency of this stormwater system for removing pollutants and excessive sediments.

North River, Salem, 1989. B.Chase

MANCHESTER BAY

STUDY AREA

Manchester Bay is located in the North Shore Coastal Drainage (Halliwell et al. 1982), between the Danvers River and Cape Ann. There are numerous small creeks that flow into the coastal waters of Beverly and Manchester. Most of these creeks are unnamed and drain freshwater wetlands within a few kilometers of the coast. In 1988, eight streams were surveyed for the presence of potential smelt spawning habitat. Only three locations were found to possess suitable freshwater flow and substrate. Chubb Creek and Bennett Brook were selected for monitoring during 1988-1990 because they were known spawning locations (H.R. Iwanowicz, DMF, *pers. comm.*). Sawmill Brook was not a documented smelt run, but was added to the monitoring program in 1990 after smelt eggs were found in 1989. The main branch of Chubb Creek is the border between the towns of Beverly and Manchester at Rt. 127. The two branches of Chubb Creek drain freshwater wetlands in Beverly and Manchester. Bennett Brook flows from wetlands in Manchester into Manchester Harbor. Sawmill Brook flows from Cedar Swamp in northern Manchester into Manchester Harbor. The drainage area of Sawmill Brook is 13.0 km^2 and both Chubb Creek and Bennett Brook are less than 7.8 km^2 (Wandle 1984). Ichthyoplankton and water chemistry samples were taken from the wood bridge at the western branch of Chubb Creek and the railroad bridge at the mouth in 1988 and 1989. There were no streamflow gauges located on any of the Manchester Bay creeks.

No previous studies have been conducted on the fishery resources of these Manchester Bay tidal creeks. Chubb Creek was listed as a smelt run Reback and DeCarlo's (1972) anadromous fish survey of the late 1960s. The Chubb Creek salt marsh was recognized as the largest salt marsh (44 acres) in the study area of the DMF estuarine report for Salem Sound (Jerome et al. 1967). Smelt fishing in Manchester Harbor has declined in recent years. As recently as 20-25 years ago, a traditional fishery produced routine catches of smelt from structures along Manchester Harbor during the fall and winter. Fishing effort over the past 15 years has involved very few individuals with sporadic catches.

RESULTS

Smelt spawning was documented at each of the three creeks monitored within the Manchester Bay region during the study period of 1988-1990. Smelt spawning was found each year at the known spawning sites in Chubb Creek and Bennett Brook, and Sawmill Brook was designated as a smelt run based on observed egg deposition. These creeks support very small spawning runs of smelt: the total amount of available spawning habitat was only 706 m^2 for the three runs combined. Additional details are available in an earlier DMF report on Manchester Bay smelt (Chase 1995).

Spawning Habitat

Chubb Creek. Smelt spawning in Chubb Creek was limited to a short reach near the tidal zone where egg deposition was found for 58 m downstream of the Rt. 127 culvert opening. Eggs were not found upstream of Rt. 127 and the upstream limit was less than a half meter inside the downstream culvert opening. The highest concentration of eggs was found immediately below the culvert along a 10 m riffle. The average width of the creek where spawning occurred was slightly more than a meter, and the area of spawning habitat was estimated at 71 m^2. This limited amount of spawning habitat makes Chubb Creek one of the smaller active smelt runs in the study area.

Bennett Brook. Smelt egg deposition in Bennett Brook was found over a 172 m brook length starting 12 m below Bennett Street and ending upstream where passage is blocked by the remnants of a mill dam. The average width of the spawning habitat 1.7 m and the estimated area was 296 m^2. During each season the first eggs were found at riffles below Bennett Street in the tidal zone. Egg deposition was found to be continuous throughout the stretch, but the highest densities were directly below the old dam footing and lowest densities were below Bennett Street. Similar to Chubb Creek, this narrow tidal brook supports a relatively small population of smelt.

Spawning habitat in Sawmill Brook. B.Chase

Sawmill Brook. Smelt eggs were first found in Sawmill Brook (the freshwater zone is also known as Cat Brook) during April 1989 and the following season the brook was routinely monitored. In 1990, egg deposition was found in the vicinity of School St. over a 98 m brook length with an average width of 3.2 m, and a spawning habitat area of

339 m^2. Sawmill Brook has a greater capacity to support a smelt population than the other two smelt runs of Manchester Bay. It is a larger freshwater brook with suitable substrate of cobble and attached moss. Egg deposition observed in 1990 was lightly scattered and well below habitat capacity, but still exceeded that observed in Chubb Creek and Bennett Brook. Passage is not impeded above the upper limit of egg deposition observed in 1990. There is a reach of suitable habitat for over 50 m immediately upstream of the 1990 upper limit. Beyond that point, the presence of suitable spawning riffles becomes intermittent as the brook slows with a higher proportion of deeper pools.

Spawning Period. Because of the limited available spawning habitat in each creek, smelt eggs were easily found and the start dates of the spawning period were readily determined for all three seasons (Table 5.15 - 5.17). The April start of the spawning period in Chubb Creek for each season was considerably late compared to most other smelt runs in the study area. The start dates for Bennett Brook and Sawmill Brook were also later than typical, resulting in warmer starting water temperatures and a shorter spawning period duration relative to other regions in Massachusetts. The recorded end dates of the spawning period were typical. The spawning period was longest for Bennett Brook and Chubb Creek in 1989 when much higher egg densities were observed compared to the sparse deposition seen in 1988 and 1990.

Water Chemistry

Chubb Creek. Water chemistry measurements were made at the wood walk bridge located 20 m downstream of the Rt. 127 culvert (Table 5.18, A.86-A.88). Tidal influence was routinely observed at the walk bridge during high tides. The extent of the salt wedge at this location depended on discharge and tidal elevation. Bottom salinity of 17-27‰ was found on five occasions during high tides. Surface salinity was recorded only once; 10‰ during a 11.6 ft high tide. The salt wedge would run along the bottom into the Rt. 127 culvert during the highest tides. Chubb Creek base flows were found to be acidified and a threat to smelt egg survival. Sixty-five % of all pH measurements violated surface water quality criterion for supporting aquatic life (<6.5). During the wet spring of 1990, all but one measurement was below 6.5 and the mean was 6.2 for the spawning season. Dissolved oxygen was found to be adequate to support aquatic life throughout the spawning period.

Bennett Brook. Water chemistry and flow measurements were made at the downstream mouth of the Bennett Street culvert (Table 5.19, A.89-A.91). Tidal influence approached the sample site with each flood tide. The highest encroachment of tidal influence was observed during a 11.6 ft high tide on March 3, 1989, when freshwater flow was backed up 25 m above Bennett Street. On this occasion, the surface water salinity was 1‰ and the bottom water was 28‰ at the sample site. Under most flood tide conditions the salt wedge did not reach Bennett Street. Bennett Brook was also acidified, but not to the extent of Chubb Creek. Forty-six % of all pH measurements violated surface water quality criterion for supporting aquatic life (<6.5). Dissolved oxygen was found to be adequate to support aquatic life throughout the spawning period.

Sawmill Brook. Water chemistry was measured at the upstream opening of the School Street bridge (Table 5.20, A.92). Stream flow and smelt passage in Sawmill Brook are influenced by a dam and tidegate at the harbor opening on Rt. 127. Average tides are prevented from entering the brook when the tidegate is closed. Tidal influence was not observed at School Street during 1990, but has been observed during dry summers. During the wet spring of 1990, 67% of pH measurements violated surface water quality criterion for supporting aquatic life (<6.5). Dissolved oxygen was found to be adequate to support aquatic life throughout the spawning period.

Stream Discharge

No discharge records were located for these three creeks. Three visits were made to the creeks in 1991 to measure discharge during the smelt spawning period (Chase 1995). Chubb Creek had the lowest discharge with an average of 0.013 m^3/s (0.5 cfs). Bennett Brook's average discharge was 0.045 m^3/s (1.6 cfs), and Sawmill Brook's average was substantially larger at 0.415 m^3/s (14.7 cfs). The discharge at all three creeks is subject to sharp fluctuations from runoff following precipitation. Discharges of 0.010 m^3/s at Chubb Creek and 0.017 m^3/s at Bennett Brook on April 19, 1991 resulted in the exposure of small amounts of spawning substrate. More data are needed to adequately describe discharge in these three creeks.

Ichthyoplankton

Seventeen ichthyoplankton samples were collected from two locations in Chubb Creek during the 1988 and 1989 seasons. The primary location was the railroad bridge at the mouth of Chubb Creek. Six samples were also collected from the wood bridge at the confluence of the west branch and main stem of Chubb Creek for the purpose of determining if smelt larvae were found in the west branch. At least 12 species of finfish were represented by eggs and larvae captured in the 17 samples (Tables 5.21, B.12). Rainbow smelt were the most frequently caught and most abundant larvae in these spring samples at Chubb Creek. Smelt larvae were captured on four occasions, all occurring in May, at an overall density of 72/100 m^3. This relatively high density was influenced by a single sample on May 15, 1989 that captured many yolk-sac smelt larvae (603/100 m^2) exiting the estuary. Smelt larvae were caught at the west branch bridge on two occasions (Table B.13). It is

Table 5.15 Smelt spawning period in Chubb Creek, Manchester,1988-1990.
The spawning period is an estimation based on observations of viable smelt eggs.

			Water Temperature (°C)			
Year	Spawning Period	Days	Start	End	Range	Mean
1988	April 24th - May 21th	28	11.5	14.5	8.0 - 18.0	12.1
1989	April 8th - May 27th	50	7.5	15.0	7.0 - 15.0	10.9
1990	April 5th - May 19th	45	5.5	10.0	5.0 - 16.0	10.0

Table 5.16 Smelt spawning period in Bennett Brook, Manchester, 1988-1990.
The spawning period is an estimation based on observations of viable smelt eggs.

			Water Temperature (°C)			
Year	Spawning Period	Days	Start	End	Range	Mean
1988	April 7th - *not delineated*		11.5	-	-	-
1989	March 21st - May 16th	57	5.0	14.0	4.5 - 15.5	9.6
1990	March 22nd - May 9th	49	7.0	13.0	5.0 - 15.0	8.9

Table 5.17 Smelt spawning period in Sawmill Brook, Manchester, 1990.
The spawning period is an estimation based on observations of viable smelt eggs.

			Water Temperature (°C)			
Year	Spawning Period	Days	Start	End	Range	Mean
1990	March 28th - May 12th	46	5.0	14.5	4.0 - 16.0	9.3

likely these larvae hatched at the Rt. 127 spawning location and entered the west branch during flood tide. The most common fish egg was from the Paralichthyes-Scopthalmus egg group (most likely windowpane flounder), occurring in four samples at an overall density of 20/100 m^3.

Other Surveyed Tributaries

Seven freshwater drainages were surveyed in the Manchester Bay region during 1988-1989 with all possessing little or no potential smelt spawning habitat. Two creeks were visited more frequently during the peak spawning seasons to be certain there was no spawning activity. The western branch of Chubb Creek was visited several times and no evidence of spawning was found. This tidal creek winds a long distance from the main stem Chubb Creek before meeting freshwater flows on the upland side of Rt. 127. Minor base flows and limited spawning riffles reduce the attraction for spawning smelt in this branch. Of the seven drainages, the west branch of Chubb Creek has the highest potential to be colonized by spawning smelt. Days Creek, that crosses Beach Street at the eastern side of Manchester Harbor, was also visited. No evidence of spawning was found in the sandy substrate of this tiny creek.

The following five creeks were surveyed and not selected for monitoring because suitable flow and substrate conditions were nearly absent: an unnamed creek that flows under Rt. 127 to the western side of Manchester Harbor; an unnamed creek at Plum Cove, Beverly; Curtis Brook that flows through an underground culvert to Patch Beach at Beverly Cove, Beverly, and two creeks in Kettle Cove (north of Manchester Bay but part of the same watershed), Wolf Trap Brook and a tidal creek running into Clark Pond. The Clark Pond creek running through the Coolidge Reservation is interesting because at low tide it possesses the physical appearance of suitable spawning habitat. However, at high tide, saline water flows through the creek into Clark Pond. Under these conditions, no spawning habitat is present. At low tide an elevation rise at the beach prevents smelt passage into the creek and the outflow from Clark Pond is brackish.

Other Diadromous Species

Only American eel were observed during the monitoring period. American eel elvers were seen in low numbers near the sampling stations for each creek. No records were found indicating the former presence of other anadromous species in Manchester Bay creeks.

Table 5.18 Water chemistry and weather summary for the Chubb Creek spawning habitat station, 1988-1990. Data are averages (Tables A.86-A.88) except station visits and NOAA rainfall data are total values. Air temperature and rainfall data were recorded at Peabody, Massachusetts (NOAA 1988-1990).

Sample Period	**Station Visits** (No.)	**NOAA Air Temp.** (^oC)	**NOAA Rainfall** (cm)	**Water Temp.** (^oC)	**Water Salinity** (ppt)	**Water pH**	**Water D.O.** (mg/l)
1988							
March	9	3.6	9.4	3.4	0.0	6.5	
April	8	7.8	7.4	9.1	0.0	6.6	
May	8	14.0	11.2	12.5	0.0	6.6	
Season	25	8.5	28.0	8.1	0.0	6.5	
1989							
March	9	2.8	7.6	3.8	1.1	6.5	12.5
April	8	7.2	10.9	8.8	0.0	6.1	11.2
May	6	15.0	10.2	12.2	0.0	6.3	10.5
Season	23	8.3	28.7	7.7	0.4	6.3	11.5
1990							
March	8	3.7	4.8	4.1	0.0	6.2	13.4
April	9	8.8	15.8	8.9	0.0	6.2	11.8
May	7	12.2	16.5	12.4	0.0	6.3	10.2
Season	24	8.2	37.1	8.3	0.0	6.2	11.9

Table 5.19 Water chemistry and weather summary for the Bennett Brook spawning habitat station, 1988-1990. Data are averages (Tables A.89-A.91) except station visits and NOAA rainfall data are total values. Air temperature and rainfall data were recorded at Peabody, Massachusetts (NOAA 1988-1990).

Sample Period	**Station Visits** (No.)	**NOAA Air Temp.** (^oC)	**NOAA Rainfall** (cm)	**Water Temp.** (^oC)	**Water Salinity** (ppt)	**Water pH**	**Water D.O.** (mg/l)
1988							
March	9	3.6	9.4	4.8	0.0	6.4	
April	8	7.8	7.4	9.3	0.0	6.8	
May	8	14.0	11.2	13.2	0.0	6.8	
Season	25	8.5	28.0	8.9	0.0	6.7	
1989							
March	9	2.8	7.6	4.4	0.1	6.7	13.1
April	8	7.2	10.9	9.3	0.0	6.4	11.8
May	6	15.0	10.2	12.3	0.0	6.4	10.9
Season	23	8.3	28.7	8.2	0.0	6.5	12.0
1990							
March	8	3.7	4.8	4.8	0.0	6.4	13.8
April	9	8.8	15.8	9.2	0.0	6.4	12.3
May	7	12.2	16.5	12.9	0.0	6.4	10.8
Season	24	8.2	37.1	8.8	0.0	6.4	12.4

DISCUSSION

In terms of available spawning habitat and population size, the three Manchester Bay runs are relatively small, and Chubb Creek is one of the smallest in the study area. All three Manchester Bay smelt runs are reported to be well below historical levels of abundance. Numerous comments were received from local residents on recent changes in smelt populations. In summary, residents reported that in the 1960s and 1970s, a robust smelt fishery existed in Manchester Harbor and large numbers of smelt were often observed in the daytime at Bennett Brook (1970s) and Sawmill Brook well past School Street (1960s). Presently, very little smelt fishing occurs in Manchester Harbor and some neighbors expressed the belief that the smelt runs were gone. Without baseline data on population sizes or spawning habitat conditions it is difficult to identify factors causing the declining populations. The following sections discuss conditions unique to each smelt run in Manchester Bay.

Chubb Creek

Chubb Creek contributes a low volume of freshwater to a relatively small estuary. With each low tide, the entire estuary drains out of a narrow opening into Manchester Bay, typically leaving only freshwater in shallow channels throughout the estuary. Many larger estuaries with smelt runs have deeper channels where smelt aggregate prior to moving upstream to spawn at night. No such resting pools were found in Chubb Creek, indicating that smelt probably leave the estuary after each night of spawning. The flood tide brings saline water to the lower limits of spawning habitat below Rt. 127. The daily exodus of smelt from Chubb Creek brings up the question over the spawning fidelity of Manchester Bay smelt to specific spawning habitats. With the close proximity of Bennett and Sawmill brooks, and limited attraction of Chubb Creek freshwater flow, it is possible that Manchester Bay smelt do not have discrete fidelity to one spawning habitat. The diurnal draining of Chubb Creek may also contribute to the late onset of spawning. Very few smelt runs monitored in this program have been found to commence in April. Chubb Creek spawning started in April during all three seasons. Because the smelt do not take up residence in the estuary prior to spawning, they may not be exposed to the freshwater discharge and temperature that triggers earlier spawning.

Observations since 1990. The current status of the Chubb Creek spawning run could be described as threatened. Very little egg deposition has been observed in Chubb Creek since the relatively high egg densities seen in 1989. Visits to Chubb Creek in recent years have found few individual smelt eggs or none. The cause of poor productivity in recent years is not certain, although the very small size of the creek discharge and spawning habitat raise the concern over a limited capacity to buffer against stormwater and acidification impacts.

Presumably, smelt formerly passed under Rt. 127 and spawned well above the salt wedge upstream of Rt. 127. No smelt eggs were found upstream of Rt. 127 from 1988-1990. During the winter of 1999/2000 it was discovered that the culvert under Rt. 127 had collapsed and an emergency repair was made by the MHD. An assessment of the culvert found that the pipe had probably been in poor condition for years, rendering fish passage difficult and eliminating upstream riffles by raising the water elevation. The culvert repair had the immediate effect of improving drainage which lowered the water elevation upstream of Rt. 127 and led to the scouring of the creek bed and the formation of a two minor upstream riffles. Smelt passage upstream occurred as evident by a dozen smelt eggs found at the upstream riffles during two visits in the spring of 2000. The culvert repair also had the negative effect of widening the channel immediately downstream of the culvert opening. A stone-lined pool was created for drainage purposes at the primary riffle where most egg deposition was found during 1988-1990. An enforcement order by the ACOE required the repair of the pool in 2001. The repair narrowed the pool resulting in slightly higher velocity; however, no egg deposition was found at this reach during 2001-2003. This recent alteration is an example of how unintentional construction activities can have an immediate impact (negative downstream and positive upstream) to smelt spawning habitat.

Bennett Brook

With nearly 300 m^2 of spawning habitat, Bennett Brook has the potential for a larger population of smelt than Chubb Creek. Bennett Brook egg deposition in 1989 was much greater than observed in 1988 and 1990, yet was still well below habitat capacity. The drop in egg production from 1989 to 1990 was remarkable. Spawning was continuous in the month of April in 1989, and egg densities below the old mill dam were some of the highest seen north of Boston during the time period. In 1990, the egg deposition peaked in early April and eggs were difficult to locate by the beginning of May. The population has clearly declined from conditions of 20-25 years ago when local residents reported observing schools of smelt filling the brook channel in the daytime. The causal factors behind the decline in population size are not known.

The low volume of freshwater flow in Bennett Brook could make the spawning habitat susceptible to run-off impacts from Bennett Street. The substrate does contain a large amount of sand in the vicinity of Bennett Street that appears to originate from the street drains that were clogged with sand. The spawning habitat upstream of Bennett Street contains stretches of clean gravel with adequate shading. The threat from episodic pH depressions on egg survival is another concern for Bennett Brook. The passage impediment from the sill of old mill at the upstream limit of egg deposition is not perceived as a limiting factor because the upstream channel is overgrown with vegetation and has no suitable spawning riffles.

Table 5.20 Water chemistry and weather summary for the Sawmill Brook spawning habitat station, 1990. Data are averages (Tables A.92) except station visits and NOAA rainfall data are total values. Air temperature and rainfall data were recorded in Peabody, MA (NOAA 1990).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)
1990							
March	8	3.7	4.8	3.9	0.0	6.4	13.8
April	9	8.8	15.8	8.8	0.0	6.3	12.2
May	7	12.2	16.5	12.9	0.0	6.4	10.4
Season	24	8.2	37.1	8.4	0.0	6.4	12.2

Table 5.21 Ichthyoplankton collected during 17 samples at Chubb Creek, Manchester, 1988-1989. Sizes are average total length for larvae and diameter for eggs. Larvae density is the absolute density collected in total sample volume (1,136 m^3).

Species		Type	FOC	Period	No.	Size (mm)	Density (No./100 m^3)
rainbow smelt	*Osmerus mordax*	larva	4	5/8 - 5/15	813	6.2	71.6
sand lance	*Ammodytes americanus*	larva	2	3/9 - 4/3	2	6.7	0.2
grubby	*Myoxocephalus aenaeus*	larva	2	4/3 - 4/5	3	11.2	0.3
Myoxocephalus sp.	*Myoxocephalus sp.*	larva	1	5/27	1	5.3	0.1
threespine stickleback	*Gasterosteus aculeatus*	juvenile	2	5/8 - 6/6	2	41.5	0.2
winter flounder	*Pleuronectes americanus*	larva	1	6/6	1	6.4	0.1
striped seasnail	*Liparis gibbus*	larva	1	5/8	1	4.0	0.1
Atlantic cod	*Gadus morhua*	juvenile	1	5/15	1	22.0	0.1
American plaice	*Hippoglossoides platessoides*	egg	3	4/5 - 4/24	10	2.4	0.9
Atlantic mackerel	*Scomber scombrus*	egg	1	5/13	7	1.4	0.6
P-S group	*Paralichthys-Scopthalmus*	egg	4	5/13 - 6/6	231	1.1	20.3
L-L group	*Labridae-Limanda*	egg	1	6/6	82	1.0	7.2
G-G group	*Gadidae-Glyptocephalus*	egg	1	5/13	1	1.4	0.1

Sawmill Brook

Of the three Manchester Bay smelt runs, Sawmill Brook possesses the highest discharge, most available spawning habitat and best quality of substrate for egg attachment and survival. The stretch above School Street has excellent flow conditions and a fair amount of attached moss. Despite the better conditions, the smelt egg deposition observed in 1989 and monitored in 1990 was sparse relative to habitat capacity. During 1989-1990, smelt eggs were first found 60 m below the School Street bridge. The highest densities of eggs were found in the swift, channelized flow 20 m upstream of School Street. Suitable spawning habitat was available upstream of the upper limit of egg deposition in 1990. It appeared likely that this habitat would be utilized during a stronger run, possibly doubling the amount of available spawning habitat to about 200 m in length and over 600 m^2 of stream substrate area.

Similar to the other two smelt runs, road run-off and low pH are potential sources of negative impacts at Sawmill Brook. Another concern identified was the dam at the mouth to Manchester Harbor on Rt. 127 that can impede smelt passage to upstream spawning habitat and may be a negative influence on the run's productivity. Smelt can pass over the flood control dam at Central Street but only during the highest stage of above average high tides. A tidegate is located at the bottom of the dam for flood control openings. The dam has created a small impoundment between Rt. 127 and School Street that smelt must pass through to reach suitable spawning habitat.

Observations since 1990. In the late 1990s, two efforts were made to assist the Sawmill Brook smelt run in coordination with Salem Sound Coastwatch and the Town of Manchester. A tidegate opening schedule was adopted by the Manchester DPW to give smelt an opportunity to pass through the tidegate at the bottom of the dam during lower tides. This opening schedule has been conducted each year since 1999. These same partners received a grant from the NOAA Restoration Center and the FishAmerica Foundation in 2001 to repair a segment of the stone channel wall along the prime spawning habitat upstream of School Street. These activities have been accompanied by egg deposition monitoring by DMF, which have found low densities of smelt eggs. Concerns over low pH were raised again when water chemistry measurements at the same School Street station in 1997 by DMF resulted in an annual mean of 6.3 (N = 11, May-December), that included two low individual measurements of 5.2 and 5.7 (Chase et al. 2002).

RECOMMENDATIONS

1. Stormwater Impacts. Street drains are located in close proximity to spawning riffles for each of these Manchester Bay creeks. It is recommended that the capacity and function of these catch basins be evaluated and sediments be removed on an annual basin prior to the smelt spawning season.

2. Improvements to Chubb Creek Spawning Habitat. The recent replacement of the Rt.127 culvert may allow routine passage to upstream riffles that have benefited from the improved drainage. This stretch should be evaluated to determine if structural improvements to the spawning substrate could enhance the quality of this spawning habitat. The stone lined pool downstream of the Rt. 127 culvert should be evaluated to determine if further modifications can be made to restore this once productive spawning riffle.

3. Improvements to Sawmill Brook Spawning Habitat. The repair of the Sawmill Brook channel wall upstream of School Street was beneficial to this stretch. There are additional segments of channel wall, both upstream and downstream of this location that should be repaired to maintain the integrity of the spawning habitat, keep passage open, and limit the entry of eroded sediments. This work is recommended along with tree plantings to improve shading.

4. Sawmill Brook Dam and Tidegate. The recent openings of the Central Street tidegate should assist smelt passage to Sawmill Brook spawning habitat. This spring activity should continue in the near-term; however an evalution is needed to ensure smelt can pass at the bottom opening tidegate and to identify the most beneficial schedule given smelt spawning requirements, tidal conditions, and DPW constraints. In addition, an appraisal should be made of the long-term interest in modifying the dam to allow free passage without the need for scheduled openings.

CAPE ANN

STUDY AREA

The Cape Ann region includes the freshwater drainages associated with the Annisquam River, and the coast of Gloucester and Rockport. The Annisquam River is tidal and shows little depression in salinity from freshwater contributions (Jerome et al. 1969). There are numerous small creeks in this region that are fed by wetlands, small ponds and former quarries. Many of these creeks are unnamed and lose elevation quickly as they run across granite bedrock to sea level. The freshwater discharges from these creeks are minor and were not documented. One of the largest is the Little River that flows from Gloucester water sources and has a drainage area of 4.6 km^2 (Kooken et al. 2000). Only the Little River was previously documented as a smelt run (Reback and DiCarlo 1972). Smelt fishing was formerly a popular sportfishing activity in the region, and continues today at low levels of participation mainly at shoreline structures along Gloucester Harbor in the fall.

In order to select potential smelt spawning locations, site visits were made in 1988 to numerous creeks around Cape Ann, including several visits with George Oakes and Robert Knowles two local fisheries enthusiasts with over fifty years experience in local smelt fisheries. These efforts identified Little River as the only certain smelt run, three other Annisquam River tributaries as probable former smelt runs, and several creeks with potential spawning habitat. The Little River was monitored for smelt spawning habitat for three seasons, 1988-1990. The Mill River, with flows originating from Alewife Brook and Babson Reservoir, was monitored in 1988. An unnamed creek that enters Lobster Cove after draining from Langsford Pond was monitored in 1988 Piggery Creek flowing from wetlands in West Gloucester and joining the tidal Little River was monitored in 1989. The Goose Cove creek flowing from Duck Pond was monitored during 1988 and 1989. Surveys of additional creeks continued in1989 and two were selected for monitoring in 1990: an unnamed creek flowing into the Anniquam River at Stanwood Point, and Saratoga Creek in Rockport. One ichthyoplankton station was sampled at outlet of Goose Cove on the Rt. 127 bridge.

RESULTS

Seven spawning habitat stations were monitored and 17 other creeks were surveyed during the period of 1988-1990. Evidence of smelt spawning was only found in the Little River. No smelt eggs were found in the Little River during 1988 and low densities of smelt eggs were found along a small section of habitat during 1989 and 1990. Mill Brook and Sawmill Brook in Rockport were surveyed during this period and no evidence of smelt spawning was found; however, a few smelt eggs were found in 2000 at both brooks during site visits by NMFS and DMF, resulting in the classification of these two creeks as smelt runs.

Spawning Habitat

Little River. Smelt eggs were found over an 88 m stretch of the Little River in 1989 and 1990 that was centered by the stone-wall culvert that runs under Rt. 133. The downstream limit of egg deposition was 37 m below the Rt. 133 culvert along the salt marsh. This area was intertidal and received the salt wedge with each flood tide. Spawning continued under the road and for 14 m upstream into the alewife fishway. The total area where smelt eggs were found was 192 m^2. Smelt are presently limited to a short stretch of suitable habitat because of the elevation rise in the upstream fishway and the exposure to high salinity downstream of Rt. 133. A large majority of all deposited eggs were found at a discrete location, from 3 m downstream of the culvert's downstream opening to 2 m inside the culvert. Smelt were apparently attracted to spawn at the swift water velocity created by the culvert opening.

Spawning Period. The spawning period was only accurately delineated in 1990 (Table 5.22). No eggs were found in 1988 and smelt eggs were first found on April 10th in 1989 but it is possible that earlier deposition was overlooked. In 1990, a typical spawning period for a small smelt run in the study area of late March to early May was observed. The spawning period was not easily delineated for this smelt run despite the observation that a large majority of spawning occurred over a 5 m stretch at the Rt. 133 culvert opening. The difficulty in finding eggs over such a small area implies the Little River smelt run was comprised of few spawning adults.

Water Chemistry

Little River. The water chemistry at the Little River smelt spawning habitat was not ideal because of routine high salinity at high tide and acidic base flows (Table 5.23, A.93-A.95). The salt wedge would enter the Rt. 133 culvert with each high tide, resulting in up to a meter in depth and high salinities at the culvert opening where most egg deposition occurred. Surface flows were typically freshwater but dependent on tide stage and precipitation. Bottom flows were fresh during low tide and consistently saline (mean = 27‰) within 1.5 hours of high tide. Mean pH values were slightly acidic during each season, although there was evidence of exposure to lower pH at low tides and following precipitation. The mean pH was 6.5 for all values within 3 hours of low tide.

Stream Discharge

No stream flow gauges were located on any of the Cape Ann freshwater drainages. Stream discharge was measured at the downstream face of the Little River culvert on Rt. 133 on three occasions during the spring of 1991. The mean depth, velocity and discharge for these measurements were 0.11 m, 0.42 m/s and 0.066 m^3/s (2.3 cfs), respectively. These streamflow measurements reflect on the small size of the Little River, which was the largest freshwater discharge among the seven Cape Ann creeks monitored.

Other Monitored Creeks

Mill River. Mill River in Gloucester was monitored during 1988 and water chemistry was measured at the outlet of the Rt. 127 tidegate (Table A.96). Mill Pond is a 22 acre tidal pond set at sea level above a 2 m tidegate. The average surface salinity at the outlet was 17‰ during March-May and bottom salinity averaged 29‰. No evidence of smelt spawning was found at near the tidegate or at two small creeks that flow into Mill Pond from Strangman Pond and Babson Reservoir. Minimal potential spawning habitat was found at the two creeks. An alewife run occurred in Mill River prior to alterations in the river system for municipal water supply (Belding 1921). Smelt were known to occur in Mill Pond over 30 years ago (George Oakes and Robert Knowles, *pers. comm.*). The minor freshwater inputs and daily intrusion of saltwater keeps outflow from Mill Pond saline, which provides little attraction for smelt seeking spawning habitat.

Lobster Cove creek. The unnamed creek that flows from Langsford Pond to Lobster Cove was monitored in 1988 with no evidence of smelt spawning found. Water chemistry was measured at the base of a seawall downstream of Rt. 127 (Table A.97). This location was thought to be a smelt run in the 1960s (George Oakes, *pers. comm.*). Little available substrate was found that could possibly be used by smelt for spawning and the discharge was very low. The elevation rise at Rt. 127 prevents smelt passage upstream. Downstream of Rt. 127 the creek flows briefly on a homeowner's lawn before dropping over a small seawall (~1 m). Tidal influence approaches the seawall with each flood tide; however, passage was only possible for above average high tides. There was about 10 m both upstream and downstream of the seawall where freshwater riffles could attract spawning smelt. No smelt eggs were found during 1988 or subsequent visits.

Goose Cove creek. Three unnamed freshwater creeks flow into tidal Goose Cove which connects with the Annisquam River under the Rt. 127 bridge. One creek flows from Goose Pond Reservoir and is accessed from Holly Street. This creek had minor freshwater discharge and was not monitored because of the near absence of suitable spawning habitat. A second creek flows from Sheep Pond under Dennison Street has similar conditions to the first creek. A third creek flowed from Duck Pond and crossed Dennison Street to meet Goose Cove. This creek was identified as a potential smelt run (George Oakes, *pers. comm.*) and monitored during 1988 and 1989. No smelt eggs found during 1988 and 1989 and no smelt larvae were caught at the bridge station. The area of potential smelt spawning habitat was actually very small. During low tide, less than 10 m of turbulent flow was provided by boulders and large cobble. At high tide, this flow was obscured. The water chemistry station below Dennison Street received saline bottom water at higher tidal amplitudes and freshwater base flows were often below 6.5 pH (Tables A.98-A.99). Measurements at the Rt. 127 bridge found the water column completely mixed with saline water at all tides (mean = 29‰), a condition that would provide poor attraction to adult smelt.

Piggery Creek. A creek known locally in West Gloucester as Piggery Creek flows under Concord Street to meet the Little River was identified as a former smelt run (Robert Knowles, *pers. comm.*). This creek was monitored during 1989 and no evidence of smelt spawning was found. The creek flows through two culverts that pass under Concord Street. The culverts are raised above the substrate resulting in an obstruction to upstream passage during most tides. The habitat below the culverts is exposed to the salt wedge and degraded by sedimentation. Upstream passage above Concord Street was likely about 35 years ago when the creek was free flowing before the installation of the underground culverts. Freshwater base flows for this creek were typically acidic (<6.5 pH) (Table A.100).

Stanwood Point Creek. An unnamed creek that flows into the Annisquam River at Stanwood Point was identified as a potential smelt spawning location (George Oakes, *pers. comm.*) and monitored in 1989. No evidence of smelt spawning was found in 1989. The area of potential spawning habitat was very small because the creek grade fell quickly before the intertidal zone. Minor freshwater flows resulted in a 10 m stretch with potential spawning riffles between the intertidal zone and an elevation rise too steep for smelt passage. The pH of this creek averaged 6.1 in 1989 (Table A.101) with precipitation flows typically below 6.0 pH.

Saratoga Creek. Two small creeks feed into Saratoga Creek at Long Beach in Rockport. These creeks were surveyed and the western creek (East Brook) was selected for monitoring in 1990. Saw Mill Brook flowing from Rum Rock Lake to meet the tidal zone in eastern Saratoga Creek was surveyed but not selected for monitoring. No evidence of smelt spawning was found in East Brook and very little potential spawning habitat was found. East Brook was heavily silted with organic detritus and lacked spawning riffles during lower flows. At higher flows, there was less than 10 m of substrate that provided potential spawning habitat. Water chemistry was measured below a man-made stream baffle above the tidal zone (Table A.102). The water pH was acidic, averaging 5.4 and ranging from 4.9 to 6.0, which raised concerns for supporting aquatic life. No fish, aquatic insects or the nearly ubiquitous Gammarid amphipods were observed at the water chemistry station.

Other Surveyed Creeks

In addition to the surveyed creeks mentioned above, 14 other tidal creeks were surveyed in the Cape Ann region. These creeks were typically small, shallow discharges that presented little or no attraction for spawning adults. The

Table 5.22 Smelt spawning period in the Little River, Gloucester, 1988-1990. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (^oC) Start	End	Range	Mean
1988	no eggs found					
1989	not delineated - May 10th			13.5		
1990	March 19th - May 12th	55	7.0	14.3	5.5 - 15.5	9.9

Table 5.23 Water chemistry and weather summary for the Little River spawning habitat station, 1988-1990. Data are averages (Tables A.93-A.95) except station visits and NOAA Rainfall data are total values. Air temperature and rainfall data were recorded at Marblehead, Massachusetts (NOAA 1988-1990).

Sample Period	Station Visits (No.)	NOAA Air Temp. (^oC)	NOAA Rainfall (cm)	Water Temp. (^oC)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)
1988							
March	9	3.3	10.9	4.8	1.3	6.6	
April	8	7.7	5.6	9.6	1.0	7.0	
May	8	13.4	11.9	14.4	0.4	7.0	
Season	25	8.1	28.4	9.4	0.9	6.9	
1989							
March	9	2.3	9.4	5.8	0.0	6.8	12.9
April	8	6.8	10.4	10.5	0.0	6.4	11.3
May	5	14.4	11.7	14.1	0.0	6.4	10.3
Season	22	7.8	31.5	9.4	0.0	6.6	11.7
1990							
March	8	3.8	5.1	6.0	0.0	6.7	12.6
April	9	8.1	15.5	10.4	1.6	6.5	11.6
May	7	12.0	16.5	13.1	0.4	6.5	10.5
Season	24	8.0	37.1	9.7	0.7	6.6	11.6

Table 5.24 Ichthyoplankton samples collected during 10 dates at the Route 127 Bridge station on Goose Cove, 1988-1989. Sizes are average total length for larvae and diameter for eggs. Larvae density is the absolute density collected in total sample volume (407.5 m^3).

Species		Type	FOC	Period	No.	Size (mm)	Density (No./100 m^3)
grubby	*Myoxocephalus aenaeus*	larva	4	3/13 - 4/19	11	7.2	2.7
sand lance	*Ammodytes americanus*	larva	3	3/18 - 5/3	4	11.0	1.0
radiated shanny	*Ulvaria subbifurcata*	larva	1	5/17	13	6.8	3.2
seasnail (*L. sp*.)	*Liparis sp.*	larva	1	5/17	2	4.9	0.5
seasnail	*Liparis atlanticus*	larva	1	6/1	1	6.4	0.2
American plaice	*Hippoglossoides platessoides*	egg	3	5/4 - 6/1	20	2.2	4.9
P-S group	*Paralichthys-Scopthalmus*	egg	2	5/17 - 6/1	28	1.0	6.9
G-G group	*Gadidae-Glyptocephalus*	egg	2	5/4 - 6/1	14	1.2	3.4
L-L group	*Labridae-Limanda*	egg	1	6/1	151	1.0	37.0

following creeks were surveyed for potential spawning habitat and not selected for monitoring because suitable habitat was lacking or passage obstructions were found: a creek running from West Pond, Magnolia; a creek discharging at Norman's Woe, Magnolia; a creek running from Bushwell Pond and another unnamed tidal creek within Freshwater Cove, Gloucester Harbor; a creek running along Rt. 128 in northern Little River; a creek crossing Atlantic Avenue in the Jones River tributary to the Annisquam River; Sleepy Hollow Creek running into the Jones River; a creek in Hodgkins Cove; a creek in Plum Cove; a creek in Lane's Cove; two creeks running into Folly cove, including Stony Brook; and two creeks running to Good Harbor Beach, Gloucester, South Brook flowing from Cape Pond Reservoir; and an unnamed creek flowing from Day's Pond. Of all these creeks, only the northern Little River creek (near the Sudbay auto dealership) and the Sleepy Hollow creek were considered by Robert Knowles (*pers. comm.*) to have been possible smelt runs prior to the present watershed alterations.

Ichthyoplankton

The Goose Cove bridge on Rt. 133 was the only suitable ichthyoplankton sampling station located on the monitored creeks in the Cape Ann region. Ten samples were collected at this station during 1988-1989 (Table 5.24, B.14). No smelt larvae or eggs were caught. At least eight species of fish were represented by the eggs and larvae sampled, of which grubby larvae occurred most frequently (40%), followed by sand lance larvae (30%) and American plaice eggs (30%).

Other Diadromous Species

The only discharge on Cape Ann with a known river herring run in recent decades is the Little River (Reback and DiCarlo 1972). Modest numbers of alewives were seen entering the Little River fishway during each season of monitoring. Large numbers of American eel elvers were seen each season entering the Rt. 133 culvert and aggregating on the upstream side below the fishway. The number of elvers observed during 1988-1990 were surprisingly high for a creek of this size. No other anadromous fish were observed while monitoring other stations. Low numbers of elvers were seen at the Lobster Cove creek in 1988. Moderate numbers of elvers were seen throughout May at Goose Cove in 1988; however no elvers were seen at this station in 1989. Elvers were not observed during single seasons of monitoring at Mill River, East Brook, and the Concord Street and Stanwood Point creeks, but their presence in these creeks is possible. Elvers are reported to be commonly found in Sawmill Brook, Rockport (Eric Hutchins, NMFS, *pers. comm.*).

DISCUSSION

The monitoring from 1988-1990 found the Cape Ann region to lack a single discharge that could possibly provide more than a few hundred square meters of potential smelt spawning habitat. There were over ten creeks that had some potential spawning habitat, but most had minimal freshwater discharge and less than 100 m^2 of marginally suitable riffle habitat. Smelt spawning was only found at the Little River where egg deposition was observed at very low densities, including during 1989 when elevated smelt runs were seen throughout Massachusetts Bay. These observations do not explain anecdotal reports of popular fall smelt sportfisheries that flourished in the 1950s and 1960s, and faded in the late 1970s and early 1980s to the present low levels of effort and catch. The popularity of smelt fishing in the Little River resulted in a smelt fishing pier constructed on the Little River in the 1980s close to Rt. 133. To my knowledge, this is the only fishing pier built specifically for smelt in Massachusetts. The pier stands today in good condition, but is reported to have had little use in over a decade (Robert Knowles, *pers. comm.*).

It is probable that several other creeks supported smelt runs in past decades. The Mill River and Piggery Creek were reported by George Oakes, Robert Knowles and other residents as having smelt runs in the 1950s and 1960s. The Little River was probably the primary spawning habitat for smelt in the Annisquam River, but at higher levels of population abundance smelt may have colonized other freshwater drainages each spring. It is also likely that under higher levels of abundance that smelt hatched in the Essex River and possibly Ipswich Bay runs would visit the Annisquam River for feeding opportunities and become exposed to local sportfisheries. These feeding movements and the potential to colonize other spawning habitats could result in periodic spawning in any of these creeks with potential spawning habitat.

The potential for smelt populations to rebound in the Cape Ann region is limited by more than the small amount of suitable spawning habitat. It is likely that drainage alterations for recent developments have obstructed smelt passage to spawning habitat (ex. Mill Pond and Piggery Creek). Several of these creeks are subject to sedimentation from the roadway, and Little River has been degraded by sedimentation from the water filtration plant located slightly upstream from the smelt spawning habitat. A settlement basin is located immediately upstream of the Rt. 133 culvert. Sediments from the basin were flushed out to the spawning habitat downstream each spring during 1988-1990 while plant maintenance occurred. The growing demand for municipal water uses may have impacted drainages that run from reservoirs (ex. Mill River). Finally, the geology of Cape Ann appears to limit the buffering capacity of these creeks against acidification. All these creeks were acidic, and some showed depressions of pH following precipitation that would negatively affect smelt egg survival.

The observations of smelt eggs in Sawmill Brook and Mill Brook in Rockport provide strong arguments for not underestimating the capability of smelt to colonize any freshwater drainage. Mill Brook offers a minimal amount of spawning habitat and no more attraction to adults or suitable substrate for egg survival than most of the creeks surveyed and not selected for monitoring. With this in mind, it is possible that smelt could have previously used, or in the future use other creeks in the Cape Ann region for spawning habitat. Few habitat restoration projects that would specifically create spawning habitat are apparent for creeks in this region. However, potential spawning habitat may benefit from efforts to increase base flows, improve water quality and reduce sedimentation.

The 24 drainages either surveyed or monitored in the Cape Ann region can be categorized as: annual smelt runs, altered creeks that likely supported former smelt runs, creeks with minimal spawning habitat but potential candidates for colonization, and creeks with limited attraction flows and substrate. The Little River has the most suitable spawning habitat by virtue of the available base flow and gravel/cobble substrate near Rt. 133; and as a consequence was the only location found with a smelt run during the monitoring period. It is not hard to imagine that Mill Creek and Piggery Creek possessed small smelt runs prior to substantial alterations to stream hydrology and channel morphology. Beyond those three streams, few in the region have adequate base flows and spawning riffles to support a smelt run. Sawmill Brook in Rockport presently has the highest potential to support an annual run after Little River. Mill Brook in Rockport and perhaps the Sleepy Hollow creek and Goose Cove creek fall into the category of creeks most likely to be colonized by spawning smelt due to short reaches of suitable spawning substrate with no passage barriers.

Observations at Cape Ann Creeks since 1990. Given the low potential of tidal creeks on Cape Ann for supporting smelt runs, little effort was made to survey creeks following the 1988-1990 monitoring. The Little River was visited during most years and low numbers of smelt eggs were found during most visits. In 1999, a NMFS biologist found smelt eggs in both the Mill Brook and Sawmill Brook in Rockport (Eric Hutchins, NMFS, *pers. comm.*). Two visits were made in 2000 to Mill Brook and several dozen smelt eggs were found in the tidal zone where Mill Brook discharges to Back Harbor Beach. Two visits were made to Sawmill Brook in 2000 and less than 10 viable eggs were found on shallow riffles upstream of the salt marsh in Saratoga Creek. A single visit was made to each brook in 2001 and a few eggs were found in Mill Brook and none in Sawmill Brook. Both these creeks were not previously known as smelt runs. Based on these observations, these two creeks were designated as smelt runs.

The occurrence of smelt spawning at these two small creeks raises interesting questions on smelt fidelity to spawning habitats. It is possible that discrete spawning runs have long existed in these creeks. However, a large run in Mill Brook at Back Harbor Beach should have been noticed and known locally. These spawning events may reflect on a tendency smelt have to colonize any discharges detected during the spawning period. In retrospect, it is apparent that Sawmill Brook contains more potential spawning habitat than the East Brook station monitored in 1990. All potential spawning riffles in Sawmill Brook were surveyed on two dates during the prime spawning period dates in 1990 and no eggs were found. Sawmill Brook is similar in habitat quality to Chubb Creek in Manchester and may have supported a small annual run in years past when regional smelt populations were higher. The proximity of Mill Brook to the open ocean is unique among smelt spawning runs in Massachusetts. It is possible this habitat may only be used intermittently by colonizing schools from other smelt runs. Smelt eggs were found over less than 20 m of a loosely defined streambed of cobble and gravel where the brook fans out to a sand beach. Eggs were not found above the road where the brook is contained in a narrow channel. Upon hatching, the larvae would immediately move passively into an ocean environment.

RECOMMENDATIONS

1. Mill Pond Tidegate. The Mill River system may offer one of the few opportunities to establish a smelt run in the Cape Ann region. Alterations to the tidegate may improve the attraction flows for adult smelt and upstream freshwater flow management and habitat improvement could provide suitable spawning habitat. Increased flushing at the tidegate would benefit marine life in Mill Pond regardless of the outcome for smelt restoration. It is recommended that the ongoing cooperative effort to improve flushing in the Mill River tidegate be supported and smelt restoration be evaluated as a component of this effort.

2. Little River Water Filtration Plant. Maintenance at the water filtration plant on the Little River has caused sedimentation and water quality degradation to the smelt spawning habitat. It is recommended that the City of Gloucester evaluates the operation and maintenance of the plant's settlement basin to avoid impacts to anadromous fish runs and that an evaluation be made on structural alterations to the settlement basin to improve spawning and migration habitats for smelt, alewife and American eel.

3. Road and Drainage Improvements. It is recommended that future construction to improve roadways and drainage systems in the Cape Ann region should consider the potential to improve potential diadromous fish habitat in freshwater creeks running to tide lands by reducing sedimentation and passage obstructions, and improving tidal flushing and water quality.

ESSEX RIVER

STUDY AREA

The Essex River is located in the North Shore Coastal Drainage (Halliwell et al. 1982), between Cape Ann and Plum Island. The freshwater segment of the Essex River is called Alewife Brook and flows from Chebacco Lake, in Hamilton and Essex, and runs for 9 km to Essex Bay. Route 133 crosses the Essex River in Essex, after which the river meanders unimpeded through an extensive salt marsh (2,320 acres - Chesmore et al. 1973). The drainage area of the Essex River system at the Rt. 133 crossing is 24.4 km^2 (Wandle 1984). No stream flow gauges are location within the Essex River system. In addition to the Essex River, several small creeks contribute minor amounts of freshwater to the estuary. The Essex River estuary is relatively shallow, resulting in a dominant influence of tidal exchange on water volume and chemistry (Chesmore et al. 1973).

Historically, the Essex River smelt fishery was well-known, and the sale of smelt catches was important economically in the region from about the 1830s to 1930s (Chesmore et al. 1973). Concern over declining catches in the 1940s prompted smelt egg stocking efforts by DMF from 1950-1955. Reback and DiCarlo (1972) and Chesmore et al. (1973) both noted an "excellent" winter sportfishery for smelt in the 1960s. Despite these positive reports from the early 1970s, by the late 1980s there was local concern for sharply declining catches in the winter smelt shack fishery in the upper estuary. The known smelt spawning location off Landing Road near the Essex town dump was selected for monitoring in 1990 and 1991. Several tidal creeks were surveyed for potential smelt spawning habitat during 1988-1991. Walker Creek in Gloucester was selected for monitoring in 1989 and 1990. Walker Creek flows from Haskell Pond in Gloucester for 4.5 km to meet the Essex River as it empties to Essex Bay. Walker Creek was a former smelt run with the status unknown before the monitoring period (Reback and DiCarlo 1972; and Robert Knowles, *pers. comm.*). Two ichthyoplankton stations were selected at the Rt. 133 bridge on the Essex River and at the Concord Court bridge on Walker Creek.

RESULTS

Smelt eggs were found at the Essex River monitoring station only during 1990. Low densities of smelt eggs were found at the fresh and saltwater interface for less than a month in 1990, and none were found during extensive monitoring in 1991. No smelt eggs were found in Walker Creek in during two seasons of monitoring despite the collection of smelt larvae in that creek and the presence of over 400 m^2 of suitable spawning habitat.

Spawning Habitat

Essex River. Smelt eggs were found in 1990 on either side of Landing Road over a river stretch of 123 m and 921 m^2 of substrate. The sparse egg deposition found was unexpected given the appearance of high quality spawning habitat. The substrate was comprised largely of clean cobble and gravel with adequate water depth over riffles. There was ample shading and periphyton growth was not excessive. Unlike many smelt runs in Massachusetts, the spawning habitat in the Essex River has no passage impediments and has retained the natural setting where the spawning riffles are found slightly upstream of the tidal interface. There was potential spawning habitat in the salt marsh downstream of the lower limit of egg deposition in 1990 and upstream of the upper limit before the grade becomes too steep for smelt to pass. The total length of potential spawning habitat was 283 m and the total substrate area was 1661 m^2.

Spawning Period. The spawning period may not have been accurately delineated in 1990 because of sparse egg deposition. The starting date of spawning was accurately estimated as March 22nd when several dozen viable smelt eggs were found a few meters downstream of the Landing Road bridge. Very low numbers of smelt eggs (2-6) were found on only three other dates, ending on April 16th. Four smelt eggs were collected on March 26th and hatched at the laboratory and identified as smelt larvae. These observations and finding no eggs in 1991 indicate few adult smelt are participating in the Essex River spawning run.

Water Chemistry

Essex River. Water chemistry was measured at the upstream face of the Landing Road bridge. This location was routinely subject to tidal influence as each flood tide would back up freshwater flows to depths of 1-1.5 m. However, no salinity was detected in surface or bottom measurements during two seasons of monitoring. Dissolved oxygen and pH measurements were in a range adequate to support aquatic life (Table 5.25, A.103-A.104). Water pH was slightly acidic during most baseflow conditions. Low specific conductivity was measured (mean = 0.145 mmho/cm) during 1991 monitoring.

Essex River, Route 133 Bridge. A wide range of salinity (0-28‰) was measured at the bridge station where ichthyoplankton collections were made (Tables A.105-A.106). A depression of salinity from freshwater flows was found at all tide stages. Salinity stratification was found during flood tides and close to high tide. Near lower tide stages the outgoing flow was typically fully-mixed, low salinity (<10‰) water with depths from 0.5 - 1.0 meters.

Walker Creek. Water chemistry was measured at a potential spawning riffle 100 m downstream of the Rt. 133 culvert during 1989 and 1990. Water temperatures were cooler at Walker Creek (Tables A.107-A.108) than at the Essex River spawning habitat station. Dissolved oxygen and pH measurements were in a range adequate to support aquatic life. The acidity of Walker Creek water could be a concern for smelt spawning: the mean water pH was 6.5

and 6.4 for the two seasons, and precipitation could lower pH to below 6.0. No salinity was detected at this station although above average high tides would increase the depth of freshwater flows.

Stream Discharge

Essex River. Three discharge measurements were made at the upstream face of the Landing Road bridge during the spring of 1991. The mean depth, velocity, and discharge of the three measurements were: 0.19 m, 0.41 m/s, and 0.50 m^3/s (17.7 cfs). The May 26th measurement of 0.14 m^3/s was during low flows that resulted in exposed cobble within the spawning habitat.

Walker Creek. Two discharge measurements were made a few meters downstream of the sampling station at Walker Creek during the spring of 1991. The depth (0.12, 0.14 m) and discharge measurements (0.064 m^3/s and 0.063 m^3/s, ~ 2 cfs) reflect the small size of this tidal creek.

Ichthyoplankton

Essex River. Eight ichthyoplankton sets were made at the Rt. 133 bridge on the Essex River in 1990 and 1991 (Table 5.26, B.15). Eight species of fish were identified from the samples, with smelt as the most abundant and frequently caught larva (50% of sets). The catches of smelt larvae in 1990 were higher than expected given the sparse egg deposition observed. Smelt larvae were caught during 3 of the 4 sets made from late-April through May, including moderate densities of 18 larvae/100 m^2 on both April 23rd and May 21st in 1990. Only four smelt larvae were caught in 1991 (on April 26th) during three sets. These larvae confirmed the presence of smelt in the river system despite no observations of smelt eggs during monitoring.

Walker Creek. Eight ichthyoplankton sets were made at the Concord Court bridge on Walker Creek during 1989 and 1990 (Table 5.27, B.16). Six species of fish were identified from the samples, with three occurrences each from sand lance, smelt and grubby. Smelt larvae were caught in each of three May samples during the two years. The average size for smelt larvae was 8.5 mm, with a range of 6.3-10.3 mm (N = 7). Only one larva (6.3 mm) contained a yolk-sac.

Other Diadromous Species

The Essex River is a known alewife run (Reback and DiCarlo 1972) that was once one of the larger runs on the North Shore. For reasons unknown, it is considered a run that begins earlier (late-March) than most in the region (H.R. Iwanowicz, DMF, *pers. comm.*). Small schools of alewives were seen both seasons, starting on March 23rd in 1990 and April 10th in 1991. A single river herring was seen in Walker Creek on May 10, 1990. American eel elvers were commonly seen in the Essex River with increasing numbers in early May. The earliest elver observation during the two seasons was on March 20th in 1991.

Other Surveyed Tributaries

Four tidal creeks that contribute to the Essex River system were surveyed during 1989-1990 and not selected for monitoring because potential spawning habitat was absent: Soginese Creek that crosses Rt. 133 north of the Essex River, Ebben Creek that crosses Rt. 133 south of Essex River, Lufkin Creek located between Ebben Creek and Walker Creek, and an unnamed discharge to Alewife Brook downstream of the Landing Road station. No smelt eggs were found at these tidal creeks that possessed minimal freshwater baseflow and potential spawning riffles.

DISCUSSION

The sparse evidence of an Essex River smelt run found during 1990 and 1991 monitoring was not expected given the recent history of smelt fishing in the Essex River and the appearance of good quality spawning habitat. The DMF study of Essex Bay contained a section on the "excellent" smelt fishery and included photos of the spawning habitat and a line of smelt shacks during the winter fishery in the late-1960s (Chesmore et al. 1973). In a 20 year period, the spawning run has declined to a very low level of detection and fishery is essentially gone. Visually, the spawning habitat has good characteristics of water flow and depth, and well-structured riffles with fairly clean gravel and cobble. Given the large size (1,600 m^2), lack of impediments, and suitable substrate, this spawning habitat appears to be the least impacted on the North Shore.

Smelt populations have declined throughout Massachusetts during the last 30 years. In most river systems there are several causal factors identified by this study as probable negative influences on recruitment. More so than perhaps any other smelt run in the study area, the Essex River was not obviously impacted by typical concerns. The Essex River is not subject to municipal water withdrawals. The spawning habitat is well buffered by salt marsh in the tidal zone and woodland in the freshwater zone. No passage impediments limit access to smelt spawning habitat. The basic water chemistry parameters measured were adequate to support aquatic life, with pH slightly acidic. The growth of periphyton was modest relative to most other smelt runs in Massachusetts. In many smelt runs in the study area it is not difficult to list negative influences that will negatively influence smelt migrations and egg survival. This is not the case for the Essex River. Overall, the present status of the Essex River spawning run is not well-assessed, and suggestions of causal factors would at this time be speculative.

The presence of smelt larvae in Walker Creek and Essex River in 1991 raises questions over the origin of larvae in rivers where smelt eggs were not found. Extensive monitoring for egg deposition at the Essex River station occurred in 1991 with no success; yet smelt larvae were caught in late-April at the Rt. 133 bridge station. No

Table 5.25 Water chemistry and weather summary for the Essex River spawning habitat station, 1990-1991. Data are averages (Tables A.103-A.104) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Middleton, MA (NOAA 1990 and 1991).

Sample Period	Station Visits (No.)	NOAA Air Temp. (^oC)	NOAA Rainfall (cm)	Water Temp. (^oC)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1990								
March	8	3.7	3.1	6.5	0.0	6.8	12.9	-
April	9	7.3	14.0	10.9	0.0	6.8	11.8	-
May	7	12.1	14.8	13.9	0.0	6.8	10.3	-
Season	24	7.7	31.9	10.3	0.0	6.8	11.7	-
1991								
March	9	4.1	8.0	5.9	0.0	6.9	12.0	0.136
April	8	9.3	12.8	12.2	0.0	7.0	10.8	0.160
May	4	15.6	3.7	19.5	0.0	7.1	9.1	-
Season	21	9.7	24.5	10.9	0.0	7.0	11.0	0.145

Table 5.26 Ichthyoplankton samples collected during eight dates at the Essex River, Essex, 1990-1991. Sizes are average total length for larvae and diameter for eggs. Density data are the absolute density collected in total sample volume (911.2 m^3).

Species		Type	FOC	Period	No.	Size (mm)	Density (No./100 m^3)
rainbow smelt	*Osmerus mordax*	larva	4	4/23 - 5/21	60	8.1	6.6
sand lance	*Ammodytes americanus*	larva	2	4/26 - 5/7	3	9.1	0.3
grubby	*Myoxocephalus aenaeus*	larva	1	4/23	1	6.4	0.1
Atlantic silverside	*Menidia menidia*	larva	1	5/26	1	7.0	0.1
rock gunnel	*Pholis gunnellus*	larva	1	3/30	1	17.0	0.1
northern pipefish	*Pungitius pungitius*	larva	1	5/26	1	14.0	0.1
L-L group	*Labridae-Limanda*	egg	1	5/26	59	1.0	6.5
G-G group	*Gadidae-Glyptocephalus*	egg	1	5/13	5	1.0	0.1

Table 5.27 Ichthyoplankton samples collected during 8 dates at the Concord Court bridge on Walker Creek, 1989-1990. Sizes are average total length for larvae and diameter for eggs. Larvae density is the absolute density collected in total sample volume (725.1 m^3).

Species		Type	FOC	Period	No.	Size (mm)	Density (No./100 m^3)
sand lance	*Ammodytes americanus*	larva	3	3/23 - 4/23	9	8.4	1.2
rainbow smelt	*Osmerus mordax*	larva	3	5/4 - 5/21	7	8.5	1.0
grubby	*Myoxocephalus aenaeus*	larva	3	3/30 - 4/23	4	6.4	0.6
rock gunnel	*Pholis gunnellus*	larva	1	3/30	3	15.0	0.4
seasnail	*Liparis atlanticus*	larva	1	4/23	1	2.6	0.1
P-S group	*Paralichthys-Scopthalmus*	egg	1	4/23	2	1.0	0.3

smelt eggs were found at all in Walker Creek with steady monitoring of relatively small riffles, and smelt larvae were caught during each May collection in 1989 and 1990. Because of the larger size of the Walker Creek larvae and effort expended to find smelt eggs, I suspect that the Walker Creek larvae entered that tributary from the Essex River or Little River in Gloucester. The presence of Essex River smelt larvae in 1991 is probably the result of spawning that escaped detection during monitoring. This conclusion is more likely than the potential that larvae originated at one of the other tidally dominated tributaries in the Essex River system.

The 1991 spawning season produced poor spawning runs throughout the study area. No smelt eggs were found in the Charles River after low numbers were found in 1990 and a strong run was evident in 1989. Therefore, there may have been a regional trend that influenced the low egg densities that may have been present in 1991. The egg deposition observed in 1990 in the Essex River was remarkably low, as less than 50 viable eggs were seen all season. Far more eggs were found during 1990 in Chubb Brook, Manchester, and Little River, Gloucester, despite these locations having about 10% of the spawning habitat area found in the Essex River. All these observations indicate the presence of a very small spawning run in Essex River.

Walker Creek was not designated as a smelt run because no eggs were found during two seasons of monitoring. The stretch of Walker Creek with potential habitat was 215 m in length and 428 m^2 of substrate area. The creek was shallow (<0.5 m) and narrow (2 m) with a few well-defined riffles that could support smelt spawning. It does seem very likely that Walker Creek once supported a smelt run: either a specific spawning population or strays from the Essex River. A neighboring property owner commented that he last caught smelt on the Concord Court bridge in 1958 and Robert Knowles (*pers. comm.*) recalls an annual smelt run in Walker Creek in the 1950s.

In the event that causal factors for the poor status of smelt in the Essex River system can be identified, both these spawning stations may be candidates for smelt population restoration efforts. Walker Creek possesses over 400 m^2 of potential spawning habitat, with several suitable spawning riffles. These conditions allow the ranking of Walker Creek above all the many creeks surveyed in the neighboring Cape Ann region for restoration potential.

RECOMMENDATIONS

1. Essex River Smelt Population Decline. The Essex River smelt run has declined as sharply as any smelt run in the study area during the last 30 years, and the causal factors are not apparent. Additional investigations should be conducted to determine if any watershed activities or contaminant discharges occurred in this period and can be linked to the smelt run.

2. Essex River Enhancement. The Essex River should be considered a candidate location for stock enhancement if successful methodologies are developed for Massachusetts' smelt populations. The Essex River contains suitable spawning habitat that was underutilized by the spawning run monitored in 1990 and 1991. In the event that enhancement efforts are initiated, additional monitoring should be conducted in the Essex River to document success and potentially identify factors limiting recruitment.

3. Walker Creek Restoration. Walker Creek possesses suitable spawning habitat that previously supported a smelt spawning run. Although not a large amount of potential spawning habitat, outside of the Danvers River, it is one of the better candidates for restoration on the North Shore. If successful enhancement methods are developed, the Walker Creek should be considered for an enhancement project. This project should include stream grooming techniques to improve the creek channel and the substrate at spawning riffles.

CHAPTER 6. PLUM ISLAND SOUND AND MERRIMACK RIVER

The region of Plum Island Sound and Merrimack River surveyed for this study included all coastal streams found from the Essex River to the New Hampshire state border. This region contains the Ipswich River, Parker River and Merrimack River watershed basins (Halliwell et al. 1982). A total of 28 specific locations were surveyed within the following river systems: Rowley River, Ipswich River, Parker River, and Merrimack River. From these surveyed locations, 13 stations were monitored as potential smelt spawning habitats from 1990 to 1992. Smelt spawning habitat was identified at four locations within the four river systems, and subsequent observations resulted in the designation of two additional smelt runs (Table 6.1).

The Plum Island region differs from the other regions in the study area because of minor urban development and presence of Plum Island estuary (largest salt marsh in the state) and the Merrimack River (largest coastal river in the state). This region is the least developed of the four study areas and contains relatively few, but larger river systems. The Rowley River, Ipswich River and Parker River all possessed popular recreational fisheries for smelt that declined sharply in catch and effort during the 1980s and 1990s. These fisheries were unique in Massachusetts by more resembling the northern New England winter ice-shack smelt fisheries than the typical fall dock fisheries in Massachusetts Bay. Despite the few spawning locations, a large amount of spawning habitat is found in this region. With nearly 14,000 m^2 of available spawning substrate, the Ipswich River has most spawning area among all smelt runs in the study area. The Merrimack River was designated a smelt spawning run, but the spawning habitat was not delineated because of the challenge of locating deposited eggs in this large river. It is possible that the potential spawning habitat area in the Merrimack River exceeds all other river systems monitored for this study.

The average starting date of the smelt spawning period at the Parker, Ipswich and Rowley Rivers was March 15th. The mid-March start of spawning in this region was consistent, and is typical of many smelt runs in the study area. The completion of the spawning run was early May in the Ipswich River, which is also typical; however, no May spawning was found in the Parker or Rowley rivers. Spawning in these two rivers peaked early in April and few smelt eggs were found by the third week in April. The average duration of the spawning period was 46 days and the average starting water temperature was 3.5 ºC. For all rivers combined, the total range of dates when smelt eggs was observed was March 10th to May 13th.

The water chemistry sampled at all the spawning habitat stations was adequate to support aquatic life considering the parameters measured. Dissolved oxygen was near saturation for most measurements during the spring spawning period, and pH measurements were close to neutral at all rivers, although more recent measurements have raised concerns over acidification, particularly in the Ipswich River. Ichthyoplankton collections were made at two bridge stations and in the main stem Merrimack River to record the presence of smelt larvae. Very few fish larvae were caught at the three ichthyoplankton stations, and smelt larvae were caught only once in May in both the Parker River and the Merrimack River.

Table 6.1 Smelt spawning habitat locations in Plum Island Sound and Merrimack River region. The reported positions are the downstream and upstream limits of observed egg deposition.

Name	River System	Town	Downstream Latitude	Downstream Longitude	Upstream Latitude	Upstream Longitude	Length (m)	Area (m^2)
Ipswich River	Ipswich	Ipswich	42° 40.678'	70° 50.035'	42° 40.659'	70° 50.262'	544	13,898
Egypt River	Rowley	Ipswich	42° 42.022'	70° 52.023'	42° 41.888'	70° 52.155'	363	1,989
Mill River	Parker	Rowley	42° 44.701'	70° 53.796'	42° 44.350'	70° 54.025'	934	9,990
Ox Pasture Creek	Parker	Rowley	42° 44.410'	70° 53.303'	42° 44.405'	70° 53.290'	21	82
Parker River	Parker	Newbury	42° 45.062'	70° 55.638'	42° 45.003'	70° 55.744'	300	4,630
Merrimack River	Merrimack	several	unknown		unknown		unknown	

IPSWICH RIVER

STUDY AREA

The Ipswich River is located within the Ipswich River Basin (Halliwell et al. 1982) between Cape Ann and the Merrimack River on the north coast of Massachusetts. The river originates from tributary flows beginning in Burlington and flows 32 km through 22 communities to discharge into Plum Island Sound (MDEP 2004). The drainage area is extensive (404 km^2) and includes many tributaries (Wandle 1984). The Ipswich River has a low hydraulic gradient and a poorly defined channel through many stretches. The Ipswich River has been used extensively as a municipal water supply for over 100 years and presently, the impact of reduced streamflow on aquatic resources is a major concern for the river (MDEP 2004). There are currently 19 state Water Management Act permits issued for Ipswich River water withdrawals, of which 12 are for municipal water supplies (MDEP 2004). Two USGS streamflow gauge stations are located on the Ipswich River: the South Middleton station has operated since 1938 and the station at the Willowdale Dam in Ipswich has operated since 1930.

Historical accounts depict a rich presence of anadromous fish in the Ipswich River, including large runs of American shad and alewife (Jerome et al. 1968). However, by the early 1900s, the influence of dams and water withdrawals had greatly reduced the presence of anadromous fish. Belding (1921) reported that no alewives were present in the Ipswich River at the time of his survey and that alewives had lost access to their former principal spawning area, Wenham Lake (224 acres). Reback and DiCarlo (1972) noted substantial obstacles to river herring passage but did not record the presence or absence of river herring in the river during the 1960s. A smelt fishery and smelt spawning habitat was known to occur in the Ipswich River during the 1960s (Jerome et al. 1968; and Reback and DiCarlo 1972). Ipswich River smelt spawning habitat and water chemistry monitoring stations were selected at the former Sylvania Dam, the County Road Bridge, and the Green Street Bridge and visited during 1990 and 1991.

RESULTS

Spawning Habitat

A patchy distribution of smelt eggs were found in all river stretches from the Sylvania Dam downstream to the Green Street Bridge during 1990 and 1991. Three areas received the highest densities of egg deposition: along the former Sylvania parking lot below the Sylvania Dam; between the Choate Bridge (Rt. 1A) and the County Road Bridge along a south side gravel bank; and below the County Road Bridge associated with the rubble of a former dam. The river possessed a large amount of high quality habitat upstream of County Road. The basin below County Road received about two meters of tidal influence (primarily freshwater backing up). Smelt can only pass above the old dam near high tide when the turbulent flow below the dam becomes obscured by the high water. The downstream limit of spawning habitat was recorded as a sand and gravel bank 165 m downstream of County Road. Smelt eggs were found downstream of this location at remnants of a former dam at the Green Street Bridge on one occasion in 1990. This location is not expected to provide much attraction for adult smelt or foster high egg survival. It appears that smelt may be induced to spawn as water velocity increases at the constriction of Green Street Bridge during lower tide stages.

Overall, there was large amount of suitable spawning habitat in the Ipswich River that possessed adequate depth, gravel substrate and water velocity for smelt spawning and egg survival. The substrate was also largely free of excessive periphyton growth that is common to smelt spawning habitat throughout the study area. The total area of river substrate from the lower limit to upper limit of egg deposition was estimated as 15,136 m^2; the largest amount of available spawning habitat for a smelt run on the Gulf of Maine coast of Massachusetts. The river length where eggs were found (excluding below the Green Street Bridge) was 544 m and the average width of this stretch was 25.7 m. Smelt eggs were not distributed throughout the wetted perimeter of this habitat. Four river bends created low velocity zones where no eggs were found. The removal of these "no egg-zones" results in a spawning habitat estimate of 13,898 m^2, which is still the largest amount recorded for an individual spawning location in the study area.

Table 6.2 Smelt spawning period in the Ipswich River, 1990-1991.
The spawning period is an estimation based on observations of viable smelt eggs.

			Water Temperature (°C)			
Year	Spawning Period	Days	Start	End	Range	Mean
1990	(not delineated) - May 13th			17.0		
1991	March 14th - May 7th	55	3.6	16.0	3.6 - 17.5	10.0

Spawning Period. Smelt eggs were found from March 23rd to mid-May during 1990, although the start date was not confirmed during this first year of monitoring due to strong river flow and unfamiliar habitat. In 1991, the start date was estimated as March 14th and the end date was estimated as May 7th (Table 6.2). Smelt eggs were first found both seasons in the rubble of the old dam below County Road. The peak of egg deposition appeared to occur in mid-April during both seasons. Based on qualitative observations, the overall amount and densities of smelt eggs observed in 1990 greatly exceeded that seen in 1991 throughout the spawning habitat.

Water Chemistry

Water chemistry was recorded at the three sampling stations in 1990 and the results for water temperature, pH and dissolved oxygen were nearly identical for each station. All three stations received tidal influence although surface flows were freshwater throughout spring and only the Green Street bridge station received the salt wedge along the bottom. Only the County Road bridge station was monitored in both 1990 and 1991 where water chemistry was measured at the downstream opening of the north arch of the County Road Bridge. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 6.3, A.109-A.110). Air and water temperatures were cooler during the spring of 1990 than in 1991. Water pH was near neutral for most measurements. Dissolved oxygen was at or near saturation for all measurements, and low specific conductivity was recorded in 1991 (mean = 0.23 mmho/cm).

River Discharge.

The USGS streamflow gauge station at the Willowdale Dam (#01102000) is located closest to smelt spawning habitat (drainage area, 324 km^2) and provides an excellent long-term record of discharges (USGS, http://waterdata.usgs.gov). The monthly mean discharge values for the spring spawning period from 1930-2003 are: March - 450 cfs; April - 435 cfs; and May - 240 cfs. During the monitoring season of 1990 the March mean discharge was below average (278 cfs) and the April (410 cfs) and May (303 cfs) discharges were near average. Mean discharges in 1991 were below average for each spring month (March - 281; April - 256 cfs; and May - 189 cfs).

Three discharge measurements were made in the Ipswich River during spring 1991. Two measurements were made at the County Bridge, 12.3 m^3/s (434 cfs) on March 29th, and 32.05 m^3/s (1132 cfs) on April 24th. A third measurement of 3.17 m^3/s (112 cfs) was made at Choate Bridge (112 cfs) on May 26th. The April measurements included depths over 1.0 m and the mean velocity exceeded 1 m/s at the downstream opening of the County Bridge arches. These measurements indicate that high flow conditions could limit upstream movements of spawning adults and may scour eggs from the substrate.

Other Diadromous Species

No other diadromous species were observed during the smelt habitat monitoring in 1990 and 1991. Small numbers of river herring were known locally to run up the Ipswich River at the time of the monitoring and DMF began stocking blueback herring in the Ipswich during 1990 and continued throughout the 1990s (Reback et al. 2004). During subsequent visits to inspect smelt spawning habitat in the 1990s observations were made of elver American eel, sea lamprey, and blueback herring eggs (identified by hatching) along the riffles between the Choate Bridge and Sylvania Dam.

Other Surveyed Tributaries

Only one tributary to the Ipswich River was surveyed for potential smelt spawning habitat. The Labor in Vain

Table 6.3 Water chemistry and weather summary for the Ipswich River, County Road Bridge, 1990-1991. Data are averages (Tables A.109-A.110) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Middleton, MA (NOAA 1990 and 1991).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1990								
March	7	3.7	3.1	3.6	0.0	6.9	12.0	-
April	8	7.3	14.0	10.5	0.0	7.0	10.7	-
May	6	12.1	14.8	15.7	0.0	7.0	9.4	-
Season	21	7.7	31.9	9.7	0.0	7.0	10.5	-
1991								
March	9	4.1	8.0	5.4	0.0	6.9	12.2	0.211
April	8	9.3	12.8	11.6	0.0	7.0	10.8	0.262
May	5	15.6	3.7	18.7	0.0	7.2	9.4	-
Season	22	9.7	24.5	10.7	0.0	7.0	11.1	0.231

Creek is located south of the main stem Ipswich River and enters the estuary below the smelt spawning habitat. Tidal flows dominated this creek and no potential spawning habitat was found during a 1990 visit.

DISCUSSION

Relative to the 29 river systems in which smelt spawning habitat was delineated on the Gulf of Maine coast of Massachusetts, the Ipswich River possesses the largest amount of available spawning substrate and has the appearance of suitable conditions to support large numbers of spawning adults and high egg densities. Despite these conditions, the apparent decline in the Ipswich River smelt run is as precipitous as any in Massachusetts. No quantitative measures are available of the Ipswich River smelt population or fishery. Anecdotal reports from local interests depict a 30 year decline from a viable winter shack fishery to present conditions of little to no participation. A photograph from Jerome et al. (1968) shows nearly 20 smelt shacks set up in 1966 to fish for smelt through the ice below the Green Street Bridge. A single smelt shack has been observed at this location in recent winters with very low reported catches.

The causes for the smelt population decline are uncertain and observations for the Ipwich River run counter to the obvious spawning habitat impacts seen at most other smelt runs in the study area. The smelt spawning habitat in the Ipswich River displays less evidence of eutrophication than any other smelt run in the study area. The substrate in spring is well-scoured with large patches of clean gravel and aquatic moss that is favorable for egg attachment and survival. Unlike the upper watershed that has received more attention than most in Massachusetts due to concerns over water withdrawals, there is little biological or chemical information available on the Ipswich River from the Sylvania Dam to the estuary. The MDEP Watershed Assessment report for the Ipswich River Watershed lists this river segment as "not assessed" (MDEP 2004). Two watershed concerns that have been identified are the effects of water withdrawals and acidification. No information is available on influences of smelt mortality outside Ipswich River in estuarine and marine habitats.

Water Withdrawal. Given the large number and volume of water withdrawals in the Ipswich River for municipal water supplies, concerns over impacts to anadromous fish spawning habitat are reasonable. Belding (1921) voiced this concern specifically for the Ipswich River over 90 years ago. However, negative influences on the spring smelt spawning run are difficult to identify without time series information. During the monitoring years of 1990 and 1991 there were adequate flows for much of March and April to provide suitable depth and velocity for smelt spawning and egg survival. River flow levels did decline in the third week of April in 1990 and resulted in large numbers of dead smelt eggs on the gravel bank between Choate Bridge and County Road. This same pattern of declining flows was also observed in late-April and May 1991, although egg mortalities were not observed, in part due to the lower egg densities seen in 1991. It is not known if these observations are routine occurrences associated with the timing of rainfall and smelt egg deposition.

Long-term data from the Willowdale gauge station show a generally flat trend for average monthly flows in March, April and May (Figure 6.2). These data and field observations imply that spring flows in the Ipswich River have been stable and typically provide suitable coverage for the smelt spawning habitat. However, USGS analyses on summer flows indicate that groundwater withdrawals are chronically reducing summer low flow levels to well below that expected naturally (Zarriello 2002). These conditions could be limiting the production of other anadromous fish species and have negative impacts on smelt mortality during early life stages. Smelt larvae depend on estuarine salinity gradients to forage on zooplankton that concentrate at such gradients. The ebb and flow of tidal exchange keep these gradients within the estuary and provide smelt with summer nursery habitat. With greatly reduced summer freshwater flows these gradients could be poorly established and result in reduced foraging opportunities for smelt larvae as well as other ichthyoplankton and zooplankton.

Recently, extensive efforts have been made to document the impact of water withdrawals in the Ipswich River and to develop water conservation plans. Federal, state and local partners have developed a Regional Water Conservation Plan for the Ipswich River Watershed that recognizes that aquatic resources in the Ipswich River are severely threatened by chronic low flows and offers Best Management Practices (BMPs) to improve flows (IRWMC 2004). The BMPs include voluntary measures to improve water conservation, water storage, stormwater infiltration and land-use policies. The implementation of this plan will be important for the interest of restoring anadromous fish populations in the Ipswich River.

Acidification. The Ipswich River water pH measurements from the 1990 and 1991 and earlier sampling did not raise concerns over acidification. DEQE conducted pH measurements on two dates in September 1978 at the Green Street Bridge and Sylvania Dam and recorded a mean pH of 7.7 (range 7.4 - 7.9) (DEQE 1979). DEQE returned to these stations on three dates in 1985 and measured a mean of 7.0 pH (range 6.7 - 7.5) (DEQE 1985). The sampling for this project in 1990 and 1991 found a two-year mean of 7.0 during spring measurements (N = 40, range 6.7 - 7.4). A rain event during April 3rd and 4th in 1990 brought nearly three inches of rain to the watershed and caused a moderate depression of river water pH of approximately 0.3 - 0.4 pH units to 6.8. More recent measurements have found lower pH levels and cause concern over potential acidification affects on smelt egg survival. Watershed assessment sampling (MDEP 2004) at an Ipswich River station in Middleton (No. IP02) found a mean water pH of 6.1 in 1995 (N = 3) and 6.4 in 2000 (N = 6). A DMF study on the effects of eutrophication on smelt spawning habitat (B. Chase, DMF, unpublished data) recorded a mean spring pH of 6.9 in 2002 (N = 15) and 6.4 in 2003 (N = 15), including a 5.9 pH measurement that represents a level of acidification that would negatively influence smelt egg survival (Geffen 1990).

RECOMMENDATIONS

1. Ipswich River Water Conservation. The recommended BMPs of the Regional Water Conservation Plan for the Ipswich River Watershed should be adopted by all local authorities and citizens. These practices can assist the interest of sustaining anadromous fish populations and habitats. The ongoing efforts to understand aquatic resource impacts of water withdrawals need to be expanded to include detailed analyses on anadromous fish in the freshwater zone and estuary.

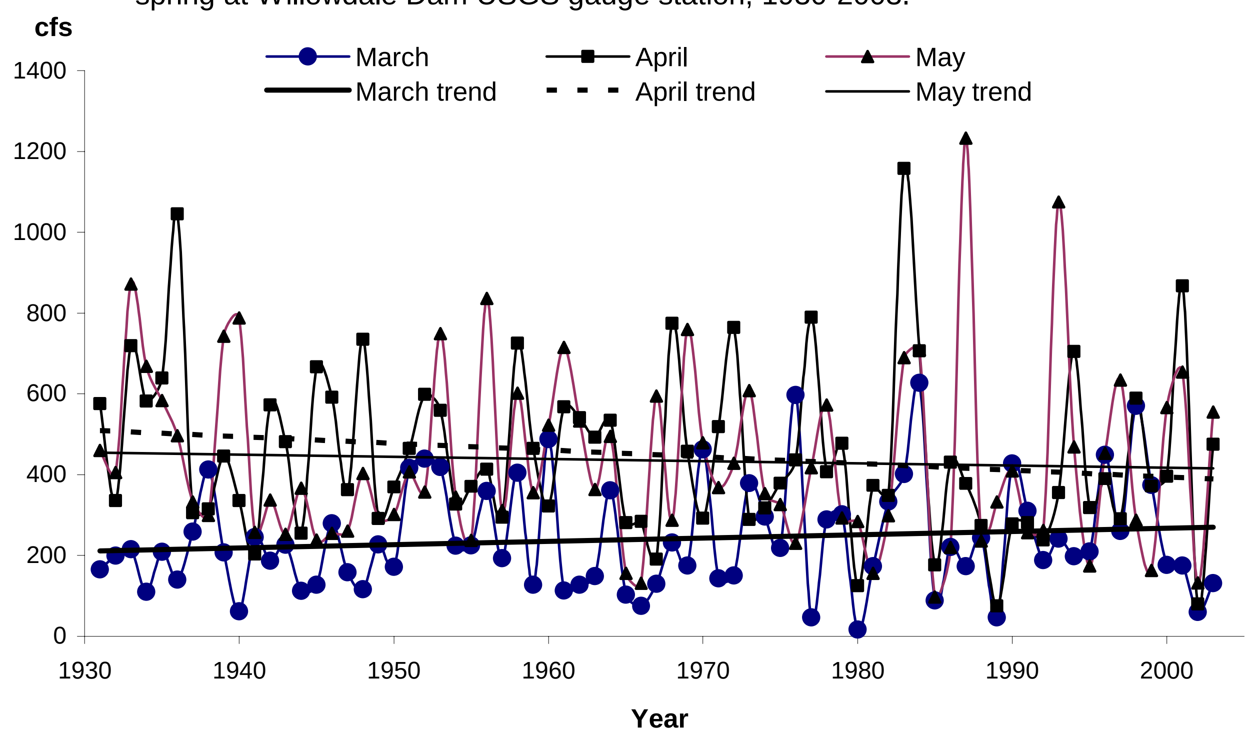
2. Farley Brook Stormwater Remediation. A large stormwater culvert discharges Farley Brook runoff from the center of Ipswich village directly to prime smelt spawning habitat between Sylvania Dam and Choate Bridge. Observations were made during project monitoring of large volume flows discharging highly turbid stormwater over spawning habitat. Remedial alternatives for this stormwater system should be evaluated to reduce the load of stormwater pollutants into the Ipswich River.

3. Spawning Habitat Water Chemistry Investigation. The role of water quality on declining anadromous fish populations in the Ipswich River has not been investigated in sufficient detail. There is some evidence that water acidification is increasing and eutrophication may not presently be a threat of the same magnitude seen in most other rivers in the study area. Higher frequency sampling is needed in the Ipswich River in order to relate water chemistry to other environmental influences and the condition of anadromous fish spawning habitat.

4. Prohibit Wading in River during Spawning Season. Observations were made during the two monitoring seasons of anglers fishing along the gravel bank between Choate Bridge and County Bridge. In 1990, anglers were wading directly over locations where relatively high densities of smelt eggs were deposited. This foot traffic can result in needless smelt egg mortality. DMF has the authority to prohibit in river wading during the smelt spawning season and should do so for the Ipswich River spawning habitat.

5. Evaluate Removal of Sylvania Dam. The upstream limit of smelt spawning habitat is the former Sylvania Dam. The dam currently does not provide hydropower and may be a candidate for removal in the interest of river restoration. It is recommended that this removal be evaluated and that consideration is given to extending the upper limit of smelt spawning habitat upstream.

Figure 6.2 Ipswich River average monthly discharge and trendline during spring at Willowdale Dam USGS gauge station, 1930-2003.



ROWLEY RIVER

STUDY AREA

The Rowley River is located in the Parker River Basin (Halliwell et al. 1982) between Cape Ann and the Merrimack River on the north coast of Massachusetts. Freshwater flows primarily originate at the Bull Brook Reservoir (9 acres) and Dow Brook Reservoir (17 acres), both water supplies for the town of Ipswich. The freshwater section of the river below the reservoirs is called Egypt River. From the reservoirs, the river flows approximately 9 km to Plum Island Sound and the entire drainage area is 25.7 km^2 (Wandle 1984). Muddy Run is a freshwater tributary that originates in freshwater swamps of Ipswich and meets the Rowley River in the estuary. The drainage area of the Muddy Run is 6.9 km^2 (Wandle 1984). Smelt were known to spawn below Rt. 133 in the Egypt River and also a minor run occurred in Muddy Run (Jerome et al. 1968). A sample station was selected at known smelt spawning habitat in the Egypt River for monitoring smelt spawning in 1990 and 1991, and Muddy Run was monitored in 1990.

No previous studies have been conducted on smelt in the Rowley River, although the occurrence of a spawning run and fishery was noted in Reback and DiCarlo (1972) and Jerome et al. (1968). Jerome et al. (1968) reported a viable, recreational smelt fishery in the Plum Island Sound estuary during the mid-1960s, including the observation of nine smelt shacks set up in the Rowley River during the 1967 winter ice fishery. Freshwater discharges in the Rowley River system are subject to manipulations at the reservoirs. No discharge records were available for the Rowley River. A municipal electric generating station is located on Rt. 133 on the Egypt River and includes a 0.5 acre cooling pond that discharges into the river.

RESULTS

Spawning Habitat

Egypt River. Low densities of smelt eggs were readily found in the Egypt River during both 1990 and 1991. Most eggs were deposited in shallow riffles within a 100 m downstream of the Rt. 133 culvert. The upstream limit of egg deposition was the first step of a fishway found 12 m upstream of the Rt. 133 culvert. Spawning continued downstream for over 200 m to where the river meets the salt marsh and widens to an intertidal basin. The entire spawning habitat where smelt eggs were found was 363 m in length and 1,989 m^2 in area of river substrate.

Below Rt. 133, Egypt River winds through woodland that provides good buffering and shading for the spawning habitat. The river bends create shallow gravel riffles that attract most of the spawning activity in the river. The second riffle below Rt. 133 (about 40 m downstream) was typically upstream of tidal influence and routinely received the most egg deposition. Sparse egg deposition was found in the lower 200 m of spawning habitat where tidal influence occurs and the salt marsh began. The observed egg mortality in the Egypt River during these seasons was unusually high, especially considering the absence of urban development.

Muddy Run. No smelt eggs were found at the Muddy Run station during 23 site visits in 1990. The monitoring station was located off of Mitchell Road in Ipswich where potential spawning riffles were found 100-200 m above typical tidal influence. The station was not routinely monitored in 1991 because of the minor potential found for attracting spawning smelt. Several visits were made to Muddy Run during the peak of the spawning season in 1991 and no eggs were found. The amount of spawning habitat was limited to several small riffles that contained approximately 100-200 m^2 of potentially suitable substrate.

Spawning Period. The onset of smelt spawning was determined each year as the first eggs were readily found within the riffles below Rt. 133. Spawning began on about March 10th in 1990 and March 14th in 1991 (Table 6.4). The spawning period was estimated to have ended on April 30th in 1990. The end date was not delineated in 1991 due to sparse egg deposition, however, there was no evidence of spawning in May. In 1990, spawning appeared to be interrupted by an intense rain event on April 3/4th (3.0 inches). All eggs deposited in the riffles above intertidal influence were flushed out. Fine sediments and coarse sands were swept out of the river and much gravel was moved downstream. After this rain, there was very little evidence of spawning activity and the few eggs found were downstream in the intertidal zone. A smaller rain event in 1991 (April 23rd) also scoured the riffles, but so few eggs were present it was difficult to determine if eggs had been displaced as in 1990. Overall, 1990 egg deposition exceeded that observed in 1991, although both years experienced low densities of deposited eggs relative to the available spawning habitat.

Water Chemistry

Egypt River. Water chemistry was measured at the upstream face of the Rt. 133 culvert in the Egypt River in 1990 and 1991. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 6.5, A.111-A.112). Water temperature in March was cooler in 1990 than 1991. Spawning began at approximately 3 °C in 1990 and between 4-5 °C in 1991. Water pH was near neutral for most measurements. Dissolved oxygen was at or near saturation for all measurements, and specific conductivity was low (mean = 0.16 mmho/cm). Tidal influence was not detected at the sample station during any visits. The following discharge measurements were made on three occasions in 1991 at the downstream face of the Rt. 133 culvert, resulting in a mean of 0.23 m^3/s (8.1 cfs): 4/2/90 - 0.150 m^3/s; 4/26/90 - 0.470 m^3/s; 5/5/91 - 0.070 m^3/s.

On April 20, 1990, a substantial oil slick was observed throughout the Egypt River spawning habitat. The source of the oil was the power plant cooling pond. Oil was observed discharging from the cooling pond outlet pipe that emptied a few meters upstream of the Rt. 133 culvert. Evidence of the discharge was seen 300 m downstream as oil residues were seen in the salt marsh when the tide receded. The discharge was reported to the power plant and no discharge of oil was observed by the next visit on April 23rd, but oil residue persisted throughout the spawning substrate.

Muddy Run. Water chemistry was measured only in 1990 at the outlet of the Muddy Run as it ran under a dirt road off Mitchell Road. Water chemistry was similar at Muddy Run as Egypt River in 1990. Water pH and dissolved oxygen were slightly lower in the Muddy Run, but suitable to support aquatic life. Tidal influence was observed on two occasions at this station during above average high tides.

Other Diadromous Species

Alewives cannot presently pass into the Bull Brook and Dow Brook reservoirs and earlier accounts do not indicate if passage was possible formerly (Jerome et al. 1968; and Reback and DiCarlo 1972). The power plant cooling pond was constructed in 1965 with a fishway to allow alewives passage into the cooling pond, and soon after spawning migrations of alewives in the Egypt River were reported (Jerome et al. 1968). Evidence of a spawning run of river herring was seen during monitoring visits for this project. A small school of river herring (<10 fish) was observed upstream of the Rt. 133 culvert on May 11, 1991, and again on June 3, 1998 during a periodic visit to the spawning habitat. In addition, four dead, juvenile American eels were observed on three dates in the Egypt River during 1990.

DISCUSSION

Similar to other smelt runs in the Plum Island Sound region, the Rowley River smelt run has declined in the last 20-30 years without obvious alterations to the spawning habitat. Smelt have declined over a similar time period throughout coastal Massachusetts; however, in urban regions, negative alterations to smelt passage and spawning habitat are more identifiable. The extent that the Rowley River smelt run has declined is not documented. There are no smelt population or fishery assessments conducted for the Rowley River or any other run in the region.

Concerns for the Rowley River smelt run were present in the early 1980s when interest from a local sportfishing club prompted a smelt egg transplant project (Russell

Table 6.4 Smelt spawning period in the Egypt River, Rowley, 1990-1991. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (°C) Start	End	Range	Mean
1990	March 10th - April 30th	52	2.8	16.8	2.0 - 19.0	8.3
1991	March 14th - (not delineated)		4.6	-	-	-

Table 6.5 Water chemistry and weather summary for the Egypt River spawning habitat station, 1990-1991. Data are averages (Tables A.111-A.112) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Middleton, MA (NOAA 1990 and 1991).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1990								
March	9	3.7	3.1	3.9	0.0	7.0	12.3	-
April	8	7.3	14.0	10.6	0.0	7.1	10.9	-
May	6	12.1	14.8	16.0	0.0	7.1	9.5	-
Season	23	7.7	31.9	9.4	0.0	7.0	10.8	-
1991								
March	9	4.1	8.0	5.4	0.0	7.0	12.3	0.152
April	8	9.3	12.8	11.9	0.0	7.2	11.0	0.179
May	5	15.6	3.7	19.5	0.0	7.4	9.6	-
Season	22	9.7	24.5	10.9	0.0	7.2	11.2	0.162

Iwanowicz, DMF, *pers. comm.*). Smelt eggs were moved from the Jones River, Plymouth, to the Egypt River for several seasons. The amount of eggs transferred and influence on the smelt run were not assessed. Observations from this monitoring program and anecdotal reports from local fishermen indicate the decline is substantial and exceeds expectations for this river system. Very low egg deposition relative to available spawning habitat was observed in 1990 and 1991 and later in the 1990s during spawning season visits to the Egypt River. Smelt fishing in the Rowley River during the 1990s has essentially ceased, with low levels of effort possible in some years.

The reason for the poor status of the smelt run is not known. The spawning habitat in the Egypt River has several attributes that should be favorable to a robust smelt run. The woodland buffer along the Egypt River below Rt. 133 has probably changed very little in the last 50 years. The shallow riffles below Rt. 133 provide suitable spawning substrate for smelt, and after the scouring of a spring freshet, these riffles can appear to offer ideal spawning habitat. Unlike many smelt runs, there are no physical obstructions to prevent adult movement from tidal to freshwater habitat. The following two paragraphs contain potential sources of negative impact to the Rowley River smelt run. In the absence of detailed assessments, the impacts from sources are uncertain, but should be discussed as areas where more information is needed.

Ipswich Municipal Power Plant. Local smelt fishermen have raised concerns over the acute and chronic impact of petroleum and copper sulfate discharges from the power plant on Rt. 133 into the Egypt River. For some fishermen, it is accepted that the power plant discharges eliminated the smelt run from Egypt River. However, no cause and effect data are available on this concern and a small population of smelt still return to the Egypt River. Anecdotal reports indicate that discharges in the 1960s and 1970s probably reduced smelt egg survival to some degree. The oil discharge observed in 1990 may have negatively impacted egg survival during that season. Observed egg mortality in 1990 and 1991 seemed excessively high for spawning habitat that appeared to be in good condition.

Watershed Hydrology. A common threat to smelt in coastal Massachusetts is the alteration of base flows through increases in municipal water withdrawals and changes in drainage patterns. This concern is difficult to assess without discharge data for freshwater inputs to the Rowley River. Residential growth in the watershed during the last few decades may have resulted in a reduction of the water released at the Ipswich reservoirs. We did not observe overt impacts to spawning habitat due to water levels in 1990 and 1991. The water depth over spawning riffles provided ample coverage during the slightly wet spring of 1990 and slightly dry spring of 1991 (Jan.-May precipitation was approximately 9 cm above normal in 1990 and 9 cm below normal in 1991, (NOAA 1990 and 1991). Reduced base flow is a concern for egg survival as well as adult attraction. This could be a concern for the Rowley River where the spawning habitat is located a long distance from Plum Island Sound. A wider ranging concern is changes to the hydrology of Plum Island Sound by reductions in freshwater contributions from the major rivers in the regions. Smelt larvae are flushed from the freshwater habitat immediately and received nutrition from their yolk-sac for about a week. In this time, they must locate stratified edges of fresh and salt water where zooplankton concentrate. Major changes in watershed discharges of freshwater could present a challenge to smelt larvae habitat requirements. Clearly, more information is needed on the alterations of watershed hydrology in this region.

RECOMMENDATIONS

1. Egypt River Discharge. Data are needed on the contribution of freshwater tributaries in the Rowley River system and the regulation of water at the outlets of the Ipswich reservoirs. It is recommended that an evaluation be made on establishing discharge records in the Egypt River, and that the Town of Ipswich and MDEP develop a plan within the Waters Management Act permitting process to maintain adequate flows during the spring smelt spawning season.

2. Power Plant Operations. It is recommended that the Town of Ipswich develop a management plan to ensure that power plant activities do not negatively impact the Egypt River smelt run or other aquatic resources. It is possible that the plant's operation and maintenance plan can be made modified to clearly limit discharges during the spring smelt spawning season, and reduce the potential for releasing contaminants from the plant.

3. Egypt River Stewardship. The spawning habitat in the Egypt River was typically in good condition, although minor impediments to adult smelt passage were observed on a few occasions. These impediments were partial blockages created by logs and debris at the Rt. 133 culvert and at river bends lower in the spawning habitat. It is recommended that the Ipswich Conservation Commission and local stewards develop a plan to visit the Egypt River once each spring to clear out such blockages.

4. Egypt River Habitat Improvement. The fishway steps upstream of Rt. 133 serve no current purpose and prevent smelt from passing further upstream. The steps may also inhibit movements of freshwater species, and during low flows it is possible that the steps could also limit river herring passage. These steps should be removed during a designed, cooperative restoration project that also considers stream bank stability and shading at this stretch of Egypt River.

PARKER RIVER

STUDY AREA

The Parker River is located within the Parker River Basin (Halliwell et al. 1982) between the Ipswich River and the Merrimack River on the north coast of Massachusetts. The river originates from the flows of two unnamed brooks in West Boxford wetlands and runs for 37 km through nine communities to discharge in Plum Island Sound (Johnson 1986). The primary headwater ponds are Rock Pond (51 acres) and Pentucket Pond (87 acres) in Georgetown (Reback and DiCarlo 1972). The drainage area is 156.4 km^2 (Wandle 1984) and includes the Rowley River which empties directly into Plum Island Sound. Several tributaries discharge to the Parker River main stem, the largest being the Mill River (drainage area 33.2 km^2). Land use in the watershed is mainly forest and residential with minor industrial development and increasing residential development in recent decades (GSE 2003). The Parker River estuary winds through extensive marshland before meeting Plum Island Sound. The combination of shallow estuarine depth, relatively low freshwater discharge and high tidal exchange results in minimal stratification of estuarine waters during most of the year. Much of the tidal Parker River is included in the Parker River National Wildlife Refuge: the largest area of protected coastal habitats in Massachusetts north of Cape Cod. One USGS streamflow gauge station is located on the Parker River in Byfield and has operated since 1945.

Historically, the Parker River system was known to support large runs of anadromous fish (Jerome et al. 1968). During 1965, when the DMF estuarine study of Plum Island Sound was conducted, a former American shad and winter striped bass fisheries were recalled by local fishermen and a popular white perch and smelt fisheries flourished (Jerome et al. 1968). Jerome et al. (1968) noted 48 smelt shacks set up in the Parker River estuary during the winter of 1967, and recorded common intertidal seine catches of alewife, blueback herring and smelt and common subtidal trawl catches of alewife and white perch during 1965. Formerly known to have had large runs of river herring, the DMF surveys of Belding (1921), Jerome et al. (1968) and Reback and DiCarlo (1972) indicate the Parker River run declined in the 2oth century.

The smelt runs of the Parker River were previously investigated by two graduate studies in the mid-1970s (Clayton 1976; and Murawski 1976). These studies defined the smelt spawning locations in the Parker River system and provided quantitative population data on Parker River smelt: the only smelt run other than the Jones River with historical population data in the study area. During the 1974 and 1975 studies, smelt spawning was found to occur in the Parker River below the Central Street Dam, in the Mill River below the Glen Mills Dam (Jewel Mill), and in Cart Creek. These three locations were selected as monitoring stations during 1991 and 1992 and an ichthyoplankton station was selected at the railroad bridge in the Parker River estuary.

RESULTS

Spawning Habitat

Smelt eggs were readily found in the Mill River and Parker River during 1991 and 1992. The physical appearance of both the Mill and Parker rivers was conducive to productive smelt spawning habitat, although the low densities of smelt eggs observed were well below the capacity of these habitats. Smelt eggs were observed in the Parker River over a 300 m stretch below the Central Street Dam. Smelt eggs were also found at a small creek that runs under Orchard Road and meets the main stem Parker River at the downstream basin of the spawning habitat. This unnamed creek provides about 300 m^2 of spawning habitat, however, because of its proximity and connection with the main stem, it was not considered an independent spawning location. The total spawning substrate area of the Parker River spawning habitat was estimated at 4,630 m^2. Egg deposition in the Mill River occurred over a long stretch of suitable habitat (934 m) from the Jewel Mill Dam to salt marsh below Rt. 1 that contained 9,990 m^2 of spawning substrate.

No smelt eggs were found in Cart Creek during the monitoring period or subsequent visits. Cart Creek contained less than 200 m^2 of potential spawning habitat along a 50 m stretch where the creek gradient rose quickly upstream of the salt marsh. Smelt eggs were found in Ox Pasture Brook, a tributary of Mill River, many years after the study period. This small creek escaped detection during the study period and was not visited until 2006 following the suggestion of Tim Puritan (Mass. Riverways). A few dozen smelt eggs were found below a tidal zone dam on DFW property for 21 m, covering 82 m^2 of substrate. It is likely that this brook receives annual spawning activity from smelt migrating upstream in the main stem Mill River. The 2006 egg observations in Ox Pasture Brook are the first recorded for this brook and result in its designation as a smelt run.

Spawning Period

Parker River. Smelt eggs were found below the Central Street Dam during both 1991 and 1992 from the third week in March until late April (Table 6.6). The start date of spawning was estimated each season after a light scattering of eggs was detected about a 100 m downstream of the dam. The end of the spawning season was not well detected both seasons because of the very low densities of smelt eggs present during April. The spawning season was relatively short and no evidence of May spawning was found during the two seasons. These observations imply that a small number of smelt participated in the Parker River smelt run.

Mill River. Smelt eggs were found upstream and downstream of Rt. 1 in the Mill River during 1991 and 1992 from mid-March until late April (Table 6.7). Spawning commenced earlier in the Mill River than in the Parker River during both seasons. Spawning began slightly later in 1992 than 1991 in both rivers, possibly due to lower March water temperatures in 1992. Similar to the Parker River, the Mill River spawning run was truncated relative to most smelt runs in the study area. There was no May spawning or a peak period with high densities of deposited eggs evident. The duration of the spawning season and area receiving egg deposition in the Mill River exceeded that observed in the Parker River.

Water Chemistry

Parker River. Water chemistry was recorded 100 m downstream of the Central Street Dam on the south bank of the Parker River in 1991 and 1992. This station received routine tidal influence at high tides but the salt wedge was not detected during any spring measurements. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 6.8, A.113-A.114). On average, pH was slightly basic and specific conductivity was low (~ 0.20 mmho/cm). Dissolved oxygen was at or near saturation for all measurements. The mean water temperature during March in 1992 was 2.3 °C lower than in 1991 and corresponds to a later spawning onset.

Mill River. Water chemistry was recorded 20 m downstream of the Rt. 1 bridge on the roadside bank of the Mill River in 1991 and 1992. This station received routine tidal influence at high tides but the salt wedge was not detected during any spring measurements. For the parameters measured, water quality conditions were adequate to support aquatic life (Table 6.9, A.115-A.116). Water pH averaged 7.25 for the two seasons and specific conductivity was low (~ 0.23 mmho/cm). Dissolved oxygen was at or near saturation for all measurements.

Cart Creek. Cart Creek water chemistry was measured only in 1991 at the confluence of salt marsh and woodland in the Downfall Wildlife Management Area. Water chemistry measurements in Cart Creek (A.117) were similar to those made in the Mill and Parker River. A single discharge measurement was made in Cart Creek on May 20, 1992. The transect for this small creek was one meter wide, the average depth was 18 cm, and the discharge was 0.08 m^3/s (2.8 cfs).

Ichthyoplankton Station. Water chemistry was measured at the ichthyoplankton station in the Parker River estuary at the railroad bridge crossing during 1991 and 1992 (A.118). This location was under tidal influence at all tide stages. The water depth exceeded two meters at high tides and was less than a half meter at lower tides. The water column was typically well-mixed with similar measurements of pH, salinity, DO, and conductivity at the surface and bottom. No evidence of stratification was found at any tide stage. Salinity was present at all tide stages, ranging from approximately 2-18 ppt for surface and bottom measurements.

River Discharge.

The USGS streamflow gauge station in Byfield on the Parker River (#01101000, drainage area 55.2 km^2) provides a long-term record of discharges (USGS, http://waterdata.usgs.gov). The monthly mean discharge values for the spring spawning period from 1945-2003 are: March - 85.1 cfs (2.40 m^3/s) ; April - 83.2 cfs (2.36 m^3/s); and May - 49.3 cfs (1.40 m^3/s). The monthly mean discharges during the spring months of 1991 and 1992 were all between 20-30% below the corresponding monthly mean for the data series. There was no streamflow gauge on the Mill River.

Two discharge measurements were made in the Parker and Mill rivers during spring 1992. The Parker River measurements in the culvert under the Central Street Bridge found the same volume of water (1.8 m^3/s or ~62 cfs) on April 10th and May 11th. On both dates the mean transect velocity was about 0.65 m/s with a maximum velocity approaching 1.0 m/s. The two measurements made in the Mill River at the Glen Street culvert found discharges of 0.68 m^3/s (24 cfs) on April 10th and 0.76 m^3/s (27 cfs) on May 11th. The mean transect velocity in the Mill River was about 0.35 m/s with a maximum of 0.8 m/s.

Other Diadromous Species

Blueback herring were commonly observed in low numbers in the Mill River and moderate numbers in the Parker River during 1991 and 1992. The earliest observation of adult blueback herring was in the Parker River on April 10th, 1992. High densities of blueback herring eggs were seen below the Central Street Dam on May 13th in 1991 and May 14th 1992. These large spawning events were both followed by rapid egg mortality that left a very small percentage of viable eggs. Additional large spawning events were seen in both years until monitoring ceased at the end of May. Attempts to hatch the blueback eggs failed during both seasons. Eggs collected on April 10th, 1992 were hatched and confirmed as smelt. Blueback eggs were also observed in Cart Creek during May along with small schools of adults. The impediment of the Central Street Dam appears to aggregate blueback herring below the dam resulting in spawning episodes that leave high densities of eggs that suffer high mortality. This condition also results in blueback herring using the same distinct spawning habitat as smelt with potential overlap of spawning period. American eel elvers were observed in April and May in the Mill and Parker rivers during both seasons. A few individual adult sea lamprey were observed in the Mill and Parker rivers during May.

Table 6.6 Smelt spawning period in the Parker River, Newbury, 1991-1992. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (°C) Start	End	Range	Mean
1991	March 18th - April 18th	32	5.2	10.8	3.2 - 14.5	8.8
1992	March 22nd - (late April)	-	1.8	-	-	-

Table 6.7 Smelt spawning period in the Mill River, Newbury, 1991-1992. The spawning period is an estimation based on observations of viable smelt eggs.

Year	Spawning Period	Days	Water Temperature (°C) Start	End	Range	Mean
1991	March 11th - April 25th	46	3.9	13.8	3.5 - 14.5	8.5
1992	March 13th - (late April)	-	2.6	-	-	-

Table 6.8 Water chemistry and weather summary for the Parker River spawning habitat station, 1991-1992. Data are averages (Tables A.113-A.114) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Middleton, MA (NOAA 1991 and 1992).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1991								
March	8	4.1	8.0	5.2	0.0	7.1	12.5	0.191
April	8	9.3	12.8	11.4	0.0	7.1	11.1	0.246
May	4	15.6	3.7	18.8	0.0	7.4	9.3	-
Season	20	9.7	24.5	10.4	0.0	7.1	11.3	0.214
1992								
March	9	1.1	8.7	2.9	0.0	7.0	13.6	0.188
April	6	7.1	7.1	10.4	0.0	7.0	11.2	0.190
May	6	12.9	5.0	15.3	0.0	7.1	9.8	0.206
Season	21	7.0	20.8	8.6	0.0	7.0	11.8	0.194

Table 6.9 Water chemistry and weather summary for the Mill River spawning habitat station, 1991-1992. Data are averages (Tables A.115-A.116) except station visits and NOAA rainfall are total values. Air temperature and rainfall data were recorded at Middleton, MA (NOAA 1991 and 1992).

Sample Period	Station Visits (No.)	NOAA Air Temp. (°C)	NOAA Rainfall (cm)	Water Temp. (°C)	Water Salinity (ppt)	Water pH	Water D.O. (mg/l)	Water Sp. Cond. (mmho/cm)
1991								
March	9	4.1	8.0	5.2	0.0	7.1	12.3	0.230
April	8	9.3	12.8	11.3	0.0	7.2	11.2	0.271
May	4	15.6	3.7	18.4	0.0	7.4	9.3	-
Season	21	9.7	24.5	10.0	0.0	7.2	11.3	0.246
1992								
March	9	1.1	8.7	3.2	0.0	7.1	13.4	0.221
April	6	7.1	7.1	10.4	0.0	7.3	12.0	0.227
May	6	12.9	5.0	14.9	0.0	7.4	10.2	0.246
Season	21	7.0	20.8	8.6	0.0	7.3	12.1	0.229

Other Surveyed Tributaries

The Little River which enters the north side of the Parker River estuary was the only additional tributary surveyed for potential smelt spawning habitat. The Little River was surveyed in the vicinity of Rt. 1 where former spawning habitat was known of occur. Although not certain, it appears that changes to the stream bed may have increased channel width, eliminated riffle habitat, reduced water velocities and increased sedimentation. No smelt eggs were found in 1991 and there was little potential to attract adult smelt. Smelt spawning in the Little River was reported in the 1960s (Reback and DiCarlo 1972), however, no smelt eggs were found during repeated visits in 1974 and 1975 by Murawski and Cole (1978). Ox Pasture Brook meets the south side of the Mill River salt marsh in Rowley. This brook was reported to have no history of supporting a smelt run and not surveyed during the study period or visited until 2006.

Ichthyoplankton

Very few fish larvae were caught during seven net sets at the railroad bridge ichthyoplankton station during 1991 and 1992 (Table B.17). The mid-estuary location appeared to be suitable for ichthyoplantkon collections but low ebb tide velocities (0.2-0.4 m/s) were not optimal for the operation of the net and catches were poor relative to all other ichthyoplankton stations in this study. Five net sets caught no fish eggs or larvae. Single threespine stickleback and Atlantic silverside were caught on March 29, 1991 and five smelt larvae were caught on May 5, 1992.

DISCUSSION

The present status of the Parker River smelt population is similar to that found in the Ipswich River. A substantial amount of suitable spawning habitat exists, yet the winter smelt fishery is essentially gone and observations of egg deposition indicate few adult smelt are participating in the spawning runs. The available spawning habitat in the Mill and Parker rivers combined is nearly 15,000 m^2 which rivals the Ipswich River as having the largest amount of smelt spawning habitat on the Gulf of Maine coast of Massachusetts. The Mill River itself contains about 10,000 m^2 of spawning habitat over nearly a kilometer of river length. When river flows are above average and the substrate is well-scoured, the Mill River riffles appear to offer as good of spawning habitat as anywhere in Massachusetts, similar to the Fore River, where one of the largest smelt runs in the state presently occurs. The Mill River contains large amounts of small-gravel riffles which provide excellent attraction for adult spawning and good substrate for egg survival. The Parker River contains larger sized substrate material, predominately cobble and boulder, and relatively higher densities of aquatic moss which provides an even better substrate for egg survival than small gravel.

The causes for the Parker River smelt population decline are even more uncertain than for the Ipswich River. In the Ipswich River there are clear concerns over water withdrawal and potential episodic threats from acidification. These two concerns were not identified in the Parker River. Water flows and depth may be a problem during the latter half of the spawning season in the Mill and Parker River, however, this has not been documented or evaluated. In addition to the fishery and spawning habitat observations that indicate a depressed smelt population, two other concerns were observed during monitoring. First, the growth of periphyton in 1992 greatly exceeded that seen in 1991 in both the Mill and Parker rivers. The growths of gelatinous matrices of periphyton increased in early April and peaked by early May. Eggs attach readily to the periphyton but consequent survival was very low. In the Mill River the growth was remarkable in 1992 and produced large globs of dark, brown periphyton by late April. Secondly, large events of blueback herring egg deposition were observed several times each season and in each case they were followed by rapid mortality of nearly all deposited eggs. This occurrence could be influenced by crowding at the Central Street Dam. However, the extent of the egg mortality over the length of the spawning habitat implies that other factors may contribute to the poor egg survival. It is possible that the factors influencing blueback herring egg survival also affect smelt egg survival.

Watershed Influences

The Plum Island Ecosystem Long Term Ecological Research Project (PIE-LTER) is conducting investigations on the ecology of Plum Island Estuary that is providing a baseline of watershed conditions and water quality for the Parker River system (http://ecosystems.mbl.edu/pie). The PIE-LTER studies could be a useful source of information on anthropogenic impacts to the health of anadromous fish populations. Land-use in the Plum Island Estuary watersheds changed markedly in the last century as agriculture diminished, followed by reforestation, and the current trend of rapid residential development since the 1960s. Concerns have been identified over municipal water withdrawals, prevalent use of septic systems for sewage disposal, stormwater water quality and nutrient enrichment. Observations from the 1991/1992 smelt habitat monitoring indicate that nutrient enrichment may be negatively impacting the spawning habitat. Monthly nutrient measurements have been made in the Parker River watershed by PIE-LTER since 1993 in order to assess nutrient loading. High seasonal concentrations of inorganic nitrogen have been observed at some stations seasonally, however, overall nutrient loading appears to be low relative to other East Coast estuaries. A more detailed focus on the spring spawning period of anadromous fish will be needed to determine if eutrophication is impacting spawning habitat and to address general concerns on the response of higher trophic levels to nutrient and water chemistry fluxes.

The influence of watershed drainage patterns and withdrawals on diadromous fish populations in the Parker River are not known. Spring discharges show modest reductions during the period the Byfield USGS gauge has been operating (Figure 6.3). Smelt monitoring observations typically found adequate March and April flows to cover smelt spawning habitat in the Parker River system. However, late spring and summer low flows are a growing concern. A Gomez and Sullivan Engineers, P.C. (2003) low flow study commissioned by EOEA found that summer flows were significantly lower during 1990-2002 when compared to 1946-1989. The most significant factor in this change was increasing annual and seasonal water withdrawals for public supplies. This topic needs further investigation in relation to impacts to smelt spawning and nursery habitat, and other diadromous fish populations.

Smelt Population Dynamics

The graduate studies of Murawski (1976) and Clayton (1976) provided baseline population and spawning habitat information on the Parker River smelt run that is not available for other smelt runs in Massachusetts. Tagging studies reported by Murawski et al. (1980) showed that adult smelt spawning at the Cart Creek, Mill River and Parker River spawning habitats belonged to a homogenous breeding population for the Parker River system. Murawski and Cole (1978) reported on population parameters for Parker River smelt that include estimates of average total annual mortality rate for adult smelt of 72% and a fishing mortality rate of 27%. They expressed concern that increases in fishing mortality could effect future stock recruitment. This is the only information available for Massachusetts that suggests the winter recreational smelt fisheries could approach harvest levels that were detrimental to sustainable populations. It is possible that the winter shack fisheries of the 1960s and 1970s contributed to the smelt population decline by intercepting large numbers of the spawning stock in the narrow and shallow Parker River estuary. It is clear from the collective sampling efforts during 1974 and 1975 that large numbers of smelt were available during the spawning run and winter ice fishery. Thousand of adult smelt were readily sampled each season. This availability of smelt has certainly declined substantially to the present status of no winter ice fishery and low levels of detection for smelt egg deposition.

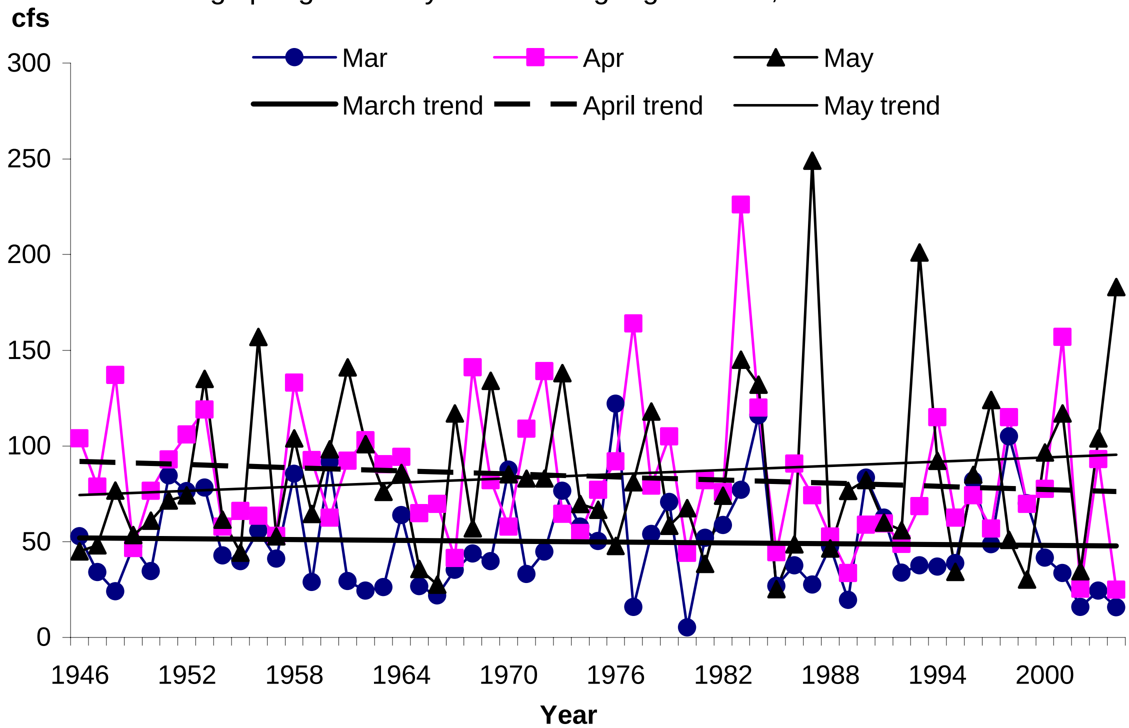
RECOMMENDATIONS

1. Parker River Smelt Population Monitoring. The Parker River is one the few rivers in Massachusetts with historical age/size structure data and the only river with detailed data on population survival and mortality rates. Population data are needed to manage smelt runs in Massachusetts. Because of the historical baseline, the Parker River would be a suitable candidate for future monitoring on smelt population structure.

2. Water Quality Influences on the Health of Anadromous Fish Runs. The existing water quality data sets do not indicate a clear connection between water quality and the poor status of Parker River smelt and the observations of high mortality of recently deposited blueback herring eggs. The range of parameters and sampling frequency may not be extensive enough to evaluate the concern that water quality is associated with anadromous fish population impacts. It is recommended that existing data sets are further evaluated and additional studies are designed to address this concern.

3. Base flow Impacts to Aquatic Resources. Impacts to anadromous fish and other aquatic resources due to water withdrawals and the influence of land use changes on base flows is a concern for the Parker River system. In times of low precipitation, water depths over the smelt spawning habitat in the Mill and Parker rivers can be reduced to levels that do not provide adequate protection for demersal eggs. In addition, smelt nursery habitat in the estuary could be degraded from reduced summer flows and minimal stratification. The existing status of local manipulations on base flow should be evaluated in relation to influences on the health of aquatic resources.

Figure 6.3 Parker River average monthly discharge and trendline during spring at the Byfield USGS gauge station, 1946-2004.



Land development in the Parker River watershed. B. Chase

MERRIMACK RIVER

STUDY AREA

The Merrimack River drainage system covers an expansive region in New Hampshire and Massachusetts, originating in the White Mountains of New Hampshire and running for 186 km through a drainage area of 12,970 km^2 to discharge in the western Gulf of Maine near the Massachusetts border with New Hampshire. It is the largest river on the Gulf of Maine coast of Massachusetts. The lower 35 km of the Merrimack River is tidal and the estuary remains stratified for most of the year. There is much variation in the upstream movement of the salt wedge depending on seasonal discharge. The salt wedge has been located as far upstream as river km 16 during low summer flows (Keiffer and Kynard 1993). The lowermost USGS streamflow gauge station is the Lowell Station (#01100000) which has operated since 1923 covering a drainage area of 12,005 km^2. The Merrimack River discharge is by a wide margin the largest among rivers monitored for this study with the following mean daily spring discharges: March - 12,950 cfs (367 m^3/s) ; April - 19,340 cfs (548 m^3/s); and May - 11,600 cfs (328 m^3/s) (USGS, http://waterdata.usgs.gov).

The Merrimack River historically had abundant diadromous fisheries with important colonial fisheries for American shad, Atlantic salmon, and sturgeon (Belding 1921; and Jerome et al. 1965). Reback and DiCarlo (1972) also referenced colonial fisheries for smelt and eel. The Merrimack River was used extensively for hydropower and waste disposal during the industrial revolution, resulting in dams and industrial pollution that severely limited diadromous resources (Belding 1921). The lowermost dam in Lawrence was built in 1848 at river km 46 with a 9.5 m spillway height. At the time of Reback and DiCarlo's survey (1972), modest runs of shad and alewife were known. Since that time, extensive state and federal cooperative efforts have enhanced fish passage at the Lawrence Dam and upstream facilities.

There is little documentation of smelt in the Merrimack River and no specific knowledge on spawning habitat (Rusty Iwanowicz, DMF, *pers. comm.*). Jerome et al. (1965) conducted seining at stations in the tidal lower Merrimack River and caught modest numbers of YOY smelt at four of the five stations. A graduate study during the 1970s on Merrimack River ichthyoplankton provides the only evidence related to early life history that indicates the Merrimack River may be a smelt run (Peterson 1975). Weekly sampling during the spring and summer of 1974 resulted in smelt larvae catches ranking third among all fish larvae and a wide range of smelt larvae sizes were present including yolk-sac larvae. Despite the high rank of smelt larvae the total number and density of the catches were relatively low compared to some rivers sampled for this study. No other references were found on smelt in the Merrimack River.

The large size of the Merrimack River limited the use of substrate monitoring methods that had been successful in all other river systems in this study. The first course of action was to survey all tributaries in the tidal region of the Merrimack River to identify tributaries with riffle habitat that could be used as smelt spawning habitat. Twenty tributaries were surveyed in 1991 and 1992 and five were selected for routine monitoring in 1992: Cottles Creek, Cobbler Creek, Johnson Creek, Crystal Lake creek, and Powwow River. Following that season, efforts were made to collect ichthyoplankton and smelt eggs on artificial substrata deployed in the main stem.

RESULTS

No smelt eggs were found during the 1992 monitoring of five Merrimack River tributaries or during subsequent efforts in the main stem during 1993-1995. Two smelt larvae were caught during main stem ichthyoplankton sampling on May 22, 1996. This monitoring effort was not successful in documenting the location of smelt spawning habitat in the Merrimack River. The collection of smelt larvae combined with earlier observations supports the designation of the Merrimack River as a smelt run.

Potential Spawning Habitat

Powwow River. The Powwow River is the largest freshwater tributary in the tidal zone of the Merrimack River. It is located on the north side of the Merrimack River less than 2 km upstream of Rt. 95. The Powwow River runs through downtown Amesbury receiving flows from Lake Gardner and the tributary Back River. A sharp elevation rise in downtown Amesbury clearly marks the upstream limit of potential smelt spawning habitat. Potential smelt spawning habitat was found downstream of the elevation rise, in the Back River below Clarks Pond, and along the banks of the river downstream of Rt. 495 near the confluence with the Merrimack. Water chemistry was measured 50 m upstream of the Main Street bridge. High tide at this location increased water depth by nearly 2 m as freshwater flow backed up. At lower tide stages water velocity increased to provide potential spawning habitat along the cobble banks. This habitat was routinely monitored and egg collection plates were deployed in deeper locations. No evidence of smelt adults, larvae or eggs were found and no anecdotes were a received from locals on the presence of a smelt run. The potential habitat in downtown Amesbury was difficult to access during higher flows and therefore was not adequately monitored in 1992.

Cobbler Brook. Cobbler Brook is located on the north side of the Merrimack River near the village of Merrimacport. Water chemistry was measured on the downstream side of River Road close to the confluence with the Merrimack. Cobbler Brook did not possess very suitable smelt spawning habitat. The potential spawning habitat near River Road received tidal influence each high tide to reduce water velocity and riffle habitat. Freshwater base flows were low and large amounts of sand were deposited in this stretch. The potential spawning habitat was adequately monitored during 1992 visits. No evidence of smelt spawning was found and a single local anecdote was received from a property owner on the creek that felt certain he observed a smelt run here about 15 years prior during one season only (late 1970s).

Cottles Creek. Cottles Creek is located on the north side of the Merrimack River in Haverhill between the Rocks Village bridge and Groveland Bridge. Water chemistry was measured on the downstream side of the East Broadway Bridge. The mouth of Cottles Creek receives routine tidal influence and is heavily silted, but as the creek elevation rises upstream of East Broadway the cobble substrate improves to provide potential spawning habitat. This stretch was adequately monitored during 1992 visits with no evidence of smelt spawning found. One property owner on the creek with recollections to the 1930s stated that large numbers of small silvery fish came up the creek each spring until 20-30 years ago. A second property owner on the creek stated with confidence that a large run of smelt came up Cottles Creek during a spring about ten years prior (about 1982) and he had not seen smelt there before then or since.

Johnson Creek. Johnson Creek is located on the south side of the Merrimack River and discharges near the Bradford/Groveland border. Water chemistry was measured on the downstream side of Main Street in Groveland. At the water chemistry station and downstream to a man-made pond on a construction company property the substrate suffered from petroleum residues and the deposition of large amounts of sand. Downstream of the pond the creek narrowed and patches of suitable spawning riffles were found. These riffles were adequately monitored in 1992 and no evidence of smelt spawning was found. Local anecdotes of former runs of sea lamprey and sea-run brook trout were heard, but not on the presence of smelt.

Crystal Lake creek. The furthermost upstream monitoring station was a creek that flows from Crystal Lake and West Meadow Brook in Haverhill near the first Rt. 495 bridge. The creek crosses under Rt. 110/113 to discharge to the Merrimack River less than a km upstream of Rt. 495. Water chemistry was measured 50 m upstream of the Rt. 110/113 overpass. A man-made elevation rise at the confluence could hinder fish passage to potential upstream spawning habitat. It appears that the combination of tidal influence and above average spring flows would allow smelt passage. Very good riffle habitat was found upstream of Rt. 110/113. The quantity and quality of this potential spawning habitat exceeds that of a majority of the rivers that have existing smelt runs in Massachusetts. However, no evidence was found of any life stages of smelt during 1992 and no local anecdotes were heard related to a smelt run.

Water Chemistry

Water chemistry measurements were made during 20 spring visits to the five Merrimack River tributaries in 1992. The water chemistry for the parameters measured was supportive of aquatic life (Appendix, Tables A.119-A123). No unusual measurements were made for DO, pH and specific conductivity. Tributary conductivity was low and average pH was near neutral or slightly basic at each station. No salinity was detected at any of the stations during spring sampling. Powwow River and Cobbler Brook were subject to routine tidal influence during high tides. Under these conditions, the water measured probably originated from the main stem Merrimack River. Tidal influence was also observed at the mouths of the three remaining upstream stations, but did not reach the monitoring stations in Johnson Creek and the Crystal Lake creek and only during the highest tidal amplitudes at the Cottles Creek station.

Ichthyoplankton

The only ichthyoplankton station sampled during the 1992 tributary monitoring was at the Main Street Bridge on the Powwow River. Five samples were collected from March 20th to May 27th. Four of the five samples had no fish eggs or larvae. The May 27th sample had one unidentified fish larvae (not smelt). Ichthyoplankton samples were also collected in the main stem Merrimack River in 1993 to document the presence of smelt larvae. The same ichthyoplankton net used throughout this project was towed from a 16 ft boat on May 5th and 14th, 1993, at 1 m depth to sample a target volume of 100 m^3. On May 5th, five tows were made between the Rocks Bridge and Groveland Bridge. On May 14th, three tows were made in the vicinity of downtown Bradford. No fish larvae were caught on either date.

On May 22, 1996, the services of the R/V Mariah and Megan were donated to this project to conduct more ichthyoplankton tows from Rt. 1 to the mouth of the Merrimack River. Ten tows were made (six surface and four mid-water column) and only 11 fish larvae were caught, including two smelt larvae caught at a station slightly inside the mouth of the river. They were yolk-sac larvae at 6.8 and 7.3 mm TL. These efforts were exploratory and do not describe Merrimack River ichthyoplankton during spring and are not comparable to ichthyoplankton sampling for this project in other river systems. However, the catch of two smelt larvae does establish the presence of smelt in the Merrimack River during the study period.

Other Diadromous Species

A single river herring was observed swimming in Johnson Creek on May 27th, 1992. No other observations were of diadromous fish were made. The minimal observations are by no means adequate for conclusions on species presence/absence. Only one season of monitoring was conducted and coverage of the main stem Merrimack River was beyond the scope of this project.

Other Surveyed Tributaries

Fifteen additional tributaries to the Merrimack River were surveyed in 1992 and not selected for monitoring because of unsuitable or poor conditions to attract spawning adults and promote egg survival. Five tributaries (an unnamed creek near Rt. 95, Artichoke River, Indian River, and two unnamed creeks crossing River Road between Bridge Street and Coffin Street) in West Newbury on the south side of the river between Rocks Bridge and Rt. 95 were silted and lacked riffle habitat. On the north side of the river in Merrimac between Rocks Bridge and Rt. 95 six tributaries (Goodwin Creek, two unnamed creeks crossing Pleasant Valley Road, Presbys Creek, and two unnamed creeks crossing River Road near Rocks Bridge) were silted and lacked riffle habitat. Three unnamed creeks on the south side of the river in Bradford (between Johnson Creek and Boston Road) were silted and lacked base flows and riffle habitat. One unnamed creek in Haverhill crossing East Broadway on the north side of the river was silted and lacked base flows and riffle habitat. Given the large area along the Merrimack River from the Lawrence Dam to the mouth and the limited survey visits, it is possible that some potential spawning habitat was overlooked or underestimated. However, of the 15 tributaries surveyed but not selected for monitoring, none of these possessed flow and substrate conditions that approached the potential of the five monitoring stations where no evidence of smelt spawning was found in 1992.

Additional Investigations

During the two 1993 ichthyoplankton boat trips and a single 1994 shore trip shallow stretches of the main stem Merrimack River were inspected for the presence of potential smelt spawning habitat. Four locations with shallow depths and potential riffles were inspected: downstream of Kimball Island near the Methuen/Haverhill border, along Stanley Island downstream of Rt. 495 in Haverhill, bedrock outcroppings upstream of the railroad bridge in downtown Bradford, and boulder and bedrock substrate downstream of the Rt. 125 bridge in downtown Bradford. The gravel beds in Haverhill were actually shallow enough (< 1m) to inspect for attached eggs using egg scoops on May 14th, 1993 (no eggs found). The Kimball Island location is the approximate upstream limit of tidal influence (Kieffer and Kynard 1993). All of the locations contained swift water velocity and irregular substrata that could serve as potential spawning habitat.

In April 1997, four boat trips were made to the Merrimack River to set artificial substrata in the main stem for smelt egg collection. On April 4th, 12 weighted egg collection trays were set from Rt. 95 to Carr Island. The egg trays were checked on April 10th and 20 trays were deployed from Rocks Village to Carr Island. These trays were checked on two more dates in April. No smelt eggs were found on the trays. The river flows were above average in April 1997 (daily mean = 25,600 cfs); elevated by an early April snow storm. During the four boat trips, surface water velocities were high at all tide stages except close to high tide. Main stem water chemistry was measured during three 1997 boat trips and during the two 1993 boat trips (N = 9, nine stations during five dates) from the Bradford railroad bridge to Carr Island. For all measurements, surface and bottom samples were similar: no salinity, low specific conductivity (0.15 to 0.20 mmho/cm), and slightly acidic pH. Despite the strong tidal influence seen in this region (reversal of currents over the tide cycle), these measurements indicate that spring flows were fully mixing the water column and limiting the upstream movement of the salt wedge.

DISCUSSION

The Merrimack River presented unique challenges to the project goal of delineating smelt spawning habitat. The large size of the river, high average depth and discharge prevented the successful use of project methods to document where and when smelt spawning occurs. The collective efforts of tributary monitoring and main stem reconnaissance should not be considered as adequate to meet the project goals: as clearly evident by the absence of smelt egg observations. Despite this outcome, the Merrimack River is still designated as a smelt run, based on previous observations of smelt larvae, anecdotal reports, and the presence of smelt larvae in 1996.

The question remains as to where smelt spawn in the Merrimack River. While I do not doubt that there is a smelt run in the Merrimack, the location of spawning is still subject to speculation and there is little evidence that large numbers of smelt are using the Merrimack River for spawning habitat. It is interesting that there is no known Merrimack River smelt fishery (Rusty Iwanowicz, DMF, *pers. comm.*). Even some of the smaller Massachusetts Bay smelt runs have established recreational fisheries in close proximity to spawning habitat. Some of the docks and shoreline structures in the tidal stretches of the Merrimack River should allow angling for smelt if adults were routinely available. The 1974 ichthyoplankton collections of smelt larvae did not record many high density catches smelt larvae and caught few smelt larvae upstream of the estuary (Peterson 1975). The average catch was 22.4 smelt larvae/100 m^3. The earliest catch came on April 12th and the peak catches came during the third week of May in the estuary. The frequency and periodicity of the 1974 smelt larvae catches strongly indicate a local spawning run of smelt occurred within the river, although the study design does not allow for speculation on the location of spawning habitat.

The spring hydrology of the Merrimack River provides a basis to consider where smelt may spawn. The salt wedge is known to advance on the north side of the river (Jerome et al. 1965; and Peterson 1975). The upstream limit of tidal influence (backing up of river water) is near Bradford at river km 35 (Peterson 1975; and Kieffer and Kynard 1993), and the upstream movement of the salt wedge can reach river km 16 during low summer discharges (Kieffer and Kynard 1993) (Figure 6.4). Spring conditions of tidal influence and salt wedge are not well documented. There is likely much variation in the upstream limit each season depending on discharge. Observations during this project found a clear reversal of flow direction during spring with each flood tide up to river km 20-25 (Groveland to Rocks Village). At the lower end of this range swift tidal current were observed. Tidal influence extended upstream to Bradford, but the tidal current dissipated at the upper end of this range. At lower tides, the velocity of river flows observed from Rt. 95 upstream in 1997 would present a challenge to adult smelt moving upstream. This difficulty would increase to a wider range of the tide cycle as smelt attempted to pass beyond Rocks Village and on to Bradford. Kieffer and Kynard (1993) recorded peak spring river velocities of 1.7 m/s at the head of the tide in Haverhill. It is unlikely that adult smelt could advance against high spring flows beyond Haverhill.

The flood tide current would facilitate smelt movements upstream of Rt. 95 and at the same time, neutralize favorable bottom velocities for attracting spawning from Rocks Village down to the estuary islands below Rt. 95. With the exception of the constriction at the Rocks Village Bridge, this region has more area of sandy substrate and depositional zones than larger substrata that could provide potential spawning riffles (Keiffer and Kynard 1995). Therefore, the combination of the flood tide and spring discharges probably limits suitable main stem spawning habitat from Rocks Village upstream to the vicinity of Haverhill.

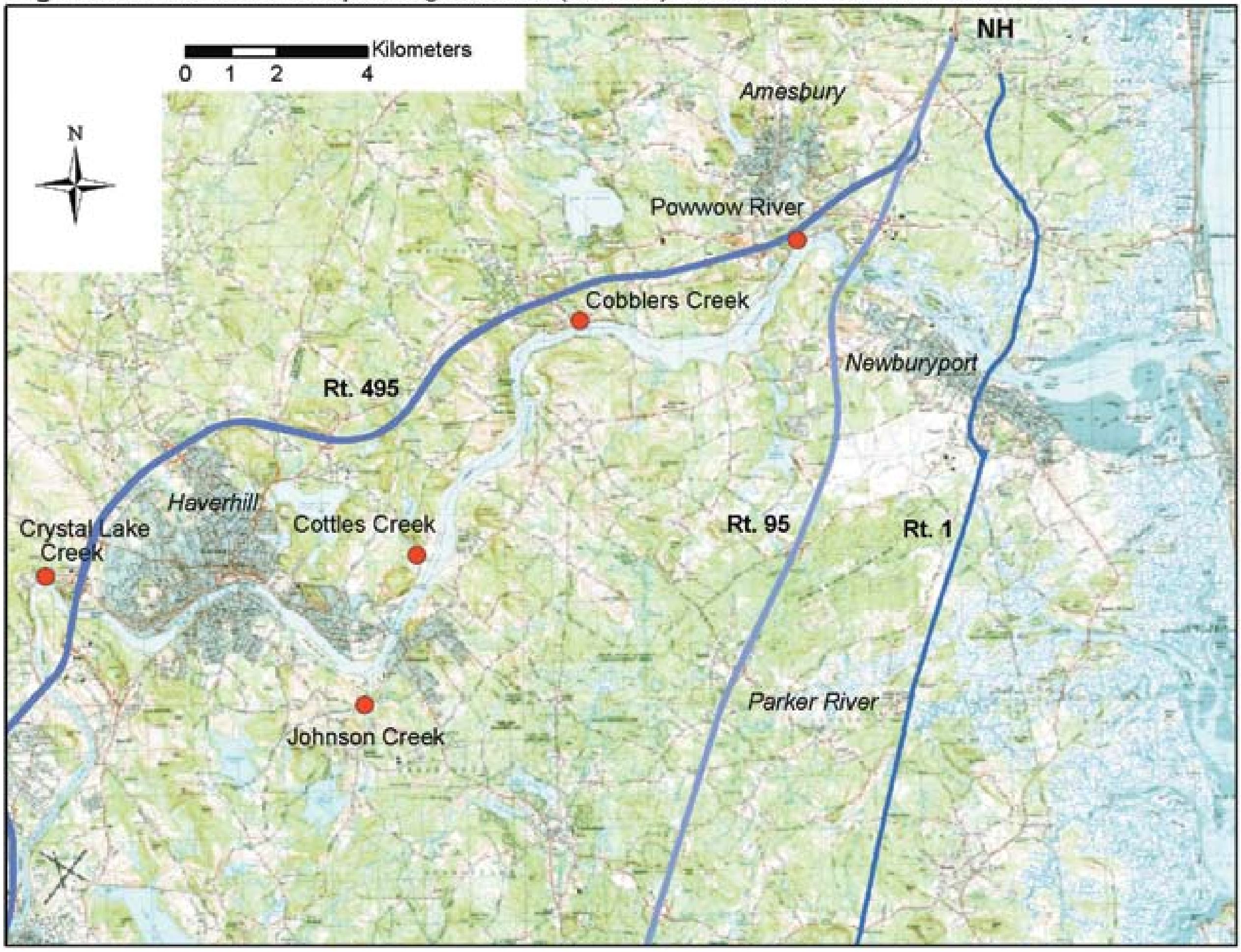
With this hydrology and project observations in mind, three hypotheses can be presented on the location of smelt spawning habitat in the Merrimack River. Two north side tributaries were described by locals as former smelt runs. The salt wedge moving along the north side of the river could allow for passage upstream of Rt. 95 where tributary discharge could be detected prior to reaching the higher main stem velocities upstream of Rocks Village. The Powwow River in particular has a large amount of suitable habitat that could be reached during most spring conditions. The second hypothesis is that main stem spawning could occur concurrently with tributary spawning or be limited to lower flow years in the shallow bedrock and cobble riffles observed in 1997 near downtown Bradford and upstream in Haverhill (and possibly the constrictions of the Groveland and Rocks Village bridges). Spring discharges above average may bring velocities that would not allow smelt to reach these riffles. In low flow years it is possible that passage could continue further, even up to the Lawrence Dam. Before 2006, this suggestion was only speculation, yet a single adult smelt was caught in the Lawrence Dam fish lift for the first time, during the very low flows in April (Kristen Ferry, DMF, *pers. comm*.). Thirdly, it is hypothesized that during high flow years spawning could occur near the main stem constrictions presented by Deer and Eagle Island downstream of Rt. 95. It is possible that zones of spawning habitat could occur along the edge of salt wedge on the north side of the river and the swift freshwater flow near the islands.

RECOMMENDATIONS

1. Locating Spawning Habitat. The task of delineating smelt spawning habitat in this large river system required resources that were beyond the scope of this project. This information would be useful to obtain and would require a dedicated project for the Merrimack River. Such a project should focus a more detailed analysis of river hydrology, revisiting the north side tributaries and egg collection on artificial substrata at the hypothesized spawning locations.

This study was conducted as a Special Investigation

Figure 6.4 Potential smelt spawning locations (red dots) monitored in the Merrimack River.



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Much appreciation is due to Abigail Childs who conducted routine smelt spawning habitat monitoring as a DMF biologist for the Boston area in 1988 and 1989. Abby also entered water chemistry data and processed ichthyoplankton samples for those years, and was an essential advisor and motivator during the Boston Harbor monitoring. Two technicians, Allison Roderick and Beth Hilloran, assisted the project from the Cat Cove Marine Laboratory for one season each in the early 1990s. I am especially thankful for their help processing ichthyoplankton samples and entering water chemistry data.

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I am grateful and fortunate to have spent time in the field with Stubby Knowles, Ted Fyreburg, and George Oakes, locals with rich fishing and natural resource knowledge who gave me valuable insight on watershed changes that may have influenced smelt runs. I am also thankful for the many individuals who shared similar information when meeting by chance in the field.

Smelt spawning habitat in the Egypt River. B. Chase

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