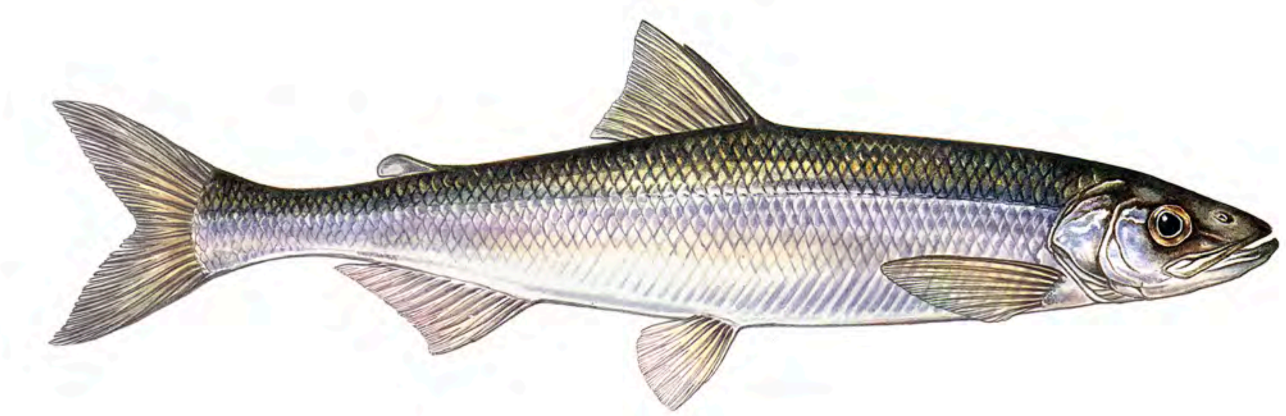
# A Regional Conservation Plan

*for*

# Anadromous Rainbow Smelt in the U.S. Gulf of Maine



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## INTRODUCTION

The rainbow smelt *(Osmerus mordax)* is a small anadromous fish that overwinters in estuaries and bays prior to spawning each spring in coastal streams and rivers. Smelt have supported culturally important commercial and recreational fisheries throughout New England since at least the 1800s. However, in recent years, concerns have risen about the population status of rainbow smelt. The species has disappeared from the southern end of its geographic range, which once extended to the Chesapeake Bay and now may extend only as far south as Buzzards Bay, Massachusetts. High numbers of rainbow smelt that once supported commercial fisheries in New England have declined precipitously since the late 1800s to mid-1900s. While recreational fisheries for rainbow smelt continue, declining catches have also been noted by anglers, particularly since the 1980s.

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Based on these observations of range contraction and abundance declines, the National Oceanic and Atmospheric Administration (NOAA) listed rainbow smelt as a federal Species of Concern in 2004; New Hampshire also lists sea-run rainbow smelt as a Species of Special Concern. Although rainbow smelt population declines have been widely documented, the causes are not well understood. In listing the species, factors identified as potential contributors included structural impediments to their spawning migration (such as dams and blocked culverts) and chronic degradation of spawning habitat due to stormwater inputs that include toxic contaminants, nutrients, and sediment.

Following the designation of rainbow smelt as a species of concern, the Maine Department of Marine Resources received a 6-year grant from NOAA's Office of Protected Resources to work in collaboration with the Massachusetts Division of Marine Fisheries and New Hampshire Fish and Game Department to document the status of and develop conservation strategies for rainbow smelt (NA06NMF4720249). This conservation plan represents a summary of key elements of the project, which focused on several objectives:

1) Documenting range contraction and range-wide population declines based on historical data and accounts
2) Evaluating the status of rainbow smelt populations in the Gulf of Maine region
3) Developing a population index to track the strength of spawning runs
4) Assessing a range of potential threats to rainbow smelt populations
5) Proposing management actions to help conserve rainbow smelt throughout the Gulf of Maine region.

This study has significantly advanced our understanding of the biology, status, and threats to rainbow smelt in the Gulf of Maine. A major contribution was the development of standardized procedures for indexing the abundance of spawning rainbow smelt. Four years of fyke net sampling of spawning runs throughout the Gulf of Maine region have provided important baseline information about the status of the species. Observations of truncated age structures within the spawning run, high male to female ratios in some rivers, and lower survival rates and a higher portion of age-1 spawners than historically observed all indicate that Gulf of Maine rainbow smelt populations are currently stressed.

Further evidence of the decline can be derived from a survey of historically active spawning sites throughout the state of Maine, using a study from the 1970s (Flagg 1974) as a valuable baseline for comparison. The recent survey found that 13% of the historically active spawning streams no longer support rainbow smelt spawning, and most of the streams that remain active now support smaller runs than they did historically. The substantial decline in strong spawning runs merits concern and attention.

Many threats to rainbow smelt spawning habitat were identified as part of this study. Obstructions such as dams and improperly designed culverts may physically impede smelt migration to appropriate spawning sites. Further, extremely high or low flows can impede swimming ability or impair the cues smelt rely on to undertake this migration. Once on the spawning grounds, water quality conditions may affect the hatching and survival of smelt eggs. In many rivers studied as part of this project, pH, turbidity, nutrient levels, and dissolved contaminants warranted concern for water quality. Field observations also showed an association between nitrogen levels and periphyton growth at spawning grounds, and laboratory experiments demonstrated that high periphyton growth significantly impaired the survival of smelt embryos.

Many of these threats—particularly flow patterns and water quality—are not driven by factors within the spawning rivers themselves, but rather by activities in the surrounding watersheds. Across a suite of water quality and heavy metal parameters, we found that high levels of development in the watershed were associated with poorer conditions for rainbow smelt, while high proportions of forest in the watershed supported high quality stream conditions. In conjunction, watershed development was negatively associated with the strength of smelt spawning runs, while forested watersheds supported stronger runs in their receiving streams.

Our goal in assessing threats to rainbow smelt was to identify conditions that appear to negatively and positively affect smelt throughout their life cycle so that management actions can effectively target these factors. Based on our assessment of critical threats, management recommendations to protect and restore rainbow smelt populations include:

- Maintain the federal Species of Concern designation for rainbow smelt
- Continue monitoring population trends and biological characteristics in the extant range, and expand efforts towards estimating rainbow smelt population size
- Restore historical or degraded spawning habitat
- Maintain and, where necessary, improve fishery monitoring to ensure that fishing effort is compatible with sustainability of local and regional rainbow smelt populations
- Expand research initiatives to anticipate direct and indirect effects of

climate change and variability on rainbow smelt

- Invest in research to further study environmental requirements, stressors, and drivers in order to effectively manage recovery
- Stock marked larvae to re-establish rainbow smelt runs at restored sites, as needed and as appropriate given considerations of genetic diversity and donor population viability

This Conservation Plan provides: a description of the life history of anadromous rainbow smelt; an account of the historical fishing pressure on the species; a summary of the current population status and monitoring efforts; explanation of the threats to the species at different life stages, including the marine phase; and conservation and management strategies for the region and for each state in the Gulf of Maine. Our intent is that this information will provide important baseline information regarding the status of smelt populations at the present time and that it will offer coastal and fishery managers guidance on appropriate actions and priorities to protect and restore rainbow smelt moving forward.

# 1 – SPECIES STATUS

Rainbow smelt *(Osmerus mordax)* are small anadromous fish that live in nearshore coastal waters and spawn in the spring in coastal rivers immediately above the head of tide in freshwater (Buckley 1989, Kendall 1926, Murawski et al. 1980). Landlocked populations of smelt also naturally occur in lakes in the Northeast U. S. and Canada and have been introduced to many freshwater systems, including the Great Lakes. Anadromous smelt serve as an important prey species for commercially and culturally valuable species, such as Atlantic cod, Atlantic salmon, trout, Atlantic gray seals, striped bass (Clayton et al. 1978, O'Gorman et al. 1987, Kircheis and Stanley 1981, Kirn 1986, Stewart et al. 1981). Historically, the range of rainbow smelt extended from Chesapeake Bay to Labrador (Buckley 1989, Kendall 1926), but over the last century, the range has contracted and smelt are now only found east of Long Island Sound.

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## 1.1 – BASIC BIOLOGY

### Life History

Smelt are small-bodied and short-lived, seldom exceeding 25 cm in length or five years of age in the Gulf of Maine region (Murawski and Cole 1978, Lawton et al. 1990). By age two, smelt are fully mature and recruited to local recreational fisheries and spawning runs. Life history appears to be influenced by latitude; few age-1 smelt become mature and participate in Canadian smelt runs, however in Massachusetts, New Hampshire, and southern Maine, age-1 individuals are present in the spawning runs (Collette and Klein-MacPhee 2002). Studies in Massachusetts found that the majority of age-1 spawners were male (Murawski and Cole 1978, Lawton et al. 1990). Our current spawning surveys have found that runs in the Gulf of Maine are dominated by age-2 smelt, with few older smelt in Massachusetts, New Hampshire, and southern Maine; however the older ages are better represented in midcoast and eastern Maine. Fecundity estimates of approximately 33,000 eggs for age-2 smelt and 70,000 eggs for age-3 smelt were reported by Clayton (1976).

### Habitat Use

Annual movements and habitat use by adult rainbow smelt have been largely assumed based on discrete sampling or patterns in recreational and commercial fishing. Mark and recapture studies have focused on distinct phases of the life cycle, such as movements between spawning areas (Murawski et al. 1980), composition of late and early populations of spawning adults (McKenzie 1964) and winter movements within a river system (Flagg 1983). Larger annual and regional migrations have been synthesized from anecdotal reports by anglers and commercial fishermen as well as from beach seine and spawning surveys.

Rainbow smelt overwinter in estuaries and bays and then spawn in early spring in pool and riffle areas above the head-of-tide in coastal streams and rivers. The spawning habitat characteristics are discussed in detail in sections 2.1 – Threats to Spawning Habitat Conditions, and 2.2 – Threats to Embryonic Development and Survival. Because males have a longer physiological spawning period, they may return to spawning grounds multiple times within the same year (Marcotte and Tremblay 1948). Mark and recapture studies have observed the same male at different spawning sites within a given year, suggesting that males are able to spawn multiple times (Murawski et al. 1980, Rupp 1968). Murawski et al. (1980) hypothesized that spawning in different streams may be facilitated by passive tidal transport, however this has not been directly observed. Females, on the other hand, rarely ascend to the spawning grounds more than once in a season, based on recent mark-recapture surveys (C. Enterline, unpublished data). Because female smelt are broadcast spawners, their spawning is expected to occur in a single event as most or all of their eggs are deposited in a single event.

Spawning females deposit demersal (sinking) adhesive eggs that attach to the substrate and hatch in 7-21 days, depending on temperature. Upon hatching, larvae are immediately transported downstream into the tidal zone, at which point the larvae begin feeding on zooplankton. Larval dispersion is mostly passive in response to river flow and coastal circulation patterns, but there is also an active (swimming) component (Bradbury et al. 2006b). Although horizontal movements of smelt larvae appear passive, they actively migrate vertically in response to tidal flow in order to maintain their position in zooplankton rich water and minimize downstream movement (Laprise and Dodson 1989, Dauvin and Dodson 1990, Sirois and Dodson 2000). This active swimming behavior is overwhelmed by passive transport in local circulation patterns. The importance of local circulation on larvae dispersion is discussed more in the genetic stock structure section below.

Juvenile smelt remain in the estuary, bay, or sheltered coastal area through the summer, and sometimes through the early fall (NHF&G and ME DMR Juvenile Abundance Surveys, 1979-2011, analysis for current study). In Great Bay, NH, juvenile smelt are most abundant in August, while in the Kennebec and Merrymeeting Bay estuary complex in Maine, abundance is more evenly distributed between August, September, and October (Figure 1.1.1). In Maine, catches of juvenile smelt occur from July to October, while in New Hampshire, catches range from June to November.

Habitat use in marine waters is largely unknown but can be inferred through interviews with coastal fishermen and state trawl surveys. Smelt may migrate in search of optimum water temperatures, moving offshore during the summer months to greater depths with cooler water (Buckley 1989). Based on low catches by fishermen in freshwater and larger catches in brackish and saltwater in May, the presumed end of the spawning run, it has been assumed that adults return to estuaries and coastal waters immediately after spawning (Bigelow and Schroeder 1953). However, recent findings indicate that rainbow smelt may remain within estuaries and bays contiguous to their spawning sites for up to two months after spawning (C. Enterline, unpublished data).

Recent trawl surveys have found small schools of smelt as far from the coast as 60 km and in depths up to 77 m (data from the Maine-New Hampshire and

Massachusetts Trawl Surveys). Spring trawl surveys find smelt further from the coast and in deeper water (spring avg. depth = 29.7 m) than during fall trawl surveys (fall avg. depth = 19.9 m) (Figures 1.1.2 and 1.1.3; t-test comparing depth, $p = 0.0338 < 0.05$), however the average spring catch is smaller compared to the fall (spring average catch 2001-2012 = 31, fall average catch 2000-2011 = 129, Wilcoxon non-parametric test of means, $p < 0.0001 < 0.05$), likely because adult smelt are within coastal streams and rivers as part of the spawning event during the spring period. The smelt that are caught further offshore in the spring are smaller, with lengths associated with age-1 fish; these are likely young fish that are not recruited to the spawning run.

As offshore water temperatures drop in the fall, smelt likely move towards the coast, eventually migrating into the upper estuaries where they overwinter (Buckley 1989; Clayton 1976; McKenzie 1964). Anecdotal reports from recreational hook-and-line ice-fishermen describe smelt moving in tidal rivers with the nighttime flood tide and out with the ebb tide, and some moving as far up as the head of tide each night. These foraging movements are the basis for robust recreational fisheries in the fall and winter at many locations in the Gulf of Maine.

## *Genetic Stock Structure in the Gulf of Maine*

Understanding the genetic structure of a species and the driving factors behind that structure is central to well-designed species management. A species may be comprised of one or more genetic stocks, separated by different spawning areas or physical barriers. Managing a species at too large a scale (i.e., assuming there is only one stock when there are multiple) may lead to the loss of genetic structure and the benefits of local adaptation. Managing at too small a scale (i.e., assuming stocks are isolated within individual rivers when in fact there is some mixing), neglects the important role of gene flow and results in loss of genetic variation (Kovach et al., in press).

From 2006-2010, we collected genetic samples at 18 spawning site index stations spanning the Gulf of Maine to understand if unique genetic stocks existed and the extent of gene flow between spawning populations. All information presented in this conservation plan was reported by the University of New Hampshire and in detail by Kovach et al. (in press). The three most genetically divergent populations were found in Cobscook Bay, Maine, Massachusetts Bay, and Buzzards Bay, Massachussetts. Penobscot and Casco bays in Maine also showed some differentiation. Gene flow was high between rivers from downeast coastal Maine, the Kennebec River, ME, and Great Bay, NH to northern Massachusetts; all were dominated by the same genetic signal. Midcoast Maine also seemed to be part of this large stock, but also showed distinct signals from Penobscot Bay and Casco Bay (Figure 1.1.4). These groupings can assist management decisions on stocking efforts, with the goals of maintaining distinct stocks where possible, while still preserving gene flow to maintain and replenish genetic diversity.

Although the study did not find evidence of genetic bottlenecking, genetic variation was significantly reduced in the two most distinct regions: Buzzards Bay (Weweantic River), and Cobscook Bay (East Bay Brook) (Kovach et al., in press). The reduced diversity in the Weweantic River is consistent with its location at the southern extent of the species range, where populations can have reduced gene flow and lower spawning population sizes (Schwartz et al. 2003). The reduced variation in Cobscook Bay is more likely due to isolation by circulation patterns. The reduced diversity and distinctive nature of these smelt runs warrant further population monitoring and possibly updated protection measures.

The divergence patterns observed may be explained partly by coastal circulation patterns (Kovach et al., in press). Because the movement of smelt larvae is largely passive during the early development (Bradbury et al. 2006b), their dispersal is determined first by river flow and secondly by marine circulation. The Gulf of Maine Coastal Current (GMCC) has a counter-clockwise pattern, which is strongest in the summer months when smelt larvae are present in coastal waters. The GMCC consists of two distinct portions. The Eastern Maine Coastal Current (EMCC) flows from the Bay of Fundy southwest along the coast and, in the area of Penobscot Bay, often splits southward and offshore. The remaining portion of the EMCC combines with outflow from Penobscot Bay and continues southwestward towards coastal New Hampshire and Massachusetts, creating the Western Maine Coastal Current (WMCC; Pettigrew et al., 1998, 2005). Backflow eddies are associated with large rivers (like the Penobscot) and to a lesser extent with Casco Bay, and as a result, larvae may be maintained within the nearshore area. Continuing further southwest along the coast, Massachusetts Bay maintains high larval retention as the strength of the WMCC pattern has largely diminished by this point (Incze et al. 2010).

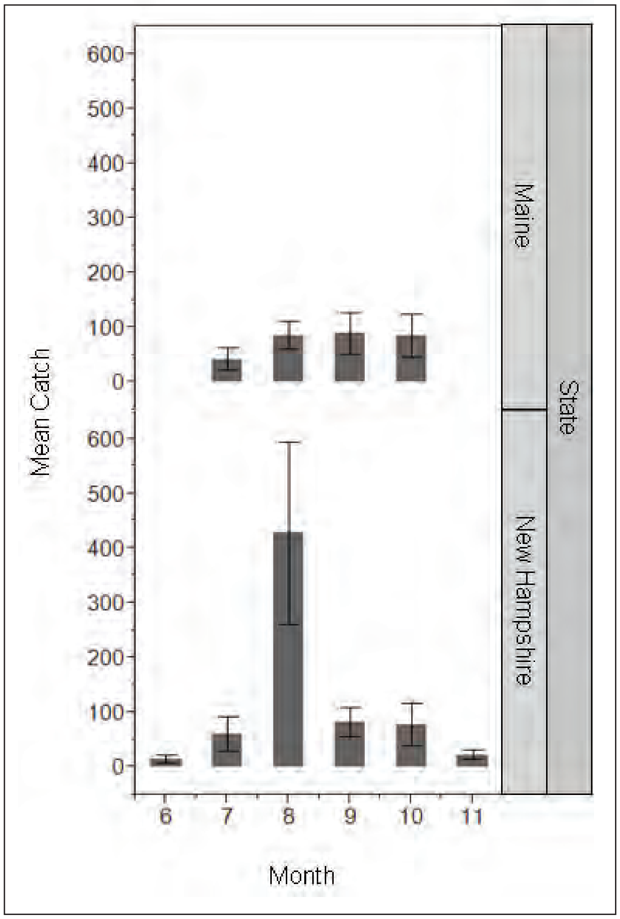

*Figure 1.1.1. Mean smelt catch by month in the Maine and New Hampshire Juvenile Abundance Surveys 1979-2011 for all survey sites combined. Error bars represent one standard error from the mean.*

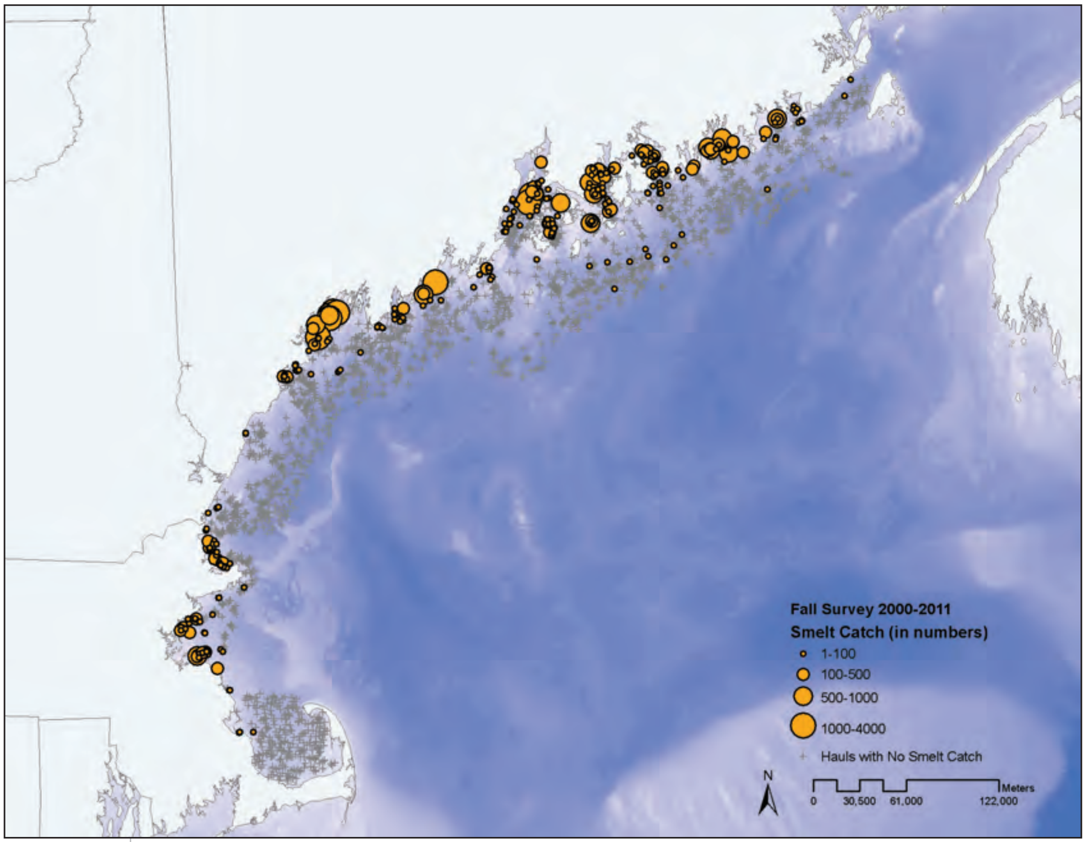

*Figure 1.1.2. Smelt catches in the fall state nearshore trawl surveys for Massachusetts, New Hampshire, and Maine 2000-2011.*

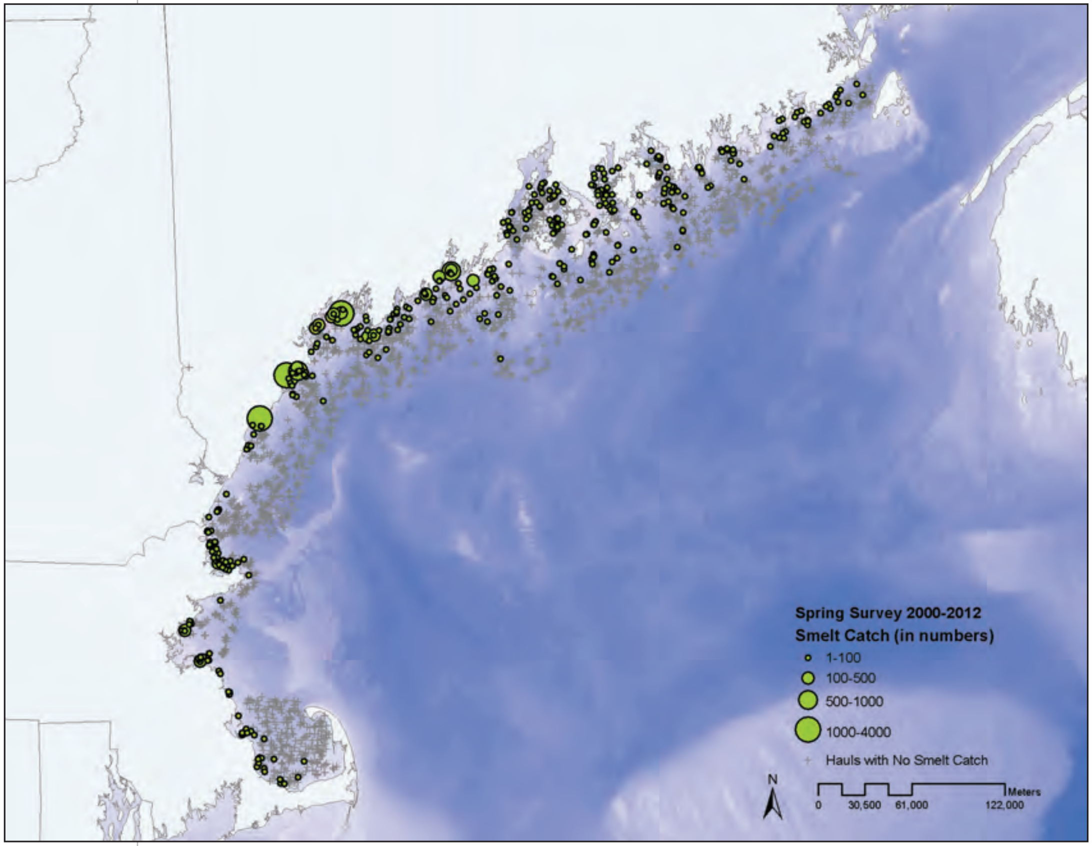

*Figure 1.1.3. Smelt catches in the spring state nearshore trawl surveys for Massachusetts (2000-2011), New Hampshire, and Maine (2000-2012).*

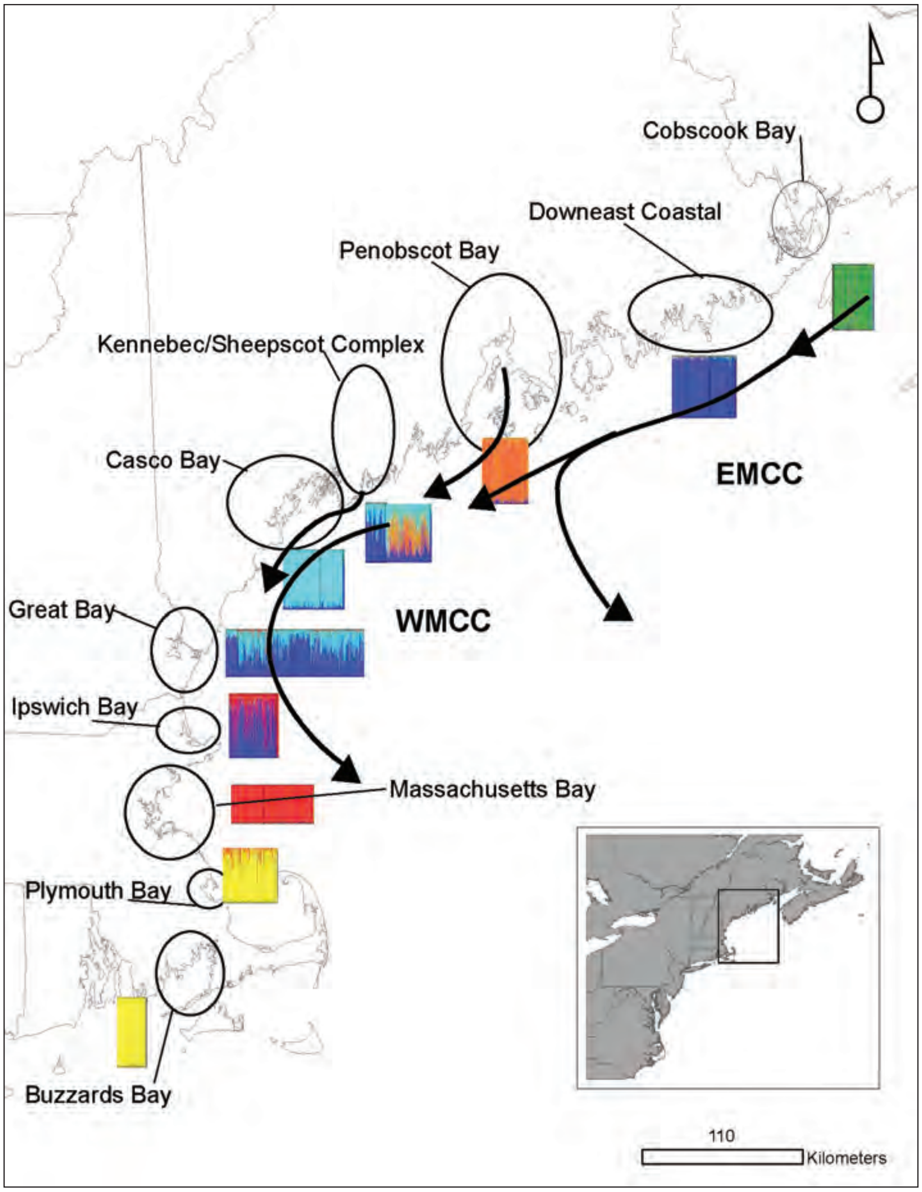

*Figure 1.1.4. Genetic differentiation of smelt stocks in the Gulf of Maine from Kovach et al., ("in press"). Divergence may be explained by circulation patterns, where the Gulf of Maine Coastal Current carries larvae from downeast coastal Maine to New Hampshire and northern Massachusetts, while other localized circulation patterns maintain the distinctiveness of Penobscot Bay, Casco Bay, Massachusetts Bay, and Buzzards Bay. The color boxes display the 6 genetic signals – boxes with the same colors indicate the same signal. Length of boxes represents number of samples taken from the region.*

## 1.2 – HISTORICAL SMELT FISHERIES

Smelt fishing is a longstanding tradition in many coastal communities of New England and the Canadian Maritimes. During winter and early spring, smelt schools enter estuaries and embayments and aggregate in preparation for the spring spawning run. During this period of migration, commercial, and recreational fisheries target smelt through the ice and from shore. Some shore fisheries also occur in fall, mainly with hook and line, during foraging movements that precede the spawning migration. Fishing methods for smelt vary by state; including weirs, hook and line, seines, dip nets, bag nets, and gill nets.

This section will describe the historical range of rainbow smelt and the fisheries that targeted them. We focus on the Gulf of Maine, but provide some background on populations throughout the range. We rely heavily on the classic work "The Smelts" by Kendall (1926) and the thorough recent literature review found in Fried and Schultz's (2006) investigation in Connecticut.

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The earliest record of smelt harvest in the U. S. was likely by Captain John Smith in 1622; Smith noted the smelts were so plentiful that the Native Americans would harvest the fish by simply scooping them up in baskets (in Kendall 1926). There is little additional information about early New England smelt harvests until the mid-1800s, although extensive subsistence and local commercial harvest occurred before this time, based on occasional references and town records. Early uses of smelt included livestock feed and fertilizer to enrich farm fields. The abundance of smelt in the mid-1800s can be pictured from the account of French settlers along the Buctouche River in New Brunswick harvesting 50 to 60 barrels (36 gallons/barrel) annually to serve as fertilizer for each homestead (Perley 1849 in Kendall 1926). About this time, food markets developed for smelt as human populations grew in coastal cities. By the late 1800s, with the advancement of rail transport, smelt were an important export product shipped on ice from the Canadian Maritimes and Maine to the Boston and New York markets (Kendall 1926).

### Mid-Atlantic

Smelt are considered a cold water fish, with a historical center of abundance north of Cape Cod but southerly populations ranging south to the Mid-Atlantic. Early references of smelt range include Virginia, Maryland and Delaware (Goode 1884, Kendall 1926, Bigelow and Schroeder 1953), but we found no information on smelt populations or harvests for these states. Later references on smelt range list New Jersey as the southern limit (Scott and Scott 1988, Collette and Klein-MacPhee 2002). Overall, references south of Delaware Bay are not well documented. The presence of smelt in states south of New Jersey may have been sparse, an indication of occupancy at the edge of the species' range, or alternatively the fisheries may have faded before the onset of recorded commercial harvest data in the early 20th century.

### New Jersey

In 1833, smelt were observed to be plentiful in New Jersey with "wagonloads" of smelt harvested in Newark Bay, yet by 1849, smelt were reported as declining (New York Times 1881 in Fried and Schultz 2006). The Delaware

River had been listed as a southern smelt run, including an early observation in a tributary, the Schulykill River, of cast net fishing for smelt during late winter (Norris 1862). Spring runs of smelt, also called frost fish, were reported in the Delaware, Hackensack, Passaic and Raritan rivers during the late 1860s. By this time, only the Raritan River supported a lucrative commercial fishery, with annual catches nearing 10,000 lbs (NJCF 1872). The New Jersey Commissioners of Fisheries (NJCF) 1872 report also suggested that industrial water pollution in the rivers was severely impacting all anadromous fisheries. The last regular commercial catch in New Jersey was reported in 1921 (Fried and Schultz 2006).

Smelt were considered endangered in New Jersey by 1877 and the state launched an effort in the 1880s to study the reproductive biology of smelt and to stock smelt fry hatched from eggs collected in viable smelt runs to depleted smelt runs (NJCF 1886).

No evidence of stocking success has been located and by 1941 smelt were considered extirpated from New Jersey (Camp 1941 in Fried and Schultz 2006). The New Jersey Fish and Game Department has conducted trawl surveys throughout their coastal waters since the early 1980s, and no smelt have been detected during this time.

### New York

Historical references indicate that tributaries near the Hudson River and Long Island once supported prominent recreational and commercial fisheries but that overfishing and poor water quality likely caused declines before the end of the 19th century (Kendall 1926). The smelt trade at the Fulton Market in New York City was reported to average 1,352,000 lbs annually in the 1870s (Scott 1875 in Kendall 1926). By 1887, the smelt fishery was no longer considered commercially viable (New York Times 1881, Mather 1887, Mather 1889; in Fried and Schultz 2006). State fishery agencies in New York became concerned about the declining status of smelt in the late 1800s and embarked on extensive stocking efforts that included placing 127 million eggs in Long Island streams during 1896-1898 (Kendall 1926). The stocking efforts faded when smelt eggs became scarce in the early 20th century (Kendall 1926). Commercial catches declined and became sporadic in the 20th century. Routine commercial harvests exceeding 1,000 lbs annually were last reported in the 1950s (Fried and Schultz 2006).

Since the 1970s, annual surveys in New York have detected rainbow smelt, but catches have become increasingly infrequent and have been rare since the 1990s. The Hudson River Estuary Monitoring Program has conducted ichthyoplankton and juvenile fish surveys throughout the estuary since 1973, and the data show a dramatic decrease in smelt abundance since the mid-1990s, with only trace numbers detected today (ASA A&C 2010). Fish sampling efforts conducted by New York State Department of Environmental Conservation (NY DEC) have produced similar results, with very few adults detected since the 1980s. Today, smelt are considered extirpated or at extremely low numbers in the Hudson River system (C. Hoffman, NY DEC, pers. comm. Sept. 2010).

### Connecticut

A synopsis of early fisheries records shows that smelt runs were present in most tidal rivers in coastal Connecticut, and economically important commercial fisheries targeted the seasonal occurrence of smelt (Visel and Savoy 1989, Fried and Schultz 2006). Smelt were targeted primarily with haul seines and gill nets in the Housatonic, Connecticut and Pawcatuck rivers (Visel and Savoy 1989). Hook and line angling was also common in the 19th century at numerous locations; smelt were described as an important export fish to New York City markets. Smelt landings were reported as peaking in Connecticut in the 1880s at 27,000 lbs and steadily declining with minor and intermittent landings since the 1930s (Fried and Schultz 2006). There was a modest increase in landings in the 1960s when several thousand pounds were reported annually. The last years with significant smelt runs in Horseneck Brook of Greenwich, were 1965 and 1966 (Visel and Savoy 1989).

By the 1980s, smelt were recognized as nearly absent from Connecticut's coastal rivers. Similar to regions south of New England, concern centered on the role of point and non-point pollution sources (Visel and Savoy 1989). The decline of smelt in Connecticut prompted dedicated efforts to document their presence in the 2000s. The smelt fishery was formally closed to harvest in 2005, and smelt were listed as a state endangered species in 2008. Fried and Schultz (2006) carried out intensive surveys in five estuaries along the central and eastern Connecticut coast. They documented no evidence of smelt spawning but did catch 9 adults while seining in the upper Mystic River during 2004. State beach seine surveys infrequently encounter smelt, however there have been recent observations of a few adult smelt in 2007 (T. Wildman, CT DEP Inland Fisheries Division, pers. comm. Nov. 2010). The State of Connecticut is currently considering listing smelt as extirpated from the state.

### Rhode Island

Smelt landings first appear in Rhode Island records in 1880 with landings of 95,000 lbs, which remains the peak annual harvest for this state (Fried and Schultz 2006). Since that point, landings records steadily declined with minimal landings reported after 1932. Landings rebounded slightly during 1965-1970 when several thousand pounds were reported annually. Since this time, minimal commercial landings have been reported (Fried and Schultz 2006). In response to declining populations, the Rhode Island Division of Fish and Wildlife (RIDFW) began a smelt stocking and monitoring program in 1971 (RIDFW 1971). Over the next seven years, approximately 44 million smelt eggs were transferred from populations in Massachusetts and New Hampshire to four rivers in Rhode Island. Extensive monitoring was conducted at the four recipient rivers, and no evidence was found of successful recruitment following stocking (RIDFW 1978). The monitoring only found evidence of a viable smelt run in the Pawcatuck River where low densities of smelt eggs were observed in 1974. The stocking effort was considered unsuccessful and discontinued in 1977 (RIDFW 1978). In the last decade smelt were briefly listed as endangered in Rhode Island, then delisted and considered extirpated with a chance of a trace populations present. Adult smelt have been captured on rare occasions during coastal pond and bay surveys since the 1990s (A. Libby, RI DFW, pers. comm. Oct 2011).

## Massachusetts

### *Historical Fisheries*

Early accounts indicate that smelt populations in Massachusetts supported culturally important sustenance fisheries that evolved into small-scale commercial and recreational fisheries as coastal populations grew. The smelt fisheries prior to 1874 targeted fall and winter feeding aggregations with baited hooks and used dip nets and seine nets during the spring spawning runs (Kendall 1926). The local importance of these fisheries and the potential abundance of the populations is reflected in accounts that describe over nine million smelt taken from the Charles River at Watertown in 1853 (Storer 1858), and over 2,300 fishermen at Hough's Neck in Quincy in one day targeting smelt (Kendall 1926). Overfishing concerns were raised in the 1860s that were attributed to with the use of nets during the spawning run. This concern led the Massachusetts State Legislature to prohibit net fishing for smelt during the spawning run in 1868 (Kendall 1926).

In 1874, a law prohibited the taking of smelt by any method other than hook and line in all state waters with a few exempted rivers – most of these exemptions were revoked by the end of the century. Kendall (1926) relates accounts of rebounding smelt fisheries in the 1870s and praise for the net ban. Catch records are sporadic and largely town or county specific during the latter half of the 19th century. However, there was a general declining trend in this period, and by the 1910s and 1920s there was growing concern about smelt fisheries in Massachusetts and the influence of industrial pollution. A quote the Massachusetts Commissioners on Fisheries and Game in 1917 expressed the concern of the period, "The smelt fishery of Massachusetts is in a depleted condition, and strenuous and radical measures will be required to save this species from extinction" (MCFG 1917).

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Smelt fisheries are poorly documented in Massachusetts after Kendall's 1926 report. The annual reports of the state fisheries agency depict contrasting trends along a gradient. In southern Massachusetts, there was a sharp decline in commercial importance and the disappearance of smelt in some locations. However, north of Cape Cod and in the greater Boston area, an active and popular fall and winter sportfishery persisted through the 1970s. Fried and Schultz (2006) summarized federal commercial catch records that show three time-series peaks in Massachusetts harvest: 1880 (82,034 lbs), 1919 (39,000 lbs), and 1938 (25,000 lbs). The early landings data were based on the available town and county records and are expected to be incomplete (Kendall 1926). It is likely that no records adequately describe the true extent of smelt harvest at any time in Massachusetts's history. The view provided by the combined historical and anecdotal accounts suggests that smelt supported important seasonal fisheries that attracted large numbers of anglers and that smelt occurrence and abundance greatly exceeded the species' present status.

### *Recent Trends*

Striking changes appear to have occurred in smelt detection and abundance in Massachusetts since Kendall's report (1926). Contemporary studies began with river-specific work in the Jones and Parker rivers in the 1970s (Lawton et al. 1990, Murawski and Cole 1978, and Clayton 1976). These studies were the first to report biological characteristics of the spawning runs and timing of movements in Massachusetts. Concerns over declines in smelt abundance grew after these studies, as sportfisheries' catches declined sharply in the late 1980s. The MA DMF responded to concerns from the sportfishing community with a survey of all smelt spawning habitats on the Gulf of Maine coast within Massachusetts during the 1990s (Chase 2006) and the initiation of fyke net monitoring in 2004 to develop population indices.

Specific mention of Buzzards Bay is warranted because it is presently the southern limit of the documented spawning range. Buzzards Bay lies directly south of Cape Cod, which separates the Virginian marine ecoregion to the south from the Gulf of Maine/Bay of Fundy ecoregion to the north (Spalding et al. 2007). No historical records have been found of spawning runs on Cape Cod, a likely result of its glacial formation and flat gradient. Goode (1884) reported smelt harvest in coastal weir fisheries in Buzzards Bay in 1880. More recently, an anadromous fish survey from 1967 reported 10 rivers in Buzzards Bay with active smelt spawning runs (Reback and DiCarlo 1972). An estuarine survey of the Westport River in Buzzards Bay in 1966-1967 found smelt in seine and trawl surveys and reported a known spawning run and associated fishery in the river (Fiske et al. 1968). Smelt runs in the region have since quietly faded to low levels of detection. Fisheries monitoring during the last 10 years has documented the presence of smelt in only three Buzzards Bay rivers; with a lone viable spawning run in the Weweantic River.

## New Hampshire

### *Historical Fisheries*

Significant smelt fisheries of commercial and cultural importance have occurred in the Great Bay estuary of New Hampshire since the 18th century or earlier. Hook and line fishing has mainly occurred in winter through ice on tidal waters. Additionally, bow nets were traditionally fished under the ice, and weirs were deployed during spring spawning runs (Warfel et al. 1943). Historical fisheries in New Hampshire are poorly described relative to Maine and Massachusetts. Kendall (1926) provides very little information on coastal New Hampshire smelt runs, focusing more on landlocked populations. He does provide annual smelt harvest estimates for coastal fisheries as follows: 1888 – 36,000 lbs, 1908 – 2,600 lbs, and 1924 – 3,835 lbs. The reported peak of commercial catch in New Hampshire was between 1940-1945, with an estimated 150,000 lbs harvested per year (Figure 1.2.1; Fried and Schultz 2006). It is expected that the historical records substantially underreported actual harvest from the Great Bay fisheries.

### *Recent Trends*

The state of New Hampshire has monitored smelt fisheries in Great Bay since the 1970s, when concerns were voiced from fishery participants about declining catches. To this end, an angler creel survey was started in 1978 and a smelt egg deposition survey began in 1979. A project was also launched at that time to improve commercial harvest data by mandating bow net and weir net fishermen to record their catches in log books. In 1981, a statewide smelt fishery management plan was written by the New Hampshire Fish and Game Department (NHF&G) to maintain sea-run smelt populations and support commercial and recreational fisheries (NHF&G 1981).

Data collected by the NHF&G indicate declining population trends in recent decades. The angler creel survey data depict a reduction in CPUE and total catch during the 2000s (Sullivan 2010). The smelt egg survey shows egg densities in the 2000s that are an order of magnitude lower than the 1980s (Sullivan 2007); the survey was discontinued in 2008 due to concerns over methodology and very low presence of smelt eggs. The commercial harvest records in New Hampshire have also recorded declines since 1987 (Figure 1.2.1). Commercial dip net and bow net permits remain active, but the fisheries have declined to low levels of catch and effort (J. Carloni, NHF&G, pers. comm., 2011). Despite the apparent decreasing trends, recreational fishing for smelt in Great Bay still remains a popular winter fishery that attracts higher catch and effort than fisheries to the south in Massachusetts.

## Maine

### *Historical Fisheries*

Commercial and sustenance smelt fisheries were important to Maine's colonial inhabitants as early as the 18th century, but are poorly documented. Kendall (1926) provides detailed accounts of valuable commercial hook and line and net fisheries from the 1880s to 1920s. The opening of export markets to New York and Boston after the mid-1800s, coupled with growing use of seine and bag nets, led to increases in harvest and the development of a significant commercial fishery. Goode (1884) provides the first reported commercial smelt harvest records for Maine, with landings exceeding a million pounds in the 1880s. In 1894 the smelt fishery was reported to support 1,100 fishermen with shore fishery landings that were the fourth most valuable behind lobster, clams, and sea herring (Whitten 1894). Statewide records are absent before this time, however subsequent catch data show a steep decline after the 1890s (Squires et al. 1976; Figure 1.2.1). The last year the Maine catch exceeded a million pounds was in 1903. As early as 1920, a report by the Maine Commission of Sea and Shore Fisheries described the depleted status of smelt runs and the negative impacts of targeting spring spawning aggregations for commercial harvest (MECSSF 1920). An early management response to this decline was performing egg transfers from both landlocked and sea-run smelt populations to depleted runs (Kendall 1926); these were largely undocumented. While the commercial fishery continued to decline in the 20th century, the recreational fishery that targeted smelt both through the ice and during spawning runs increased in catch and effort starting in the 1940s. The rental ice shack fishery, in particular, grew in economic importance as out-of-state anglers were attracted to Maine's coastal rivers.

### *Recent Trends*

Recognizing the traditional importance of the smelt fishery and continued population declines, the Maine Department of Marine Resources (ME DMR) developed a Smelt Management Plan in 1976 (Squires et al. 1976). The plan outlined present conditions and made recommendations to improve fisheries and spawning habitat. It also attributed the dramatic decline observed in the mid 20th century to increased industrial pollution in Maine's rivers after World War II (Figure 1.2.1). The ME DMR also launched studies at this time to record the presence and distribution of smelt in coastal Maine and investigate causes of the historic decline (Flagg 1974). Flagg's (1974) work on Maine's sea-run smelt documented catches at camp fisheries on the Kennebec River and Merrymeeting Bay, and catalogued spawning runs on 134 coastal streams. As part of the present study, the ME DMR has reinstituted creel surveys and spawning habitat investigations so that current catch records can be compared to the 1970s monitoring. Maine continues to have important recreational fisheries featuring winter ice fishing on tidal rivers and spring dipnet fishing at spawning runs, although annual harvest is at historic lows. A modest commercial harvest continues in downeast Maine, largely centered on the Pleasant River in Columbia Falls, where gill and bag nets are allowed to fish in late winter.

## Canadian Provinces

### *Historical Fisheries*

*Anadromous smelt populations in Canada have long supported valuable commercial fisheries that greatly exceed the collective harvest from the United States.*

Anadromous smelt populations in Canada have long supported valuable commercial fisheries that greatly exceed the collective harvest from the United States. Among provinces, New Brunswick has had the largest fishery, which historically targeted smelt for use as fertilizer and bait (Goode 1884). Growing export markets were driven by the Canadian harvests, which were, and continue to be, the largest commercial harvests in the species' range. Records are sparse before the 20th century, however Kendall (1926) cites accounts of fast developing export markets to Boston and New York in the 1870s that created demand for large harvests – exceeding two million pounds by the 1880s. In 1901, the shipment records of one export company in New Brunswick approached eight million pounds. The highest aggregate landings reported for Canada was just over nine million pounds in 1914 (Kendall 1926). A report from the U. S. Bureau of Fisheries in 1920 noted that while the Maine smelt fishery had declined in the early 1900s, the New Brunswick fisheries had undergone "remarkable" growth to support the market demands in the U.S. (USDOC 1920). The Miramichi River in New Brunswick was long a center of the province's smelt fishery. Shipments of smelt to U. S. markets from the Miramichi River region exceeded 4.3 million lbs for the winter fishery in 1924 (Kendall 1926), making the fishery one of the most valuable industries in the Province at that time.

### *Recent Trends*

New Brunswick and Nova Scotia continue to support important commercial fisheries. There is less evidence of population declines in these provinces than in the U. S. portion of the range. The capitalization of a Great Lakes fishery for smelt in the 1960s and 1970s resulted in high landings that suppressed prices and may have reduced effort in the New Brunswick fishery (McKenzie 1964, DFO 2011). In spite of depressed prices, the eastern New Brunswick smelt fishery remained stable between 1988 and1998, with total reported landings between 1.5 and 2.5 million lbs, a sum that may under represent actual landings (DFO 2011).

The smelt fisheries of the St. Lawrence River have shown a decline comparable to U. S. fisheries. Reduced commercial and recreational fisheries and spawning habitat abandonment in the St. Lawrence River tributaries triggered survey and restoration efforts in the 2000s (Trencia et al. 2005). The fisheries remain culturally important today while operating at historically low harvest levels with ongoing restoration efforts by Quebec's Ministry of Natural Resources (Verreault et al. 2012).

## Summary

Dramatic changes have occurred in both Gulf of Maine smelt fisheries and the distribution of smelt on the East Coast since the start of the 20th century. Culturally and economically important smelt fisheries have disappeared or faded to historic lows. The trend is evident of wide-scale abandonment of the historic southern extent of the range, where commercial smelt fisheries were viable before the 20th century. Currently, the southern extent of the species range is likely in the Buzzards Bay, Massachusetts region, with higher population levels observed in more northern rivers.

Popular recreational fisheries remain in Maine and New Hampshire, although these fisheries also appear to be harvesting at historically low levels. The traditional Massachusetts ice shack fisheries have been reduced to very low levels of participation and catch, and they are faced with warmer winters that bring insufficient ice to support shacks. The causes of this steep decline in smelt fisheries on the U. S. East Coast have not been defined, but have been discussed for over a century. Industrial pollution at spawning rivers, structural barriers, and overfishing have received the most attention as causal factors. Watershed alterations, natural predation and climate change are potential factors that have been implicated more recently.

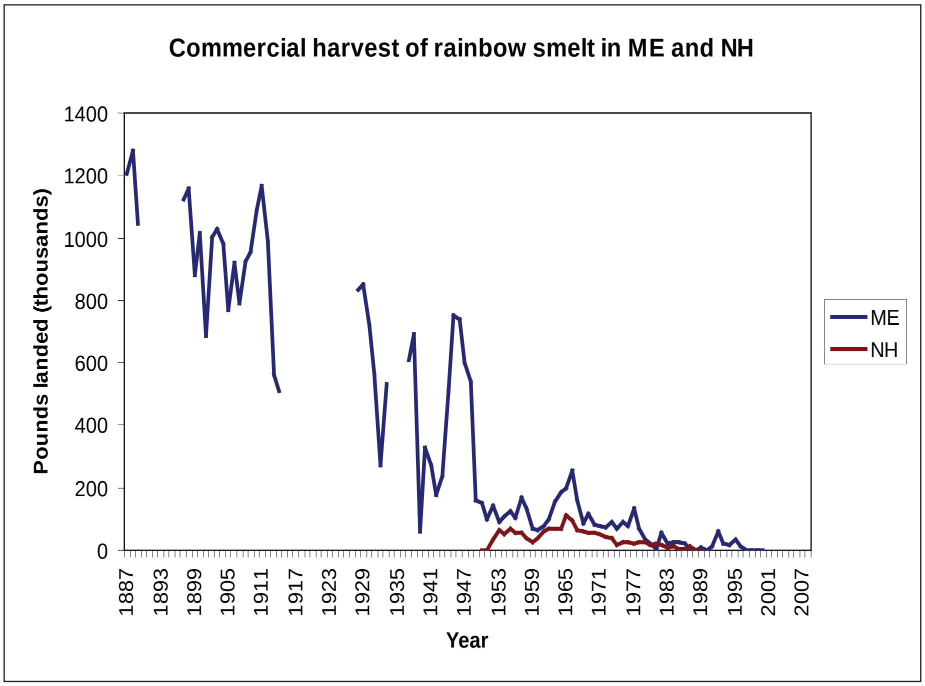


*Figure 1.2.1. Commercial smelt landings for Maine (1887-2009) and New Hampshire (1950-2009). Data sources: U.S. Commissioners Report, U.S. Bureau of Fisheries, State of Maine landings data (as summarized by Squiers et al. 1976), and NMFS website.*

## 1.3 – POPULATION STATUS IN THE GULF OF MAINE

Concerns have grown over the health of anadromous rainbow smelt populations throughout much of their range. This concern has prompted interest in assessing smelt populations and developing restoration strategies. Limited information is available from both fisheries-dependent and independent sources on the present status of populations in New England. The Species of Concern (SOC) project reviewed existing smelt population data in New England to consider the potential for developing indices of abundance, and initiated field projects during 2008-2011 to establish new data series to provide information on the status of smelt runs.

### *Previous Smelt Population Studies*

*Studies conducted in the late 1950's described several life history characteristics that we also observed in the present study, such as declining average length as the spawning run progresses and few smelt over the age of three.*

The earliest smelt population studies occurred in northern portions of their range, likely in response to the commercial importance of smelt fisheries in these regions. Kendall (1926) focused on smelt fisheries but did provide smelt length data gathered from various sources during the 1850s to 1920s. Not much information can be gleaned from these sparse data, except to say the maximum size of smelt from that time period of about 26-28 cm (total length) is quite similar to the maximum size found in the present study (27 cm). Warfel et al. (1943) reported smelt age data for Great Bay, NH; this study provided some of the first age data for the area and perhaps the first documentation of age-1 smelt participating in the spawning run. Summary statistics for Warfel et al. (1943) and the following studies are presented in Table 1.3.1.

McKenzie (1958 and 1964) followed the Great Bay study with a detailed study of the life history of smelt and their fisheries in the Miramichi River of New Brunswick during 1949-1953. McKenzie (1964) demonstrated several life history characteristics that have been confirmed in the present study, such as: declining average length of smelt as the run progresses, a more balanced sex ratio in the winter fishery than during the spawning run and few smelt older than age-4. The age composition in the Miramichi River during 1949-1953 had consistently higher representation of age-3 (22-49% annually) and age-4 (2-8% annually) than seen in the present study and had older fish present each year, although at low proportions (age-5 and age-6 at <0.5% and <0.1%, respectively). Murawski and Cole (1978) calculated an annual survival rate (S) of 0.35 for the overall proportions in McKenzie's age composition data, a value found to be the highest among reported survival data for anadromous rainbow smelt (Chase et al. 2012).

The ME DMR devoted considerable time to the assessment of smelt fisheries in the 1970s and 1980s (Squiers et al. 1976, Flagg 1983). The majority of the effort was fishery-dependent assessments of the winter smelt fishery. The size composition data from these winter fishery studies may not be directly comparable to spawning run size composition. However, summary data on sampling proportion by age and mean length at age are included in Table 1.3.1 because the data document the size composition of smelt populations at the time and the relatively larger contribution of older smelt in the catch.

Murawski and Cole (1978) provided size, age and mortality data from the Parker River, Massachusetts spawning run and winter fishery during 1974-1975. This study sampled both the winter sport fishery catch and spring spawning run with a fyke net, providing a valuable comparison to the Parker River data in the present study. Five age classes were represented in the fyke catches, with a majority at age-2. Murawski and Cole (1978) also provided one of the few estimates of smelt population mortality and survival rates. They reported mean values of the annual survival rate (S) of 0.28 and the instantaneous total mortality (Z) of 1.27 for both sexes using three analysis methods for the spawning runs. They considered the estimated overall annual mortality rate of 72% of the adult population to be high and that increases in fishing pressure could limit reproductive success in the Parker River.

Lawton et al. (1990) investigated biological aspects of the Jones River (MA) smelt spawning run during 1979-1981. The study used a lift net at the upstream limit of smelt spawning habitat to collect mature smelt. All biological data collected by the lift net may not be directly comparable to the present study, wherein a fyke net was deployed downstream of the lowermost spawning habitat. However, the study did produce an age/length key based on length-stratified age subsamples that should be representative of the spawning run demographics and comparable to the fyke net age/length data. Five age classes were found in the Jones River with an age-2 majority for most years and very few age-5 smelt. For the three spawning seasons sampled, age-2 and age-3 smelt comprised 83-99% of the spawning smelt. Lawton et al. (1990) also estimated the Jones River spawning population by extrapolating smelt egg densities to total spawning habitat area. The spawning stock abundance model calculated the spawning run of 1981 to exceed four million adult smelt. They also reported evidence of a strong 1978 year class with relative contributions of this cohort evident in the subsequent three spawning runs.

The smelt runs of the St. Lawrence River have supported culturally and economically important fisheries in Québec for decades. Declining smelt fisheries landings attracted the interest of the Québec Ministry of Natural Resources to conduct biological monitoring in the 1990s. Pouliot (2002) reported on size and age sampling of the spawning run in a St. Lawrence River tributary, the Fouquette River, during 1991-1996. A standardized dipnet sampling method was used at night at the spawning habitat. The results provide the first detailed population demographics and mortality estimates for smelt in the St. Lawrence River watershed. The Fouquette River smelt runs during the 1990s contained four or five cohorts in most years. Estimates of the annual rate of total mortality were 74% for females and 73% for males.

## *Current Fisheries Dependent Monitoring*

### *New Hampshire Creel Survey*

NHF&G has conducted winter creel surveys since 1978. The survey occurs from ice in to ice out, generally between the months of December and March. Four locations are sampled: the Lamprey, Oyster/Bellamy and Squamscott rivers as well as Great Bay. From 1983-1986 no survey was conducted due to lack of funding, and in 2002 and 2006 fishing, and subsequently surveys, were not possible due to lack of ice cover.

Biologists interview all anglers (or a sub-sample when large groups of anglers are present) for catch and effort information during a two hour survey period per day, visiting locations on a rotating basis. The information collected is expanded to provide estimates of catch, effort and catch per unit effort (CPUE) by month and location. Biological information from the smelt catch, including length, sex and scales for ageing, are taken from 150 fish weekly.

The average CPUE for 1987-2011 is 4.48 fish/hour over the entire sample period. High CPUEs have not been observed in the last ten year period (2000-2011, max CPUE = 5.6), compared to the previous twenty year period (1980-1989 max CPUE = 10.3; 1990-1999 max CPUE = 10.6; Figure 1.3.1). In most recent years, the CPUE has been below the series average (4.48) until 2011 when it increased to 5 fish/angler hour. There has not been a peak in CPUE over 6 fish/angler hour since 1995. The CPUE shows large inter-annual variability, and seems to follow a 5-10 cyclical pattern (Figure 1.3.1).

### *Maine Creel Survey*

Adopting sampling methods currently used by NHF&G (Sullivan 2009) and methods used in a 1979-1982 study conducted by the ME DMR (Flagg 1983), ME DMR again began conducting creel surveys in 2009 in the Kennebec River and Merrymeeting Bay area. As part of this survey, ME DMR staff visited participating camps two or three times per week on a rotating basis to collect biological information about the recreational catch. Staff collected biological information from a subset of each angler's catch (up to 100 fish per angler), including length, sex, scale samples for ageing and fin clip samples for genetic sampling. The number of anglers, fishing hours, and the number of fishing lines used was also recorded.

CPUE was calculated as the total number of smelt caught per line-hour of fishing, as opposed to NHF&G calculation of CPUE as smelt caught per angler hour – ME DMR currently calculates CPUE using line-hour to remain consistent with surveys conducted by ME DMR 1979-1982. The recent survey found a slightly lower CPUE (0.48), compared to the 1979-1982 study CPUE (0.64), however inter-annual variability was significantly larger than the comparison between the two study periods (Figure 1.3.2, Flagg 1983). While annual fluctuations in CPUE occurred in both surveys, the recent survey had the lowest CPUE recorded (0.17) during the two time series.

Catch Card boxes were also posted at each camp for fishermen to voluntarily report information about their total smelt catch and any bycatch; responses varied widely between sites and between years. There were 122 responses in 2009, 6 in 2010, and 37 in 2011 for all camps combined. It is our hope that with continued interaction with anglers and camp owners that the number of responses will increase. Despite the low number of responses in 2010, the Catch Cards still reflected the catch patterns found in creel survey data.

## Current Fisheries Independent Monitoring

### *State Inshore Trawl Surveys*

The three state fisheries agencies perform inshore small-mesh trawl surveys twice a year, in the spring (MA DMF in May, NH/ME in late May, early June) and fall (MA DMF in September, NH/ME in October, early November). The MA DMF has been performing surveys since 1978, while the ME DMR began sampling the New Hampshire and Maine waters in fall 2000. These surveys provide information about marine habitat use and migration patterns of rainbow smelt, as discussed in section 1.1 – Basic Biology. However, this survey is designed to monitor groundfish abundance, and has limited application for pelagic species like rainbow smelt. The data are helpful in determining the presence or absence of smelt in certain regions and depths, and can give a picture of inter-annual age cohort strength from size data, but are not powerful in showing trends in rainbow smelt abundance. However, trends in catches in both state surveys seem to have a 5-10 year cyclical pattern similar to the creel surveys and juvenile abundance surveys (Figure 1.3.3), although the causal factor behind these cycles is unknown.

### *Maine and New Hampshire Juvenile Abundance Surveys*

In 1979, ME DMR established the Juvenile Alosine Survey for the Kennebec/Androscoggin estuary to monitor the abundance of juvenile alosines at 14 permanent sampling sites, sampled June through November. Four sites are on the upper Kennebec River, three on the Androscoggin River, four on Merrymeeting Bay, one each on the Cathance, Abadagasset, and Eastern rivers. These sites are in the tidal freshwater portion of the estuary. Since 1994, ME DMR added six additional sites in the lower salinity-stratified portion of the Kennebec River. The seine is made of 6.35 mm stretch mesh nylon, measures 17 m long and 1.8 m deep with a 1.8 m x 1.8 m bag at its center. The net samples an area of approximately 220 $m^2$.

Of all the river sections, the lower Kennebec catches considerably more juvenile smelt than all upstream sections; the average catch over the time period for the lower Kennebec was 92 smelt/haul/year, while all others were under 10 smelt/haul/year, and catches are sporadic. Though the highest average annual catch occurred in 2005 (316 smelt/haul) in the lower Kennebec, juvenile smelt abundance in this river segment has been low since 2007, with three of the four lowest average annual catches occurring in the past four years. Trends in abundance also seem to follow a 5-10 cyclical pattern similar to the other surveys (Figure 1.3.4).

The NHF&G has conducted an annual Juvenile Abundance Survey since 1997. It is designed as a fixed station survey, as opposed to a stratified random survey, because strong tidal currents, rocky shorelines, and various anthropogenic structures limit the amount of suitable beach seining locations. A total of 15 fixed locations are sampled monthly from June to November. The stations are located within the Great Bay and Hampton-Seabrook estuaries. Seine hauls are conducted by boat using a 30.5 m long by 1.8 m high bag seine with 6.4 mm mesh deployed 10 – 15 m from the shore. Over the sampling period, the Piscataqua River has seen the highest CPUE (177 smelt/haul/year), however the highest annual average catch occurred in Great Bay in 2001 (225 smelt per haul). The lowest average catch over the entire sampling period was in the Hampton Beach/Seabrook area (11 smelt/haul/year). While these abundance data also seem to follow a cyclical pattern, there has been a decline in the juvenile rainbow smelt being captured in recent years – excluding the first year of sampling, the four lowest average annual catches have occurred within the past 6 years (Figure 1.3.5).

### *New Hampshire Egg Deposition Monitoring*

New Hampshire Fish and Game Department conducted egg deposition sampling from 1978-2007 using methodologies described by Rupp (1965). A ring of known area (20.3 $cm^2$) was tossed on natural substrate, and the number of eggs within the ring was counted. Egg counts were conducted weekly, from mid-March to mid-April, in the Oyster, Bellamy, Lamprey, Squamscott and Winnicut rivers. The mean number of eggs per square centimeter was used as an index of spawning stock abundance. Validation of the index was attempted by regressing the index with catch per unit effort (CPUE) of the creel survey but showed very poor correlation. The egg deposition sampling was discontinued in 2008 because comparisons between this dataset and other indices of smelt abundance (creel and juvenile surveys) did not correlate well, while trends in the other surveys did correlate well with each other.

### *Maine Spawning Stream Use Monitoring*

In 2005 and 2007-2009, biologists with the ME DMR worked with the Maine Marine Patrol to document coastal rivers and streams currently being used by rainbow smelt for spawning. The survey collected information about the spawning habitat (substrate, possible obstructions), and the strength of the run as characterized by the density of egg mats or number of spawning adults present. We compared the current use and strength of runs to information collected by ME DMR in the early 1970s (Flagg 1974) and to information compiled in 1984 by the U. S. Fish and Wildlife Service (USFWS 2012).

Of the 279 streams surveyed , the majority either supported smaller runs than they did historically or no longer support spawning, while only a small percentage (19%) seem to currently support strong runs (Table 1.3.2, Figure 1.3.6). Spawning decline was concentrated in southern Maine, lower Casco Bay, the Kennebec River, and the east side of Frenchman's Bay. Spawning runs remain strong in northern Casco Bay, the Medomak, St. Georges, and Penobscot Rivers, and around Pleasant Bay and Cobscook Bay.

### *Regional Fyke Net Sampling*

Earlier research on anadromous smelt populations in the Gulf of Maine has primarily consisted of short-term efforts that monitor smelt size and age structure during spawning runs. These efforts have not produced long-term population indices of abundance for smelt, and presently, no indices exist in New England. The smelt SOC project targeted the spring spawning runs as a source of information on population status. The objective was to produce fishery-independent indices of abundance, with the understanding that only mature smelt participate in the spawning runs. The approach was to record biological data from spawning runs; to conduct analyses on size and age composition, catch-per-unit-effort, and mortality; and to make comparisons as possible among rivers and to previous studies.

#### Establishing Gulf of Maine Spawning Site Indices

Methods. As part of this project, fyke net stations were selected at coastal rivers in Maine, New Hampshire, and Massachusetts for monitoring during 2008-2011 (Figure 1.3.7, Table 2.1.1). The stations were chosen for suitability to maintain a fyke net in a known smelt run and to represent a range of run sizes and watershed conditions. The fyke net was set at mid-channel in the intertidal zone below the downstream limit of smelt egg deposition. The fyke net opening faced downstream, and nets were hauled after overnight sets. This approach was adopted to intercept the spawning movements of smelt that occur at night during the flood tide. Fyke net catches were assumed to be representative of the size and sex composition of the spawning run. With each haul, smelt were counted, sexed, measured (total length) and released. Scales were sampled weekly at some stations for ageing.

After pilot deployments in 2007-2008 to identify suitable stations, eight fyke net stations were monitored in Massachusetts, three stations in New Hampshire and six in Maine (Figure 1.3.7). The sampling period in Massachusetts targeted 11 weeks from the first week of March to the third week of May to cover the known smelt spawning period. The sampling duration in New Hampshire and Maine varied due to a later ice-out and spawning season that occurs later with increasing latitude.

### 2008-2011 Results

Smelt were captured at most fyke stations during the spring spawning runs of 2008-2011. The annual catches ranged from few individual smelt in some rivers to several thousand in the larger smelt runs. The following sections and graphics describe major findings in the fyke net catch data that portray population trends across the species' distribution on the Gulf of Maine coast.

*Because smelt migrate from marine to freshwater habitats to spawn during the spring freshet, they are affected by a range of environmental factors most related to temperature and precipitation.*

Seasonality. Because smelt migrate from marine to freshwater habitats to spawn during the spring freshet, they are affected by a range of environmental factors most related to temperature and precipitation. Understanding how an unpredictable environment can influence the timing, location and strength of a smelt run is valuable for managing smelt populations. Accordingly, characteristics of the onset, peak, and overall duration of a smelt run can provide measures of population health. In this study, the onset and ending of the spawning run were based on the average date of first and last capture, respectively. Spawning run peak was determined based on the average date of maximum catch. In several cases, the onset and the ending of the spawning run were inconclusive and had to be estimated using best professional judgment. Run duration was determined based on the average yearly duration of the run from 2008-2011.

Inter-system variability was noted in the timing of the spawning run (Figure 1.3.8). Within most systems in Massachusetts and New Hampshire, the spawning run had begun by mid-March. Within several Maine systems, however, the spawning run was delayed and did not start until late-April. Similar patterns were observed in the peak and ending, with Massachusetts and New Hampshire systems having earlier peaks and earlier ending dates than those in Maine. Differences in run timing among states are presumably attributable to regional differences in climate, with cooler, more northerly systems displaying a delayed spawning run.

Run duration also varied with location. The longest run durations were observed for the Fore and Jones rivers, Massachusetts, and Tannery Brook, Maine. In these systems, average run duration appeared to exceed 70 days. Conversely, the shortest runs were observed to occur in the North, Weweantic, and Saugus rivers, Massachusetts, where average run duration did not exceed 40 days. The causes for the differences in run duration are unknown, particularly because previous studies have demonstrated shorter run durations in northern latitudes, with runs in individual tributaries often lasting less than two weeks in New Brunswick (McKenzie 1964) and Québec (Pouliot 2002). In the case of the U. S. Gulf of Maine surveys, population abundance and year class strength may be influential, however the causal factors are not currently understood.

Catch Per Unit Effort (CPUE). The number of fish captured per a given amount of sampling, known as catch per unit effort (CPUE), is a measure used by fishery scientists to assess the relative abundance of a fish population, under the assumption that higher catches for a given amount of sampling effort (e.g., time, gear, habitat area, samplers) represents greater abundance. For the fyke net survey, the number of smelt caught per haul was used as a measure of CPUE. Yearly measures of CPUE were based on the geometric mean of weekly average CPUE.

The results of this study demonstrated that CPUE varied widely among rivers and years. For the entire region, the two highest overall CPUE were found in Maine (Deer Meadow Brook = 58.07, Schoppee Brook = 37.83), while the two lowest were found in Massachusetts (Westport River = 1.01, North River = 1.37). There was an overall trend of higher CPUE in Maine compared to New Hampshire and Massachusetts – out of the 17 index sites, four out of the top five highest CPUE were found in Maine (Table 1.3.3).

Considering abundance by state, in Massachusetts, the Fore River had the highest overall CPUE (20.42), while the Westport River had the lowest (1.01). In New Hampshire, the highest overall value was found at the Oyster River (5.62), while the lowest was at the Winnicut River (1.64). In Maine, the highest was found at Deer Meadow Brook (58.07), and the lowest at Long Creek (11.39, Table 1.3.3).

Yearly CPUE peaked in five of eight Massachusetts rivers in 2008, suggesting that in these systems, the largest smelt runs were observed at the beginning of the study (Table 1.3.3, Figure A.1.1). In New Hampshire, the highest annual CPUE for all rivers was seen in 2011 (Table 1.3.3, Figure A.1.2). In southern and midcoast Maine (Long Creek, Mast Landing, and Deer Meadow Brook), the highest annual CPUE was seen in 2008 or 2009, while in eastern Maine (Tannery, Schoppee, and East Bay brooks), the highest annual geometric mean values were seen in 2010 (Table 1.3.3, Figure A.1.3). It should be noted that when CPUE is calculated as simply the number of smelt per haul, the highest CPUE for East Bay Brook occurred in 2008 (Figure A.1.3).

At this time, high levels of variability in CPUE and the limited duration of the study prohibit a statistical analysis of trends in relative abundance. However, the CPUE data from 2008-2011 for some stations should be valuable as a reference point for future comparisons.

Length and Age Composition. Length and age information yields important insights into the health of a fish population. As a general rule, the presence of a variety of age classes is indicative of a healthy population. Further, populations containing older and larger individuals, which have a relatively high reproductive potential, are considered healthier than those containing only younger, smaller individuals. Smelt are fast growing fish that mature at small size and become fully recruited to the spawning stock at age-2 in the study area. We measured total length of captured smelt to the nearest millimeter (mm). Smelt ages were determined from scale samples.

The age class composition of the runs varied between sites, but displayed geographical patterns. We found that runs in the southern portion of the Gulf of Maine (represented by the Fore River, Massachusetts, and Mast Landing, Maine) displayed two dominant age modes: one comprised mainly of age-1 smelt and second mode comprised of mainly age-2 smelt (Figure 1.3.9 and 1.3.10). Age-1 smelt were common in Massachusetts and, in some years, were the dominant age class; yet this age class was present at much lower frequencies in spawning runs in the northern range of the study area (Table 1.3.4, Figures 1.3.9-1.3.14). In the mid-portion of the region (represented by Deer Meadow and Tannery brooks, Maine), age-1 fish were encountered infrequently – the runs instead were dominated by age-2 fish, and the frequency of age-3 individuals was much higher than seen in more southern runs. Older ages (4-5) were also seen in these runs at higher rates than at all other runs, and these were the only sites to have age-6 fish represented in the runs (Table 1.3.4, Figures 1.3.11 and 1.3.12). In the northeastern portion of the Gulf of Maine (represented by Schoppee and East Bay brooks), runs were composed primarily of age-2 fish, with few to no age-1 fish observed. Age-3 fish were observed, but at a lower frequency than the mid-portion of the region. The occurrence of older ages (4-5) was higher than the southern runs, but not as high as the mid-portion (Table 1.3.4, Figures 1.3.13 and 1.3.14). The fact that fish at age-4 or older were unusual in Massachusetts, but relatively common in Maine samples, suggests higher levels of mortality in southerly systems.

Length at age also varied between sites, but again showed a geographic pattern. Because large sample sizes of age-2 males were present in each run, it is informative to compare the average lengths between sites using this category. The largest length at age was observed in the southern portion of the region (Fore River avg. age-2 male = 184 mm, Mast Landing = 178 mm, Table 1.3.4), indicating a faster growth rate at lower latitudes. Though the Oyster River geographically lies between these sites, age-2 males were comparatively smaller than the other southern sites (162 mm). This smaller age-at-length compared to surrounding sites may be evidence of a stressed population in the Oyster River, although further evidence would be needed to substantiate this idea. Comparisons between previous studies show that length-at-age is observed to decline moving northward (Table 1.3.1). We observed a similar trend, however the smallest length-at-age was observed in the mid-portion of the region (Deer Meadow Brook avg. age-2 male = 157 mm, Tannery Brook = 142 mm, Table 1.3.4). Sites at the most northeastern portion of the Gulf of Maine had larger age-2 males than in this mid-portion, but smaller than the southern sites (Schoppee Brook = 163 mm, East Bay Brook = 166 mm, Table 1.3.4). This pattern in age-at-length, as well as the pattern in run compositions discussed above, is coincident with the genetic stock structure of rainbow smelt reported by Kovach et al. (in press) and discussed in section 1.1 – Basic Biology, which found that the fish from Tannery Brook had a genetically differentiated signal that was also seen in fish from Deer Meadow Brook, but not in any other sites.

Because it was not possible to develop age-at-length keys for all sites due to low sample numbers at some sites, median length (calculated from all fish at a site) and length distributions are useful in understanding region-wide trends. Median lengths were lowest for males in the Massachusetts sites, and for females in the New Hampshire sites, and were generally higher for Maine sites (Table 1.3.5, Figure 1.3.15). The driving factor behind these patterns seems to be the age composition of each of these runs rather than the length at age – runs in the southern portion of region are composed of a large proportion of age-1 fish, while runs in the mid- and northeastern portion have a higher proportion of age 3+ fish (Table 1.3.4). While not all fish were aged, modes corresponding to specific ages can help in affirming this idea. Length frequency figures for all sites with enough samples to produce relevant figures are included in the Appendix (Figures A.1.4 – A.1.14).

Sex Ratio. Although spawning runs of most anadromous fishes are male biased, those displaying a substantially higher proportion of males may be indicative of a stressed population. Because the limiting factor for population growth is often the abundance of females, populations dominated by males may be less robust than those containing a higher proportion of females. In this study, sex ratio was determined based on the ratio of the aggregate 2008-2011 catch of males to the catch of females.

The results of the fyke net survey demonstrated that each system contained a smelt population that was male biased. Overall, this survey observed an average sex ratio of 4:1. Of the systems sampled, the most heavily male biased were the Parker River, MA, and the Squamscott and Oyster rivers, NH, which all displayed a male to female ratio of greater than 8:1. The lowest male to female ratios were found in three systems in Maine: Tannery Brook, Schoppee Brook, and the East Bay River. In each of these systems, the sex ratio was less than 2:1. We acknowledge that these sex ratios are biased themselves due to the behavior of male smelt spending more time on the spawning grounds than females (Murawski et al. 1980).

Mortality. Limited work has been done on population metrics for anadromous rainbow smelt throughout their range, but a few studies have calculated population mortality and survival rates based on age structure (Murawski and Cole 1978, Pouliot 2002). Survival and mortality analyses have potential biases that may limit their accuracy. Few age cohorts are available for the assessment: the age-1 cohort is excluded from mortality estimates because they are partially recruited to the spawning run, and age-4 smelt are presently uncommon. Secondly, the sampling method cannot distinguish the occurrence of repeat spawning movements of individual smelt; this behavior could bias measurements of mortality and survival. Under the assumption that these biases were consistent among studies, we calculated mortality and survival estimates for sites that had sufficient age data for 2008-2011 and compared them to previous studies.

Within the study area, survival rates (S) and instantaneous total mortality (Z) were calculated using the Chapman and Robson equation (Chapman and Robson 1960) at five stations in Maine and one each in Massachusetts and New Hampshire. However, the presence of some small sample sizes, few years of observations and the above discussed biases limit the reporting of these data to a relative comparison across the region and to past studies. Tannery Brook, Maine, had the highest average survival for 2008-2011 at S = 0.33, followed by S = 0.26 for 2009-2011 at Deer Meadow Brook in Maine. For sites that had at least three years of data, the Fore River, Massachusetts, had the lowest average survival at S = 0.17. The range of these spawning population survival estimates places the higher values in the present study among the highest reported by previous studies in the U.S. (Murawski and Cole 1978, Lawton et al. 1990) and

Canadian Provinces (McKenzie 1964, Pouliot 2002), and the sites at the lower range are the lowest survival values reported for anadromous rainbow smelt.

Study Area Summary

Massachusetts. Of the eight fyke net stations monitored in Massachusetts, six caught enough smelt to allow summary comments on run demographics, but only the Fore River had a sufficient sample size to generate age composition data each year. The age and length data in Massachusetts suggest the presence of a truncated age distribution, a sign of stressed populations due to high mortality and potentially poor recruitment. Male smelt in Massachusetts have similar median lengths compared to male smelt in New Hampshire and Maine. However, female smelt in Massachusetts had higher median length than the other states; a statistic driven by larger age-2 to age-4 females. Massachusetts stations are dominated by length modes that indicate age-1 and age-2 smelt, with very low presence of smelt older than age-4. The proportion of age-1 smelt in Parker River and Jones River spawning runs markedly exceeds that found in previous studies. Changes in the contribution of age-1 smelt to the spawning run between previous studies and the present study, and the higher proportion of these small smelt in Massachusetts compared to New Hampshire and Maine raises interesting questions on the significance of these apparent differences. Smelt at the southern stations may experience faster growth in their first year and are reaching a body size that supports maturity sooner than northern runs.

*The age and length data in Massachusetts suggest the presence of a truncated age distribution, a sign of stressed populations due to high mortality and potentially poor recruitment.*

New Hampshire. The presence of mature smelt was documented in fyke catches in the Bellamy, Salmon Falls, Lamprey, Squamscott, Winnicut and Oyster rivers during 2008, and the standardized fyke net sampling protocol was followed in the Squamscott and Winnicut rivers from 2008-2011, and in the Oyster River from 2010-2011. Sufficient age samples were collected at the Oyster and Squamscott rivers in 2011 to prepare length frequency and age-length graphs. Two length modes are apparent in both rivers composed of age-1 and age-2 smelt. However, more overlap is seen in these modes than is found in Massachusetts smelt age-length data. Few smelt reached age-4 in New Hampshire rivers. For each available age key, age-4 comprised less than 2% of the annual age sample. Growth rates appear to be slower within New Hampshire runs, as age-3 smelt occur at smaller lengths than seen in Massachusetts and no age-2 smelt larger than 19 cm have been sampled.

Maine. All six Maine fyke net stations produced sample sizes large enough to summarize information on smelt run status. Median smelt length for the Maine stations was slightly larger than at the other states because these runs had a lower proportion of age-1 smelt, but higher proportion of age 3+ smelt; however, average length at age was smaller, indicating a slower growth rate compared to sites further south. The Maine smelt runs also averaged higher CPUE rates and showed more balanced age distributions and sex ratios than seen in southern runs. These patterns were most evident in catch data from the easternmost Maine stations. All these observations indicate relatively healthier smelt runs in Maine than in Massachusetts and New Hampshire. The age composition of smelt in Maine's spawning runs contributes to less separation between length modes and an extended age-2+ mode. These features could reflect interesting potential differences in growth rates, maturation, and survival in Maine than at the southern runs.

## Conclusions About Regional Fyke Net Sampling

A common goal in fisheries management is to base decisions on a long-term stock assessment that generates defensible biological benchmarks on the health of the fish stock. The present study does not achieve this goal, but it starts the process of providing information on spawning run CPUE, temporal characteristics, and size and age composition of rainbow smelt in three states.

The sampling period from 2008-2011 is too brief for conclusions on population trends. However, such baseline information is vital for all fish stock assessments. The task of assessing the status of rainbow smelt in the Gulf of

*Table 1.3.1. Mean length at age and proportion at age of anadromous rainbow smelt sampled during spawning runs in earlier studies in the study area and Canadian Maritime Provinces. All length data were converted to total length.*

**Mean Length at Age**

| Location | Region | Citation | Year | Sex | N | Age-1 | Age-2 | Age-3 | Age-4 | Age-5 | Age-6 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Miramichi River | NB | McKenzie (1958) | 1949-53 | M | NA | | 157 | 178 | 196 | 211 | |
| Miramichi River | NB | " | " | F | NA | | 162 | 186 | 212 | 238 | |
| Fouquette River | Quebec | Pouliot (2002) | 1991-96 | M | NA | | 133 | 166 | 198 | 215 | 227 |
| Fouquette River | Quebec | " | " | F | NA | | 135 | 173 | 213 | 237 | 245 |
| Great Bay | NH | Warfel et al. (1943) | 1942 | both | 287 | 86 | 145 | 171 | 220 | 264 | |
| Penobscott River | ME | Squiers et al (1976) | 1974-75 | both | 260 | | 165 | 196 | 226 | 264 | |
| Kennebec River | ME | Flagg (1984) | 1980-82 | M | 1012 | | 174 | 202 | 221 | 229 | |
| Kennebec River | ME | " | | F | 680 | | 180 | 215 | 239 | 249 | |
| Parker River | MA | Murawski | 1974-75 | M | 2097 | 141 | 188 | 208 | 236 | 242 | |
| Parker River | MA | and Cole (1978) | " | F | 584 | 140 | 197 | 219 | 245 | 249 | |
| Jones River | MA | Lawton et al. (1990) | 1979-81 | M | 31394 | 132 | 184 | 208 | 221 | 242 | |
| Jones River | MA | " | " | F | 5009 | 130 | 190 | 222 | 244 | 254 | |

**Proportion (%) at Age**

| Location | Region | Citation | Year | Sex | N | Age-1 | Age-2 | Age-3 | Age-4 | Age-5 | Age-6 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Miramichi River | NB | McKenzie (1964) | 1949-53 | both | NA | | 66.2 | 29.3 | 4.1 | 0.4 | |
| Great Bay | NH | Warfel et al. (1943) | 1942 | both | 287 | 3.5 | 65.9 | 29.6 | 1.0 | 0 | |
| Kennebec River | ME | Flagg (1984) | 1979-82 | both | 1700 | | 59.9 | 33.0 | 5.5 | 0.5 | |
| Penobscott River | ME | Squiers et al (1976) | 1974 | both | 133 | | 42.1 | 39.1 | 17.3 | 1.5 | |
| Penobscott River | ME | " | 1975 | both | 127 | | 17.3 | 67.7 | 14.2 | 0.8 | |
| Parker River | MA | Murawski | 1974 | M | 343 | 38.0 | 42.5 | 15.9 | 3.2 | 0.4 | |
| Parker River | MA | and Cole (1978) | 1974 | F | 50 | 15.7 | 50.5 | 20.8 | 10.8 | 2.2 | |
| Parker River | MA | " | 1975 | M | 113 | 9.9 | 81.2 | 7.9 | 0.8 | 0.2 | |
| Parker River | MA | " | 1975 | F | 40 | 3.9 | 76.6 | 16.4 | 2.4 | 0.7 | |
| Jones River | MA | Lawton et al. (1990) | 1979 | M | 364 | 15.0 | 64.6 | 19.7 | 0.7 | <0.1 | |
| Jones River | MA | " | 1979 | F | 235 | 15.1 | 66.7 | 16.7 | 1.0 | 0.5 | |
| Jones River | MA | " | 1980 | M | 428 | 0.2 | 88.4 | 11.1 | 0.3 | 0 | |
| Jones River | MA | " | 1980 | F | 353 | 0 | 86.0 | 12.8 | 1.2 | 0 | |
| Jones River | MA | " | 1981 | M | 250 | 2.9 | 55.7 | 37.9 | 3.5 | 0 | |
| Jones River | MA | " | 1981 | F | 160 | 0.4 | 36.0 | 48.7 | 14 | 0.9 | |

**Notes**

1. Lawton et al. (1990) and Murawski and Cole (1978) age composition is based on age key proportions assigned to total length sample.
2. Murawski and Cole (1978) mean length combines 1975 winter creel survey with 1974 and 1975 spawning run data.
3. McKenzie (1958 and 1964) length data are converted to TL from SL. Age-6 smelt were caught in most years at low frequency (<0.1%).
4. Pouliet (2002) fork length data were converted to total length using the conversion, TL = (FL-0.5584)/0.9142, from Chase et al. (2006).
5. Flagg (1983) and Squiers et al (1976) size and age data are both from winter smelt ice fishery, but included for comparative value.

Maine is further complicated by the case of having distinct stock structure for some rivers, instead of a coast-wide stock complex. Finally, the assessment of anadromous fish is confounded by their migration between marine and freshwater habitats, where different factors influence their growth and survival. Despite these challenges, the fyke net data from the present study show a gradient of conditions with signs of stressed populations in southern Gulf of Maine and less evidence of stress moving north along the Maine coast, as evidenced by younger age distributions, smaller age-at-length, and lower CPUE rates.

*Table 1.3.2. Current state of smelt spawning runs in Maine with respect to their historical status.*

| Status | Number | Percent |
|---|---|---|
| Not historically listed, and currently do not support spawning | 42 | 15% |
| Historical runs that do not currently support spawning | 35 | 13% |
| Currently support smaller runs than historically | 95 | 34% |
| Currently support strong runs | 53 | 19% |
| Historical runs that were not visited, current status is unknown | 54 | 19% |

*Table 1.3.3. Catch per unit effort (CPUE) of rainbow smelt at fyke net spawning survey index sites, by annual CPUE and overall CPUE for the entire sampling period, 2008-2011.*

| | | Annual CPUE | | | | Overall |
|---|---|---|---|---|---|---|
| River | State | 2008 | 2009 | 2010 | 2011 | CPUE |
| Weweantic R. | MA | 2.81 | 1.27 | 1.47 | 1.57 | 1.78 |
| Westport R. | MA | 1.00 | 1.00 | 1.00 | 1.02 | 1.01 |
| Jones R. | MA | 9.13 | 5.58 | 7.56 | 5.13 | 6.85 |
| Fore R. | MA | 33.55 | 10.41 | 22.00 | 15.70 | 20.42 |
| Saugus R. | MA | 6.30 | 1.19 | 1.07 | 2.49 | 2.76 |
| North R. | MA | 1.39 | 1.12 | 1.08 | 1.90 | 1.37 |
| Crane R. | MA | 3.03 | 1.97 | 2.12 | 3.39 | 2.63 |
| Parker R. | MA | 7.63 | 2.56 | 1.66 | 2.47 | 3.58 |
| Squamscott R. | NH | 3.45 | 1.44 | 1.08 | 6.26 | 3.06 |
| Winnicut R. | NH | 1.60 | 1.34 | 1.36 | 2.25 | 1.64 |
| Oyster R. | NH | - | - | 5.45 | 5.79 | 5.62 |
| Long Cr. | ME | - | 18.69 | 5.56 | 9.93 | 11.39 |
| Mast Landing | ME | 52.00 | 29.84 | 8.81 | 13.80 | 26.11 |
| Deer Meadow Bk. | ME | 11.11 | 100.82 | 24.86 | 95.46 | 58.07 |
| Tannery Bk. | ME | 15.28 | 28.26 | 41.87 | 14.03 | 24.86 |
| Schoppee Bk. | ME | - | - | 38.42 | 37.25 | 37.83 |
| East Bay R. | ME | 15.48 | 4.42 | 21.66 | 11.86 | 13.35 |

**Proportion (%) at Age**

| Location | Region | Year | Sex | Length N | Age N | Age-1 | Age-2 | Age-3 | Age-4 | Age-5 | Age-6 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| East Bay Brook | ME | 2008 | both | 899 | 63 |  | 92.2 | 6.7 |  | 1.1 |  |
| East Bay Brook | ME | 2009 | both | 236 | 68 | 0.8 | 62.3 | 33.9 | 3.0 |  |  |
| East Bay Brook | ME | 2010 | both | 1387 | 261 | 2.0 | 80.7 | 13.7 | 3.6 |  |  |
| East Bay Brook | ME | 2011 | both | 1211 | 268 |  | 72.0 | 26.7 | 1.2 | 0.1 |  |
| Schoppee Brook | ME | 2010 | both | 2034 | 281 | 0.9 | 90.2 | 3.5 | 5.4 |  |  |
| Schoppee Brook | ME | 2011 | both | 1831 | 245 | 2.2 | 90.7 | 7.1 |  |  |  |
| Tannery Brook | ME | 2008 | both | 2001 | 74 |  | 60.0 | 34.2 | 5.8 |  |  |
| Tannery Brook | ME | 2009 | both | 1778 | 72 | 3.9 | 78.6 | 7.9 | 6.4 | 3.2 |  |
| Tannery Brook | ME | 2010 | both | 1892 | 344 | 2.5 | 49.6 | 45.4 | 1.4 | 1.0 | 0.1 |
| Tannery Brook | ME | 2011 | both | 908 | 172 | 6.9 | 36.6 | 48.0 | 8.5 |  |  |
| Deer Meadow | ME | 2008 | both | 179 | 85 | 5.0 | 77.1 | 17.9 |  |  |  |
| Deer Meadow | ME | 2009 | both | 2016 | 135 | 0 | 90.2 | 5.7 | 3.4 | 0.7 |  |
| Deer Meadow | ME | 2010 | both | 1366 | 320 | 2.8 | 26.0 | 64.7 | 5.0 | 1.5 |  |
| Deer Meadow | ME | 2011 | both | 1946 | 108 | 1.5 | 83.6 | 6.9 | 6.7 | 0.9 |  |
| Mast Landing | ME | 2008 | both | 1620 | 90 | 15.2 | 58.6 | 24.2 | 2.0 |  |  |
| Mast Landing | ME | 2009 | both | 1106 | 128 | 0.6 | 85.6 | 13.9 | 2.9 |  |  |
| Mast Landing | ME | 2010 | both | 355 | 268 | 75.5 | 8.7 | 13.8 | 1.7 | 0.3 |  |
| Mast Landing | ME | 2011 | both | 1833 | 275 | 44.5 | 53.5 | 0.8 | 1.2 |  |  |
| Oyster River | NH | 2010 | both | 421 | 185 | 65.8 | 29.0 | 4.5 | 0.7 |  |  |
| Oyster River | NH | 2011 | both | 401 | 231 | 11.2 | 75.1 | 13.5 | <0.1 |  |  |
| Fore River | MA | 2008 | both | 1958 | 380 | 51.9 | 41.4 | 6.2 | 0.4 | 0.1 |  |
| Fore River | MA | 2009 | both | 846 | 660 | 15.5 | 52.5 | 31.4 | 0.6 |  |  |
| Fore River | MA | 2010 | both | 1441 | 493 | 89.6 | 7.9 | 2.4 | 0.1 | <0.1 |  |
| Fore River | MA | 2011 | both | 1241 | 486 | 48.3 | 48.7 | 2.6 | 0.4 | <0.1 |  |

**Mean Length at Age**

| Location | Region | Year | Sex | N | Age-1 | Age-2 | Age-3 | Age-4 | Age-5 | Age-6 |
|---|---|---|---|---|---|---|---|---|---|---|
| East Bay Brook | ME | 2008-11 | M | 322 | 145 | 166 | 197 | 215 | 241 |  |
| East Bay Brook | ME | 2008-11 | F | 338 | 155 | 173 | 212 | 238 | 241 |  |
| Schoppee Brook | ME | 2010-11 | M | 225 | 146 | 163 | 195 | 204 |  |  |
| Schoppee Brook | ME | 2010-11 | F | 299 | 152 | 169 | 206 | 234 |  |  |
| Tannery Brook | ME | 2008-11 | M | 339 | 135 | 142 | 166 | 183 | 190 |  |
| Tannery Brook | ME | 2008-11 | F | 322 | 137 | 146 | 178 | 198 | 211 | 215 |
| Deer Meadow | ME | 2008-11 | M | 397 | 138 | 157 | 185 | 209 | 220 | 226 |
| Deer Meadow | ME | 2008-11 | F | 250 | 125 | 160 | 194 | 222 | 208 |  |
| Mast Landing | ME | 2008-11 | M | 447 | 132 | 178 | 192 | 211 |  |  |
| Mast Landing | ME | 2008-11 | F | 312 | 137 | 190 | 209 | 232 | 256 |  |
| Oyster River | NH | 2008-11 | M | 344 | 117 | 162 | 179 | 209 |  |  |
| Oyster River | NH | 2008-11 | F | 60 | 114 | 167 | 180 |  |  |  |
| Fore River | MA | 2008-11 | M | 1113 | 141 | 184 | 202 | 215 |  |  |
| Fore River | MA | 2008-11 | F | 507 | 142 | 194 | 217 | 249 | 251 | 266 |

*Table 1.3.4. Mean length at age and proportion at age of anadromous rainbow smelt sampled at fyke net stations for 2008-2011 for the present study. Age keys were applied to length samples for proportion at age.*

**MALE**

| State | River | Code | Years | N | Mean | SE | Median | Min | Max |
|---|---|---|---|---|---|---|---|---|---|
| MA | Weweantic | WW | 4 | 188 | 151 | 2.01 | 145 | 104 | 238 |
| MA | Jones | JR | 4 | 1249 | 156 | 0.93 | 143 | 106 | 254 |
| MA | Fore | FR | 4 | 4396 | 166 | 0.43 | 157 | 108 | 241 |
| MA | Saugus | SG | 4 | 401 | 162 | 1.30 | 153 | 113 | 240 |
| MA | North | NR | 4 | 79 | 150 | 2.18 | 149 | 118 | 217 |
| MA | Crane | CN | 4 | 262 | 161 | 1.44 | 156 | 121 | 221 |
| MA | Parker | PR | 4 | 1217 | 167 | 0.88 | 156 | 86 | 255 |
| NH | Squamscott | SQ | 2 | 340 | 154 | 1.85 | 159 | 86 | 227 |
| NH | Oyster | OY | 2 | 344 | 149 | 1.74 | 156 | 88 | 225 |
| ME | Long Creek | LC | 4 | 1191 | 169 | 0.41 | 168 | 110 | 228 |
| ME | Mast Landing | ML | 4 | 3099 | 163 | 0.40 | 169 | 105 | 227 |
| ME | Deer Meadow | DM | 4 | 4367 | 166 | 0.33 | 163 | 83 | 241 |
| ME | Tannery Brook | TB | 4 | 4214 | 152 | 0.27 | 152 | 104 | 223 |
| ME | Schoppee | SB | 2 | 2303 | 164 | 0.24 | 163 | 125 | 222 |
| ME | East Bay | EB | 4 | 2368 | 172 | 0.31 | 169 | 136 | 250 |
| **Total** | | | | 26018 | | | | | |

**FEMALE**

| State | River | Code | Sex Ratio | N | Mean | SE | Median | Min | Max |
|---|---|---|---|---|---|---|---|---|---|
| MA | Weweantic | WW | 3.4 | 55 | 149 | 4.29 | 139 | 107 | 225 |
| MA | Jones | JR | 2.5 | 492 | 160 | 1.69 | 144 | 100 | 258 |
| MA | Fore | FR | 4.0 | 1090 | 168 | 1.06 | 154 | 111 | 270 |
| MA | Saugus | SG | 7.7 | 52 | 172 | 5.01 | 157 | 129 | 248 |
| MA | North | NR | 3.4 | 23 | 154 | 4.71 | 153 | 113 | 214 |
| MA | Crane | CN | 2.8 | 94 | 169 | 3.31 | 162 | 114 | 257 |
| MA | Parker | PR | 9.5 | 128 | 194 | 3.18 | 204 | 112 | 272 |
| NH | Squamscott | SQ | 3.7 | 93 | 135 | 3.86 | 118 | 86 | 239 |
| NH | Oyster | OY | 5.7 | 60 | 151 | 4.80 | 166 | 88 | 224 |
| ME | Long Creek | LC | 3.3 | 360 | 178 | 0.99 | 176 | 118 | 251 |
| ME | Mast Landing | ML | 2.7 | 1136 | 177 | 0.86 | 180 | 93 | 263 |
| ME | Deer Meadow | DM | 3.6 | 1209 | 165 | 0.71 | 159 | 83 | 258 |
| ME | Tannery Brook | TB | 1.8 | 2366 | 157 | 0.46 | 154 | 108 | 236 |
| ME | Schoppee | SB | 1.5 | 1564 | 174 | 0.53 | 170 | 129 | 256 |
| ME | East Bay | EB | 1.7 | 1389 | 183 | 0.59 | 176 | 122 | 263 |
| **Total** | | | | 10111 | | | | | |

*Table 1.3.5. Rainbow smelt length data from catches at fyke net stations, 2008-2011. A few stations were excluded because of low sample sizes or potentially biased samples from few hauls. Smelt of unknown sex were excluded from this table. Sex ratio is the ratio of males to females.*

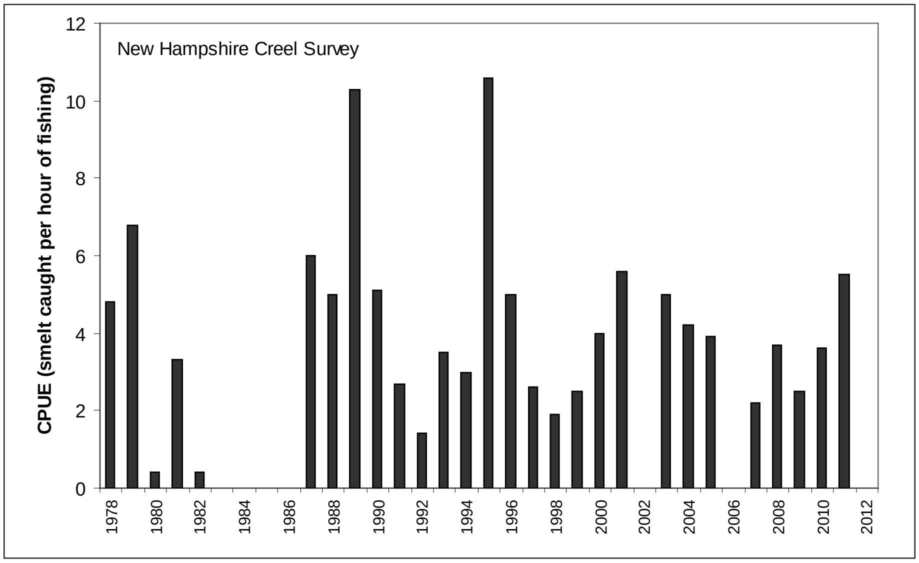


*Figure 1.3.1. New Hampshire Fish and Game Creel Survey catch per unit effort (CPUE) calculated as number of fish caught per hour of fishing 1978-2011.*

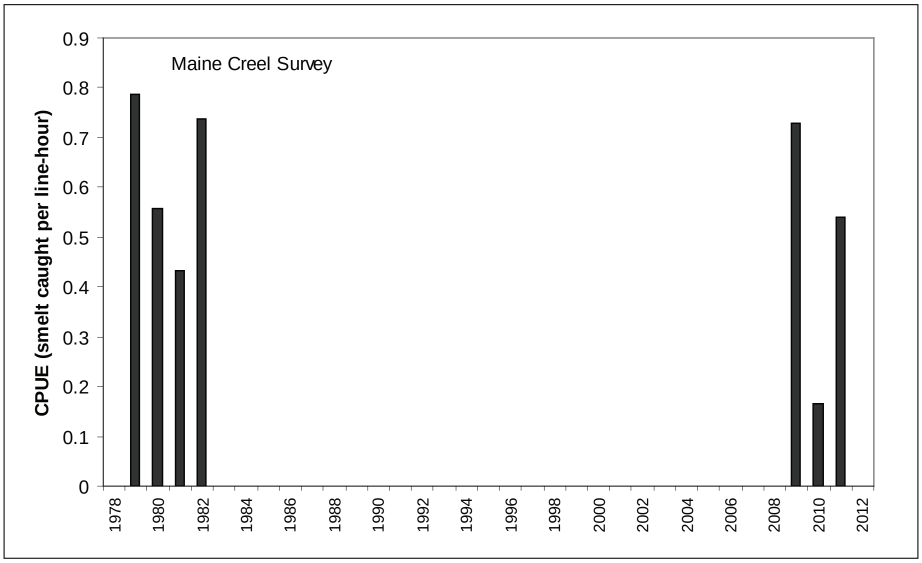


*Figure 1.3.2. Catch per unit effort (CPUE) as smelt caught per line-hour of fishing observed during the rainbow smelt winter creel survey in Maine during 1979-1982 and 2009-2011.*

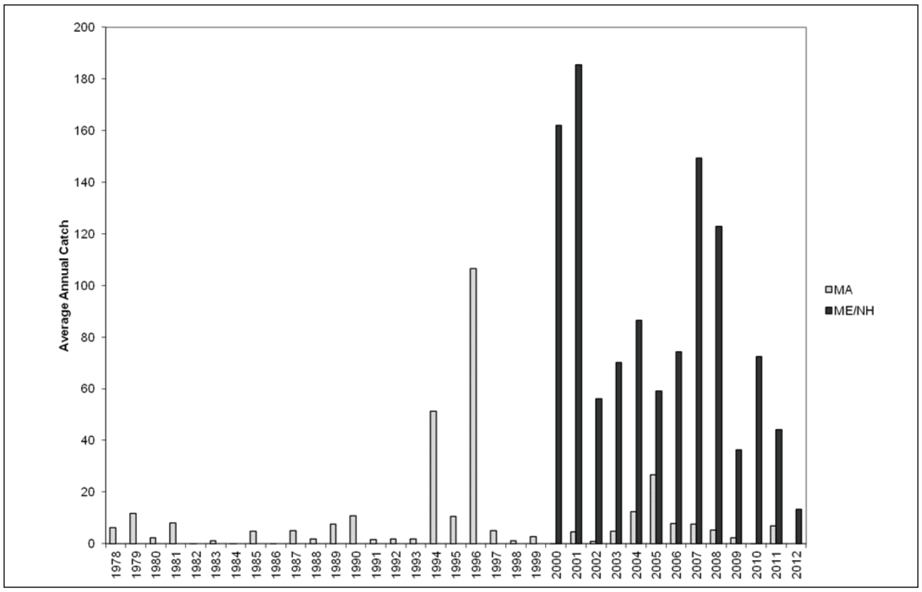


*Figure 1.3.3. Inshore Trawl Survey average annual smelt catches (in numbers of fish) from MA DMF state survey (1978-2011) and ME DMR/NHF&G combined state survey (2000-2012).*

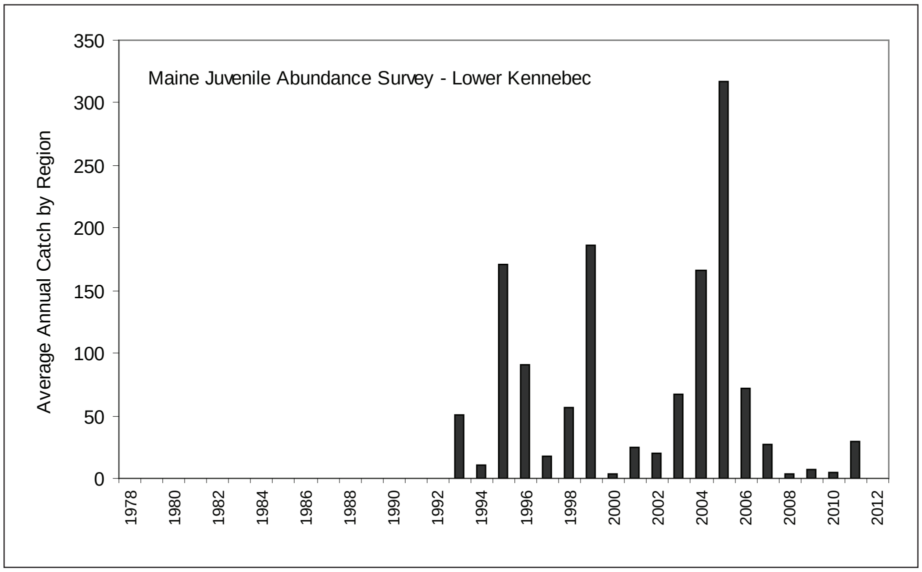


*Figure 1.3.4. Average annual catch of rainbow smelt YOY in ME DMR Juvenile Abundance Survey in the lower Kennebec River. Other sites are excluded due to low catches.*

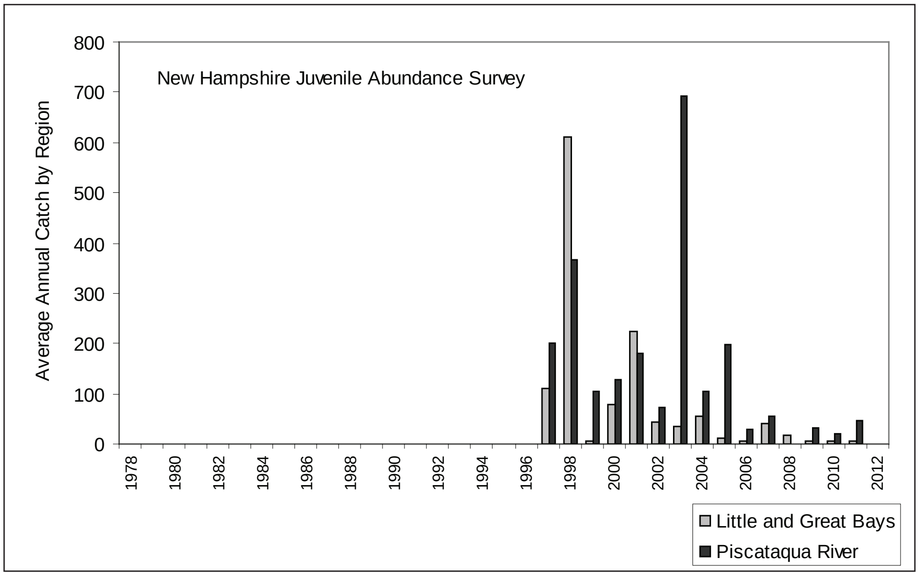


*Figure 1.3.5. Average annual catch of rainbow smelt YOY in NHF&G Juvenile Abundance Survey. The 11 locations within the Piscataqua River and Little/Great Bay were grouped into two cohorts to show annual trends. The Hampton/Seabrook area was excluded due to low catches.*

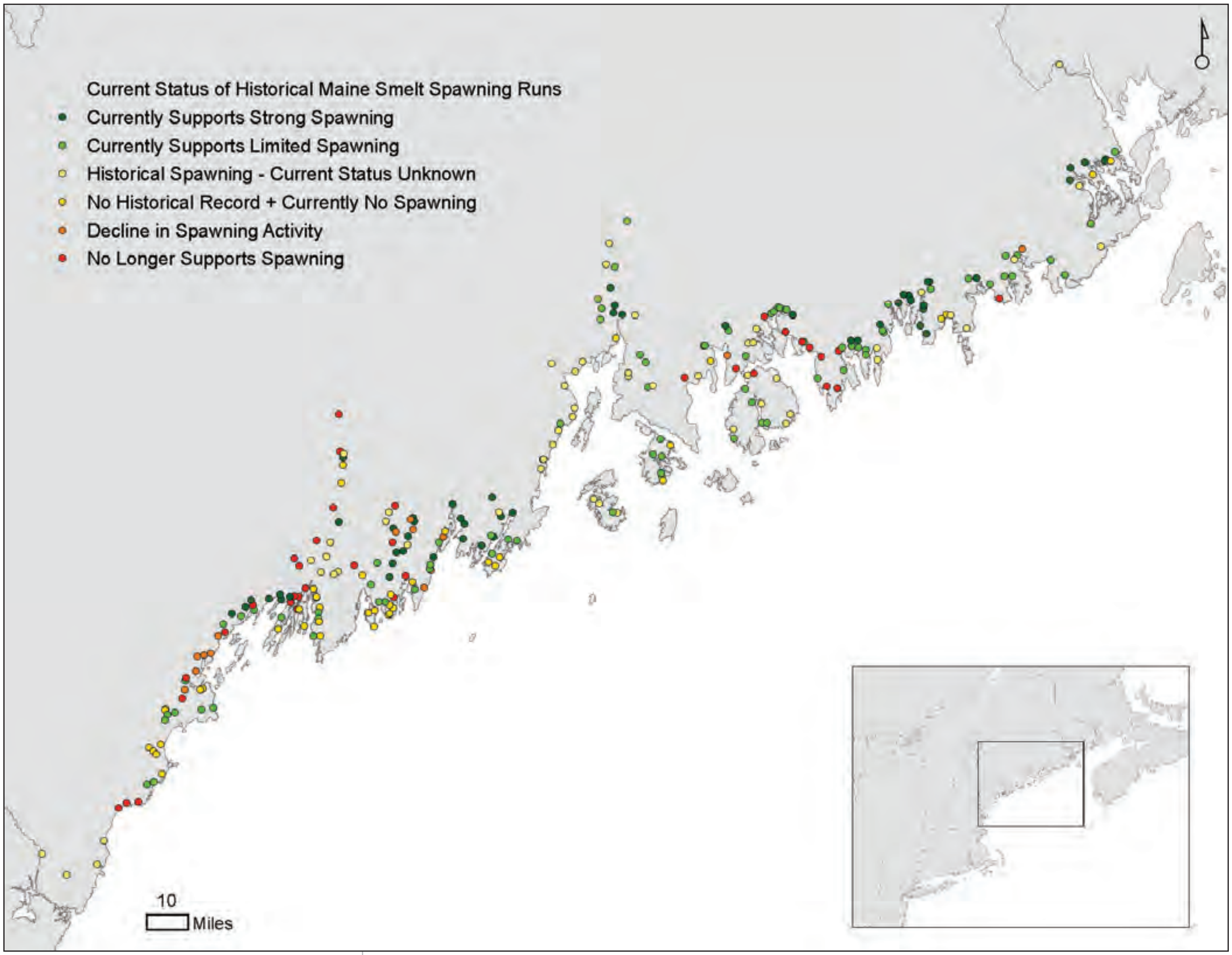


*Figure 1.3.6. Current status of smelt spawning runs in Maine and historical sites where the current status remains unknown.*

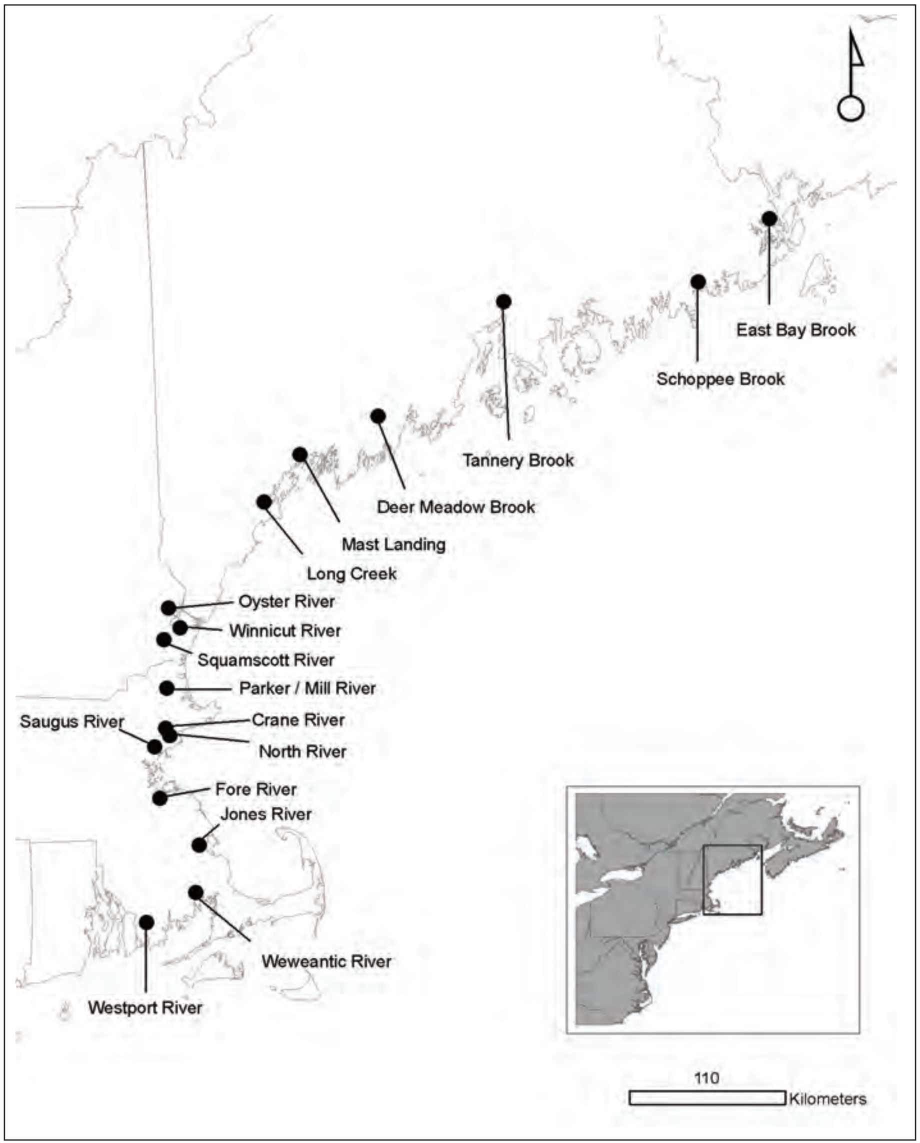


*Figure 1.3.7. Fyke net monitoring stations in Massachusetts, New Hampshire, and Maine 2008-2011.*

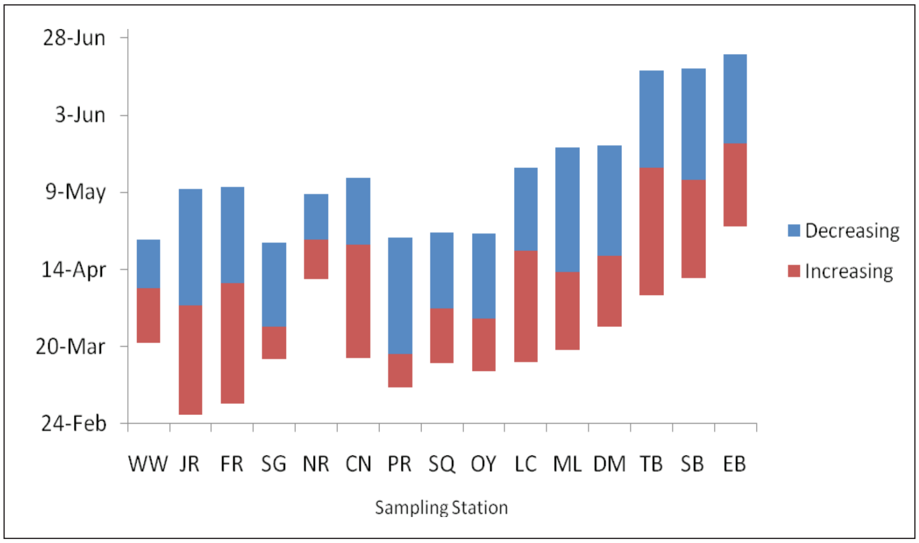


*Figure 1.3.8. Smelt runs progress in a bell-curve shape over the season, where the beginning of the run sees few smelt, and the number steadily increases to a peak in the run (red portion of the bars in the figure), after which point the run steadily declines (blue portion of the bars). These patterns are shown here, along with the average beginning and end date of each run 2008-2011. Stations are arranged from south to north starting at the x-axis origin.*

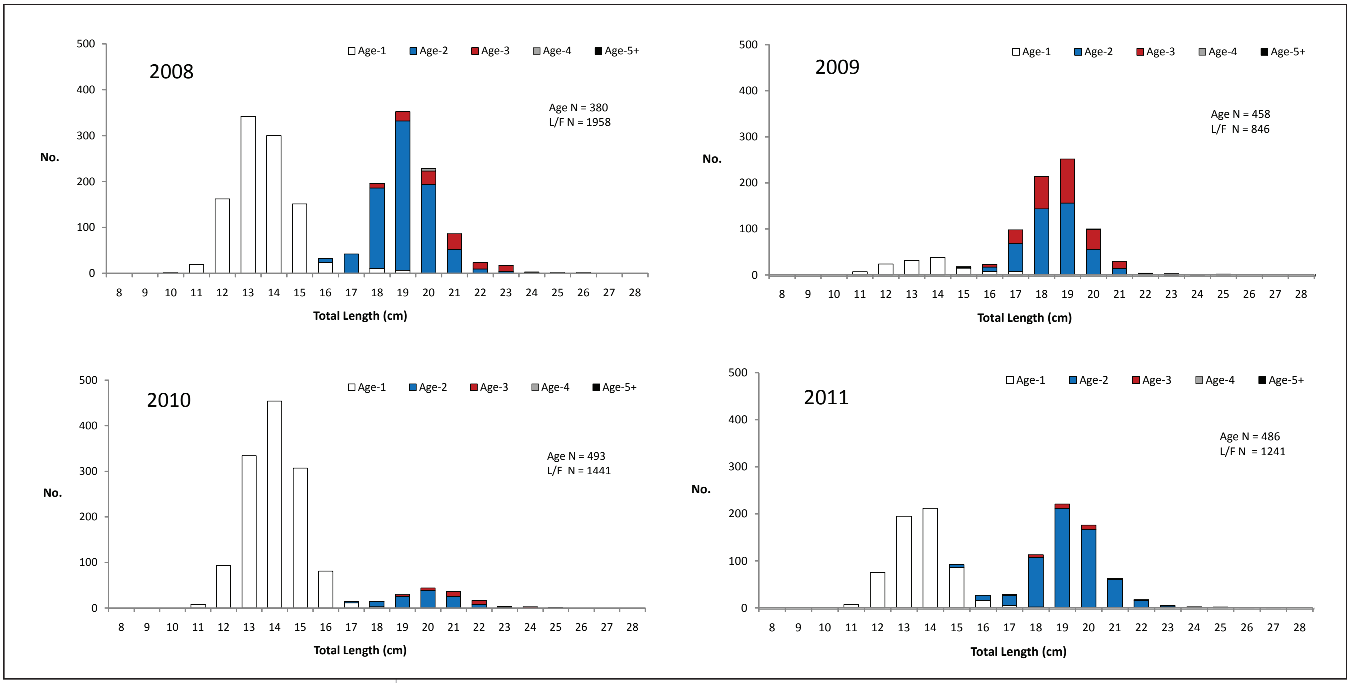


*Figure 1.3.9. Age composition of Fore River, MA, fyke net catch in 2008-2011. Both genders were combined with number of age samples reported as "Age N" and length frequency sample size reported as "L/F N".*

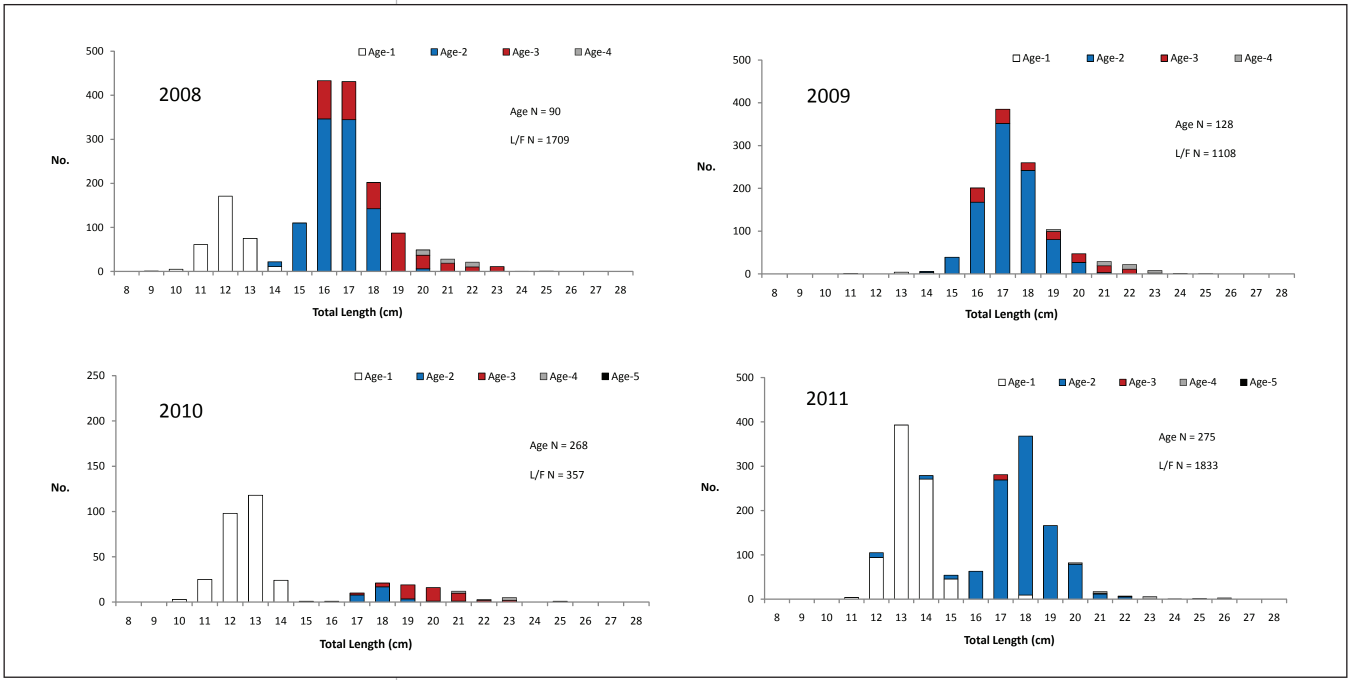


*Figure 1.3.10. Age composition of Mast Landing, ME, fyke net catch in 2008-2011. Both genders were combined with number of age samples reported as "Age N" and length frequency sample size reported as "L/F N".*

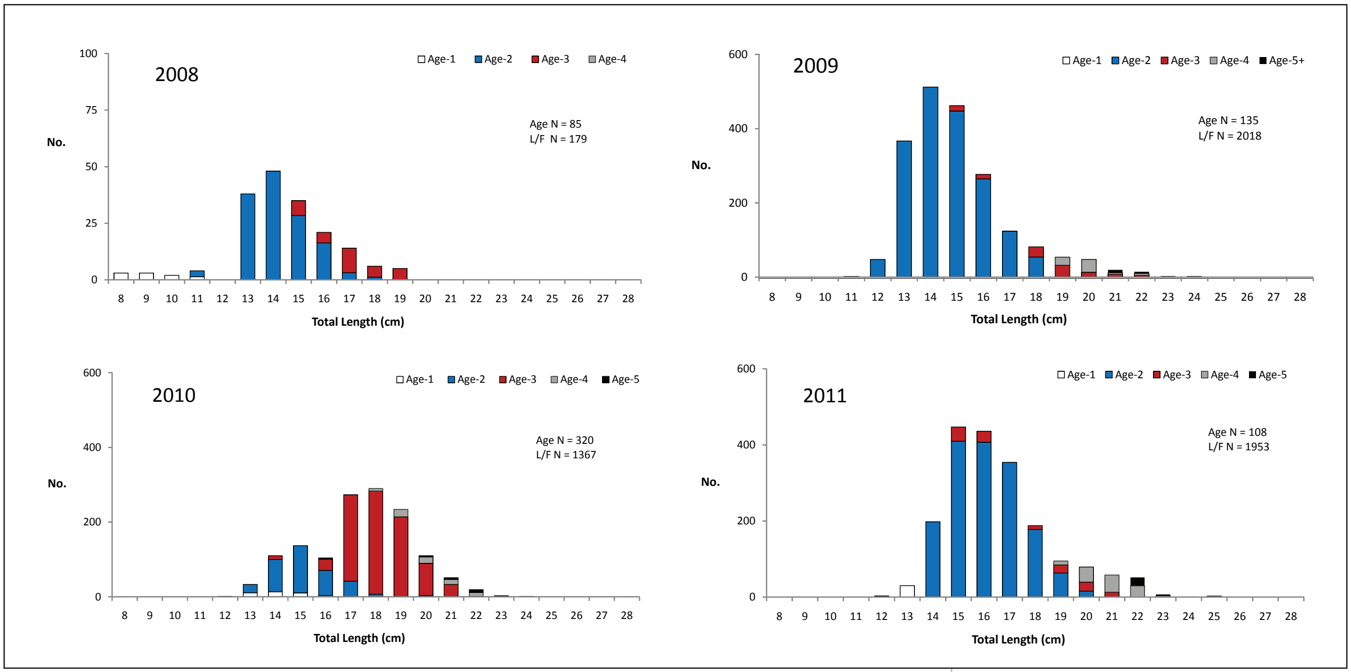


*Figure 1.3.11. Age composition of Deer Meadow Brook, ME, fyke net catch in 2008-2011. Both genders were combined with number of age samples reported as "Age N" and length frequency sample size reported as "L/F N".*

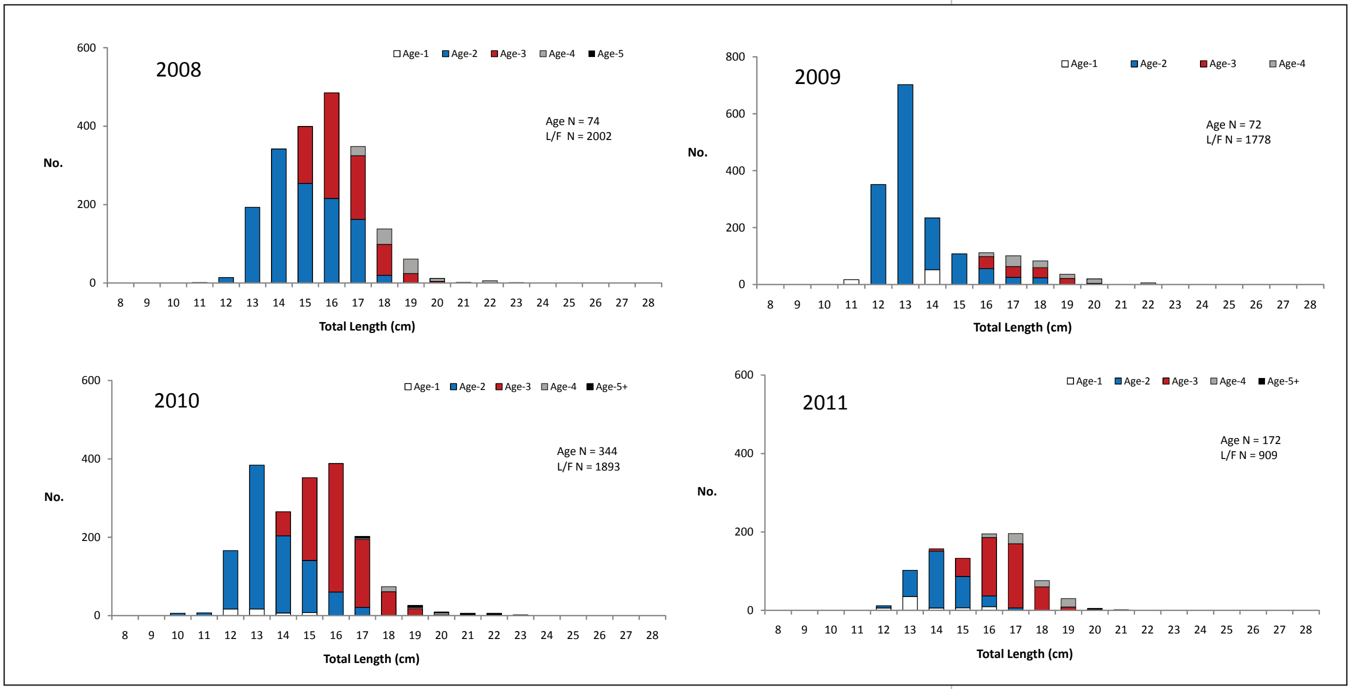


*Figure 1.3.12. Age composition of Tannery Brook, ME, fyke net catch in 2008-2011. Both genders were combined with number of age samples reported as "Age N" and length frequency sample size reported as "L/F N".*

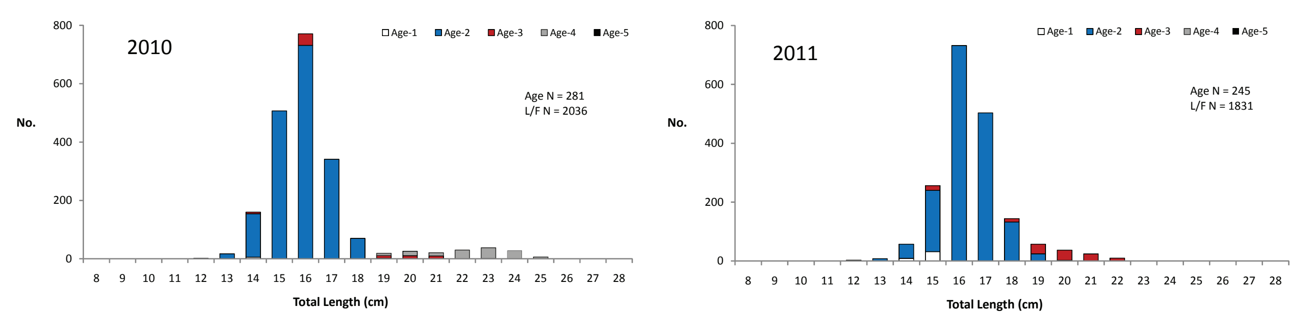


*Figure 1.3.13. Age composition of Schoppee Brook, ME, fyke net catch in 2010-2011. Both genders were combined with number of age samples reported as "Age N" and length frequency sample size reported as "L/F N".*

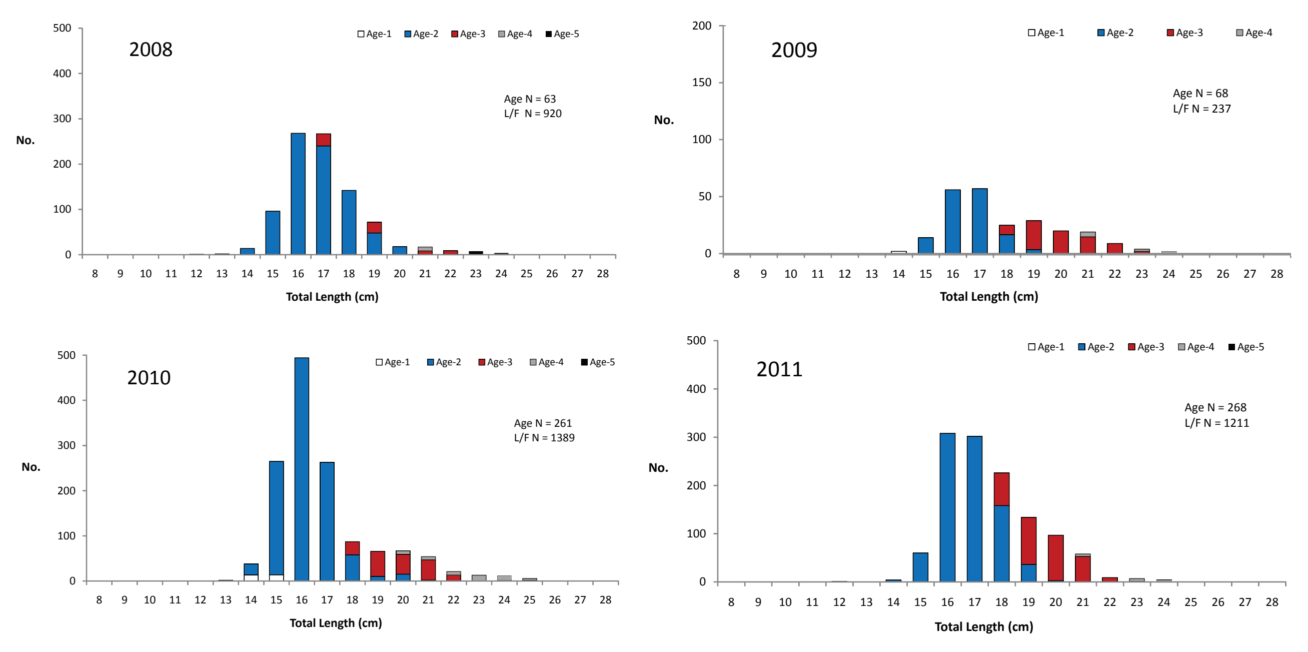


*Figure 1.3.14. Age composition of East Bay Brook, ME, fyke net catch in 2008-2011. Both genders were combined with number of age samples reported as "Age N" and length frequency sample size reported as "L/F N".*

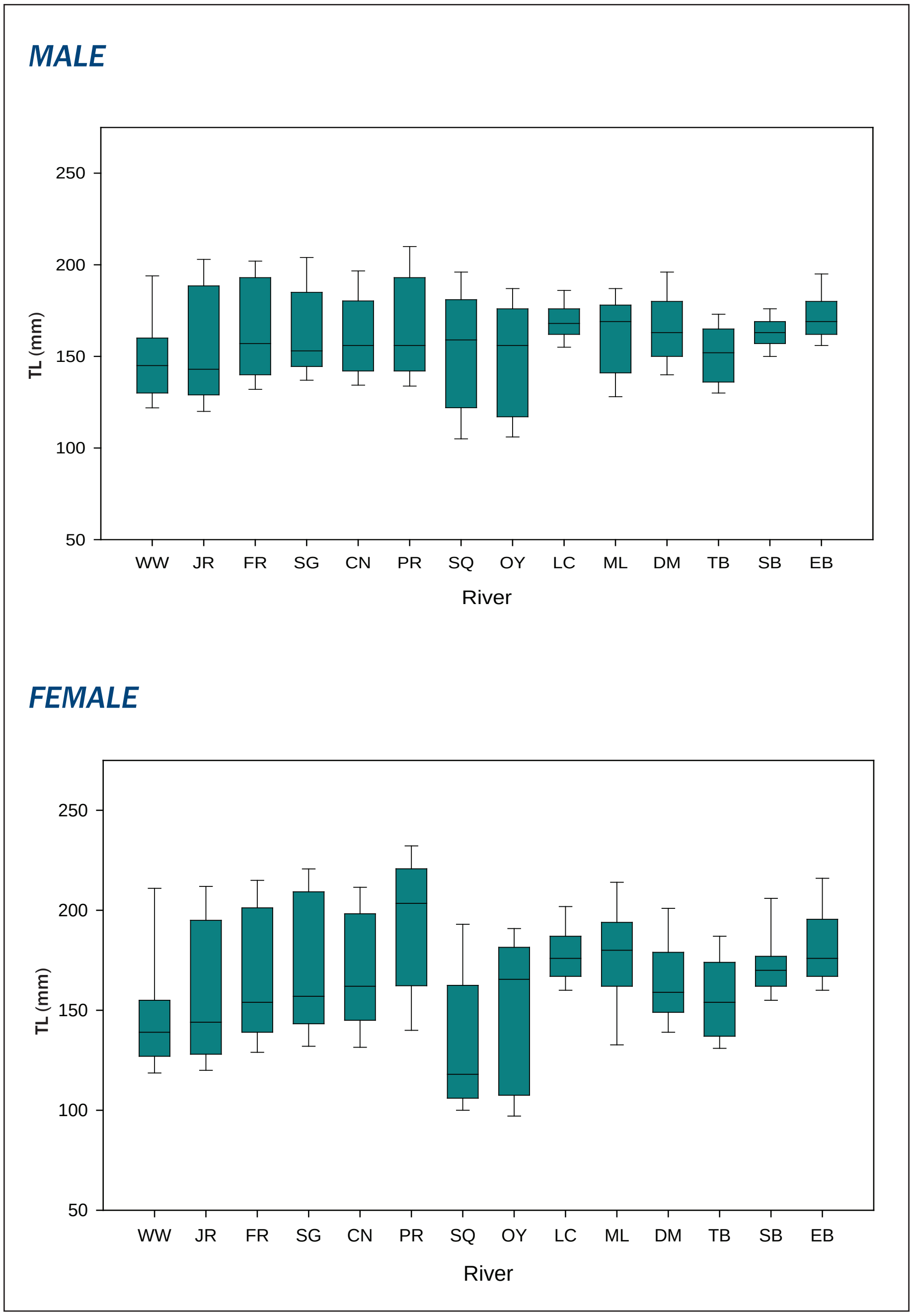


*Figure 1.3.15. Median total length of smelt caught at 14 fyke net stations in the study area, 2008-2011. The top of the box plots is the 75th percentile and the bottom is the 25th percentile. The line in the box is the median and the error bars mark the 10th and 90th percentiles. The stations are arranged on the x-axis from the southernmost MA station to the northernmost ME station. Station medians for females and males were found to be significantly different with Kruskal-Wallis test, KW = 1324.94, df = 13, p <0.001; and KW = 2000.77, df = 13, p <0.001, respectively.*

## 2 – THREATS TO RAINBOW SMELT POPULATIONS IN THE GULF OF MAINE

Rainbow smelt encounter a variety of potential threats during their freshwater and marine life stages. Dams, overfishing, and pollution have typically been considered the most important factors affecting diadromous fish, including rainbow smelt (Saunders et al. 2006, Limburg and Waldman 2009). While these factors may have played major roles in the declines of rainbow smelt, other factors may also be responsible for recent declines. Changes in trophic interactions, community shifts, watershed land use, and climate-driven environmental conditions may all need to be considered when evaluating factors that affect rainbow smelt populations.

*Dams, overfishing, and pollution have typically been considered the most important factors affecting diadromous fish, including rainbow smelt.*

### 2.1 – THREATS TO SPAWNING HABITAT CONDITIONS AND SPAWNING SUCCESS

### *Spawning Site Characteristics*

Across their distribution range, smelt spawning runs are variable in regard to habitat use, spawning substrate, spawning period, and water temperature range (Bigelow and Schroeder 1953, Hurlbert 1974, Kendall 1926, Pettigrew 1997, Rupp 1959). 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 (Chase 1990, 2006; Chase and Childs 2001; Crestin 1973; Lawton et al. 1990). In New Hampshire, spring runs begin in early to mid-March when the water temperatures reach 3-6 °C and conclude in May (NHF&G, current study). In Maine, the timing of the run varies geographically, beginning in late March in waters west of the Kennebec River, in mid-April in waters between the Kennebec River and the Penobscot River, in late April to early May in the Penobscot River and advancing to mid-May in most waters in downeast Maine. Water temperature at the beginning of runs varies from 1.5-9 °C, and most runs in Maine last four to five weeks (ME DMR, current study). There is also some evidence that rainbow smelt may spawn in the main stem of large rivers in Maine earlier than runs begin in smaller streams close to these rivers. In rivers such as the Kennebec, Penobscot, Union, and Pleasant, spawning may occur under the ice or directly following ice-out in mid-March to early April (ME DMR, current study).

The best documentation of the physical characteristics of smelt spawning habitats in the Gulf of Maine is provided by a detailed assessment of Massachusetts rivers that was conducted between 1988 and 1995 (Chase 2006). This study identified both stream attributes and water chemistry conditions that were suitable for smelt spawning. Chase (2006) documented and mapped smelt spawning habitat at 45 locations in 30 rivers on the Gulf of Maine coast of Massachusetts. Rainbow smelt egg deposition was documented to take place over stream sections ranging from 16 m to 1,111 m in length, with an average of 261 m. In most cases, the downstream limit of egg deposition occurred near the interface of salt and fresh water, while the upstream limits were typically delimited by physical impediments that prevented further passage. When passage allowed, smelt would continue spawning in freshwater riffles beyond tidal influence. The average patch size of substrate where smelt eggs were observed was 2,336 $m^2$, with a range of 16 $m^2$ to 13,989 $m^2$.

Smelt were found to spawn in shallow riffles where water velocity increased in stream channels. Within the streams where smelt eggs were found, channel width averaged 6.8 m. Depth transects conducted in 16 of these streams found that the average depth of spawning riffles was 0.28 m, and the range of average depths was 0.1 - 0.5 m under baseflow conditions. However, smelt eggs were found in depths up to 1.5 m in three surveyed rivers. The average water velocity at the riffle transects was 0.39 m/s, with a range of 0.1 to 0.9 m/s. These measurements and observations of associated egg deposition led Chase (2006) to hypothesize that 0.5 – 0.8 m/s was an optimal range for adult attraction and egg survival.

Observations in smelt spawning rivers in Massachusetts led Chase (2006) to conclude that the ideal channel configuration for 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 out egg deposition and provides resting pools. However, this scenario was not common in Massachusetts spawning rivers, and likely is not in many other rivers and streams in the Gulf of Maine. Many of the spawning streams and rivers were altered by: (1) a range of passage obstructions (undersized culverts, dams, etc.) that limited or completely blocked the smelts' ability to reach their spawning grounds, (2) channelization and flow alterations that changed water velocity and substrate conditions, and (3) removal of riparian vegetation, leading to increased amounts of polluted runoff flowing directly into the stream, as well as reduced canopy cover leading to increased water temperature. These three categories represent major threats to spawning habitat and to smelt spawning success, and they are described further in the following sections. In many cases, these threats are present simultaneously in more developed watersheds, compounding the threats to successful smelt spawning.

## Obstructions

### *Dams*

Industrial development depended on rivers for power, and over 500 dams remain on rivers in Maine, New Hampshire, and Massachusetts that may have a large impact on diadromous species (Martin and Aspe 2011). Dams block access to spawning habitats for many anadromous species, but their effect on rainbow smelt is particularly acute. The small body size of rainbow smelt makes them unable to jump to heights necessary to migrate through fish ladders, which pass other diadromous fish over dams. In Maine, at least 13 out of 275 (5%) historical and current spawning sites are either reduced in area or the spawning habitat is blocked by coastal dams (Abbott, USFWS, pers. comm., 2012). In New Hampshire, although smelt spawning occurs in most of the coastal rivers, head-of-tide dams exist on all of these rivers (with the exception of the Winnicut River), reducing habitat and forcing smelt to spawn within areas subject to tidal influence. Although the exact number has not been documented, the same situation exists in Massachusetts, where head-of-tide dams limit spawning habitat.

### *Road crossings*

The majority of smelt spawning streams in the Gulf of Maine are small coastal streams that are not dammed. More frequently, barriers are road-stream crossings. Undersized, improperly installed, or poorly maintained culverts at road-stream crossings can severely impair smelt migration. This can occur when culverts have become perched, where the downstream side stream height is well below the culvert height, or when culverts are undersized to such an extent that they create velocity barriers or reduce freshwater flow to levels that impede environmental cues for smelt. Reducing stream habitat fragmentation is critical for increasing access to smelt spawning habitat. In Maine, there is an ongoing effort to ground-survey all stream barriers. At the time of this report, 35% of the state has been surveyed. Of the 88 smelt historical or current spawning sites falling within this surveyed portion, 34 (39%) sites have potential barriers to passage. Extending the scope to the entire state, 127 historical or current spawning sites out of a total of 275 are crossed by roads at least once, and multiple times in many cases. While some of these crossings may have adequate passage, it is estimated that two-thirds of these crossings are undersized and may present passage problems for smelt (A. Abbott, USFWS, pers. comm.., 2012). The frequency of the problem is magnified in Massachusetts where only 1 of 45 mapped smelt spawning habitats were unaltered by road crossings or impediments (Chase 2006).

### *Channelization and Flow Disruptions*

#### Discharge and Velocity

In Massachusetts, New Hampshire, and Maine, most smelt runs occur in small coastal rivers or streams with low seasonal baseflows where spring stream discharge is sufficiently high to attract adults and support egg incubation. In the Northeast United States, early spring flows are typically enhanced by snow melt and precipitation, but discharge may decline progressively later in the season. In a survey of 45 spawning rivers in Massachusetts, aside from the Merrimack River, only nine had average spring discharges over 1 $m^3/s$ (35 cubic feet per second (cfs)), and only four exceeded a spring average of 10 $m^3/s$ (353 cfs) (Chase 2006).

During the current study, when USGS gauge stations were present, we recorded river discharge weekly at our smelt spawning sampling sites. None of the survey stations in Maine were located on rivers with gauge stations; however, measurements were available for two New Hampshire sites and four Massachusetts sites (Table 2.1.1). Over a two year period (2008-2009), we found an average discharge of 1.83 $m^3/s$ (65 cfs) across all sites, with most values (75%) under 1.99 $m^3/s$ (70 cfs) (Table 2.1.2). Discharge varied significantly between the sites, and was directly correlated to watershed size (Spearman's rank correlation = 0.78).

Although high discharge is not a threat to smelt spawning, if it results in sharp increases in velocity it impairs smelts' ability to reach their spawning grounds. In watersheds with large amounts of impervious surface and not managed for stormwater, infiltration of runoff is reduced and the smoother impervious surfaces allow water to run off the surface and into streams faster. The combined result is a rapid increase in both volume and velocity (Cooper 1996, Klein 1979). Substantial variability in velocity may be found within a coastal stream depending on specific location (e.g. pool versus riffle), and timing (precipitation events and tidal stage will affect daily velocities). However, as part of the current study we found that velocities at all spawning index sites fell within a fairly narrow range (0.32 m/s – 0.58 m/s) when measurements were taken within riffles when no tidal influence was present (Table 2.1.2). Velocity exceeded 0.79 m/s only 10% of the time, and generally the catch per unit effort of spawning adult smelt was lower during those high velocity events.

Conversely, low discharge may also threaten successful spawning. Sufficient freshwater flows are necessary for other anadromous species to cue their migrations and enable them to successfully locate their spawning site (Yako et al. 2002). Low discharge associated with urbanization may also lead to insufficient water mixing, resulting in higher water temperatures, lower dissolved oxygen, increased sedimentation, and increased concentrations of pollutants and contaminants (Klein 1979). Reductions in baseflow can be caused by water withdrawals and impounding as well as increases in impervious surface (Klein 1979, Simmons and Reynolds 1982). In many cases, withdrawals during the spring months may be expected to remove a small proportion of available spring flows. However, concerns are growing in urban areas where human population growth has increased water demands. Furthermore, a gradual but measured loss in snow pack over the last century has led to a reduction of spring baseflow in coastal streams, a situation that could compound concerns over water withdrawals.

### Substrate and Channel Stability

Natural stream and river channels that are vegetated and dynamic can absorb the impacts of flooding by accommodating changes in discharge and water levels. However, in urbanized areas with extensive impervious surface or where streams have been channelized by fixed walls, the runoff from large rain events flows directly into streams, leading to increases in the frequency and severity of flooding. In turn, these events can cause channel erosion and alteration of the stream bed (Klein 1979). The timing of flood events can cause positive responses to smelt spawning substrata by scouring sediment and periphyton before spawning occurs or negative responses by scouring away large egg sets (Chase 2006). Booth and Reinelt (1993) report that pool and riffle habitat may be altered and channel stability may be degraded when impervious surface exceeds 10-15% of the watershed area These impacts can be mitigated by restoring riparian buffers along stream and river banks.

### *Watershed characteristics*

Watershed activities can have a substantial influence on many of the conditions identified above as potentially affecting rainbow smelt spawning habitat. Land cover in a watershed affects habitat conditions and biological communities in receiving waters in a variety of ways (Burcher et al. 2007, Allan 2004). Urbanization and agricultural activities can contribute to erratic flow levels, warmer water temperatures, channel alterations, sedimentation, chemical and

*Our analysis found that weak spawning runs existed in rivers surrounded by urbanized watersheds, while rivers draining forested watersheds supported stronger smelt spawning populations.*

bacterial pollution, and nutrient loading (Wang et al. 2001a, Allan 2004). In addition, barriers to spawning passage are more likely to exist due to road networks in more urbanized watersheds than in less developed areas. These watershed-associated factors can all influence the suitability of streams for rainbow smelt spawning.

Associations between watershed characteristics and spawning site use have been observed for other anadromous species. Limburg and Schmidt (1990) noted that spawning activity of anadromous fishes (mostly alewife) in tributaries to the Hudson estuary was inversely related to the proportion of urban land use in the surrounding watershed. In the Pacific Northwest, Pess et al. (2002) found that median densities of spawning coho salmon were 1.5-3.5 times higher in forest-dominated areas than in urban or agricultural areas. These examples indicate that there may be linkages between spawning success and watershed characteristics. While the causal factors have not been identified, urbanization may influence in-stream habitat by increasing water velocities associated with flood events, changing substrate, removing canopy cover and thus increasing water temperature, and other habitat changes.

In this study, we evaluated correlations between rainbow smelt catch per unit effort at the spawning index sites and land use in the adjacent watersheds at two spatial scales: (1) the full drainage basin and (2) the 210 meter buffer immediately adjacent to the stream. Watersheds within which rainbow smelt spawning runs were sampled represented a wide variety of conditions (Table 2.1.1). A principal components and cluster analysis suggests that the smelt spawning watersheds can be classified into three distinct types: (1) urbanized, (2) forested, and (3) wetlands/agricultural (Figure 2.1.1). Correlations between the aggregate mean CPUE of spawning rainbow smelt over 2008-2011 (standardized based on net coverage of the stream width) indicate that weak spawning runs exist in rivers surrounded by urbanized watersheds, while rivers draining forested watersheds support strong smelt spawning populations. Interestingly, the negative association between development and CPUE was substantially stronger at the scale of the full drainage basin than when only the riparian buffer zone was considered (Table 2.1.3). This appears to be because many rivers within urbanized watersheds have extensive riparian wetlands in their buffer zones. The presence of these wetlands at the 210-m scale weakens the influence of urbanization on smelt spawning. Other land cover types and the number of downstream crossings, at either the scale of the watershed or riparian buffer zone, were not significantly correlated to the strength of rainbow smelt spawning populations.

|  | Fyke Net Location |  |  |  | Hydrologic Information |  |  | Watershed Information |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| River | Latitude | Longitude | Town | State | Channel Width (m) | Average Discharge ($m^3$/s) | Average Velocity (m/s) | Watershed (HUC 10) | Drainage Area ($km^2$) | Land Cover (1°/2°) |
| Westport River | 41.6209 | -71.0598 | Westport | MA | 11.3 | - | - | Buzzards Bay | 26.5 | Forest / Agriculture |
| Weweantic River | 41.7662 | -70.7461 | Wareham | MA | 35.7 | - | - | Buzzards Bay | 148.2 | Forest / Agriculture |
| Jones River | 41.9960 | -70.7233 | Kingston | MA | 27.3 | 1.92 | 0.492 | South Coastal Basin | 69.3 | Forest / Wetland |
| Fore River | 42.2225 | -70.9732 | Braintree | MA | 13.7 | 1.92 | 0.623 | Boston Harbor | 74.7 | Development / Forest |
| Saugus River | 42.4680 | -71.0077 | Saugus | MA | 55.4 | - | - | Boston Harbor | 55.8 | Development / Forest |
| North River | 42.5221 | -70.9116 | Salem | MA | 9.1 | 0.49 | 0.454 | North Coastal Basin | 12.6 | Development / Forest |
| Crane River | 42.5566 | -70.9364 | Danvers | MA | 8.2 | 0.17 | 0.497 | North Coastal Basin | 14.0 | Development / Forest |
| Parker River | 42.7505 | -70.9282 | Newbury | MA | 54.8 | - | 0.516 | Plum Island Sound | 66.0 | Forest / Wetland |
| Squamscott River | 42.9824 | -70.9461 | Exeter | NH | 101.0 | 5.65 | 0.384 | Exeter River | 276.9 | Forest / Wetland |
| Winnicut River | 43.0389 | -70.8455 | Greenland | NH | 36.6 | 1.05 | 0.3 | Great Bay | 45.5 | Forest / Wetland |
| Oyster River | 43.1310 | -70.1310 | Durham | NH | 32.9 | - | - | Great Bay | 59.9 | Forest / Development |
| Long Creek | 43.6332 | -70.3133 | S. Portland | ME | 24.3 | - | 0.64 | Fore River | 17.5 | Development / Forest |
| Mast Landing | 43.8587 | -70.0842 | Freeport | ME | 15.2 | - | 0.468 | Casco Bay Basin | 20.7 | Forest / Wetland |
| Deer Meadow Brook | 44.0369 | -69.5874 | Newcastle | ME | 24.9 | - | 0.489 | Sheepscot River | 27.6 | Forest / Wetland |
| Tannery Brook | 44.5706 | -68.7888 | Bucksport | ME | 67.7 | - | 0.402 | Penobscot River and Bay | 13.2 | Forest / Agriculture |
| Schoppee Brook | 44.6627 | -67.5533 | Jonesboro | ME | 16.0 | - | 0.583 | Roques Bluffs Frontal Drainages | 9.3 | Forest / Wetland |
| East Bay Brook | 44.9547 | -67.1041 | Perry | ME | 21.9 | - | 0.217 | Cobscook Bay | 3.0 | Forest / Wetland |

*Table 2.1.1. Rainbow smelt spawning habitat station locations for water quality monitoring. Drainage areas are GIS calculations set from the location of fyke net placement.*

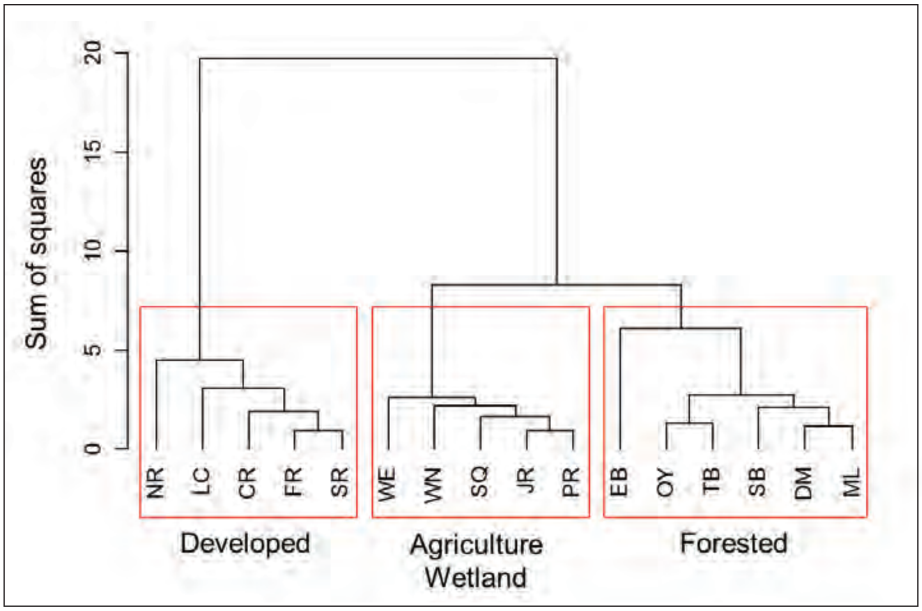
|  | Discharge ($m^3$/s) | Velocity (m/s) |
|---|---|---|
| Minimum Value | 0.04 | 0.050 |
| Lower Quantile (25%) | 0.35 | 0.323 |
| Mean | 1.83 | 0.478 |
| Upper Quantile (75%) | 1.99 | 0.579 |
| Maximum Value | 12.81 | 1.483 |

*Table 2.1.2. Discharge and velocity measurements from spawning survey index sites. Discharge measurements taken from USGS gauge stations upstream of spawning sites and velocity measurements taken by state biologists at the spawning sites (discharge n = 6, velocity n = 13) in active riffle areas.*

|  | Correlation with smelt spawning CPUE |  |
|---|---|---|
| Land Cover | Watershed Level | Stream Buffer Zone (210m) |
| % developed | **-0.62** | -0.48 |
| % developed open space (parks, golf courses) | -0.47 | -0.32 |
| % forest | **0.60** | **0.60** |
| % wetland | -0.29 | -0.28 |
| % agriculture | -0.06 | 0 |
| number of downstream crossings | -0.46 | -0.46 |

*Table 2.1.3. Spearman's rank correlation between rainbow smelt spawning CPUE and land cover at two spatial scales. Correlation coefficients in bold type indicate significance at the p = 0.5 level.*

*Figure 2.1.1. Cluster analysis (Ward's method) of study watersheds based on dominant land uses (as indicated by the proportion of developed, developed open, forest, agriculture, and wetland areas) and watershed characteristics (i.e., population density, stream crossings, and proportion of impervious surface). Station codes: NR = North River, LC = Long Creek, CR = Crane River, FR = Fore River, SR = Saugus River, WE = Weweantic River, WN = Winnicut River, SQ = Squamscott River, JR = Jones River, PR = Parker River, EB = East Bay Brook, OY = Oyster River, TB = Tannery Brook, SB = Schoppee Brook, DM = Deer Meadow Brook, ML = Mast Landing.*



## 2.2 – THREATS TO EMBRYONIC DEVELOPMENT AND SURVIVAL

Smelt deposit demersal (sinking), adhesive eggs at fast-flowing riffles, where they attach to the substrate or aquatic vegetation. The duration of egg incubation is related to water temperature (McKenzie 1964), and in the Gulf of Maine, eggs hatch 7-21 days after fertilization (Chase et al. 2008, McKenzie 1964). The success of this reproductive strategy depends on access from marine waters, low predation, and suitable water and habitat quality for successful recruitment. In many watersheds, the tidal interface is the physical location favored for the development of commerce and community centers. This change in landscape can lead to hydrologic alterations, particularly in urban areas, leaving streams vulnerable to point and non-point source pollutants; nutrient enrichment; and reduced streamflow, shading and riparian buffer.

Changes in spawning habitat may be a major factor in the decline of smelt populations. However, up to this point, the degree to which water quality impairment may be impacting smelt populations in the Gulf of Maine has not been described. With this concern in mind, we developed monitoring programs to assess baseline water and habitat conditions at smelt spawning habitat index sites spanning the entire Gulf of Maine and explored possible impacts on spawning success resulting from changing habitat conditions. This information is applied to support recommendations for conserving and restoring smelt populations and habitats.

Four indicators were measured to assess water quality at smelt spawning index sites: basic water chemistry, nutrient concentrations, periphyton growth and heavy metal concentrations. The sampling was guided by a Quality Assurance Program Plan (QAPP) for monitoring water and habitat quality at smelt spawning habitats in coastal rivers on the Gulf of Maine coast (Chase 2010). The QAPP integrates smelt life history with existing state and federal water quality criteria, with the objective of developing a standardized process to classify the suitability of smelt spawning habitat. Beyond characterizing smelt habitat, it is our hope these data will contribute to water quality and habitat restoration efforts at coastal rivers in New England.

Summary statistics were generated for water quality data by site and then compared to thresholds assembled from existing water quality criteria (Table 2.2.1). The U.S. Environmental Protection Agency (EPA) developed criteria for turbidity, total nitrogen (TN) and total phosphorus (TP) based on the 25th percentile of the distribution of observed values in an ecoregion (US EPA 2000). The 25th percentile is the value of a given parameter where 25% of all observations are below and 75% are above. The 25th percentile was adopted by EPA as the threshold between degraded conditions and minimally impacted locations. Additionally, the Massachusetts Department of Environmental Protection (MassDEP) established Surface Water Quality Standards (SWQS) for temperature, pH and dissolved oxygen (DO) as part of their Clean Water Act waterbody assessment process (MassDEP 2007). These thresholds were selected to protect designated categories of aquatic life, including fish habitat. Stations were classified as Suitable (minimally impacted) or Impaired for each parameter. Water quality data were also evaluated to explore the potential of establishing new thresholds specifically derived from smelt spawning habitat measurements.

## Water Chemistry

Basic water chemistry parameters were measured during smelt spawning runs at 19 index station stations: the 16 fyke survey sites and 3 additional spawning sites of interest in Massachusetts (Figure 1.3.7 and Table 2.1.1) following the QAPP protocol. Yellow Springs Incorporated (YSI) water chemistry sondes were used to measure water temperature (°C), DO (mg/L and % saturation), specific conductivity (mS/cm), pH and turbidity (NTU, Nephelometric Turbidity Units) in freshwater at the spawning grounds. At most stations, discrete water chemistry measurements were recorded three times per week. The seasonality of water chemistry monitoring was not synchronized for all stations due to the later onset of the spawning season at the northern end of the study area.  For this reason, detailed comparisons of some parameters, such as temperature, should be made cautiously.

### *Water Temperature*

Water temperature has an important influence on smelt metabolism, the onset of smelt spawning and the duration of egg incubation.  Median water temperatures during the spawning period were fairly consistent across the study area, with a range of 8.8 – 12.9 °C (Table 2.2.2, Figure A.2.1). No measurements exceeded the water temperature criterion of 28.3 °C adopted from MassDEP SWQS to protect aquatic life. The relatively high temperature threshold has little relevance for smelt that spawn in the cool water of the spring freshet; however, the temperature data have value for documenting baseline conditions and may have future application for monitoring reference values, such as station medians or 75th percentiles.

### *Specific Conductivity*

Specific conductivity is proportional to the concentration of major ions in solution corrected to the international standard of 25 °C.  High conductance in freshwater can indicate high watershed contributions of natural alkaline compounds or ionic contributions from pollution sources. For this reason, conductivity has been discussed as a potential proxy for pollution sources, urbanization, and eutrophication. Median specific conductivity during the spawning period ranged from 0.031 – 0.997 uS/cm (Table 2.2.2, Figure A.2.2). The four highest medians occurred at urban sites near the Boston metropolitan area.

### *Dissolved Oxygen*

Adequate dissolved oxygen (DO) concentrations are necessary for embryonic survival and normal development. The QAPP provides a DO criterion of ≥ 6.0 mg/L to protect aquatic life. Median DO concentrations during the spawning period ranged from 9.5 – 12.5 mg/L (Table 2.2.2, Figure A.2.3), and median DO saturation levels ranged from 91.0 – 107.8% (Table 2.2.2, Figure A.2.4). All individual DO measurements were well above the DO threshold. Similar to water temperature, the DO threshold may have limited relevance because of the high concentrations of DO found in turbulent riffles during the spring freshet. The distribution of DO saturation data does show increasing supersaturation in urban Massachusetts and a declining DO saturation moving north in the study area. Supersaturation of oxygen can indicate eutrophic conditions, where due to the photosynthetic cycle of the algal communities, supersaturation is observed during the daylight hours, but anoxic conditions are present during darkness (Carlton and Wetzel 1987).

### *pH*

Increased acidification of water bodies in New England is a widely recognized threat to fish populations, as low water pH can increase the impact of aluminum toxicity and disrupt fish respiration. Geffen (1990) conducted laboratory experiments to examine the influence of pH on smelt embryo survival; trials found that survival was most influenced by the duration of low pH exposure and embryo developmental stage. For example, high mortality occurred to early stage smelt eggs (4-6 days post-fertilization) at 5.5 pH when exposure ranged from 6-11 days. Fuda et al. (2007) conducted similar experiments and found survival was not affected until pH was ≤ 5.0. The QAPP adopted the water pH criterion of ≥ 6.5 to ≤ 8.3 from MassDEP (2007) to protect aquatic life. Most stations had pH measurements in a range that was not a concern for rainbow smelt. Median pH during the spawning period ranged from 5.92 – 7.67 (Table 2.2.2, Figure A.2.5). Of the 19 rivers sampled, seven were classified as Impaired (>10% of individual measurements below pH 6.5). Among the stations classified as Impaired, only four had routine measurements below 6.0 pH: the three southernmost Massachusetts stations and Schoppee Brook in Maine.

### *Turbidity*

Turbidity in water is the result of suspended inorganic and organic matter; it can be caused by natural fluctuations in sediment transport or by changes in productivity. The QAPP adopted the turbidity criterion of ≤ 1.7 (NTU) from the EPA Northeast Coastal Zone ecoregion (US EPA 2000). Most rivers had median turbidity values >1.7 NTU, and all were classified as Impaired for having at least 10% of measurements > 1.7 NTU (Table 2.2.2, Figure A.2.6). Several stations in New Hampshire and southern Maine had median values well above the threshold. However, this elevated turbidity may result from the natural suspension of sediments, either due to soil type or the naturally high turbidity in the spring associated with snow melt and higher runoff. Adopting the study's 25th percentile of 1.9 NTU would still result in all stations being classified as Impaired. The turbidity data will be further evaluated to determine if a more appropriate turbidity threshold can be established by removing precipitation effects through an analysis of baseflow data.

### *Data Analysis*

Median values of water temperature, DO, specific conductivity, pH and turbidity were compared among sampling stations (Kruskal-Wallis, $p < 0.001$), and a multiple comparison test was used to determine which stations were significantly different from others (Siegal and Castellan, 1988; R code, kruskalmc; $p = 0.05$; Figures A.2.1 – A.2.6). Significant differences were found for all parameters; trends between parameters were common among rivers and regions.  Conductivity was especially variable among sites and may be related to watershed characteristics; in the most urban sites (Crane and North rivers, Massachusetts) conductivity was significantly higher than most other sites, whereas at the forested sites (Deer Meadow and East Bay Brooks, Maine), conductivity was significantly lower than most other sites. The relation of these variables to spawning smelt populations is discussed in the Watershed Characteristics Section.

## *Nutrient Concentrations*

Nitrogen and phosphorus are vital nutrients for plants but can cause excessive growth and degrade the health of aquatic life at high concentrations. The influence of nutrient pollution on water and habitat quality in rivers and lakes is a growing concern in the United States (Mitchell et al. 2003). The health or trophic state of aquatic habitat is influenced most by light, carbon sources, nutrients, hydrology and food web structure (Dodds 2007). Among these influences in developed watersheds, nutrient enrichment is most dependent on human activity and may be most amenable to remediation efforts.  Total nitrogen and total phosphorus were recorded weekly at index stations in the freshwater portion of the streams on the spawning grounds from 2008-2011. Field sampling procedures are documented in the QAPP (Chase 2010), and the laboratory analysis followed EPA-approved Quality Assurance /Quality Control (QA/QC) protocols.

Nutrient concentrations for smelt spawning habitat were classified using EPA recommended thresholds for freshwater streams and rivers that were developed from the distribution of available water quality data (US EPA 2000). These EPA thresholds for Suitable habitat for the study area are 0.57 mg/L for total nitrogen (TN) and 23.75 ug/L for total phosphorus (TP). The EPA also recommends that states develop their own nutrient water quality criteria for protecting specific designated uses of aquatic habitat under Clean Water Act assessment and remediation processes (US EPA 2000). In this light, the TN and TP data recorded for this study were compared to the EPA nutrient criteria and the data distributions were evaluated for potential smelt habitat-specific thresholds (Table 2.2.3)

### *Total Nitrogen*

Measurements of TN at 20 stations during 2008-2011 showed a trend of higher concentrations in urban areas (Table 2.2.3, Figure A.2.7). The range of median concentrations for all stations was 0.216 - 1.395 mg/L. Only five stations were classified as Suitable for TN (≤ 10% of measurements below 0.57 mg/L; EPA 2000), with four of these stations at the northeastern end of the study area. All others were classified as Impaired. The TN 25th percentile generated from the study sites was 0.340 mg/L, which was 40% lower than the EPA ecoregion threshold.

### *Total Phosphorus*

Measurements of TP displayed a more stable trend across the study area (Table 2.2.3, Figure A.2.8). The range of median concentrations for all stations was 12.18 ug/L to 36.72 ug/L. Only 4 stations were classified as Suitable for TP (≤ 10% of measurements below 23.75 ug/L; EPA 2000). All others were classified as Impaired. The TP 25th percentile generated from the study stations was 17.56 ug/L; 26% lower than the EPA ecoregion threshold.

### *TN/TP Ratio*

While total concentrations of nitrogen and phosphorus are important for plant production, the balance or ratio of TN to TP can also influence growth and species composition. Most TN:TP ratios were in a range expected for freshwater systems in New England (15:1-30:1). Higher ratios indicating high nitrogen and possible phosphorus limitation were found at the most urbanized stations, and low ratios most influenced by high phosphorus were only found at a few stations where watershed development was low.

### *Data Analysis*

Comparisons of median TN, TP and TN:TP ratios among sampling stations found significant differences for all three parameters (Kruskal-Wallis, $p < 0.001$). A multiple comparison test was used to determine which stations were significantly different from others (Siegal and Castellan, 1988; R code, kruskalmc; $p = 0.05$). The box plots in Figures A.2.7 – A.2.8 represent a graphic display of the multiple comparisons. The high TN concentrations at Crane River and North River (> 1.0 mg/L) in Massachusetts were significantly different from all stations except the Saugus River. The four stations with median TN < 0.3 mg/L were significantly lower than most the remaining stations, all but one found in urban areas of Massachusetts and New Hampshire.

## Periphyton

Periphyton is the complex of benthic algae, detritus and other microorganisms that attaches to the river bed and is an important indicator of primary production and environmental disturbances in aquatic habitats. Periphyton growth responds to nutrient enrichment and can reach excessive or nuisance growth in eutrophied systems (Biggs 1996). Eutrophication has been identified as a major concern for smelt spawning habitat due to the potential impact of excessive periphyton growth on smelt embryo survival at spawning riffles in Massachusetts (Chase 2006). These concerns have also been raised for smelt runs in tributaries to the St. Lawrence River in less urban regions of Québec (Lapierre et al. 1999). Periphyton monitoring was conducted to provide a biological response variable for nutrient concentrations that may be directly related to successful embryonic survival. Laboratory experiments studying the effect of periphyton growth on smelt embryo survival complimented the field monitoring. The lab results demonstrated that embryo survival was significantly lower on substrata with high periphyton growth/concentrations than on clean surfaces (Wyatt et al. 2010).

Field monitoring measured the growth of periphyton on spawning ground substrate at the index sites during the spawning period to determine how growth may differ between sites. Ceramic tiles were deployed to collect periphyton during the 2008-2009 spawning period at riffle habitat where smelt deposit eggs. Periphyton growth on the tiles was collected biweekly to quantify daily growth and describe algal species composition. Ash-free dry weight (AFDW, g/m$^2$/day) was calculated as a measure of periphyton biomass. Average periphyton growth ranged from 0.006 to 0.120 g/m$^2$/day at 12 smelt spawning habitat stations (Table 2.2.3). The range of periphyton growth included very low growth at the easternmost Maine stations to high growth at urban centers in Massachusetts.

No algal biomass thresholds are available specifically for smelt spawning habitat. In the absence of published thresholds, the 25th percentile of 0.0143 g/m$^2$/day was calculated from the AFDW medians observed during this study and compared to all values. All river stations exceeded this threshold and were classified as Impaired for periphyton, except for Deer Meadow Brook, Chandler River and East Bay Brook, Maine. The periphyton data suffer from high variability and low sample sizes at some sites. However, there appears to be potential value in using the 50th percentile (0.0533 g/m$^2$/day) as a threshold for moderately impacted rivers. At the stations with medians above the 50th percentile (Figure 2.2.1), the periphyton could be characterized as excessive growth that could impede egg incubation and appears to be associated with higher TN and urbanization. However, more work is needed to understand the range of periphyton growth at different spawning streams, how this varies annually in response to environmental conditions, and the point at which periphyton growth impairs embryo survival.

### Heavy Metal Concentrations

Heavy metals such as cadmium, chromium, copper, iron, lead, manganese, mercury, silver and zinc can be absorbed by both fish embryos and larvae and lead to developmental abnormalities and reduced survival (Finn 2007, Jezierska et al. 2009, Wegwu and Akaninwor 2006). Short-term, high-intensity contamination mostly occurs in the spring months during snowmelt periods, when mild water acidification that is associated with snow melt leads to free metal ions being leached from sediments (Jezierska et al. 2009). Long term exposure to lower concentrations of heavy metals may be of equal concern. The toxic effects of aluminum on salmonid embryos are seen when pH is below 6.5; at this level, pH can inhibit the swelling of the egg shell, reducing the amount of space for the embryo to develop and move, and leading to stunted growth or physical abnormalities (Finn 2007). Cadmium, lead and copper at low levels can exacerbate these effects at any pH (Jezierska et al. 2009). Above critical thresholds, mercury, lead, cadmium, chromium, iron, and zinc have all been shown to reduce the number of embryos successfully hatching (Wegwu and Akaninwor 2006), as well as to disturb skeletal growth, impair hemoglobin (red blood cell) formation, cause osmoregulatory failure, and limit overall growth because the organism's energy is spent ridding the body of the toxic contaminants (Finn 2007; Jezierska et al. 2009).

We sampled heavy metal concentrations and other minerals (calcium and magnesium) at all index sites during baseflow conditions over the course of the spawning period in 2010 and 2011 to describe the range of concentrations to which smelt embryos are chronically exposed. Although not part of this study, corollary laboratory experiments should be performed to ascertain which metals and what concentrations reduce survival and impair normal development in smelt embryos and larvae.

Of the heavy metals, silver, cadmium, and mercury concentrations were below detection levels for all sites during all sampling periods (detection levels 0.002 mg/l, 0.5 ug/l, 0.5 ug/l, respectively). Chromium was detected only once during the sampling period, in the Oyster River, New Hampshire (0.003 mg/l; detection level 0.002 mg/l). Although these metals were not detected, or detected only once, it should not be assumed that they are not present. They may in fact be present either at concentrations below the detection levels or during runoff or precipitation events neither of which our sampling captured. All other metal concentrations were detected at most sites, and the range of values followed a log distribution. As log distributions are typical of metal concentrations in many regions, the values we measured likely represent much of the range of metal concentrations present in the region during the smelt spawning season (Table 2.2.4).

A principal components analysis (PCA) was performed using the 2010-2011 average concentrations (log transformed to produce normal distributions) to determine which metal and mineral concentrations trended together, and which seemed to vary on their own. From this analysis, we find that lead (Pb; abbreviations refer to labels in associated figure, and are not the full elemental symbols with ionic sign), copper (Cu), and zinc (Zn) are highly related and trend opposite from aluminum (Al). This pattern indicates that when high values of lead, copper, and zinc were present, aluminum values were low, and vice versa. Being drivers of water hardness, calcium (Ca) and magnesium (Mg) were highly related to hardness and alkalinity, but notably nickel (Ni) was also highly related to these variables (Figure 2.2.2).

The relationship between metal concentrations and watershed characteristics is explored in the following section.

### *Watershed characteristics*

As suggested throughout the preceding sections, watershed land use can affect water quality in receiving streams and rivers in a variety of ways. The development of wetlands, agricultural fields, or forested areas replaces porous soils with impervious surfaces, which increases the velocity of water flowing off the land and the supply of suspended sediments, nutrients, and contaminants to adjacent streams (Brenner and Mondok 1995, Corbett et al. 1997, Strayer et al. 2003, US EPA 2004). In addition, agricultural areas contribute nutrients—both nitrogen and phosphorus—to receiving streams. In aquatic ecosystems, these nutrients can promote algal blooms, deplete oxygen, and degrade fish habitat (Carpenter et al. 1998, Howarth et al. 2000).

Understanding how water quality, nutrient levels, and heavy metal concentrations are related to watershed land use is important for developing management strategies to minimize impacts to rainbow smelt eggs and larvae.

Correlations between watershed land use and water quality parameters, nutrient levels, periphyton growth, and heavy metal concentrations were evaluated using Spearman's rank correlation statistic. Results are presented in Table 2.2.5 at the scale of the full drainage basin and riparian buffer zone. Several key patterns emerge from these correlation results that are relevant to rainbow smelt conservation. First, patterns are very similar at full watershed and riparian buffer scales, indicating that land use in the broader watershed exerts a similar influence on water quality as land use immediately adjacent to the receiving stream. Second, the percent of development and forest in the watershed show the strongest associations with water quality, with the direction of influence occurring in opposition to one another. For example, higher percentages of developed areas are associated with higher stream dissolved (available) nitrogen and heavy metals concentrations; conversely, highly forested watersheds are associated with lower concentrations of nitrogen and metals (Crawford and Lenat 1994). Because periphyton growth is dependent on available nutrients (like dissolved nitrogen), and because heavy metals can negatively affect embryo development and survival, this pattern suggests that protecting forested areas is important for maintaining water quality conditions that are beneficial to rainbow smelt.

*Understanding how water quality, nutrient levels, and heavy metal concentrations are related to watershed land use is important for developing management strategies to minimize impacts to rainbow smelt eggs and larvae.*

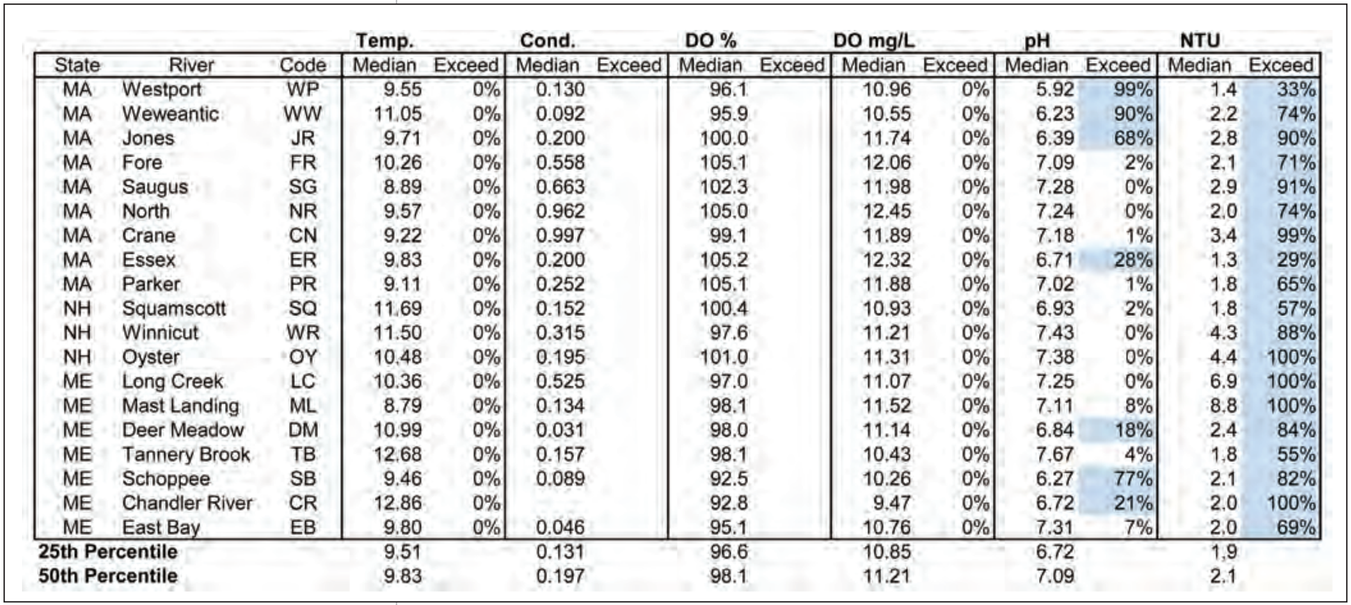
### Conclusions

When compared to the established EPA thresholds, the water quality data collected during 2008-2011 show widespread impairment due to elevated TN, TP, and turbidity and more localized impairment from acidification and excessive periphyton growth. More work is needed to evaluate existing criteria and to establish new thresholds that are specific to smelt spawning habitat. For example, the turbidity criterion is likely too low to be relevant for stream riffles during spring; conversely, the water temperature and DO criteria may be too high, as smelt embryos require a lower temperature than the current EPA threshold. The highest median values for TN, conductivity and periphyton were associated with urban sites. Most sites with few identified impairment were at the northern end of the study area.

These results provide a range of water quality conditions that affect successful embryonic survival. From high impairment in urban settings to suitable water quality in rural settings, these sites are examples of both conditions requiring remediation and demonstrating restoration targets. We encourage resource managers to use these baseline conditions to consider potential remediation measures (e.g., riparian buffers, stormwater improvements, point source reductions) to improve impairments and to plan for protecting locations with suitable conditions for supporting smelt spawning success.

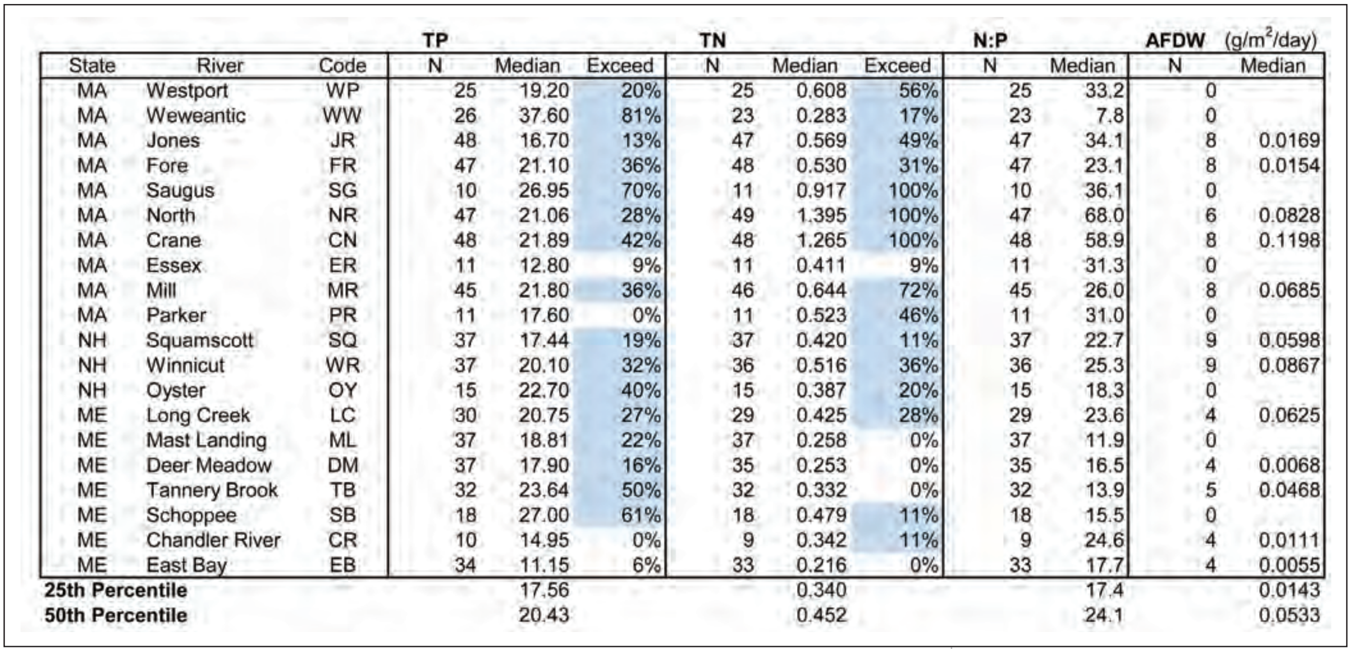
*Table 2.2.1. Water chemistry criteria related to smelt spawning habitat. The water chemistry parameters were adopted to protect Aquatic Life at Class B Inland Waters (MassDEP 2007), and US EPA reference conditions (25th percentile) for the Northeast Coastal Zone sub-Ecoregion (US EPA 2000). Potential criteria are presented based on 25th and 50th percentiles from 2008-2011 project data. Blank cells indicate either that no criterion exists or the derived percentile has limited relevance for smelt habitat.*

|  | Existing Water Quality Criteria |  |  |  |
|---|---|---|---|---|
| Parameters | Suitable<br>(MassDEP 2007) | Minimally Impacted<br>25th Percentile<br>(US EPA 2000) | Minimally Impacted<br>25th Percentile<br>(2008-2011 data) | Moderately Impacted<br>50th Percentile<br>(2008-2011 data) |
| Temperature (°C ) | ≤ 28.3 |  |  |  |
| Sp. Conductivity (mS/cm) |  |  | ≤ 0.131 |  |
| pH | ≥ 6.5 to ≤ 8.3 |  |  |  |
| DO (mg/L) | ≥ 6.0 |  |  |  |
| Turbidity (NTU) |  | ≤ 1.7 | ≤ 1.9 | ≤ 2.1 |
| TN (mg/L) |  | ≤ 0.570 | ≤ 0.340 | ≤ 0.452 |
| TP (ug/L) |  | ≤ 23.75 | ≤ 17.56 | ≤ 20.43 |
| Periphyton Biomass (g/m2/d) |  |  | ≤ 0.0143 | ≤ 0.0533 |



|  |  |  | Temp. |  | Cond. |  | DO % |  | DO mg/L |  | pH |  | NTU |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State | River | Code | Median | Exceed | Median | Exceed | Median | Exceed | Median | Exceed | Median | Exceed | Median | Exceed |
| MA | Westport | WP | 9.55 | 0% | 0.130 |  | 96.1 |  | 10.96 | 0% | 5.92 | 99% | 1.4 | 33% |
| MA | Weweantic | WW | 11.05 | 0% | 0.092 |  | 95.9 |  | 10.55 | 0% | 6.23 | 90% | 2.2 | 74% |
| MA | Jones | JR | 9.71 | 0% | 0.200 |  | 100.0 |  | 11.74 | 0% | 6.39 | 68% | 2.8 | 90% |
| MA | Fore | FR | 10.26 | 0% | 0.558 |  | 105.1 |  | 12.06 | 0% | 7.09 | 2% | 2.1 | 71% |
| MA | Saugus | SG | 8.89 | 0% | 0.663 |  | 102.3 |  | 11.98 | 0% | 7.28 | 0% | 2.9 | 91% |
| MA | North | NR | 9.57 | 0% | 0.962 |  | 105.0 |  | 12.45 | 0% | 7.24 | 0% | 2.0 | 74% |
| MA | Crane | CN | 9.22 | 0% | 0.997 |  | 99.1 |  | 11.89 | 0% | 7.18 | 1% | 3.4 | 99% |
| MA | Essex | ER | 9.83 | 0% | 0.200 |  | 105.2 |  | 12.32 | 0% | 6.71 | 28% | 1.3 | 29% |
| MA | Parker | PR | 9.11 | 0% | 0.252 |  | 105.1 |  | 11.88 | 0% | 7.02 | 1% | 1.8 | 65% |
| NH | Squamscott | SQ | 11.69 | 0% | 0.152 |  | 100.4 |  | 10.93 | 0% | 6.93 | 2% | 1.8 | 57% |
| NH | Winnicut | WR | 11.50 | 0% | 0.315 |  | 97.6 |  | 11.21 | 0% | 7.43 | 0% | 4.3 | 88% |
| NH | Oyster | OY | 10.48 | 0% | 0.195 |  | 101.0 |  | 11.31 | 0% | 7.38 | 0% | 4.4 | 100% |
| ME | Long Creek | LC | 10.36 | 0% | 0.525 |  | 97.0 |  | 11.07 | 0% | 7.25 | 0% | 6.9 | 100% |
| ME | Mast Landing | ML | 8.79 | 0% | 0.134 |  | 98.1 |  | 11.52 | 0% | 7.11 | 8% | 8.8 | 100% |
| ME | Deer Meadow | DM | 10.99 | 0% | 0.031 |  | 98.0 |  | 11.14 | 0% | 6.84 | 18% | 2.4 | 84% |
| ME | Tannery Brook | TB | 12.68 | 0% | 0.157 |  | 98.1 |  | 10.43 | 0% | 7.67 | 4% | 1.8 | 55% |
| ME | Schoppee | SB | 9.46 | 0% | 0.089 |  | 92.5 |  | 10.26 | 0% | 6.27 | 77% | 2.1 | 82% |
| ME | Chandler River | CR | 12.86 | 0% |  |  | 92.8 |  | 9.47 | 0% | 6.72 | 21% | 2.0 | 100% |
| ME | East Bay | EB | 9.80 | 0% | 0.046 |  | 95.1 |  | 10.76 | 0% | 7.31 | 7% | 2.0 | 69% |
| **25th Percentile** |  |  | 9.51 |  | 0.131 |  | 96.6 |  | 10.85 |  | 6.72 |  | 1.9 |  |
| **50th Percentile** |  |  | 9.83 |  | 0.197 |  | 98.1 |  | 11.21 |  | 7.09 |  | 2.1 |  |

*Table 2.2.2. Basic water chemistry measured at 19 smelt fyke net index stations in the U. S. Gulf of Maine and Buzzards Bay, Massachusetts. Median values were calculated from all available data from 2008-2011. The percentage of samples at each station that exceed the QAPP (Chase 2010) thresholds are presented in shaded cells, indicating an Impaired classification for the parameter. No water quality criteria are available for conductivity or DO saturation.*

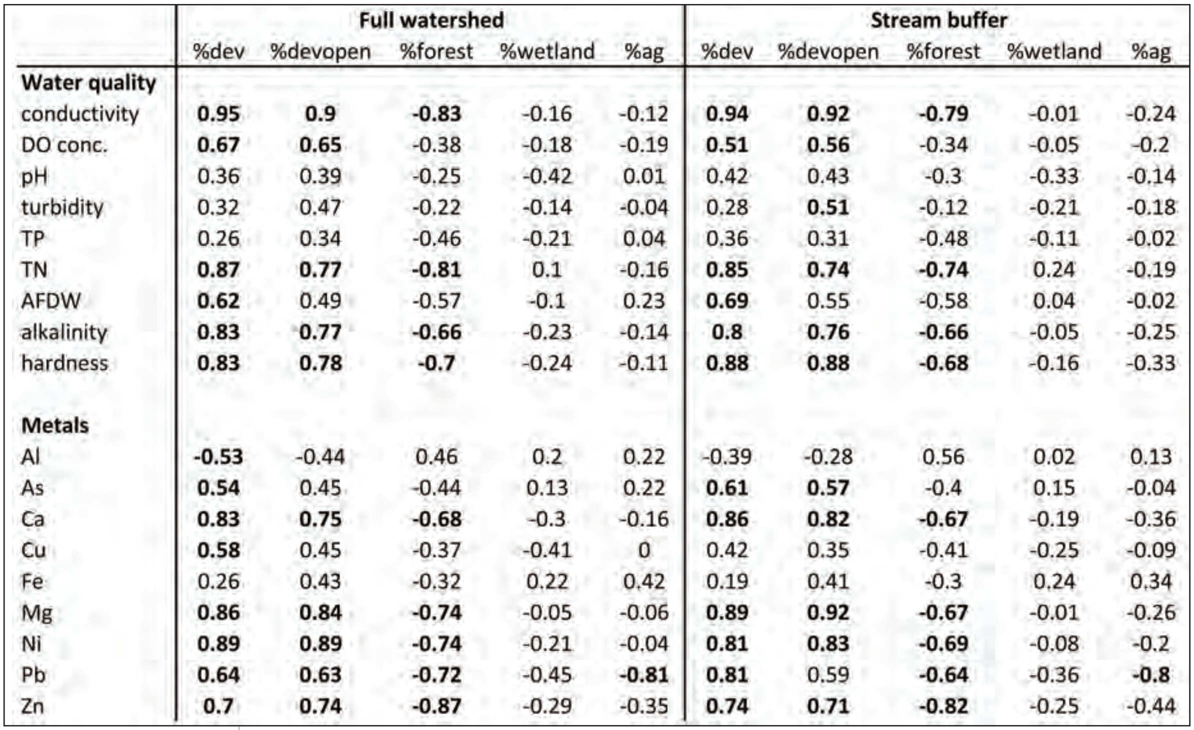


| | | | TP | | | TN | | | N:P | | AFDW (g/m$^2$/day) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State | River | Code | N | Median | Exceed | N | Median | Exceed | N | Median | N | Median |
| MA | Westport | WP | 25 | 19.20 | 20% | 25 | 0.608 | 56% | 25 | 33.2 | 0 | |
| MA | Weweantic | WW | 26 | 37.60 | 81% | 23 | 0.283 | 17% | 23 | 7.8 | 0 | |
| MA | Jones | JR | 48 | 16.70 | 13% | 47 | 0.569 | 49% | 47 | 34.1 | 8 | 0.0169 |
| MA | Fore | FR | 47 | 21.10 | 36% | 48 | 0.530 | 31% | 47 | 23.1 | 8 | 0.0154 |
| MA | Saugus | SG | 10 | 26.95 | 70% | 11 | 0.917 | 100% | 10 | 36.1 | 0 | |
| MA | North | NR | 47 | 21.06 | 28% | 49 | 1.395 | 100% | 47 | 68.0 | 6 | 0.0828 |
| MA | Crane | CN | 48 | 21.89 | 42% | 48 | 1.265 | 100% | 48 | 58.9 | 8 | 0.1198 |
| MA | Essex | ER | 11 | 12.80 | 9% | 11 | 0.411 | 9% | 11 | 31.3 | 0 | |
| MA | Mill | MR | 45 | 21.80 | 36% | 46 | 0.644 | 72% | 45 | 26.0 | 8 | 0.0685 |
| MA | Parker | PR | 11 | 17.60 | 0% | 11 | 0.523 | 46% | 11 | 31.0 | 0 | |
| NH | Squamscott | SQ | 37 | 17.44 | 19% | 37 | 0.420 | 11% | 37 | 22.7 | 9 | 0.0598 |
| NH | Winnicut | WR | 37 | 20.10 | 32% | 36 | 0.516 | 36% | 36 | 25.3 | 9 | 0.0867 |
| NH | Oyster | OY | 15 | 22.70 | 40% | 15 | 0.387 | 20% | 15 | 18.3 | 0 | |
| ME | Long Creek | LC | 30 | 20.75 | 27% | 29 | 0.425 | 28% | 29 | 23.6 | 4 | 0.0625 |
| ME | Mast Landing | ML | 37 | 18.81 | 22% | 37 | 0.258 | 0% | 37 | 11.9 | 0 | |
| ME | Deer Meadow | DM | 37 | 17.90 | 16% | 35 | 0.253 | 0% | 35 | 16.5 | 4 | 0.0068 |
| ME | Tannery Brook | TB | 32 | 23.64 | 50% | 32 | 0.332 | 0% | 32 | 13.9 | 5 | 0.0468 |
| ME | Schoppee | SB | 18 | 27.00 | 61% | 18 | 0.479 | 11% | 18 | 15.5 | 0 | |
| ME | Chandler River | CR | 10 | 14.95 | 0% | 9 | 0.342 | 11% | 9 | 24.6 | 4 | 0.0111 |
| ME | East Bay | EB | 34 | 11.15 | 6% | 33 | 0.216 | 0% | 33 | 17.7 | 4 | 0.0055 |
| **25th Percentile** | | | | 17.56 | | | 0.340 | | | 17.4 | | 0.0143 |
| **50th Percentile** | | | | 20.43 | | | 0.452 | | | 24.1 | | 0.0533 |

*Table 2.2.3. Nutrient and periphyton measurements for all index stations in the U. S. Gulf of Maine and Buzzards Bay, Massachusetts. The percentage of samples at each station that exceed the QAPP (Chase 2010) thresholds are presented in shaded cells, indicating an Impaired classification for the parameter. No criteria are available for the N:P ratio or periphyton.*

| Analyte | Unit | 2010 Detection Limit | 2011 Detection Limit | 2010-2011 Mean Value | 2010-2011 Low Value | 2010-2011 High Value |
|---|---|---|---|---|---|---|
| Aluminum | mg/L | 0.005 | 0.01 | 0.1347 | 0.0059 | 1.0000 |
| Arsenic | ug/L | 0.5 | 0.5 | 1.30 | 0.51 | 4.00 |
| Cadmium | ug/L | 0.5 | 0.5 | BDL | BDL | BDL |
| Calcium | mg/L | 0.05 | 0.05 | 13.78 | 0.55 | 52.00 |
| Chromium | mg/L | 0.002 | 0.002 | 0.003 | 0.003 | 0.003 |
| Alkalinity | mg/L | 1 | 1 | 29.14 | 3.26 | 100.00 |
| Copper | mg/L | 0.0005 | 0.0005 | 0.0013 | 0.0005 | 0.0077 |
| Iron | mg/L | 0.05 | 0.05 | 0.62 | 0.16 | 2.70 |
| Lead | ug/L | 0.5 | 0.5 | 1.05 | 0.38 | 3.10 |
| Magnesium | mg/L | 0.05 | 0.05 | 4.27 | 0.27 | 39.00 |
| Nickel | mg/L | 0.0005 | 0.0005 | 0.0016 | 0.0005 | 0.0050 |
| Silver | mg/L | 0.002 | 0.0005 | BDL | BDL | BDL |
| Zinc | mg/L | 0.002 | 0.002 | 0.006 | 0.002 | 0.021 |
| Total Hardness | mg/L | 0.35 | 0.33 | 54.6 | 2.5 | 430.0 |
| Mercury | ug/L | 0.5 | Not Sampled in 2011 | BDL | BDL | BDL |

*Table 2.2.4. Analytes measured in water samples taken at baseflow at smelt spawning index sites 2010-2011. Detection limits and mean, low, and high concentrations are shown for each analyte. BDL = below detection limit.*



| | Full watershed | | | | | Stream buffer | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | %dev | %devopen | %forest | %wetland | %ag | %dev | %devopen | %forest | %wetland | %ag |
| **Water quality** | | | | | | | | | | |
| conductivity | **0.95** | **0.9** | **-0.83** | -0.16 | -0.12 | **0.94** | **0.92** | **-0.79** | -0.01 | -0.24 |
| DO conc. | **0.67** | **0.65** | -0.38 | -0.18 | -0.19 | **0.51** | **0.56** | -0.34 | -0.05 | -0.2 |
| pH | 0.36 | 0.39 | -0.25 | -0.42 | 0.01 | 0.42 | 0.43 | -0.3 | -0.33 | -0.14 |
| turbidity | 0.32 | 0.47 | -0.22 | -0.14 | -0.04 | 0.28 | **0.51** | -0.12 | -0.21 | -0.18 |
| TP | 0.26 | 0.34 | -0.46 | -0.21 | 0.04 | 0.36 | 0.31 | -0.48 | -0.11 | -0.02 |
| TN | **0.87** | **0.77** | **-0.81** | 0.1 | -0.16 | **0.85** | **0.74** | **-0.74** | 0.24 | -0.19 |
| AFDW | **0.62** | 0.49 | -0.57 | -0.1 | 0.23 | **0.69** | 0.55 | -0.58 | 0.04 | -0.02 |
| alkalinity | **0.83** | **0.77** | **-0.66** | -0.23 | -0.14 | **0.8** | **0.76** | **-0.66** | -0.05 | -0.25 |
| hardness | **0.83** | **0.78** | **-0.7** | -0.24 | -0.11 | **0.88** | **0.88** | **-0.68** | -0.16 | -0.33 |
| **Metals** | | | | | | | | | | |
| Al | **-0.53** | -0.44 | 0.46 | 0.2 | 0.22 | -0.39 | -0.28 | 0.56 | 0.02 | 0.13 |
| As | **0.54** | 0.45 | -0.44 | 0.13 | 0.22 | **0.61** | **0.57** | -0.4 | 0.15 | -0.04 |
| Ca | **0.83** | **0.75** | **-0.68** | -0.3 | -0.16 | **0.86** | **0.82** | **-0.67** | -0.19 | -0.36 |
| Cu | **0.58** | 0.45 | -0.37 | -0.41 | 0 | 0.42 | 0.35 | -0.41 | -0.25 | -0.09 |
| Fe | 0.26 | 0.43 | -0.32 | 0.22 | 0.42 | 0.19 | 0.41 | -0.3 | 0.24 | 0.34 |
| Mg | **0.86** | **0.84** | **-0.74** | -0.05 | -0.06 | **0.89** | **0.92** | **-0.67** | -0.01 | -0.26 |
| Ni | **0.89** | **0.89** | **-0.74** | -0.21 | -0.04 | **0.81** | **0.83** | **-0.69** | -0.08 | -0.2 |
| Pb | **0.64** | **0.63** | **-0.72** | -0.45 | **-0.81** | **0.81** | 0.59 | **-0.64** | -0.36 | **-0.8** |
| Zn | **0.7** | **0.74** | **-0.87** | -0.29 | -0.35 | **0.74** | **0.71** | **-0.82** | -0.25 | -0.44 |

*Table 2.2.5. Spearman's rank correlation between water quality metrics and land cover at two spatial scales (e.g., full watershed and riparian buffer zone). Correlation coefficients in bold type indicate significance at the p=0.05 level.*

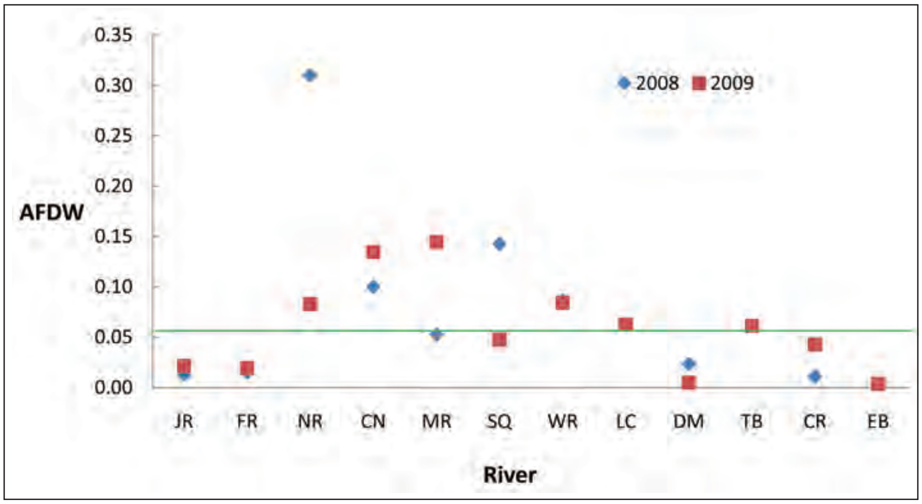


*Figure 2.2.1. Annual median periphyton growth (ash-free dry weight, g/m$^2$/day) displayed by sample station with 50th percentile of station median values marked by green line. Refer to Table 2.2.2 for river codes.*

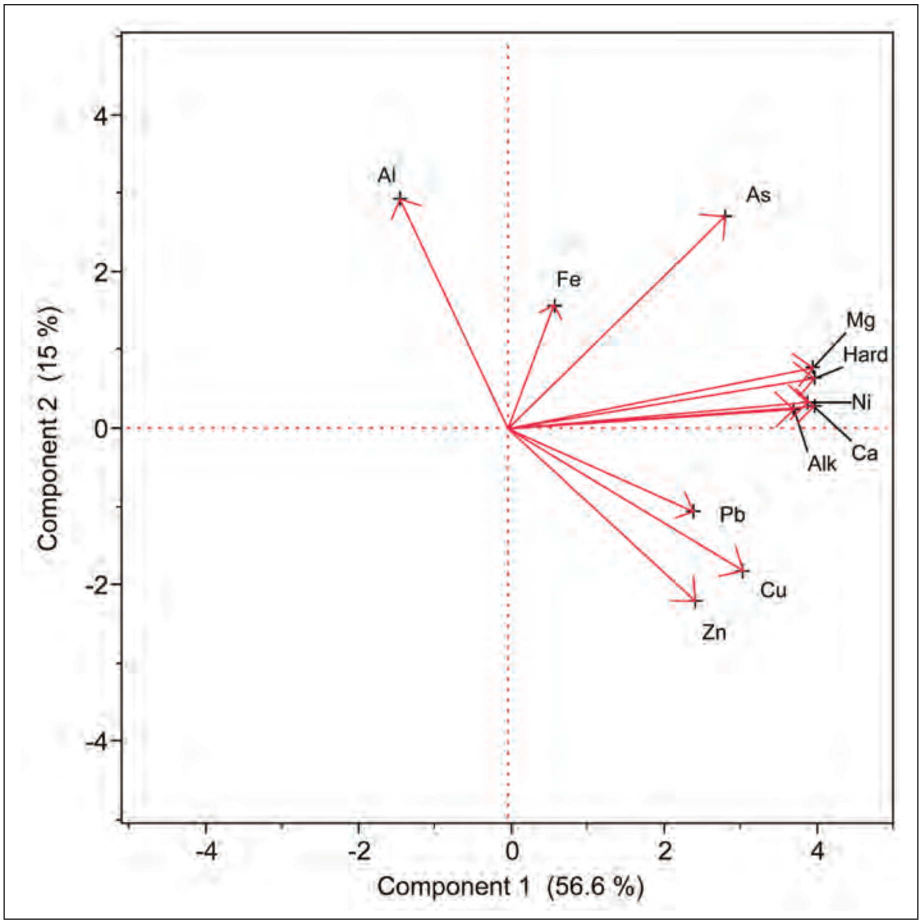


*Figure 2.2.2. Principal components analysis (PCA) performed on 2010-2011 average metal and mineral concentrations (log transformed). The first component is driven most by hardness (a variable which represents the total mineral concentration of water, driven by calcium and magnesium), magnesium, calcium, alkalinity, and nickel. The second component is driven most in the positive direction by aluminum and arsenic and less so by iron, and in the negative direction by zinc, copper, and lead.*

## 2.3 – THREATS TO SMELT IN MARINE COASTAL WATERS

Smelt spend at least half the year in marine coastal waters during the summer and fall months. As adults and juveniles they are a schooling fish that attract a wide range of predators. While monitoring this life phase can be more difficult than monitoring discrete spawning runs, it is no less important when considering the species decline. During this period, smelt are susceptible to environmental influences on survival, shifts in natural mortality and to capture in small mesh fisheries targeting other species. These topics are discussed below, using the best available information to discuss how each issue may be affecting smelt populations; however, to fully understand the implications, each requires further study.

### *Fish Health*

Improving understanding of fish health status as well as the abundance, geographic distribution, and vectors of areas of study necessary to support the development and implementation of conservation strategies designed to protect and restore rainbow smelt populations. Pathogens can adversely affect both juveniles and adults in both general and acute ways, including organ failure, energy loss, interruption of hormonal pathways and reproductive weakness (D.

Bouchard, University of Maine, pers. comm., 2011).

We characterized pathogen presence endemic to smelt at fourteen spawning index sites spanning the Gulf of Maine over a two-year period, 2009-2010 (Bouchard 2010). Sampling did not detect bacterial pathogens of regulatory concern but did detect endemic parasites that are well documented for similar anadromous species. Parasitological results were typical of wild fish populations, with various trematodes (e.g., black grub), cestodes, nematodes and protozoa observed at all sites.  A microsporidian parasite detected in various tissues of many individuals in this study was not identified as to species, but is consistent with *(Glugea hertwigi)*, which was confirmed at one site: the Fore River, Massachusetts. This parasite has been documented extensively in freshwater smelt can be detrimental to successful spawning because this parasite infests the gonads of smelt (Jimenez et al. 1982, Nsembukya-Katuramu et al. 1981). The observation of large numbers of *(Philometra spp.)*-like nematodes in the gonads of the majority of female fish in the study is also consistent with reports of this parasite as an opportunistic pathogen of spawning female fish in other species (Moravec and de Buron 2009).

Virology results revealed a viral agent from adults from Casco Bay, Maine; however, it is difficult to place any significance to this agent at the present time because the virus is not similar to currently catalogued agents (IPNV, IHNV, ISAV, and VHSV have been ruled out by PCR techniques). More analysis on this agent is needed to fully understand the physiological effects it may be having. Fish from a majority of the sites spanning the entire Gulf of Maine region showed evidence of erythrocytic disease, or degradation of red blood cells, leading to anemic effects (Bouchard 2010). This last point may be of specific concern and warrants further investigation to understand the extent of disease and causal factors.

*Fish from a majority of the sites spanning the entire Gulf of Maine region showed evidence of erythrocytic disease, or degradation of red blood cells, leading to anemic effects.*

## Fishing Mortality

### *Overfishing in historical fisheries*

While historical fisheries for rainbow smelt landed thousands (and in Maine millions) of pounds annually in the 1800s, because the relative size of the entire population was unknown, it is not possible to quantify the effect of these targeted fisheries on smelt populations.

As populations declined in the 20th century, and as regulations limited fishing gear and take in response to this decline, targeted fishing effort has also been reduced. Today, few targeted commercial fisheries exist: a dip and bow net fishery is open to permitted individuals in Great Bay, New Hampshire; and a gill and bag net fishery are allowed during a regulated time period to permitted individuals on five rivers in downeast Maine.  Large-scale recreational hook-and-line ice fisheries also exist in Great Bay, New Hampshire, and on many rivers and embayments in Maine (most notably the Kennebec River and Merrymeeting Bay area). While these fisheries are not thought to contribute high mortality for the smelt populations they target, the current extraction rates are unknown. Studies by the ME DMR in the late 1970s estimated that the ice-fishery on the Kennebec River extracted less than 5% of the total smelt population in the river (Flagg 1983).  In Maine there is also a large recreational dip net fishery that targets adult smelt on the spawning grounds during the spring runs.

While there is a limit of 2 quarts of smelt per person per day in this spring fishery, the contribution to mortality is unknown.

### *Incidental catch in small mesh fisheries*

Five small mesh fisheries operate in the Gulf of Maine, all capable of encountering rainbow smelt. Because smelt is not a regulated species for federally permitted fisheries, incidental catch (bycatch) is not required to be reported, although it is in some cases. Thus, it is difficult to determine the total amount of smelt bycatch; however, the relative impact on the species can be assessed based on reports from the Northeast Fisheries Science Center Observer (NEFSC) Program, which monitors catch from a representative sample of each fleet (NEFCS 2012). The following analyses represent all Gulf of Maine states.

The Northern shrimp fishery operates in nearshore coastal waters during the winter and early spring months. Since 1992, the fishery has been required to install a finfish excluder device in their nets, the Nordmore grate. Prior to 1992, total bycatch in this fishery comprised almost two-thirds of the catch (Howell and Langan 1992). Subsequent surveys have found that the grate is extremely effective in limiting bycatch; Eayrs et al. (2009) observed reductions to 4-8% of the total catch over a two-year period.

Using NEFSC observer records, the effect of the Nordmore grate on reducing smelt bycatch can specifically be seen. In the period directly preceding the requirement of the excluder device (1989-1992), there were 197 observed trips on vessels targeting Northern shrimp, and smelt were caught on 38 (19%) of these trips. A total of 201 lbs of smelt were caught during these trips combined, for an average of 5.3 lbs per trip. The highest was 46 lbs of smelt bycatch, although 87% of these trips caught less than 10 lbs. In the period directly following the excluder panel requirement (1993-2006), the amount of smelt bycatch on observed trips decreased, although not significantly (Wilcoxon ranked sum test: $p = 0.129 > 0.05$). During this period, smelt were observed on 74 (24%) out of 303 observed trips. A total of 289 lbs of smelt bycatch were caught during these trips, with an average weight per trip of 3.1 lbs. The highest smelt catch was 31 lbs, and 92% of these trips had less than 10 lbs. Recent data (2007-2011) show that smelt bycatch has decreased significantly from the last two time periods (Wilcoxon ranked sum test: $p < 0.0001 < 0.05$). During this most recent period, smelt bycatch was observed on only 22 162 (14%) observed trips, all of which saw less than 10 lbs. The average smelt bycatch for this recent period was 0.5 lbs, with a maximum catch of 2 lbs.

Vessel Trip Reports (VTRs) were implemented in 1996, at which point it became mandatory for vessels to report all catch. From the VTR reports, smelt were only reported in the shrimp fishery post-2006, but reported annually since then. From 2006-2011, smelt were reported in 35 trips out of 14,339 trips (0.2%). Of the trips that did report smelt, the average catch was 5.3 lbs, the highest 100 lbs (one occurrence), and 94% of trips reported less than 10 lbs. Further work is needed to estimate the total amount of smelt taken in the shrimp fishery using both observer and VTR data.

The mackerel, whiting (silver hake), Atlantic herring, and loligo squid fisheries are all also capable of encountering smelt as bycatch. These fisheries operate on multiple scales with various gear types, including pound (trap) nets at fixed locations close to shore, offshore trawling, and bag netting. Smelt bycatch has been reported on VTRs in the Atlantic herring and whiting fisheries, however too few reports have been given from the mackerel fishery to draw any inferences, and no smelt bycatch has been reported from the loligo squid fishery.

In the Atlantic herring fishery, some smelt bycatch was reported in each year 1996-2011, although was reported on fewer than five reports in 1997, 2002, and 2008-2011. For the total period, smelt were reported in 135 trips out of 5463 total Atlantic herring trips (2.4%). The average reported catch was 5.1 lbs, the highest was 100 lbs (one occurrence), and 84% of these trips reported less than 10 lbs.

In the whiting (silver hake) fishery, smelt bycatch was reported for 71 trips out of a total of 20,204 trips (0.3%) for 1996-2011. In seven of these years, fewer than 5 VTRs reported smelt (1999, 2004, 2005, 2008-2011). The average reported catch was 6.4 lbs, the highest was 42 lbs, and 73% of these trips reported less than 10lbs.

If these data are representative of smelt bycatch in these fisheries, it is likely that they are not having a large effect on smelt populations at this time. However, because we do not have a population estimate for smelt, it is not possible to ascertain the mortality rate due to bycatch in these fisheries. Further, the effect of small-mesh fisheries in the past cannot be determined. To fully understand the effect of small-mesh fisheries on smelt populations, more work is necessary to ensure that the observer and VTR programs are accurately capturing the extent of smelt bycatch.

## *Predator-prey relationships*

### *Prey Availability*

Rainbow smelt are voracious feeders on amhipods, euphausiids, mysids, shrimps, marine worms, and any available small fishes (e.g., silverside, mummichog, herring) (Scott and Scott 1988). We do not know of existing broad-scale data to evaluate changes in the prey of rainbow smelt over time, however, the prey base was likely affected by changes in primary production and zooplankton community composition during the 1990s (Greene et al. 2012), and such variability should be expected as a result of oceanographic and climate variability. In addition, the balance between small prey species and larger fishes may shift as a result of ocean acidification (Wootton et al. 2008), which will likely affect calcifying organisms such as zooplankton and shrimp.

### *Predator Population Shifts*

Predators of rainbow smelt include a variety of aquatic birds (e.g., mergansers, cormorants, gulls, terns), fish (e.g., Atlantic cod, Atlantic salmon, striped bass, bluefish), and seals (Collette and Klein-MacPhee 2002). While the abundance of some of these predators has declined since the 1990s, others have increased. For example, striped bass populations have increased dramatically over the past 20 years, although the recovery has not been seen consistently along the coast. Maine striped bass populations have actually declined or remained at low levels compared to other regions (ASMFC 2011). Striped bass predation has been shown to have a significant impact on blueback herring populations in Connecticut River, and has been attributed as one of the factors limiting blueback herring restoration in this river (Davis et al. 2009). Similarly, populations of grey seals in the Gulf of Maine have increased dramatically over the past few decades (NEFSC 2010). Like striped bass, grey seals are capable of ingesting large amounts of forage fish, and are found feeding in nearshore coastal waters in late spring when smelt are present in large schools. Although not as closely documented, cormorant populations have also sharply increased in recent years and are known to prey heavily on smelt. Striped bass, cormorants, and grey seals have received protections as managed species that have increased their populations sharply in short periods of time. Although these are natural predators that smelt have coexisted with while adapting to Gulf of Maine environments, it is possible that the impact of increasing predation on declining smelt populations results in proportionally higher natural mortality than in the past.

Recent shifts in predator range may also increase the exposure of smelt to predators. Friedland et al. (2012) suggested that the survival post-smolt Atlantic salmon may be affected by increasing predator abundance in the Gulf of Maine; increasing predator abundance that is due not necessarily to increasing population size, but to northward shifts in range due to recent changes in climatic and oceanic conditions. Because many of these species prey on a wide range of forage fish, this increasing predator abundance may affect smelt populations as well, although more research would be necessary to assess this relationship.

### *Community shifts*

Dramatic declines of diadromous fish populations have been observed across North America (Limburg and Waldman 2009; Hall et al. 2012). Saunders et al. (2006) proposed that coherent declines within a co-evolved diadromous community could negatively affect individual species. While Saunders et al. (2006) focused on benefits that may have been lost for Atlantic salmon through community-level shifts, several of these could also affect rainbow smelt. In particular, the decline of species such as alewives, blueback herring, and American shad—which are present in rivers and estuaries as juveniles during the same time as rainbow smelt—could have resulted in the loss of a prey buffer for rainbow smelt juveniles, making them more vulnerable to predation.

## *Climate-driven environmental change*

It is anticipated that climate change will influence temperature and precipitation patterns in New England, and some of these effects may already be evident in recent environmental trends. Surface water temperature has been monitored monthly nearly continuously since 1905 (ME DMR 2011). This temperature series shows periods of warming during the 1940s-1950s and again from the 1990s to mid-2000s, with the warmest water on record observed in 2006 (Figure 2.3.1). Because smelt are a cold water species, their geographic distribution shift northward may be influenced by the trend in warmer waters.

In addition to warmer coastal waters, freshwater conditions have changed in recent years as well. During the 1980s and 1990s, the Northeast experienced an increase in heavy precipitation events, and warmer temperatures have reduced ice cover and prompted earlier spring flows (Hodgkins et al. 2003, Frumhoff et al. 2007). On New England streams that are substantially affected by snowmelt, the winter/spring center of volume dates and peak flow dates advanced by 1-2 weeks between 1970 and 2000 (Hodgkins et al. 2003). Water temperature and flow changes may affect spawning migration timing (Juanes et al. 2004, Ellis and Vokoun 2009), development rates, and early life stage survival in rainbow smelt. More research is needed to understand how climate-related environmental changes influence smelt abundance and distribution changes and to anticipate future implications for rainbow smelt.

With concern to species communities and shifts that are due to climate change, evidence suggests that the balance between small prey species and larger fishes may shift as a result of ocean acidification (Wootton et al. 2008). As the amount of atmospheric carbon increases, the amount of dissolved carbon in oceanic water also increases, in turn decreasing the pH of seawater. At lower pH values, the development and survival of calcifying marine organisms like coralline algae and phytoplankton are inhibited. Because these organisms are the base of the marine food chain and the direct diet of many of smelts' prey species, a decline in these organisms may also negatively affect smelts' prey base. This hypothesis has been examined on the Pacific coast, but with no conclusive results, and has only begun to be considered in the Gulf of Maine. More research is needed to fully understand the effect of climate change on species composition changes in this region.

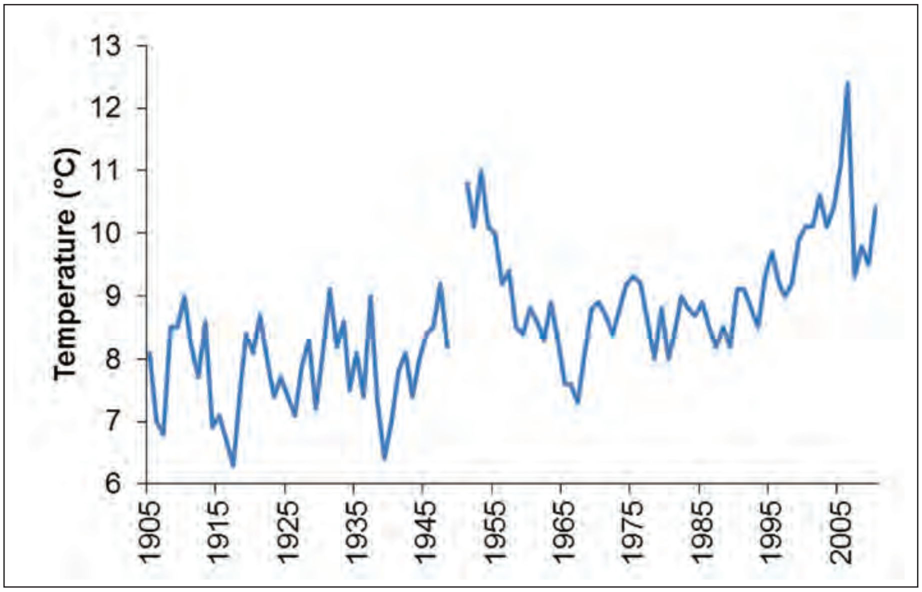


*Figure 2.3.1. Mean annual surface water temperature at Boothbay Harbor, Maine, from 1905-2010.*

# 3 – CONSERVATION STRATEGIES

We recommend that rainbow smelt remain federally listed as a Species of Concern. Populations have disappeared from their southern range in a short period of time and are also declining in their present distribution in the Gulf of Maine. The species should continue to be monitored, and factors contributing to its decline should continue to be assessed.

## 3.1 – REGIONAL CONSERVATION STRATEGIES

### *Recommendation 1: Continue monitoring programs*

Each state within the present distribution of rainbow smelt in the Gulf of Maine currently monitors populations through inshore trawl, juvenile abundance, fyke net, and/or creel surveys.

In states at the extreme southern limit of the range where spawning populations have not been documented within the past ten years, inshore trawl surveys are likely the most effective way to monitor the remnant populations. In the Gulf of Maine states, trawl surveys provide the only source of data on the marine life phase of smelt. It is necessary that these surveys continue to document smelt presence and quantify abundance, and it is recommended that biological information is collected from a sub-sample of catches.

The regionally standardized fyke net survey developed for this study should be continued in the Gulf of Maine. A standardized survey is necessary to provide long-term data that can track inter-annual variability across distinct spawning stocks. This information is critical for detecting whether populations are declining or showing signs of stress, as may be characterized by truncated age distributions, decreases in length at age, and decreases in CPUE over time. The juvenile abundance surveys should also be continued in New Hampshire and Maine as the only surveys targeting this life stage. Further, creel surveys should be maintained at recreational fishing sites to provide a measure of the impact of the fishery as well as information about changes in population size and biological characteristics over time.

Because some pathological concerns were found as part of this project (see section 2.3 – Threats to Smelt in Marine Coastal Waters), Gulf of Maine states should periodically monitor rainbow smelt from multiple spawning stocks for pathology, including parasite occurrence, viral agents, and systemic physiological problems. Further, states should cooperate with Canadian provinces to compare parasite and disease prevalence in the entirety of the species' range.

*We recommend that rainbow smelt remain federally listed as a Species of Concern and that current population monitoring efforts continue in the Gulf of Maine.*

### Recommendation 2: Restore historical or degraded spawning habitat

Spawning habitat degradation and obstructions to access have been identified as two important factors that have reduced successful spawning. Restoring in-stream habitat (e. g. substrate, water volume and velocity, pool and riffle areas), riparian buffer, improving and preserving watershed functions, and restoring access are important management strategies to improve local smelt populations.

Where possible, head-of-tide dams should be removed. Eggs deposited below dams are subject to periods of salinity during high tide and may be exposed to air at low tide if freshwater flows coming over the dam are low. Perched culverts and small water control barriers can also have this effect. When these obstructions are removed, smelt are able to ascend into freshwater, where water chemistry is more stable over time and water level is relatively constant. While undersized culverts (less than 1.2x bank-full width) may not completely block access, they can limit the number of smelt that reach the spawning grounds by creating velocity barriers. Restoration projects to improve road-stream crossings should design replacement culverts that target minimum water depth of 6 inches with average velocities in the culvert of 0.5 m/s or less, and flood velocities below 1.5 m/s (see section 2.1 – Threats to Spawning Habitat Conditions and Adult Spawning).

*Restoring in-stream habitat (e. g. substrate, water volume and velocity, pool and riffle areas), riparian buffer, improving and preserving watershed functions, and restoring access are important management strategies to improve local smelt populations.*

Additionally, water quality at the spawning grounds must support healthy embryonic development and survival. We found that diminished rainbow smelt spawning runs existed in rivers surrounded by urbanized watersheds, while rivers draining forested watersheds supported strong smelt spawning populations. Comparing watershed conditions to water quality, higher concentrations of nutrients and toxic contaminants were associated with developed areas, while highly forested watersheds were associated with lower concentrations of nutrients and metals. This pattern suggests that protecting forested areas is important for maintaining water quality conditions that are beneficial to rainbow smelt. Furthermore, regional efforts to purchase conservation lands should consider parcels in watersheds that support smelt spawning habitats. When development does occur in watersheds with smelt spawning habitat, the amount of impervious surface should be minimized, and stormwater mitigation techniques should be implemented to curtail the impacts on water quality (e. g. riparian buffers, vegetated stormwater retention pools, underground filtration systems, etc.).

### Recommendation 3: Smelt Fishery Management Actions

The results of the present study documented evidence of high population mortality (truncated age distribution) and poor recruitment (low abundance) in smelt populations in the southern portion of the study area. The time series of population data collected among the fishery dependent and independent surveys is too brief to determine the causes of these stressors on smelt populations. However, overfishing was consistently identified as a significant concern in the latter half of the 19th century and the early 20th century in the southern portion of smelt's distribution.

The sustainability of current smelt fisheries, both recreational and commercial, will require management strategies to quantify natural mortality and fishing mortality. We recommend that each state in the study area review current smelt fishery regulations and identify locations where present management may not be sufficient to protect distinct populations that display evidence of stress. We recommend that states estimate fishing mortality from all targeted smelt fisheries and review bag limits on both commercial and recreational fisheries that target smelt.

### Recommendation 4: Expand research to estimate population size and assess the potential impacts of ecosystem and climate changes

The surveys carried out as part of this project did not enable us to develop a population estimate for rainbow smelt. However, the standardized fyke net survey established by the study should be continued with additional research in order to assess smelt population status in the region, understand the impact of targeted fishing and incidental bycatch, and to understand the relative contributions of each spawning stock to the regional population. This may be accomplished through a large-scale mark and recapture effort that targets each genetic stock (Kovach et al., in press; section 1.1 – Basic Biology). Tagging studies carried out as part of this project to understand habitat use and within-season repeat spawning behavior documented few inter-annual returns (less than 1%), although approximately 200 smelt per year were tagged (assumed to be less than 10% of the entire run based on estimated fyke net catch efficiencies). Future tagging studies should tag a representatively larger sample of the spawning population to effectively monitor inter-annual repeat spawning and estimate population size. Additionally, improved and validated age structure data are needed to support future estimates of population size. Efforts should be made to maintain sufficient age structure sample sizes in each state.

Further research is needed to understand how changes in prey availability and predator abundance affect smelt populations. Other studies have found connections between increasing predator populations and depressed forage fish populations (see section 2.3 – Threats to Smelt in Marine Coastal Waters). Because these studies looked at predators that also feed on anadromous smelt, the impact on smelt populations should also be examined.

Species that are important prey of rainbow smelt may be particularly affected by changes in the chemistry of marine waters. Increases in the amount of carbon in the atmosphere are associated with increases in the amount of carbon in salt water, which leads to a reduction in oceanic pH that may negatively impact small prey species, such as calcareous plankton (Wooton et al. 2008). This relationship needs to be better quantified to understand the effect of a smaller prey base on smelt populations. Conversely, predator populations that have shifted in their range in response to climate conditions may be preying upon forage fish populations more than in previous times (Friedland et al. 2012). Further studies are necessary to understand how rainbow smelt will be affected by changes to their prey and predators as a consequence of climate change.

Climate change may also impact smelt populations by changing the extent of available spawning areas. Smelt spawn directly above the head of tide, and the upstream extent of the freshwater spawning area is typically either a natural barrier or road crossing. Thus, a rise in sea level that extends the tidal limit to these barriers may greatly reduce the number of spawning sites or the area within sites that is suitable for spawning. Conversely, a rise in sea level could increase habitat by raising tidewater above natural barriers allowing access to new reaches. Future research should model the potential effects for various sea level rise projections.

Expanded research to understand reasons for systemic health issues and reduced survival is needed to effectively guide management actions. While it is helpful to understand overall relationships such as watershed composition and smelt population responses, it is only a starting point. For example, research into dose responses to specific water quality constituents at all life stages would enable managers to develop smelt specific water quality criteria. These criteria may then be used to guide water treatment goals around which non-point or point source controls can be designed. This would be especially important in those already developed watersheds that are impractical to restore to forest. Controlled studies in both laboratory and field settings are critical to improve our understanding of cause and effect, not just correlations, and to develop measureable relationships. Lastly, post-restoration monitoring is necessary to evaluate the success of any prescribed restoration technique.

*Expanded research to understand reasons for systemic health issues and reduced survival is needed to effectively guide management actions.*

### Recommendation 5: Implement stocking of marked larvae, with continued monitoring and genetic considerations

Rainbow smelt are currently extirpated or have severely declined in many coastal rivers and streams that once supported robust spawning populations. Historical fishing pressure at the spawning grounds and degraded habitat and water quality may be causal factors. When improvements are made to water quality and habitat in these streams, restoration practices, such as stocking, may be appropriate to re-establish rainbow smelt runs at these sites.

Successful stocking efforts must include marking and subsequent recapture of hatchery stocked smelt to quantify effectiveness of restoration efforts. Utilizing recent advances in smelt culture techniques, Ayer et al. (2012) developed methods for marking otoliths in larval rainbow smelt with oxytetracycline (OTC) for monitoring returns. Using these methods, the Massachusetts Division of Marine Fisheries began a pilot program to stock OTC-marked smelt larvae in the Crane River, MA, after water quality suitability was confirmed and passage improvements were made to upstream spawning habitat (Chase et al 2008). Over 10 million marked smelt larvae have been stocked into the Crane River since 2007, and spawning adult smelt with OTC-marked otoliths have been recaptured, providing a positive response for the project to continue stocking and monitoring.

New restoration sites for rainbow smelt are being examined in both Massachusetts and Maine. In many situations, the protection and enhancement of existing habitat and water quality at both donor smelt runs and potential stocking sites will be preferential to initiating a stocking effort. Before any stocking begins, these sites will be sampled for baseline population data, and a site suitability assessment will be conducted, which will include water quality monitoring, streambed characterization, and flow measurements. Further, the genetic information presented in this plan (section 1.1 – Basic Biology) must be used in determining the appropriate parent stock. Managing at too fine a scale can lead to reduced allelic diversity and ignores the natural occurrence of gene flow, while managing at too large a scale can reduce genetic diversity and ignore local adaptations. Another important consideration is the status of donor populations to support stocking efforts. Careful planning should be made to remove a minimal proportion of a donor smelt run's productivity for stocking. Finally, long-term post-stocking monitoring should be performed to demonstrate stocking success.

## 3.2 – STATE MANAGEMENT RECOMMENDATIONS

### *Massachusetts*

Massachusetts has a long history of implementing management measures to ensure sustainable smelt fisheries. Concern over the capability of net fisheries during smelt spawning runs to negatively impact the long-term viability of smelt runs was documented in the 1860s (Kendall 1926). In 1874, the Massachusetts state legislature banned harvest using nets during the spawning period and limited harvest to hook and line for most coastal rivers in Massachusetts. By the start of the 20th century, nearly all smelt runs had this protection, and local smelt fisheries continued mainly as sportfisheries with little change until recent decades.

The only location in Massachusetts that presently allows net fishing for smelt during the spawning run is the Weweantic River in Wareham. This fishery is conducted under authority of M.G.L 67 of 1931 that gives the Town of Wareham the responsibility to manage a smelt fishery from March 1 to March 31. This recreational fishery continues today with a 36 smelt/day bag limit for each permitted fisherman and limits the net size to 5 square feet. This location was monitored as a smelt fyke net station during the present study. The smelt catch at the Weweantic River station had low CPUE for Massachusetts rivers and a size composition dominated by the age-1 mode. MA DMF intends to initiate cooperative efforts with the Town of Wareham to ensure this unique southern smelt run can be sustained.

Following the net bans of the 19th and early 20th centuries, no smelt laws or regulations were made in Massachusetts until 1941 when three provisions were added to M.G.L. Chapter 130 that focused specifically on smelt fisheries. Section 34 of Chapter 130 standardized the spawning run ban for harvest during March 15 to June 16. Section 35 standardized the method of harvest to hook and line only in Massachusetts. Section 36 gave the Division of Marine Fisheries authority to close smelt spawning river beds to entry during the spawning season. Following these three laws, no changes to smelt regulations were made until 2009 when a daily bag limit of 50 smelt per angler was adopted. Unlike Maine and New Hampshire that drafted smelt management plans in the 1970s and 1980s, no such plan has been prepared in Massachusetts.

Declining recreational smelt catches in the 1980s prompted a review of the status of smelt fisheries and spawning runs by the MA DMF. A survey of all coastal drainages on the Gulf of Maine coast of Massachusetts was conducted from 1988-1995, during which 45 smelt spawning locations were documented and mapped in 30 coastal rivers (Chase 2006). The report for this survey included specific habitat and water quality recommendations for each smelt run. Following the survey, effort was directed toward acquiring smelt population data. A grant was received from NOAA's Office of Protected Resources to develop fyke net indices at six smelt runs during 2004-2005 (Chase et al. 2006). This approach and the six fyke net stations were adopted for the present study. These contemporary efforts, when compared to the historical records and fishery accounts from the 1960s and 1970s, present evidence of a sharp decline in Massachusetts smelt populations in the past 2-3 decades. Locations that once supported popular winter ice fisheries for smelt no longer have fisheries, and some known spawning runs have had no recent evidence of spawning activity.

### *Smelt Stocking Efforts*

The transfer of smelt eggs from larger donor smelt runs to smaller runs or rivers with no smelt spawning was a common practice late in the 19th century in Massachusetts, followed by a large dedicated effort during 1910 to 1920 (Kendall 1926). The ease with which smelt eggs could be collected and the appearance of large numbers of excess eggs in some settings contributed to the zeal behind decades of stocking. Unfortunately, documentation of responses to stocking is essentially absent, other than brief narratives in annual agency reports. Short-term increases in smelt spawning run size appear to have occurred in some systems, especially for coastal to inland lake transfers. However, no evidence can be found of long-term benefits of coastal to coastal river transfers. Smelt egg transfers continued periodically through the 1980s with strong sportfishing constituency support. Recent requests to stock smelt eggs led to a MA DMF evaluation that attempted to quantify the number of eggs transferred, egg survival and returning adult smelt (Chase et al. 2008). Returning spawning adults were documented in a pilot river with no smelt run during the first year of possible returns, but low egg survival and expected low recruitment concluded with MA DMF discouraging the use of smelt egg transfers and prioritizing passage, water quality, and habitat quality improvements over stocking as methods for restoring smelt populations. MA DMF presently does not support the use of egg transfers but is conducting a pilot study on the stocking of oxytetracycline marked larvae as a potential substitute for egg stocking in specific cases where population enhancement can be coupled with habitat improvements and monitoring.

### *Habitat Restoration*

The survey of smelt spawning habitat provided recommendations for specific habitat improvement projects (Chase 2006), four of which have since been conducted. Each of these projects has focused on improving spawning substrate. Two of these projects were able to take advantage of planned culvert replacements to add substrate improvements as part of the scope of work, while the other projects specifically targeted grant and mitigation funds to augment spawning substrate. The experience gained from these projects will assist future efforts in the region.

### *Recommendations*

1) Apply the information gained from the present study and recent smelt habitat improvement projects to identify potential restoration sites and design smelt spawning habitat improvements that meet the life history requirements of smelt. Projects that can remove barriers and extend habitat connectivity for smelt and other diadromous fish should be prioritized

2) Continue monitoring smelt fyke net stations from the present study that have been identified as having promise to support long-term indices of abundance (i.e., Weweantic River, Jones River, Fore River and Parker River). Improve and maintain data collection at fyke net stations to support future development of biological population benchmarks

3) Develop water quality criteria that relate to designated uses within the Massachusetts Wetlands Protection Act in order to protect the specific habitats of anadromous fish, including smelt spawning habitat

4) Conduct a smelt habitat survey of the Buzzards Bay region of Massachusetts that was not mapped during the previous Gulf of Maine survey in Massachusetts

5) Develop a state smelt conservation plan similar those completed for Maine (1976) and New Hampshire (1981)

### *New Hampshire*

The recreational smelt fishery in New Hampshire has been monitored and regulated for decades, and current fishing pressure is not believed to pose a major threat to the smelt population in the state. Ensuring that fishing pressure is compatible with a sustainable smelt population requires continuing monitoring efforts that are already underway, including creel surveys, spring spawning run surveys, and biological sampling during the ice fishery and young-of-the-year seine surveys. Current monitoring of the fishery does not capture recreational fishing for smelt that occurs in the fall prior to the onset of ice. There is also a limited hook and line commercial fishery for smelt in New Hampshire with local markets that is not well recorded. Developing surveys that obtain data from these portions of the fishery would be helpful for appropriately characterizing fishing related mortality. Currently, the daily limit for recreational smelt fishing is 10 liquid quarts, which is approximately equivalent to half of a 5 gallon bucket. Given that smelt is a species of concern, this limit would be re-evaluated if in the future fishing pressure is believed to pose a major threat to the population. Neighboring states of Maine and Massachusetts, which have larger smelt runs, have a daily limit of 2 quarts and 50 fish, respectively.

#### *Population monitoring*

The most current statewide fisheries management plan for rainbow smelt was written in 1981, but it predominately focuses on lake smelt populations. The objectives for smelt management were to maintain or increase the population of smelt and to provide for commercial and recreational fisheries. Management measures implemented following development of the plan included closure of the fishery to net or weir fishermen from March 1 to December 15, a 10 quart daily possession limit, and implementation of a smelt egg transfer program that occurred intermittently until 1991.

To evaluate the effectiveness of the management measures and detect trends in smelt abundance, an annual creel survey of the recreational ice fishery was implemented, and a smelt egg deposition index was developed. Data have been collected for the smelt egg index from 1979-2006. The intent of the index was to provide a fisheries independent relative measurement of spawning stock abundance. Validation of the index was attempted in 1993 by regressing it with catch per unit effort of the winter fishery, but results showed very poor correlation between the two. The Department also compared data from the creel survey with the abundance of young of the year (YOY) rainbow smelt collected via a seine survey that was initiated in 1997. This comparison resulted in a much stronger correlation with age-2 smelt CPUE from the creel survey. The Department discontinued egg deposition surveys in 2006 as a result of poor data correlation with other surveys, but will continue to monitor rainbow smelt through juvenile abundance surveys, creel surveys, as well as spawning surveys at the fyke net index stations that were implemented for this project.

### *Habitat Restoration*

Improving water quality in the Great Bay Estuary is expected to benefit smelt using New Hampshire waters. An increase in the concentration of dissolved nutrients and substantial increases in nutrient loading have been detected in the estuary in recent years. These observations prompted the New Hampshire Department of Environmental Services (NH DES) and the U. S. Environmental Protection Agency to develop nutrient criteria for the estuary. Applying these criteria will result in water quality being classified as impaired in the entire estuary, including all of its tributaries. These noted nutrient increases have the potential to spur periphyton growth, which may reduce the viability and hatching of smelt eggs, as discussed in section 2.2 – Threats to Embryonic Survival and Development. The current nutrient criteria assessment is motivating local action to reduce nutrient loading, which should result in improved water quality and reduced periphyton during the smelt spawning season.

Habitat assessment and restoration are key conservation strategies that will be pursued in New Hampshire to enhance spawning conditions for smelt. While main stem spawning habitats are well known in the major tributaries to Great Bay, a comprehensive assessment of other potential spawning locations in smaller tributaries would be beneficial. Habitat improvement projects that would benefit smelt include mitigating siltation and removing head-of-tide dams to increase the amount of freshwater area available for spawning. Currently most spawning in New Hampshire occurs in intertidal areas. Intertidal bars have developed in some tributaries following recent flood events; smelt eggs are deposited on these rocky bars and are then exposed to air at low tide. Grading of these bars to minimize their intertidal exposure would reduce egg mortality.

In addition, head-of-tide dams currently block smelt migration on most of the major tributary rivers to Great Bay. One of these obstructions has recently been removed; the dam in place for 55 years on the Winnicut River in Greenland, NH, was recently demolished, restoring spawning habitat for smelt. Following the dam's construction in 1957, there was a steady decline of a once well-known large smelt run. Other head-of-tide dams in the Great Bay Estuary are under consideration for removal. The potential benefits to smelt will be a key factor in deliberations about the future options for these dams.

Finally, siltation in some rivers has reduced smelt spawning habitat. Dam removal should increase stream flows and help remove accumulated sediments, and actions to reduce nutrient inputs will also reduce sediment inputs to the Great Bay Estuary and its tributaries. These actions should improve smelt spawning habitat conditions in the tributaries.

*Recommendations:*

1) Continue monitoring efforts in place including: winter creel survey, juvenile abundance seine survey, spring spawning run fyke net sampling
2) Improve water quality and support NH DES in developing nutrient criteria for Great Bay Estuary
3) Identify habitat restoration projects to enhance smelt spawning conditions.
4) Continue to support dam removal projects to connect smelt to historical spawning habitats
5) Conduct a smelt spawning habitat assessment of coastal areas in New Hampshire.

### Maine

Through this project, we have found that while rainbow smelt populations are contracting rapidly in range, there are still strong populations in Maine. However, our surveys have also shown that smelt populations in the state are not as strong as previous Department studies have found. Comparing the number and strength of spawning runs currently to that of the late 1970's, we have found that many runs have declined, while others are extirpated (see section 1.3 – Population Status). Data collected during our fyke net survey and creel surveys has also shown that length at age has declined compared to historical records in upper Casco Bay and Kennebec River populations. Because smelt continue to support an economically important and sizable recreational fishery in Maine, as well as a locally economically important commercial fishery in Washington County, it is imperative to pursue management measures that will sustain and restore this species.

#### *Continue monitoring smelt populations at multiple life stages*

The state surveys that are currently in place target four important life history stages for rainbow smelt. The annual fyke net survey, which began in 2008, monitors the adult spawning runs at six index sites spanning the Maine coast. From this survey, we collect information about the inter-annual variability of the spawning stock, the strength of age classes, and mortality rates. The genetic information combined with movement and habitat studies show that while adult smelt may not home to the same stream each year, they do show fidelity to larger bay and estuary areas. Thus, by monitoring adult smelt during the spawning season, we can observe changes in a specific stock over time. The other surveys do not have this ability. While the inshore trawl survey can track relative population abundance over time, it likely catches mixed genetic stocks and annual CPUEs may be skewed by stock variability.

The creel survey that targeted the Kennebec River and Merrymeeting Bay beginning in 2009 was expanded with the help of the Downeast Salmon Federation in 2010 to survey anglers on the Pleasant and Narraguagus rivers. Flagg (1984) estimated an extraction rate of less than 5% on the Kennebec River in the late 1970s. However, the population during that time period was likely larger than at present (see section 1.3 – Population Status in the Gulf of Maine); the fishery may have a more significant effect when population levels are low. Given the cultural and economic value of these fisheries, the creel survey should be expanded to target aggregations of fishing camps in other locations (e.g., Great Salt Bay on the Damariscotta River), and efforts should be made to repeat the mark-recapture survey performed by Flagg (1984) to determine a current extraction rate.

The juvenile abundance survey is extremely important in understanding the reproductive success and early life stage survival in the Kennebec River and Merrymeeting Bay. Because we also monitor adult populations in this river system through creel surveys, it may be possible to compare data from the two surveys to quantitatively link adult winter catches to late summer juvenile abundance as NHF&G has been able to do. Additionally, by further understanding how juvenile abundance varies between river segments, we may be able to identify important juvenile habitat.

### *Improving connectivity and access to spawning grounds*

*Local smelt runs may be affected by a combination of factors, including habitat degradation, access problems, and current fishing practices.*

In many locations where smelt runs have historically declined or disappeared on the Maine coast, the decline is due to the inability of smelt to reach the spawning grounds. Road crossings on small coastal streams are often provided by undersized or hanging culverts or by small historic water control dams that no longer have purpose. Undersized culverts present problems when velocities increase during rain events because the water is constricted to a width smaller than the natural streambed. Because smelt are not strong swimmers, high water velocities can impede their ability to swim through the culvert, and thus to reach their spawning grounds. Hanging culverts (those where the downstream water level is lower than the culvert height) and dams that are downstream of the spawning grounds completely block access. Unlike other anadromous fishes (e.g., alewife and salmon) that can ascend fish ladders or jump vertical obstructions, smelt are unable to pass vertical obstructions over six inches.

State agencies in Maine, including ME DMR, are currently working to catalogue such obstructions and prioritize which should be removed or redesigned to allow for anadromous fish passage. As part of this effort, a web-based tool will be publicly available so that municipalities and land trust organizations can identify road crossings in their area where improvements could re-establish smelt habitat access. In many cases, removing these barriers can have immediate effects in opening smelt spawning passage into a stream when strong runs exist nearby. If this is not the case, stock enhancement may be considered in the absence of other habitat degradation. The ME DMR will continue to work with other state agencies, municipalities, and non-governmental organizations to identify barriers to historical smelt habitat and restore access.

### *Assessing causes for local decline*

Some smelt populations in Maine have declined or become extirpated, while others remain strong. In some cases, local declines can be attributed to historical overfishing; however, habitat degradation, access problems, and current fishing practices may also be impacting smelt populations in the state.

Effective stormwater management techniques can reduce the impact of development on water quality in urbanized watersheds in the state. As an example, the Maine Department of Environmental Protection has worked with the South Portland Water District and businesses within the Long Creek watershed to build stormwater retention areas that reduce the amount of nutrients and contaminants flowing directly into the stream. While the stream quality still shows the effects of development, impairment is reduced and the stream is able to support a limited smelt spawning run. Because this regional smelt project has found that development within a watershed can impact water quality to the point where smelt embryonic health and survival are impaired, watershed management efforts that reduce runoff into receiving streams are recommended in urbanized or developing watersheds.

Current fishing regulations regarding anadromous rainbow smelt limit take by season and location. Recreational fishing is allowed July 1 through March 14; there is no catch limit, but the gear is restricted to hook and line or dip net. During the spawning season (March 15 through June 30), take is limited to two quarts per person per day, and it is predominantly a dip net fishery. While the state Marine Patrol does actively enforce this regulation regarding gear and catch limitations, the number of violations that go without reprimand is unknown. Further, it is currently unknown what impact the recreational fishery may have on smelt populations. With the creel survey of the ice fishery beginning again in 2009, the ME DMR now has the opportunity to assess the extraction rate of the winter fishery and determine if a limit on take is necessary. However, at this point there is no survey of the spring dip net fishery; the effect of fishing mortality during the spawning season and the subsequent loss of possible embryos is unknown. Future work should include an effort to quantify fishing mortality due to both the recreational winter and spring fishery. In locations where there is evidence of stressed smelt runs, management action should be considered to limit mortality during spawning runs.

Commercial fishing for smelt is allowed in only six tidal rivers in the state, all in Washington County: the East Machias, Pleasant, and Narraguagus rivers from January 1 through April 10, without any limit on quantity; and the Indian, Harrington, and Chandler rivers with no limit on quantity or time period. Anyone fishing commercially for smelt must possess a Pelagic License from the ME DMR. With possession of this license, the fisherman is required to submit landings data to the ME DMR. The ME DMR is working with Downeast Salmon Federation to survey the biological composition of the catches to determine if the fishery may be impacting life history or age structure. This collaboration is necessary to monitor the fishery, and should continue in the future. If over time there is evidence of smelt population decline in this region or evidence that the commercial fishery may be contributing to a high mortality, management actions should address the fishing effort possibly by limiting take or further gear restrictions.

### *Marked larval stocking at monitored sites*

As part of this project, the ME DMR revisited historical spawning runs to document their current status and found that many sites no longer support spawning or support only limited runs (see section 1.3 – Population Status in the Gulf of Maine). When the decline at these sites can be attributed to historical fishing pressure that no longer exists or to habitat degradation or passage constraints that have been addressed, larval stocking may be an option to reintroduce smelt.

Adapting methods by Ayer et al. (2012), the ME DMR began a project to restore rainbow smelt populations to North Haven, Maine, an island in the center of Penobscot Bay that supported robust smelt populations up until the 1950s. After visits by ME DMR to identify the most appropriate stream for the project, the North Haven Community School completed pre-monitoring and found no water quality impairments that would affect smelt embryo survival. In spring 2012, the ME DMR and school worked together to mark larvae with oxytetracycline (OTC) for release at the stream. The school and ME DMR will continue to monitor adult returns in subsequent years to determine the success of the project. Following this model, the ME DMR hopes to continue to re-establish smelt populations at sites where restoration projects have improved habitat quality or connectivity. However, habitat restoration must always precede any stocking efforts.

### *Recommendations*

With continued population monitoring and threat assessment in collaboration with fisheries managers, university scientists, recreational and commercial fishermen, and interested citizens, the rainbow smelt populations in Maine could be maintained or possibly expanded. To this end, the ME DMR has begun to implement restoration efforts, including a stocking project in North Haven and assessment of culvert replacements that would provide access to historical habitat. Future work in the state of Maine to protect this species of concern should include:

1) Continuing monitoring of smelt populations through fyke net sampling, creel surveys, the inshore trawl survey, and the juvenile abundance survey
2) Developing a mark-recapture study to estimate the current extraction rate of recreational ice fishing on the Kennebec River and Merrymeeting Bay and other rivers and embayments that support recreational ice fishing
3) Restoring stream connectivity and access to historical spawning grounds with monitoring to assess pre- and post-construction conditions and smelt populations
4) Assessing threats to smelt habitat and evaluating connections between degraded habitat and local smelt population decline
5) Stocking rainbow smelt larvae marked with oxytetracycline into historical smelt spawning streams that maintain good habitat, while maintaining the genetic structure as identified by this project and annually monitoring stocking success.

*With continued population monitoring and threat assessment in collaboration with fisheries managers, university scientists, recreational and commercial fishermen, and interested citizens, rainbow smelt populations could be maintained or possibly expanded.*

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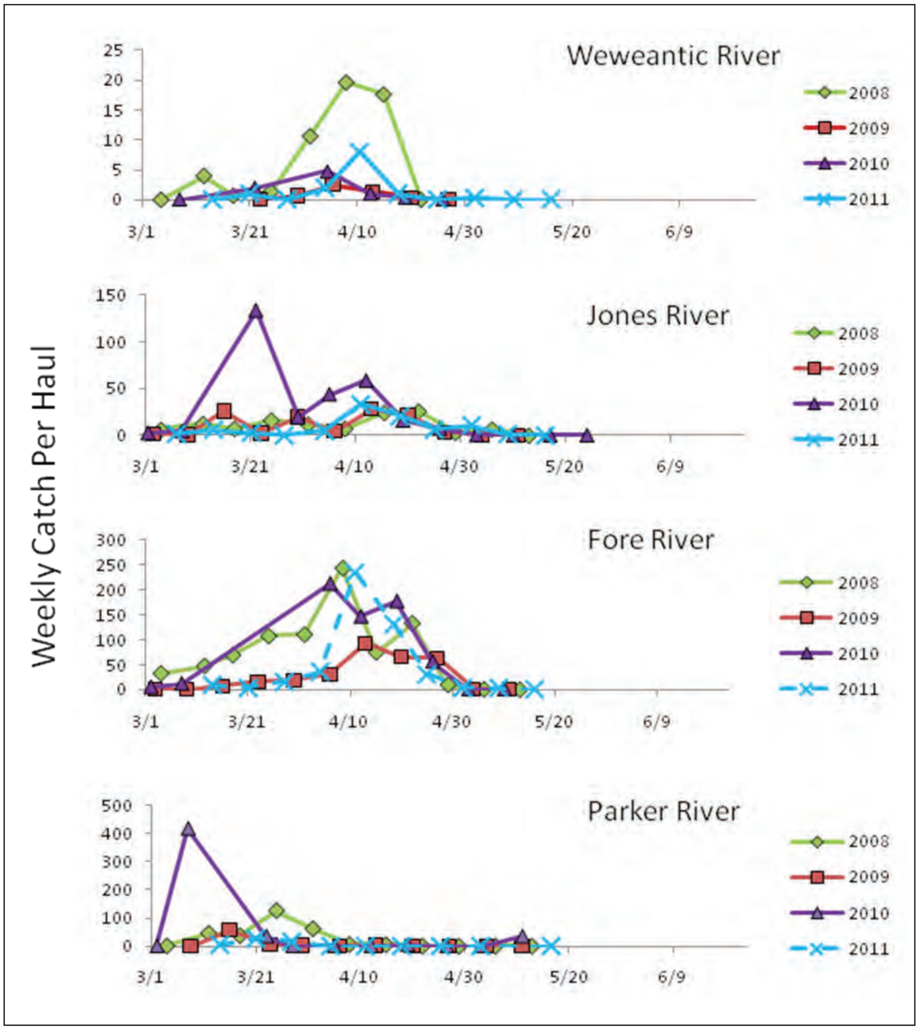


*Figure A.1.1. Catch-per-unit-effort (number of smelt per haul) at selected Massachusetts fyke net stations, 2008-2011.*

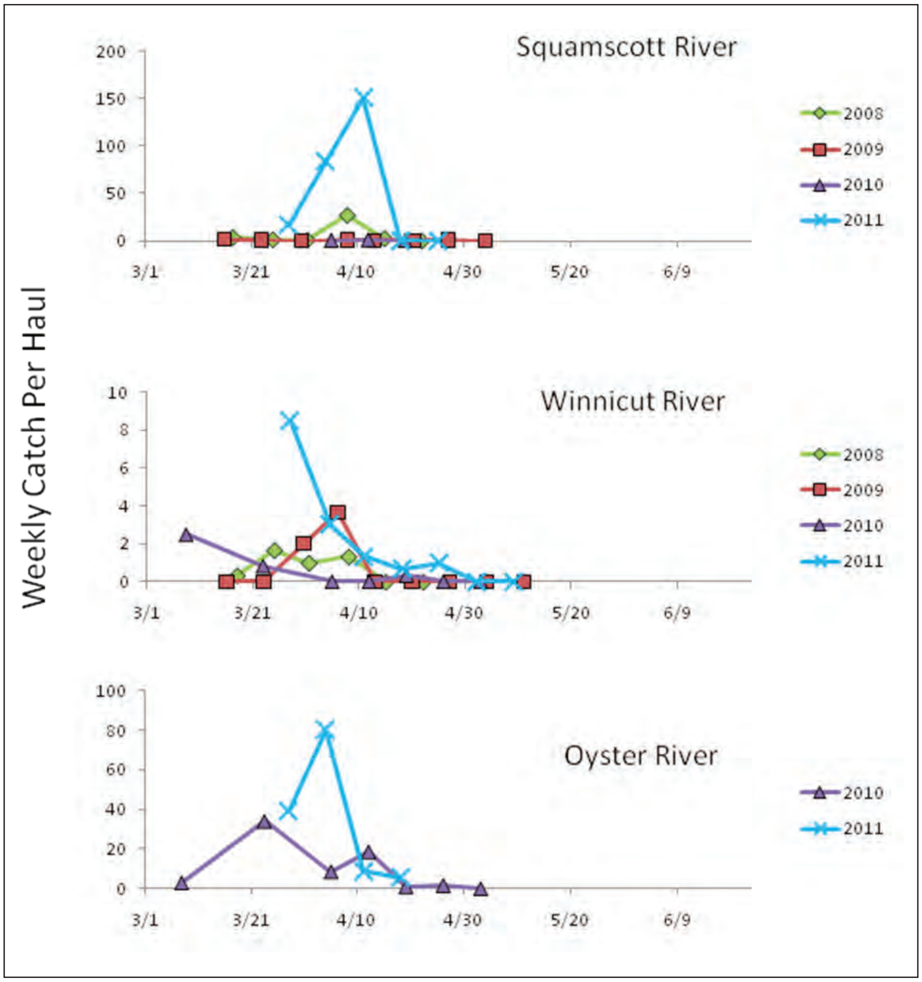


*Figure A.1.2. Catch-per-unit-effort (number of smelt per haul) at New Hampshire fyke net stations, 2008-2011.*

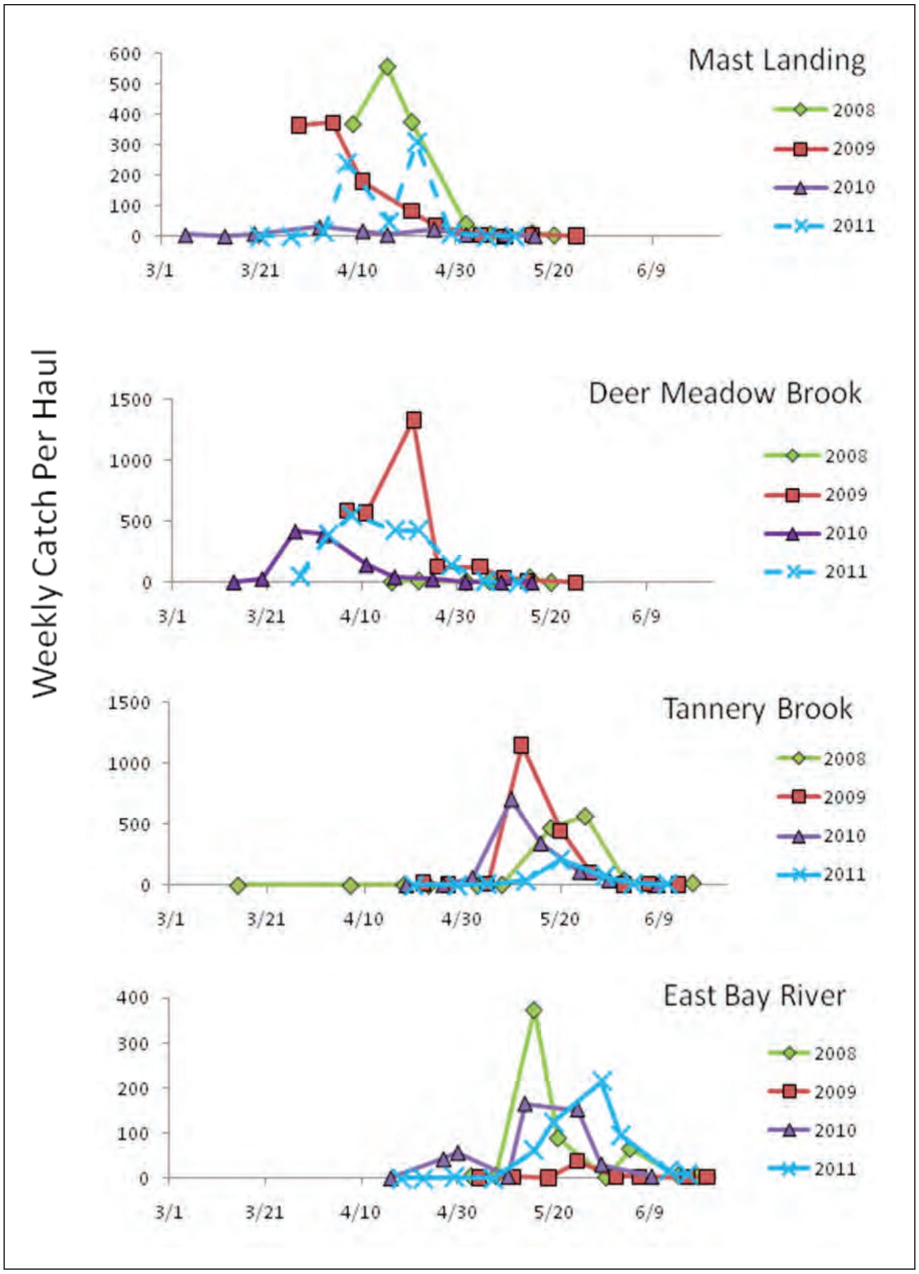


***Figure A.1.3. Catch-per-unit-effort (number of smelt per haul) at selected Maine fyke net stations, 2008-2011.***

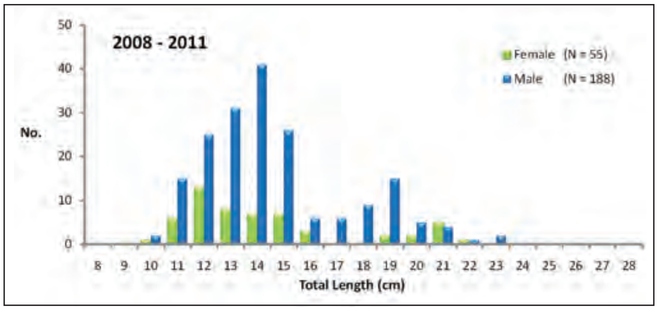


*Figure A.1.4. Length frequency of rainbow smelt caught in the Weweantic River, MA, fyke net, 2008-2011.*

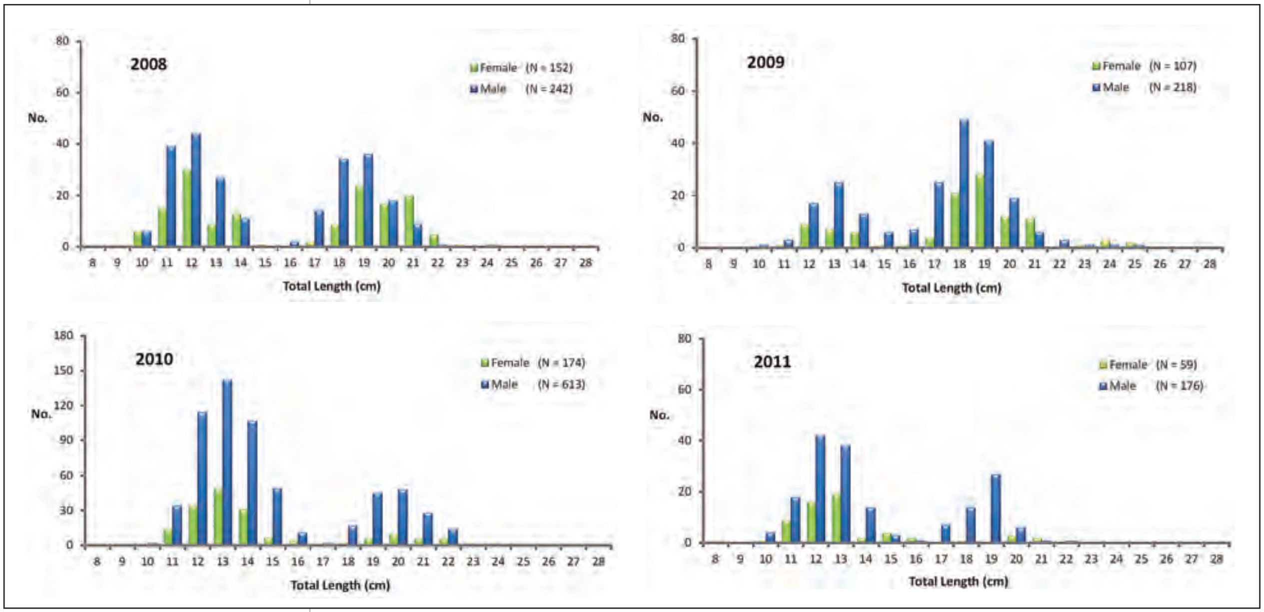


*Figure A.1.5. Length frequency of rainbow smelt caught in the Jones River, MA, fyke net, 2008-2011.*

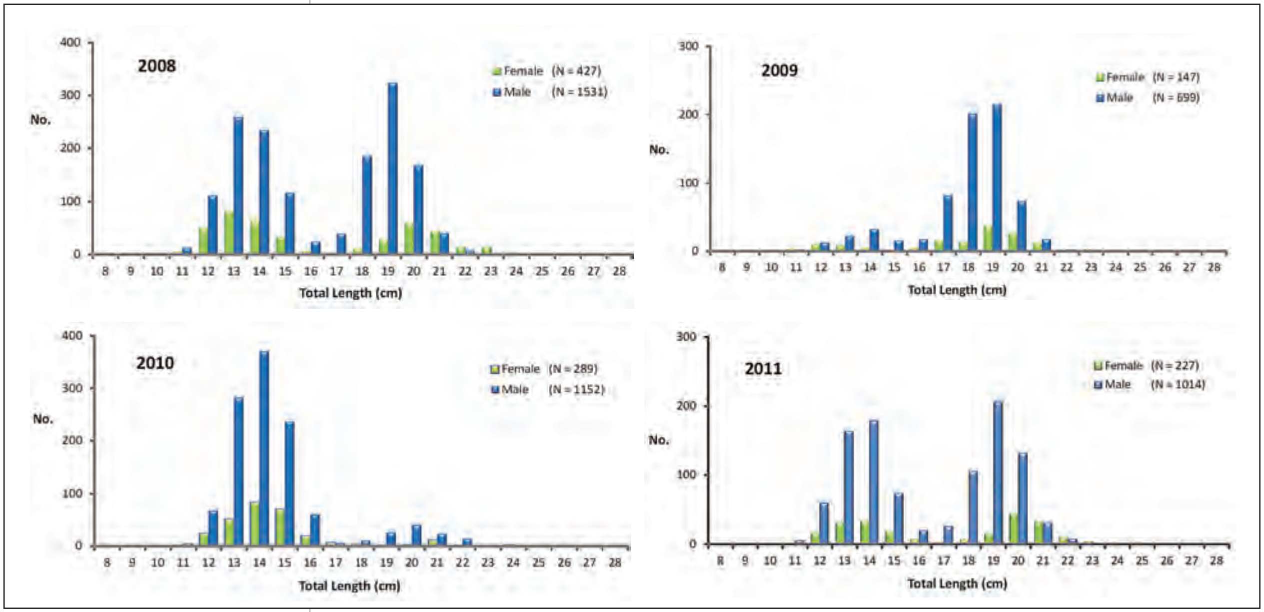


*Figure A.1.6 Length frequency of rainbow smelt caught in the Fore River, MA, fyke net, 2008-2011.*

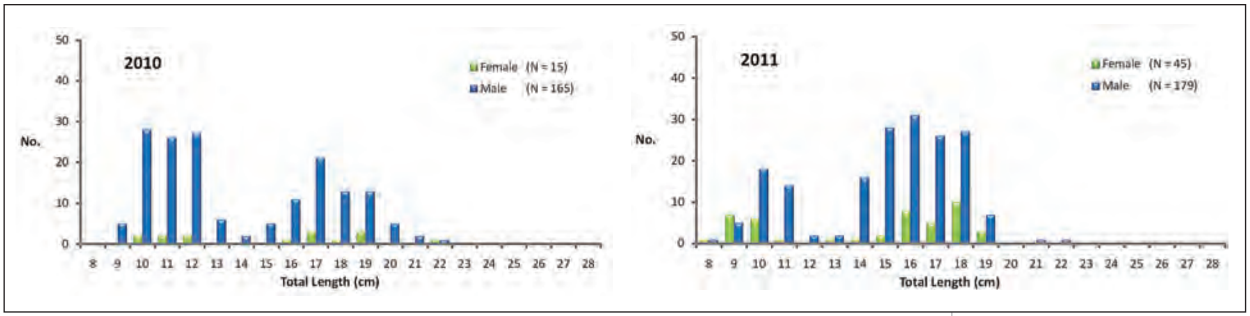


*Figure A.1.7. Length frequency of rainbow smelt caught at the Oyster River, NH, fyke net, 2010-2011.*

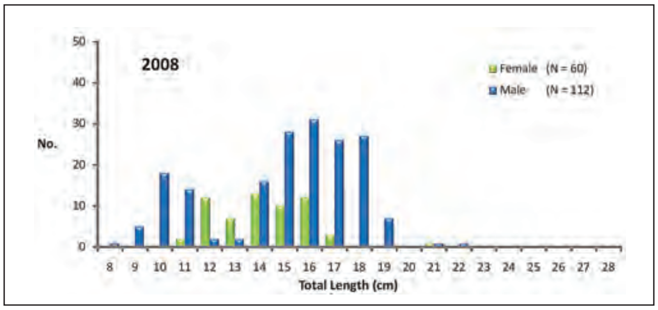


*Figure A.1.8. Length frequency of rainbow smelt caught at the Lamprey River, NH, fyke net, 2008.*

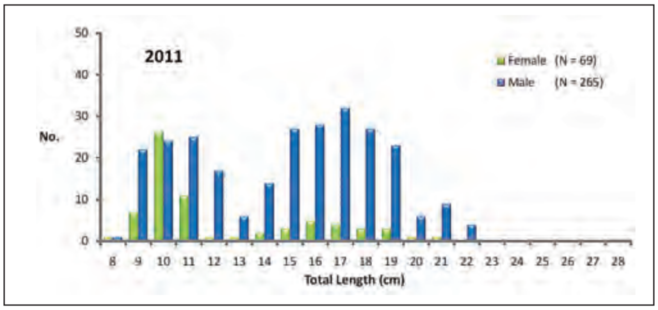


*Figure A.1.9. Length frequency of rainbow smelt caught at the Squamscott River, NH, fyke net, 2011*

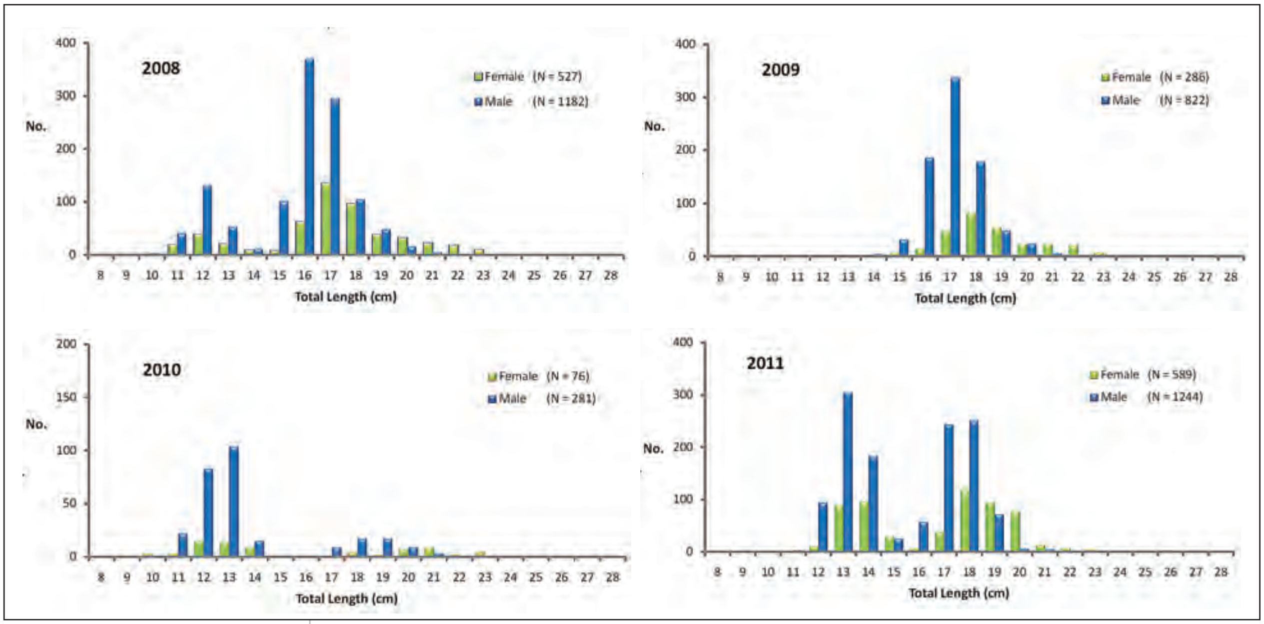


*Figure A.1.10. Length frequency of rainbow smelt caught at Mast Landing, ME, fyke net, 2008-2011.*

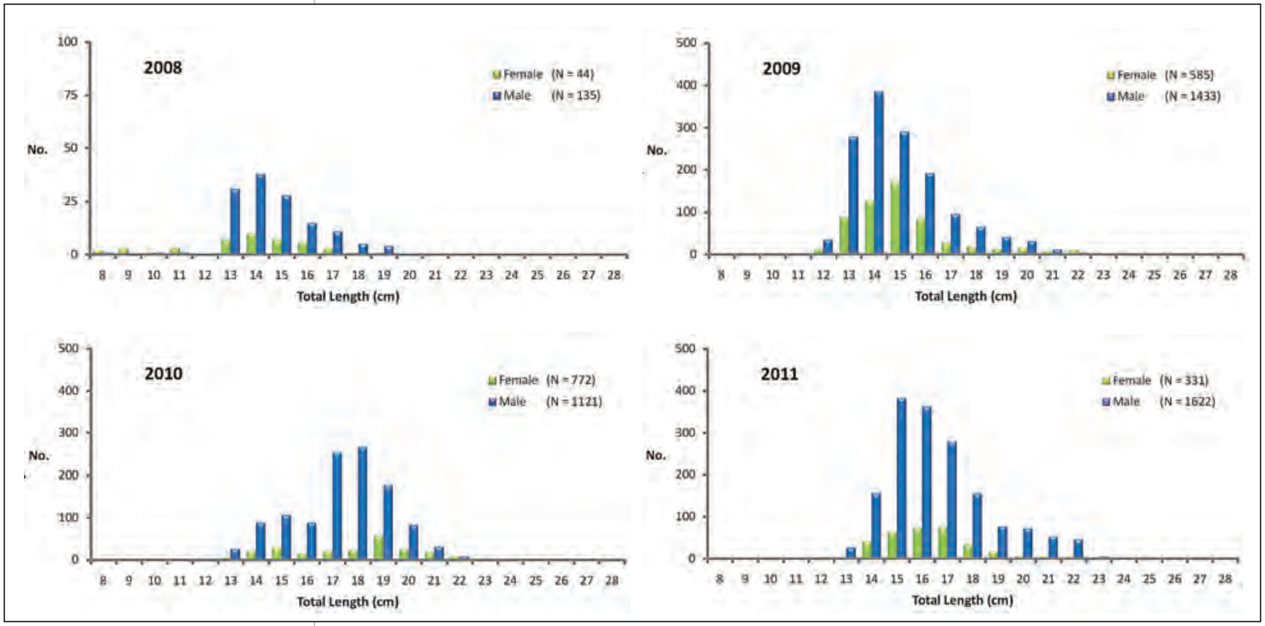


*Figure A.1.11. Length frequency of rainbow smelt caught at Deer Meadow Brook, ME, fyke net, 2008-2011.*

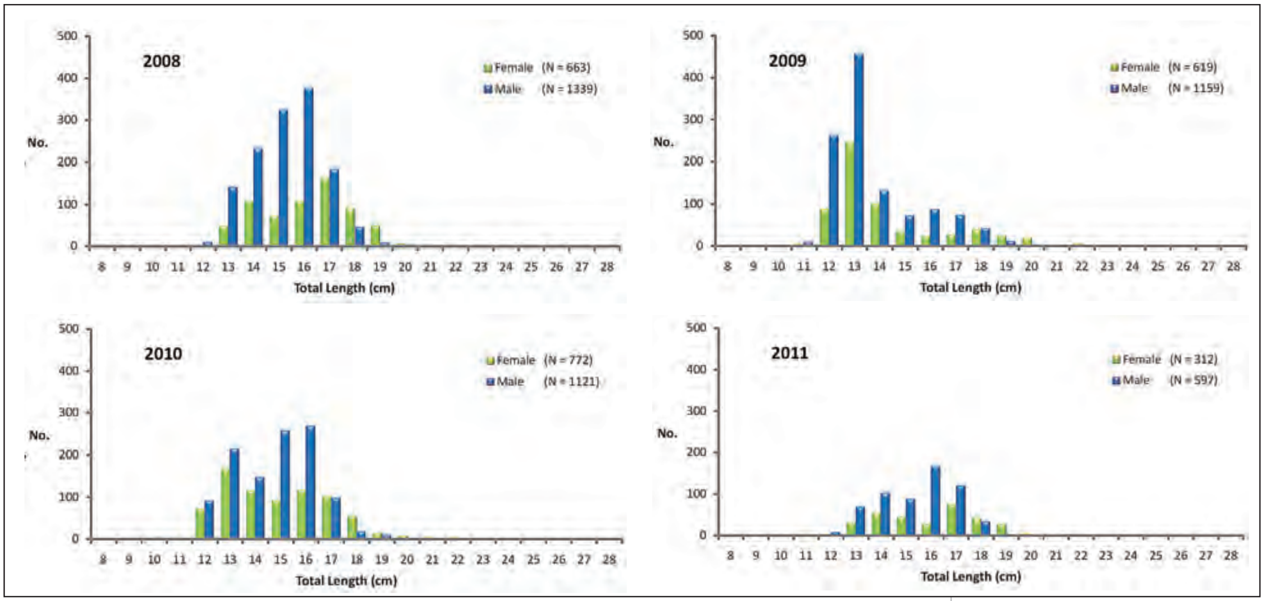


*Figure A.1.12. Length frequency of rainbow smelt caught at Tannery Brook, ME, fyke net, 2008-2011.*

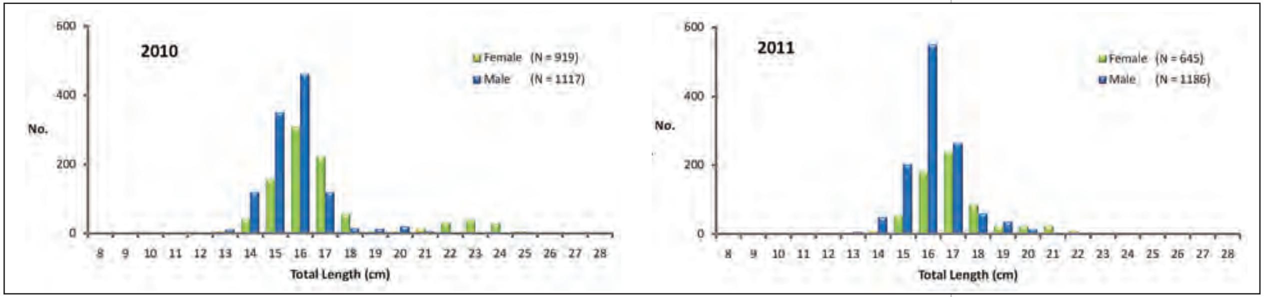


*Figure A.1.13. Length frequency of rainbow smelt caught at Schoppee Brook, ME, fyke net, 2010-2011.*

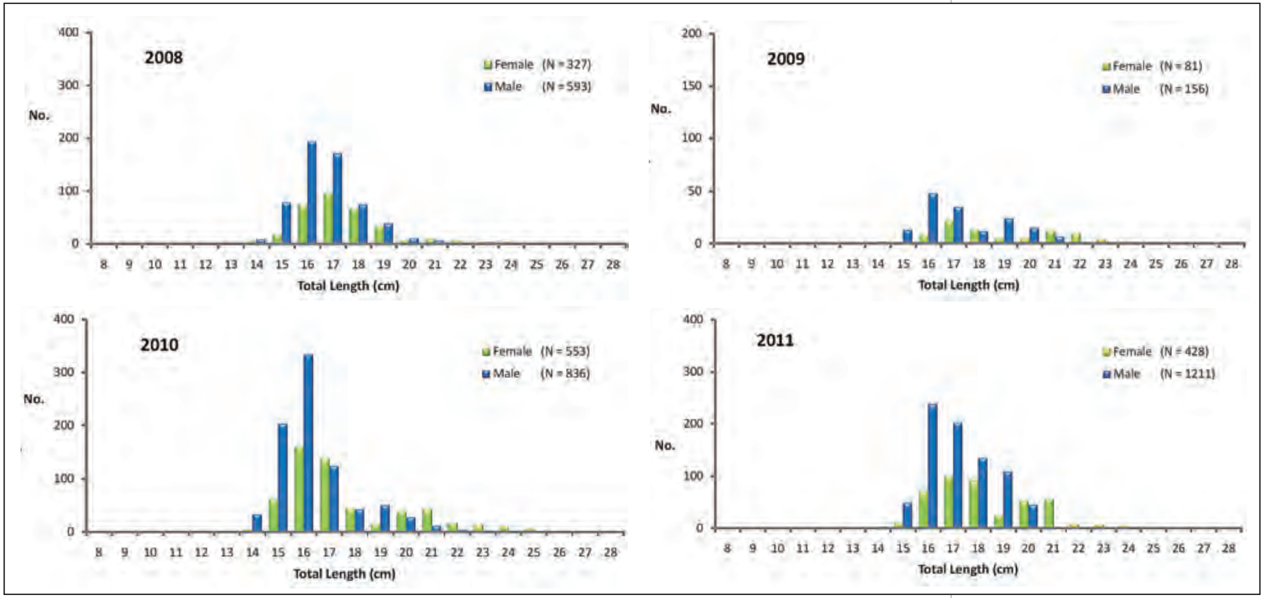


*Figure A.1.14. Length frequency of rainbow smelt caught at East Bay Brook, ME, fyke net, 2008-2011.*

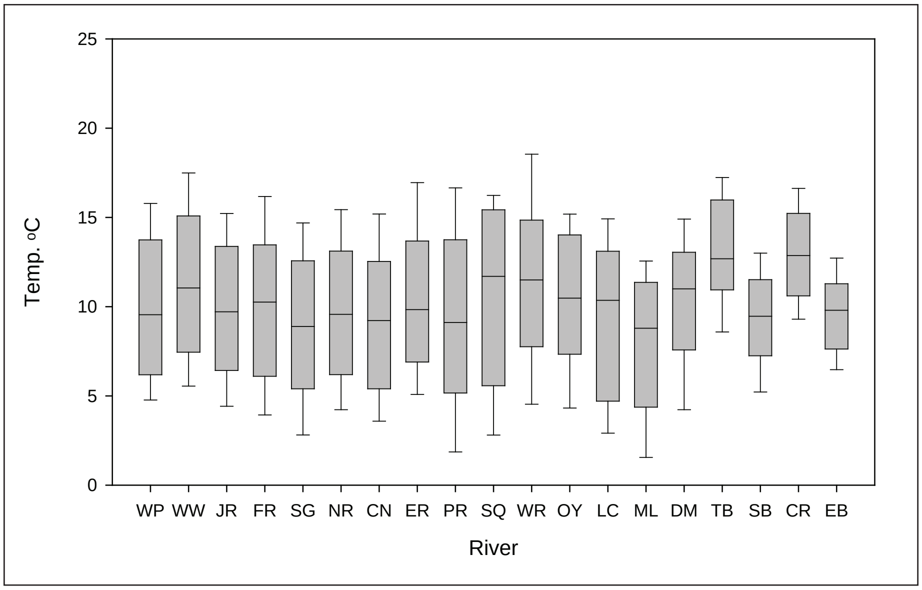


*Figure A.2.1. Water temperature data distributions for 19 smelt sampling stations in study area. The top of the box plots is the 75th percentile and the bottom is the 25th percentile. The line within the box is the median and the error bars represent the 10th and 90th percentiles. The stations are arranged on the x-axis from the southernmost MA station to the northernmost ME station. Station medians were found to be significantly different with Kruskal-Wallis test (KW = 93.21, df = 18, p < 0.001).*

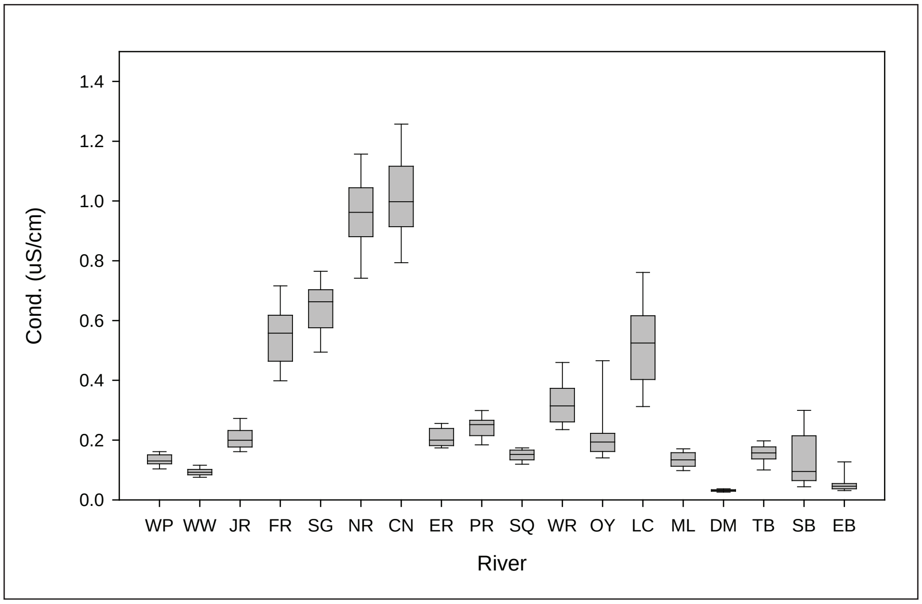


*Figure A.2.2. Specific conductivity data distributions for 18 smelt sampling stations in study area. The top of the box plots is the 75th percentile and the bottom is the 25th percentile. The line within the box is the median and the error bars represent the 10th and 90th percentiles. The stations are arranged on the x-axis from the southernmost MA station to the northernmost ME station. Station medians were found to be significantly different with Kruskal-Wallis test (KW =1374.4, df = 17, p < 0.001).*

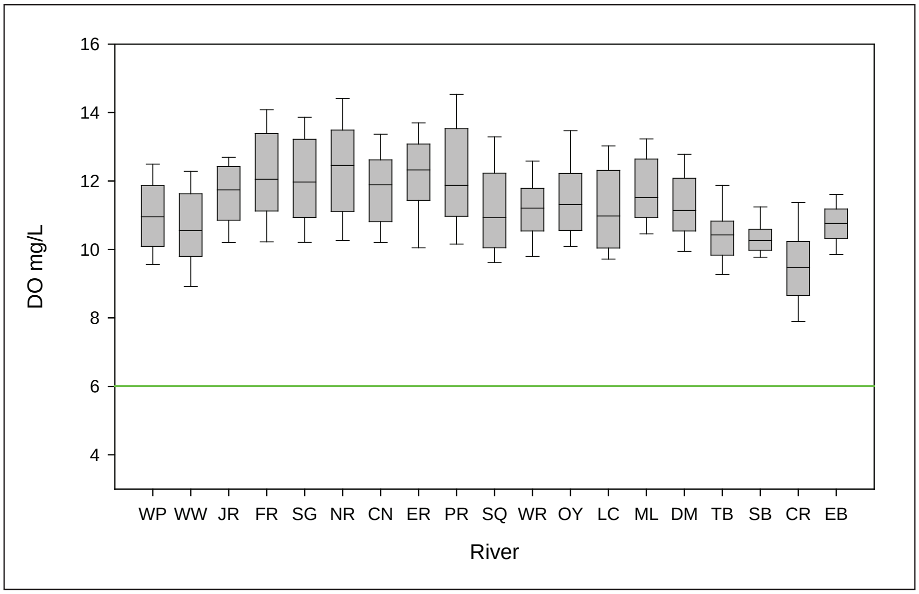


*Figure A.2.3. Dissolved oxygen (mg/L) data distributions for 19 smelt sampling stations in study area. The top of the box plots is the 75th percentile and the bottom is the 25th percentile. The line within the box is the median and the error bars represent the 10th and 90th percentiles. The stations are arranged on the x-axis from the southernmost MA station to the northernmost ME station. Station medians were found to be significantly different with Kruskal-Wallis test (KW = 439.51, df = 18, p < 0.001). The green line marks the MassDEP DO criterion (6.0 mg/L) for protecting Aquatic Life.*

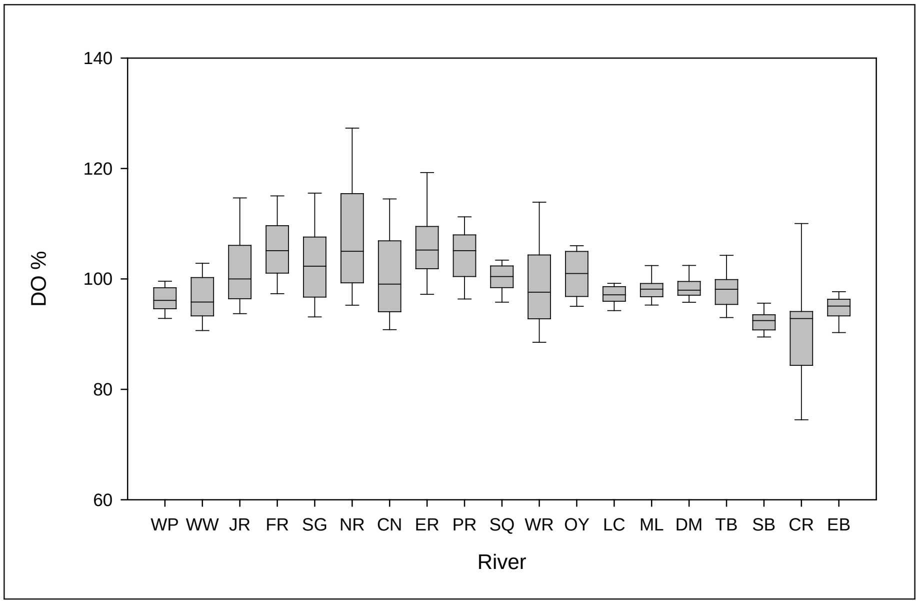


*Figure A.2.4. Dissolved oxygen (% saturation) data distributions for 19 smelt sampling stations in study area. The top of the box plots is the 75th percentile and the bottom is the 25th percentile. The line within the box is the median and the error bars represent the 10th and 90th percentiles. The stations are arranged on the x-axis from the southernmost MA station to the northernmost ME station. Station medians were found to be significantly different with Kruskal-Wallis test (KW = 439.51, df = 18, p < 0.001).*

*Figure A.2.5. Water pH data distributions for 19 smelt sampling stations in study area. The top of the box plots is the 75th percentile and the bottom is the 25th percentile. The line within the box is the median and the error bars represent the 10th and 90th percentiles. The stations are arranged on the x-axis from the southernmost MA station to the northernmost ME station. Station medians were found to be significantly different with Kruskal-Wallis test (KW = 1041.3, df = 18, p < 0.001). The green lines mark the lower MassDEP pH criterion (≥6.5 and ≤ 8.3) for protecting Aquatic Life.*

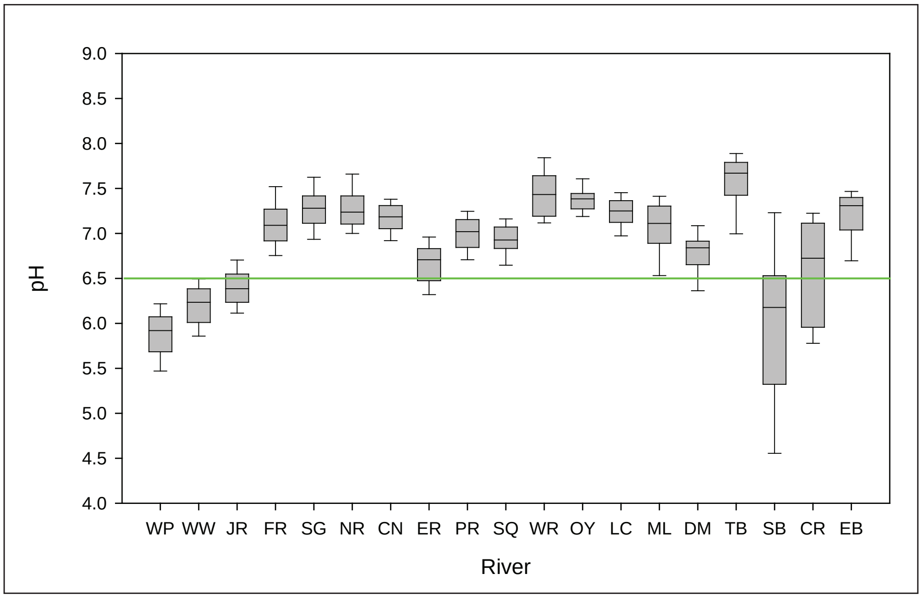
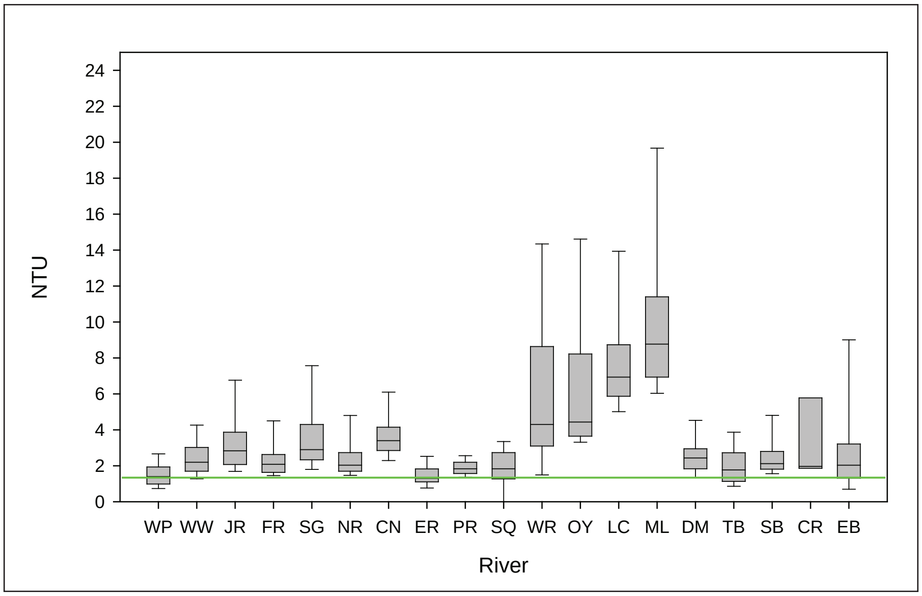


*Figure A.2.6. Turbidity (NTU) data distributions for 19 smelt sampling stations in study area. The top of the box plots is the 75th percentile and the bottom is the 25th percentile. The line within the box is the median and the error bars represent the 10th and 90th percentiles. The stations are arranged on the x-axis from the southernmost MA station to the northernmost ME station. Station medians were found to be significantly different with Kruskal-Wallis test (KW = 660.8, df = 18, p < 0.001). The green line marks the EPA turbidity criterion for minimally impacted water quality (≤ 1.7 NTU).*



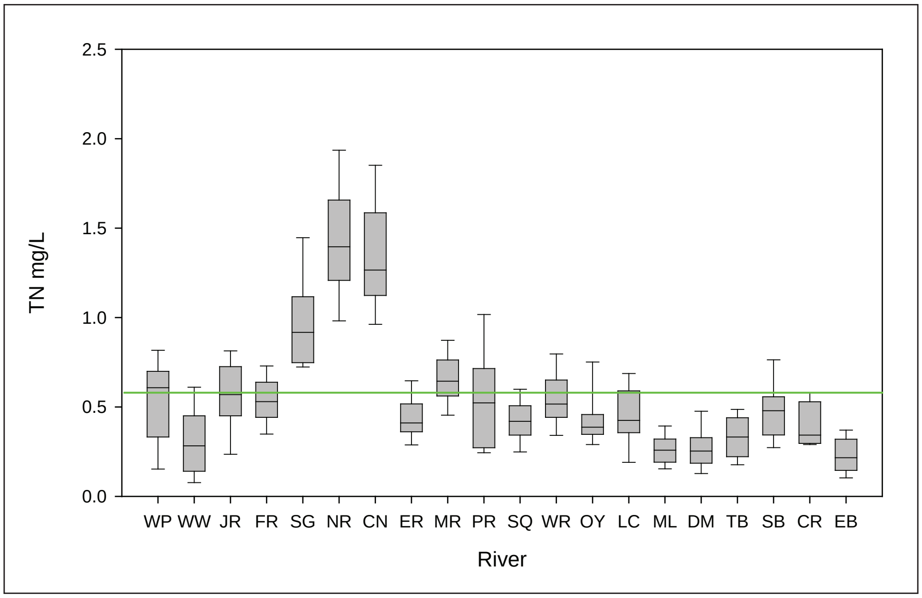


*Figure A.2.7. Total nitrogen (TN) data distributions for 20 smelt sampling stations in study area. The top of the box plots is the 75th percentile and the bottom is the 25th percentile. The line within the box is the median and the error bars represent the 10th and 90th percentiles. The stations are arranged on the x-axis from the southernmost MA station to the northernmost ME station. Station medians were found to be significantly different with Kruskal-Wallis test (KW = 408.4, df = 19, p < 0.001). The green line marks the EPA total nitrogen criterion for minimally impacted water quality (≤ 0.57 mg/L).*

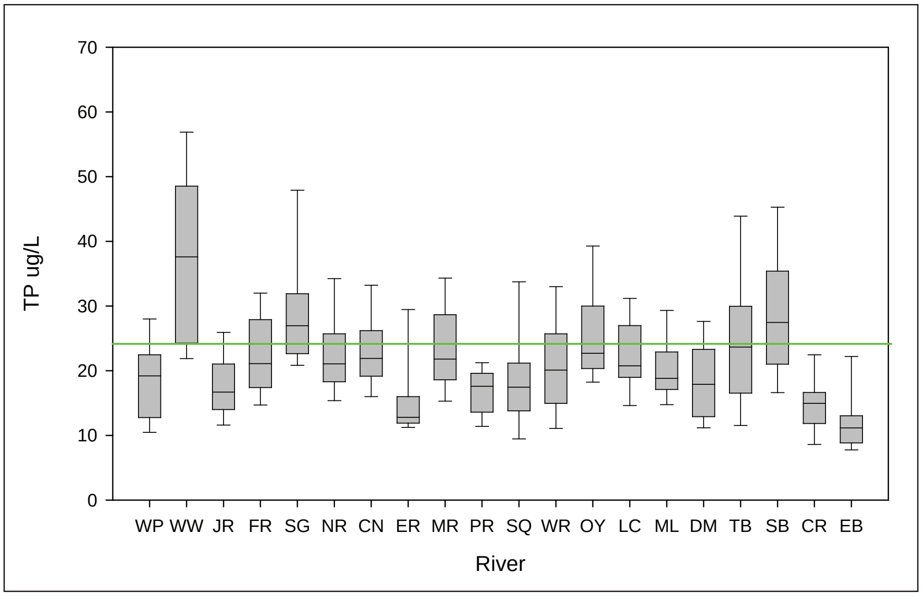


*Figure A.2.8. Total phosphorus (TP) data distributions for 20 smelt sampling stations in study area. The top of the box plots is the 75th percentile and the bottom is the 25th percentile. The line within the box is the median and the error bars represent the 10th and 90th percentiles. The stations are arranged on the x-axis from the southernmost MA station to the northernmost ME station. Station medians were found to be significantly different with Kruskal-Wallis test (KW = 174.7, df = 19, p < 0.001). The green line marks the EPA total phosphorus criterion for minimally impacted water quality (≤ 23.75 ug/L).*

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