Massachusetts Division of Marine Fisheries
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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.

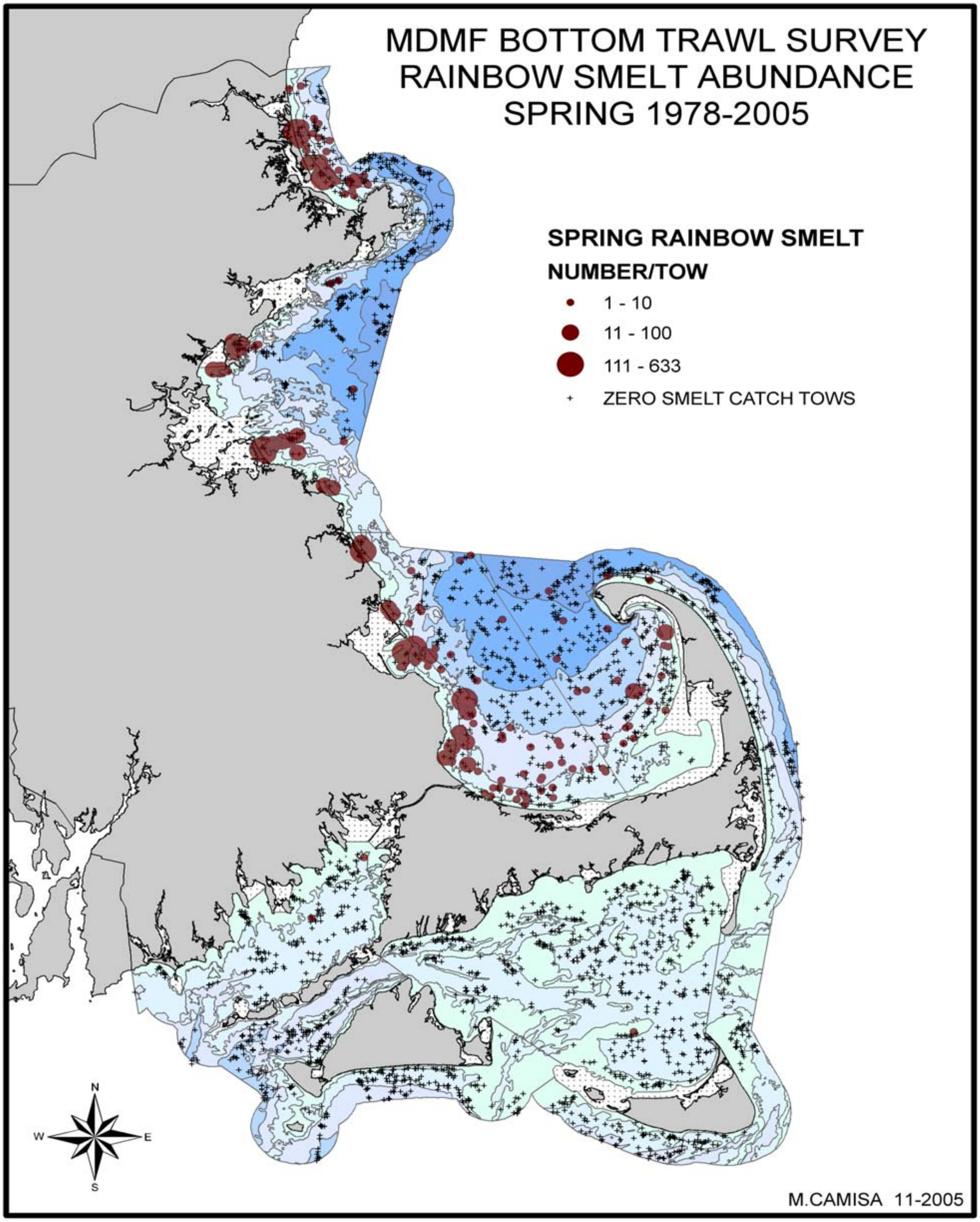
Status of Smelt Populations and Fisheries

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.

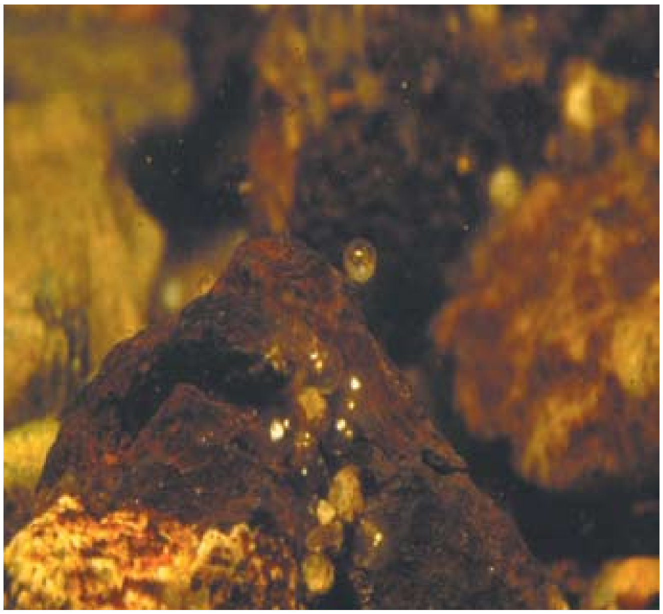
METHODS

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.

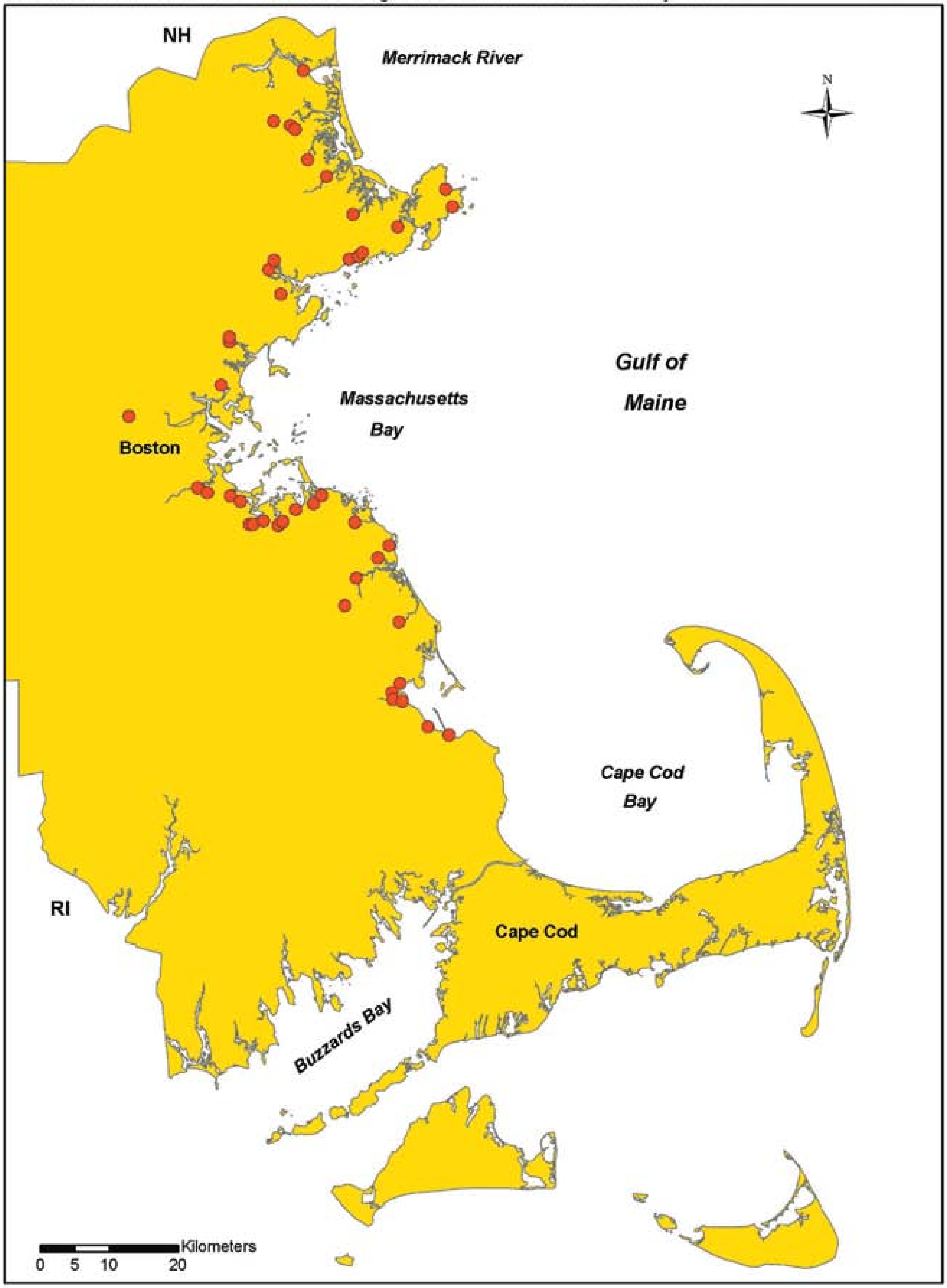


Table 2.1 List of rainbow smelt spawning locations on the Gulf of Maine coast of Massachusetts. The length and area values refer to spawning habitat where smelt egg deposition was observed. Discharge values are averages from March-May measurements for this study, except the values in bold are mean April 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.

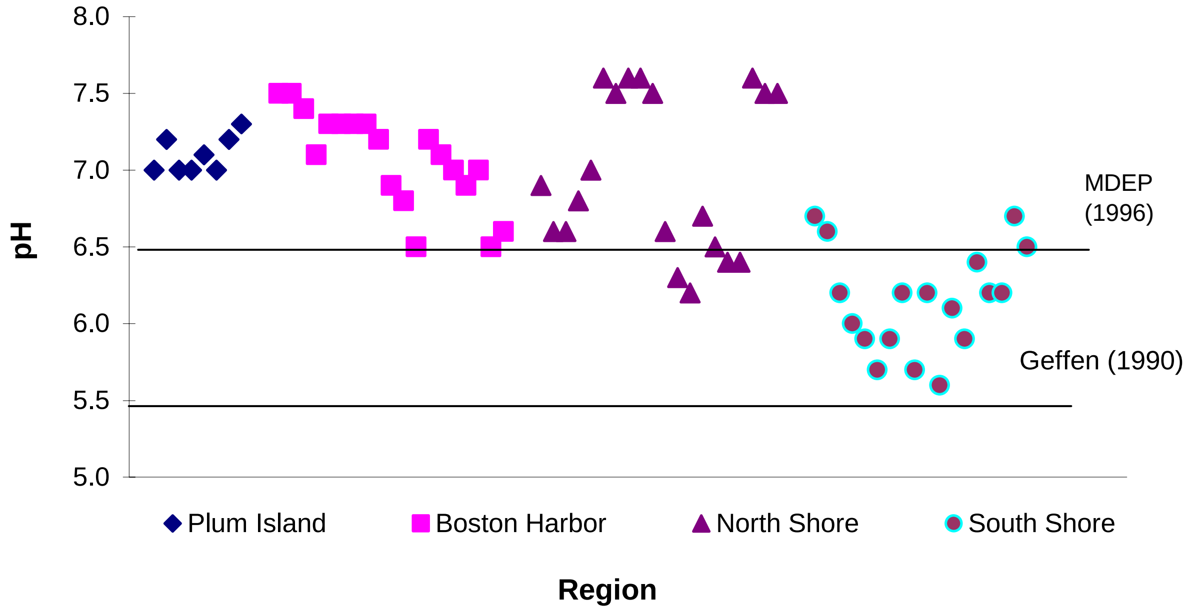
Dissolved Oxygen. No concerns on the influence of DO to support aquatic life were found during the smelt spawning season. The climatic conditions that keep stream temperatures cool during spring and the turbulence of lotic flow allows high concentrations of DO to persist throughout the spawning period. 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.

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

Sediment plume in Furnace Brook, Quincy. B. Chase

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 pollutants 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

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 (^oC) 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. (^oC)	NOAA Rainfall (cm)	Water Temp. (^oC)	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).

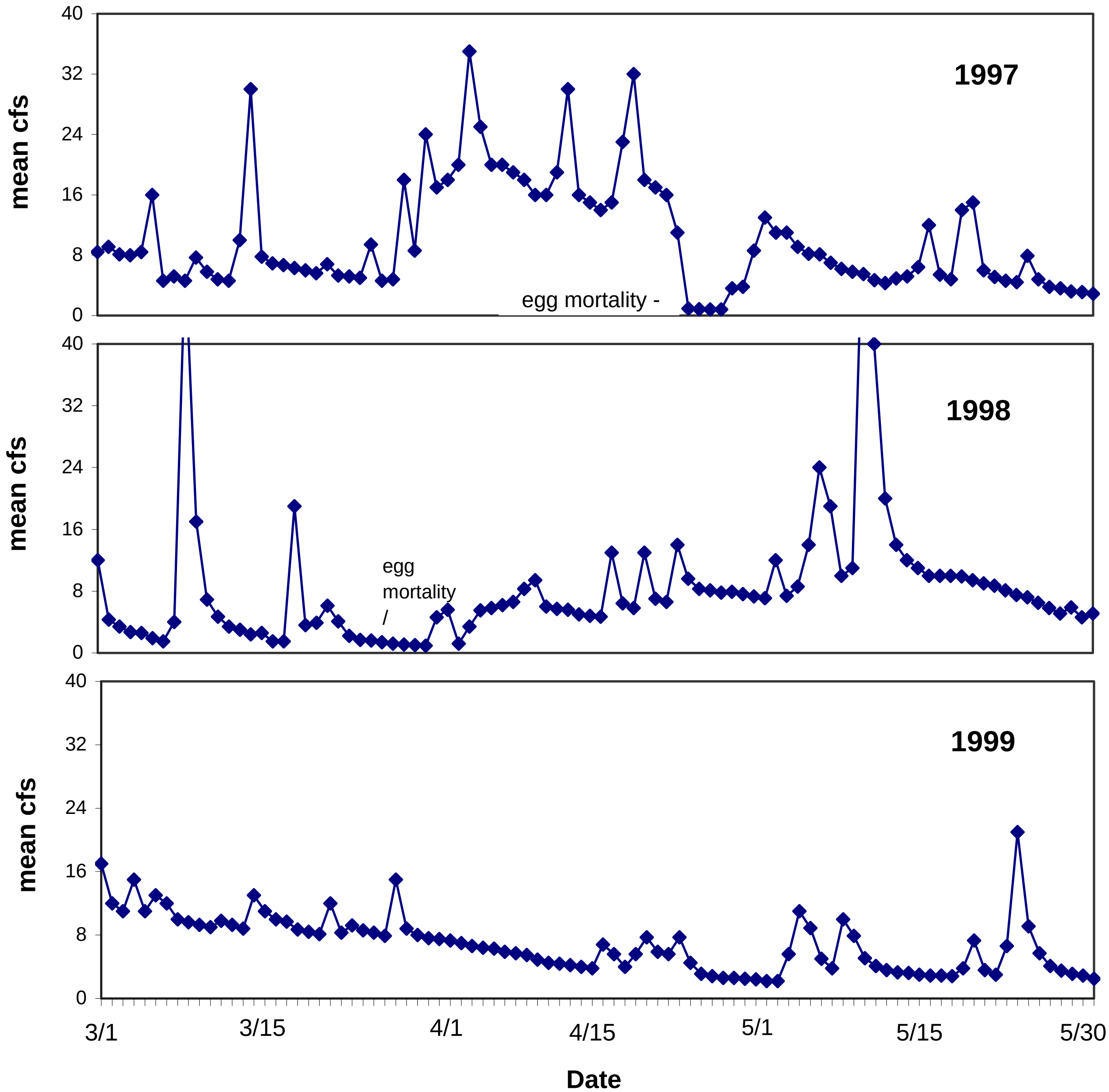
A smelt egg mortality assessment was conducted by DMF following the egg mortality event (Chase 1998). Estimates of smelt egg densities were applied to the Equivalent Adult Method (Boreman 1997) to forecast the losses of age-2 smelt due to the egg mortality event. The estimated losses for age-2 adult 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.

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Smelt spawning habitat in the Egypt River. B. Chase

LITERATURE CITED

ACOE, 1976. Operations and maintenance manual for local protection project: Weymouth - Braintree, Massachusetts, Pond Meadow Lake & Smelt Brook. New England Div., U.S. Army Corps of Engineers, Waltham, MA.

ACOE, 1980. Town Brook local protection. Feasibility Report for Water Resources Development, Town Brook, Quincy, Massachusetts. New England Div., U.S. Army Corps of Engineers, Waltham, MA.

ACOE, 1989. Saugus River and tributaries flood damage reduction study - Lynn, Malden, Revere, and Saugus, Massachusetts. Feasibility Report - Draft Environmental Impact Statement/Report. New England Div., U.S. Army Corps of Engineers, Waltham, MA.

ACOE, 1998. Environmental assessment and statement of findings incorporating Section 404 Mitigation MOA for the Bigelow Street Relief Conduit, Quincy MA. Application No. 199603132 from the Metropolitan District Commission. New England Div., U.S. Army Corps of Engineers, Waltham, MA.

Aurilio, A., Durant, J.L., and H.F. Hemond. Aurilio. 1995. Sources and Distribution of Arsenic Contamination in the Aberjona Watershed. Eastern Massachusetts. Water, Air, and Soil Pollution. 81: 265-282.

Ayer, M. H., C. Benton, W. King V., J. Kneebone, S. Elzey, M. Toran, K. Grange, and D. L. Berlinsky. 2005. Development of practical culture methods for rainbow smelt larvae. North American Journal of Aquaculture 67: 202-209.

Baird, F.T., Jr. 1967. The smelt (*Osmerus mordax*). Fish. Educ. Ser. Unit No. 5, Bull. Maine Dept. Sea and Shore Fisheries, 7 p.

Barker, S. L., D. W. Townsend, and J. S. Hacunda. 1981. Mortalities of Atlantic herring, *Clupea h. harengus,* smooth flounder, *Liopsetta putnami,* and rainbow smelt, *Osmerus mordax,* larvae exposed to acute thermal shock. Fishery Bulletin 79: 198-200.

Belyanina, T.N. 1968. Dynamics of smelt populations in sub-Artic waters. *In*: Symposium on The ecology of pelagic fish species in Arctic waters and adjacent seas, R. W. Blacker (ed.). Rapports et Proces-Verbaux des Reunions, Vol. 158, Sec. 4:74-79.

Belding, D. L. 1921. A report upon the alewife fisheries of Massachusetts. Mass. Div. of Fish. and Game, Dept. of Natural Resources, 135 pp.

Bigelow, H.B., and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish and Wild. Serv., Fish. Bull. No. 74, Vol. 53: 577 pp.

Bowden, W.B., C.J. Vorosmarty, J.T. Morris, B.J. Peterson, J.E. Hobbie, P.A. Steudler, and B. Moore III. 1991. Transport and processing of Nitrogen in a tidal freshwater Wetland. Water Resources Research, Vol. 27(3): 389-408.

Breault, R.F., L.K. Barlow, K.D. Reisig, and G.W. Parker. 2000. Spatial distribution, temporal variability, and chemistry of the salt wedge in the lower Charles River, Massachusetts, June 1998 to July 1999. U.S. Geological Service, Water Resources Investigations Report No. 00-4124.

Chase, B. C. 1990. Summary report for North Coastal Basin. Mass. Div. Mar. Fish, Massachusetts Bay Smelt Spawning Habitat Monitoring Program. STAP Doc. No. 90-102, 13 pp.

Chase, B. C. 1992. Preliminary report on the Saugus River. Mass. Div. Mar. Fish., Massachusetts Bay Smelt Spawning Habitat Monitoring Program, 47 pp.

Chase, B. C. 1993. Preliminary report on the Danvers River system. Mass. Div. Mar. Fish., Massachusetts Bay Smelt Spawning Habitat Monitoring Program. STAP Doc. No. 93-03, 49 pp.

Chase, B. C. 1995. Preliminary report on Manchester Bay. Mass. Div. Mar. Fish., Massachusetts Bay Smelt Spawning Habitat Monitoring Program, 33 pp.

Chase, B. C. 1998. Assessment of rainbow smelt egg mortality at Town Brook, Quincy, April 1997. Mass. Div. Mar. Fish., Massachusetts Bay Smelt Spawning Habitat Monitoring Program, 6 pp.

Chase, B. C. 1996. Preliminary report on the Neponset River. Mass. Div. Mar. Fish., Massachusetts Bay Smelt Spawning Habitat Monitoring Program, 28 pp.

Chase, B. C. 2000. Rainbow smelt spawning habitat in Furnace Brook, Quincy. Mass. Div. Mar. Fish., Massachusetts Bay Smelt Spawning Habitat Monitoring Program, 17 pp.

Chase, B. C. and A. Roderick, 1994. Final report on the Forest River, Salem: 1989-1990. Mass. Div. Mar. Fish., Massachusetts Bay Smelt Spawning Habitat Monitoring Program, 19 pp.

Chase, B. C. and A. R. Childs, 2001. Rainbow smelt (*Osmerus mordax*) spawning habitat in the Weymouth-Fore River. 2001. Mass. Div. of Mar. Fish., Tech. Rep. TR-5.

Chase, B.C., K. Pelto, and J. Ide. 1997. Final Report on Neponset River volunteer flow monitoring at Lower Mills, Milton, 1995-1996. Mass. Div. of Mar. Fish., Mass. Riverways and Neponset River Watershed Association, 11 pp.

Chase, B. C. Plouff J. H. and W. M. Castonguay. The Marine Resources of Salem Sound, 1997. 2002. Mass. Div. Mar. Fish., Tech. Rep. TR-6.

Chase, B. C. J. H. Plouff and M. Gabriel. *In Prep.* An evaluation of the use of egg transfers and habitat restoration to establish an anadromous rainbow smelt (*Osmerus mordax*) spawning population. *In prep.* Mass. Div. of Mar. Fisheries.

Chesmore, A. P. and A. E. Peterson. 1970. Massachusetts Estuarine Research and Protection Programs. Mass. Div. Mar. Fish., 12 pp.

Chesmore, A. P., S. A. Testaverde, and F. P. Richards, 1971. A study of the marine resources of Dorchester Bay. Mass. Div. Mar. Fish., Monograph Series No. 10.

Chesmore, A. P., Brown, D. J., and Anderson, R. D. 1972. A study of the marine resources of Lynn-Saugus harbor. Mass. Div. Mar. Fish., Monograph Series No.11.

Chesmore, A. P., D. J. Brown, and R. D. Anderson, 1973. A study of the marine resources of Essex Bay. Mass. Div. Mar. Fish., Monograph Series No. 13.

Chiasson, A. G. 1993. The effects of suspended sediment on rainbow smelt (*Osmerus mordax*): a laboratory investigation. Canadian Journal of Zoology 71: 2419-2424.

Clayton, G. R. 1976. Reproduction, first year growth, and distribution of anadromous rainbow smelt, Osmerus mordax, in the Parker River and Plum Island Sound estuary, Massachusetts. Univ. of Mass., M.S. Thesis, Amherst, MA, 105 pp.

Collette, B.B, and G. Klein-MacPhee. 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine., 3rd ed. Smithsonian Institution Press. Washington and London.

Colton, J. B. and R. L. Marak. 1969. Guide for identifying the common planktonic fish eggs and larvae of continental shelf water, Cape Sable to Block Island. U.S. Bur. Comm. Fish. Biol.Lab., Woods Hole, Mass., Ref. 69-6, 72 pp.

Cooper, J. E. 1978. Identification of eggs, larvae, and juveniles of the rainbow smelt, *Osmerus mordax,* with comparisons to larval alewife, *Alosa pseudoharengus,* and gizzard shad, *Dorosoma cepdianum*. TAFS 107: 56-62.

Crestin, D. S. 1973. Some aspects of the biology of adults and early life stages of the rainbow smelt, *Osmerus mordax* (Mitchill), from the Weweantic River Estuary, Wareham-Marion, Massachusetts, 1968. M.S. Thesis, Boston University, Boston, MA.

Delaney, R. F. and J. Wiggins, 1995. Draft Neponset River Estuary ACEC Resource Management Plan. Prepared for the Mass. Ex. Office of Environmental Affairs, 63 pp.

Dodson, J. J., J. C. Dauvin, R. G. Ingram, and B. d'Anglejan. 1989. Abundance of larval rainbow smelt (Osmerus mordax) in relation to the maximum turbidity zone and associated macroplanktonic fauna of the middle St. Lawrence Estuary. Estuaries 12: 66-81.

Dupee, D.S., and M. Manhard, 1975. The rainbow smelt "Osmerus mordax" 1974 spawning run in the Town River, Quincy, Massachusetts. New England Division, U.S. Dept. of the Army, Corps of Engineers, Waltham, MA, 30 pp.

Elliot, E. M. and D. Jimeniz. 1981. Laboratory manual for the identification of ichthyoplankton from the Beverly-Salem Harbor area. Mass. Div. Mar. Fish., Salem, Mass., 230 pp.

Essex Institute, 1971. Essex Institute Historical Collections, 1868. Essex Institute Press, Salem, MA., 65 pp. Second series, Vol. 1, part 2, reprinted 1971.

Fiorentino, J. F., L. E. Kennedy and M. J. Weinstein, 2000. Charles River Watershed 1997/1998 Water Quality Assessment Report. Mass. Dept. Environ. Protection.

Fiske, J. D., C. E. Watson, and P. G. Coates. 1966. A study of the marine resources of the North River. Mass. Div. Mar. Fish., Monograph Series No.3.

Geffen, A. J. 1990. Response of rainbow smelt, *Osmerus mordax* (Mitchill), eggs to low pH. Journal of Fish Biology 37: 865-871.

Grout, D., and B. Smith. 1994. A creel survey of the marine recreational fisheries. New Hampshire Dept. of Fish and Game, Final Report for grant F-50-R-8, 53-152 pp.

Grout, D., and B. Smith. 2004. Monitoring of the rainbow smelt resource and winter ice fishery. New Hampshire Dept. of Fish and Game, Final Report for New Hampshire Anadromous Fish Investigation and Marine Recreational Fishery Evaluation, grant F-61-R, 31-43 pp.

GSE, 2003. Parker River Low Flow Study. Gomez and Sullivan Engineers, P.C., Weare, New Hampshire. Prepared for the MA Ex. Office of Environ. Affairs.

Halliwell, D. B. W. A. Kimball and A. J. Screpetis. 1982. Massachusetts Stream Classification Program Part I: Inventory of rivers and stream. Mass. Dept. Fish. Wild. and Rec. Veh., and Mass. Dept. of Env. Quality Eng., Westborough, MA, 126 pp.

Hurlbert, P. J. 1974. Factors affecting spawning site selection and hatching success in anadromous rainbow smelt (Osmerus mordax, Mitchell). M.S. Thesis, Univ. of ME, Orono, ME, 44 pp.

IRWA, 2003. Ipswich River Watershed Management Plan. Prepared by Horsley & Witten, Inc. for Ipswich River Watershed Association.

Iwanowicz, H. R., R. D. Anderson, and B. A. Ketschke, 1973. A study of the marine resources of Hingham Bay. Mass. Div. Mar. Fish., Monograph Series No. 15.

Iwanowicz, H. R., Anderson, R. D., and Ketschke, B. A. 1974. A study of the marine resources of Plymouth, Kingston and Duxbury Bay. Mass. Div. Mar. Fish., Monograph Series No.17.

Jerome, W. C. Jr., A. P. Chesmore, C. O. Anderson Jr., and F. Grice, 1965. A study of the marine resources of the Merrimack River Estuary. Mass. Div. Mar. Fish., Monograph Series No. 1.

Jerome, W. C. Jr., A. P. Chesmore, and C. O. Anderson Jr., 1966. A study of the marine resources of Quincy Bay. Mass. Div. Mar. Fish., Monograph Series No. 2.

Jerome, W. C. Jr., A. P. Chesmore, and C. O. Anderson Jr., 1967. A study of the marine resources of Beverly-Salem Harbor. Mass. Div. Mar. Fish., Monograph Series No. 4.

Jerome, W. C. Jr., A. P. Chesmore, and C. O. Anderson Jr., 1968. A study of the marine resources of the Parker River-Plum Island Sound Estuary. Mass. Div. Mar. Fish., Monograph Series No. 6.

Jerome, W. C. Jr., A. P. Chesmore, and C. O. Anderson Jr., 1969. A study of the marine resources of the Annisquam River-Gloucester Harbor coastal system. Mass. Div. Mar. Fish., Monograph Series No. 8.

Kendall, W. C. 1926. The smelts. Bureau of Fisheries Document. Department of Commerce.

Kennedy, L. E., L. K. O' Shea, W. J. Dunn Jr., and D. LeVangie. 1995. The Neponset River Watershed 1994 resource assessment report. Mass. Dept. of Environ. Protect., Office of Watershed Mgt.

Kieffer, M. C., and B. K. 1993. Annual movements of shortnose and Atlantic sturgeons in the Merrimack River, Massachusetts. TAFSociety 122: 1088-1103.

Kooken, V. C., DelPapa, and R. Buchsbaum. 2000. Water quality assessment: Gloucester Harbor, the North River, Salem/ Peabody, the Saugus River, Smallpox Brook, Salisbury. Prepared by North Coastal Watershed Alliance for Mass. Dept. of Environ. Protection. Final Report, 55 pp.

Lawton, R., P. Brady, C. Sheehan, S. Correia, and M. Borgatti. 1990. Final report on spawning sea-run rainbow smelt (*Osmerus mordax*) in the Jones River and impact assessment of Pilgrim Station on the population, 1979-1981. Boston Edison. Pilgrim Nuclear Power Station Marine Environmental Monitoring Program Report Series.

Lindenberg, J. G. 1977. Survey of fishes at Lower Mystic Lake, Arlington. Mass. Div. Fish. Wild., Westboro, MA, 4 pp.

Lippson, A. J. and R. L. Moran. 1974. Manual for the identification of early development stages of fishes of the Potomac River estuary. Env. Tech. Center, Martin, Marietta Corp., Baltimore, MD, 228 pp.

MBP, 1997. The Fore River Mini-Bays Project: revitalizing the Fore River. Mass. Bay Program, Boston, MA.

MCFG, 1917. Annual report for 1916, Division of Fish and Game. Mass. Commissioners on Fisheries and Game, Boston, MA.

McKenzie, R. A. 1964. Smelt life history and fishery in the Miramichi river, New Brunswick. Fisheries Research Board of Canada 77.

MDC, 1994. Lower Mystic Lake Saltwater Removal Project. Metropolitan District Commission, Boston, MA.

MDEP. 1996. *Massachusetts Surface Water Quality Standards.* Mass. Dept. of Environ. Protect., Division of Water Pollution Control, Technical Services Branch, Westborough, MA (Revision of 314 CMR 4.00, effective June 23, 1996.)

MDEP. 1998. Water Quality Certificate for Widening and Channeling of Town Brook Channel near Bigelow Street. Mass. Dept. of Environ. Protect. File No. 059-0590, Quincy, MA. Applicant No. BRP WW10 from Mass. Metropolitan District Commission.

MDEP, 2004. Ipswich River Watershed, 2000 Water Quality Assessment Report. Mass. Dept. of Environ. Protect., Division of Watershed Protection.

MDEP, 2006. South Shore Coastal Watersheds 2001 Water Quality Assessment Report. Mass. Dept. of Env. Protect., Div. of Watershed Mgt., Report No. 94-AC-2.

MDEQE, 1987. Order of Conditions under the Massachusetts Wetlands Protection Act for Metropolitan District Commission's project on Town Brook and Town River, Quincy. DEQE File No. 59-196, Mass. Dept. Environ. Quality Engineering.

MDEQE, 1989. Water Quality Certificate for Storm Water Discharge Town River, Town Brook, Quincy. Mass. Dept. Environ. Quality Engineering, Application No. 87W-045 from U.S. Corps of Engineers and Mass. Metropolitan District Commission.

MDMF, 1960. Salt water sports fishing in Massachusetts. Mass. Div. Mar. Fish., report to Mar. Fish. Advisory Comm., Aug. 25, 1960.

MDPW, 1970. Report on Town Brook & Home Meadow, Hingham, Massachusetts. Commonwealth of Mass., Dept. of Public Works, Division of Waterways.

MDPW, 1991. Salem-Beverly Harbors Transportation Project, Final Supplemental Environmental Impact Review. Mass. Dept. of Public Works. EOEA No. 0756, Vol. 1, Section 4.0.

MHD, 1999. Cunningham & Furnace Brook Improvements, Quincy & Milton, Massachusetts, Drainage Study. Prepared by Weston and Sampson, Peabody, MA, for the Mass. Highway Department.

Moore, J. K., and C. DelPapa, 1992. A report to the Salem Conservation Commission on the results of preliminary sampling of dissolved oxygen levels in the Forest River Estuary over the summer of 1991. Salem, MA.

MRI, 1987. Saugus River biological monitoring program post-operational summary report, 1986-1987. Marine Research Inc. Prepared for Wehran Engineering, Middleton, MA. 52 pp.

MRI, 1989. Biological monitoring program Saugus River, Saugus, Massachusetts, additional post-operational entrainment studies (spring 1989). Marine Research, Incorporated. Prepared for Wheelabrator Environmental Systems, Inc., Saugus, MA. 16 pp.

MRI, 1999. Weymouth-Fore River fisheries studies related to the Fore River Power Station. Prepared by Marine Research, Inc. for Sithe Edgar Development, LLC, Charlestown, MA, 68 pp.

MRI, 2001. Smelt Brook smelt study, Weymouth Landing, Massachusetts. Prepared by Marine Research, Inc. for Mass. Bay Transportation Authority, Boston, MA, 19 pp.

Murawski, S. A. 1976. Population dynamics and movement patterns of anadromous rainbow smelt, *Osmerus mordax* (Mitchill), in the Parker River, Massachusetts. M.S. Thesis, Univ. of MA, Amherst, MA.

Murawski, S. A., and Cole, C. F. 1978. Population dynamics of anadromous rainbow smelt, *Osmerus mordax*, in a Massachusetts river system. TAFS 107: 535-542.

Murawski, S.A., G. R. Clayton, R. J. Reed, and C. F. Cole. 1980. Movements of spawning rainbow smelt, *Osmerus mordax*, in a Massachusetts estuary. Estuaries 3: 308-314.

NOAA. 1988. Climatological Data Annual Summary: New England 1988. National Oceanic and Atmospheric Admn., National Climatic Data Center, Asheville, NC., Vol. 100, No. 13.

NOAA. 1989. Climatological Data Annual Summary: New England 1989. National Oceanic and Atmospheric Adm., National Climatic Data Center, Asheville, NC., Vol. 101, No. 13.

NOAA. 1990. Climatological Data Annual Summary: New England 1990. National Oceanic and Atmospheric Adm., National Climatic Data Center, Asheville, NC., Vol. 102, No. 13.

NOAA. 1991. Climatological Data Annual Summary: New England 1991. National Oceanic and Atmospheric Admn., National Climatic Data Center, Asheville, NC., Vol. 103, No. 13.

NOAA. 1992. Climatological Data Annual Summary: New England 1992. National Oceanic and Atmospheric Adm., National Climatic Data Center, Asheville, NC., Vol. 104, No. 13.

NOAA. 1993. Climatological Data Annual Summary: New England 1993. National Oceanic and Atmospheric Adm., National Climatic Data Center, Asheville, NC., Vol. 105, No. 13.

NOAA. 1994. Climatological Data Annual Summary: New England 1994. National Oceanic and Atmospheric Adm., National Climatic Data Center, Asheville, NC., Vol. 106, No. 13.

NOAA. 1995. Climatological Data Annual Summary: New England 1995. National Oceanic and Atmospheric Adm., National Climatic Data Center, Asheville, NC., Vol. 107, No. 13.

NOAA, 2004. Species of Concern in the Northeast Region (Maine through Virginia). Nat. Mar. Fish. Serv., Proactive Conservation Program.

Ouellet, P. and Dodson, J. J. 1985. Tidal exchange of anadromous rainbow smelt (*Osmerus mordax*) larvae between a shallow spawning tributary and the St. Lawrence Estuary. CJFAS, 42: 1352-1358.

Peterson, S. J. 1975. The seasonal abundance and distribution of fish eggs, larvae, and juveniles in the Merrimack River estuary, Massachusetts, 1974-1975. M.S. Thesis, Univ. of MA, Amherst, MA.

Pettigrew, P. 1997. Suivi de la reproductio de L'eperlan arc-en-ciel de la rive sud de l'Estuaire du Saint-Laurent en 1994, 1995, et 1996. Ministere de l'Env. et de la Faune, Direction regionale du Bas-Saint-Laurent, Riviere-du-Loup, Fevrier, 52 pp.

Reback, K. E. and J. S. DiCarlo. 1972. Completion report on the anadromous fish project. Mass. Div. Mar. Fish., Publication No. 6496, 113 pp.

Reback, K. E., P. D. Brady, K. D. McLaughlin, and C. G. Milliken, 2005. A survey of anadromous fish passage in coastal Massachusetts, Part 4. Boston Harbor, North Shore and Merrimack River. Mass. Div. Mar. Fish. Tech.Rep. No. TR-18, 130 pp.

Rupp, R. S. 1959. Variation in the life history of the American smelt in inland waters of Maine. TAFS 88: 241-252.

Scotton, L. N. R. E. Smith N. S. Smith K. S. Price and D. P. DeSylva. 1973. Pictoral guide to fish larvae of the Delaware Bay, with information and bibliographies useful for the study of fish larvae. Univ. of Delaware, Delaware Bay Report, Ser. 7, 206 pp.

SESD, 1991. Draft Environmental Impact Review, Phase II Facilities Plan for Wastewater Treatment and Disposal. Camp Dresser & McKee, Inc., Cambridge, MA. for South Essex Sewer District, Salem, MA.

Sirois P, and J. J. Dodson. 2003. Critical periods and growth-dependent survival of the larvae of an estuarine fish, the rainbow smelt (*Osmerus mordax*). Marine Ecology Progress Series 203: 233-245.

Socolow, R. S., C. R. Leighton, J. L. Zanca, and L. R. Ramsbey, 1998. Water resources data, Massachusetts and Rhode Island Water Year 1997. U.S. Geological Survey, Marlborough, MA.

Tashiro, J. S., R. E. Schmidt, E. Kiviat, and D. R. Roeder, 1991. Baseline assessment of the Saugus River system, Massachusetts. Hudsonia Limited, Bard College Field Station, Annadale-on-Hudson, NY., 55 pp.

Trencia, G. 1999. Restoration of the Boyer River. *In*, Proceedings of the first North American workshop on rainbow smelt, Quebec City, February 1999. Edited by University of Laval, Quebec.

Trencia, G. and B. Langevin. 2003. Incubation d'oeufs d'eperlan arc-en-ciel au Ruisseau de L'Eglise en 2001 et 2002. Societe Faune et Parcs du Quebec, Charny, Quebec, 18 pp.

UEC, 1992. Edgar Energy Park: Final 316(a) and (b) determinations. Prepared by United Engineers & Construction, for Boston Edison Company.

Unanian, I.M., and S.G. Soin. 1963. On reproduction and development of the White Sea smelt. Vesh. Mosk. Gos. Univ. (6)4:25-36.

USEPA, 2002. Clean Charles 2005 Water Quality Report, 2001 Core Monitoring Program. U.S. Environmental Protection Agency, Office of Environment, Measurement and Evaluation, Region 1, Boston, MA, 26 pp.

Wandle, S. W. Jr. 1984. Gazetteer of hydrologic characteristics of streams in Massachusetts — coastal rivers basins of the North Shore and Massachusetts Bay. U.S. Geological Survey, Boston, MA, Water-Resources Investigations Report 84-4281, 60 pp.

Wandle, S.W. Jr. and M.A. Morgan. 1984. Gazetter of hydrologic characteristics of streams in Massachusetts — coastal river basins of the South Shore and Buzzards Bay. Boston, Mass. U.S. Geological Services, Water-Resources Investigations Report 84-4288, 30 pp.

White, R.E. 1988-1995. Eldridge tide and pilot book. Published by R.E. White, Boston, MA.

Zarriello, P. J., 2002. Effects of water-management alternatives on streamflow in the Ipswich River Basin, Massachusetts. U.S. Geological Survey, Open-File Report 01-483.