## PROGRESS REPORT

**State**: NEW HAMPSHIRE **Grant**: F-61-R-24/F21AF00591

**Grant Title**: NEW HAMPSHIRE'S MARINE FISHERIES INVESTIGATIONS

**Project I**: **DIADROMOUS FISH INVESTIGATIONS**

**Job 2**: **MONITORING OF RAINBOW SMELT SPAWNING ACTIVITY**

Objective: To annually monitor the Rainbow Smelt *Osmerus mordax* resource using fishery independent techniques during their spawning run in the Great Bay Estuary.

Period Covered: January 1, 2021 - December 31, 2021


ABSTRACT

Between January 1, 2021 and December 31, 2021, the New Hampshire Fish and Game Department conducted one investigation to monitor the Rainbow Smelt *Osmerus mordax* resource using fishery independent techniques during their spawning run in the Great Bay Estuary and possibly implement strategies that restore and maintain populations of Rainbow Smelt to historic levels. In 2021, a total of 1,389 Rainbow Smelt (140 in Oyster River, 260 in Winnicut River, and 989 in Squamscott River) were caught in fyke nets. The CPUE in 2021 was highest in the Squamscott River with 8.27 smelt per day, whereas the Oyster River (4.68 smelt per day) and Winnicut River (2.54 smelt per day) were lower. A male-skewed sex ratio was observed at all rivers, a likely result of differences in spawning behavior between sexes. The age distribution of captured Rainbow Smelt, weighted by total catch, was highest for age-2 fish, followed by age-3, age-4, and age-1 fish. Most water quality measurements (temperature, dissolved oxygen, specific conductivity, and pH) were within or near acceptable ranges for successful smelt spawning and egg incubation and development in 2021; however, turbidity was above the threshold in the Oyster River for most days monitored.


INTRODUCTION

Rainbow Smelt *Osmerus mordax* are small anadromous fish that live in nearshore coastal waters and spawn in the spring in tidal rivers immediately above the head of tide in freshwater (Kendall 1926; Murawski et al. 1980;

Buckley 1989). Anadromous smelt serve as important prey for commercial and recreational culturally valuable species, such as Atlantic Cod *Gadus morhua*, Atlantic Salmon *Salmo salar*, and Striped Bass *Morone saxatilis* (Clayton et al. 1978; Kircheis and Stanley 1981; Stewart et al. 1981; Kirn 1986; O'Gorman et al. 1987). The range of smelt historically extended from Chesapeake Bay to Labrador (Kendall 1926; Buckley 1989); but over the last century, the range has contracted and smelt are now only found east of Long Island Sound, and recent studies suggest it may only extend as far south as Buzzards Bay, Massachusetts (Enterline et al. 2012a).

Rainbow 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-2, 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 (MA), New Hampshire (NH), and southern Maine (ME), age-1 individuals are present in the spawning runs (Collette and Klein-MacPhee 2002). Clayton (1976) reported fecundity estimates of approximately 33,000 eggs for age-2 smelt and 70,000 eggs for age-3 smelt.

Concerns have risen about the population status of smelt in recent years. High numbers of smelt that once supported commercial fisheries in New England have declined precipitously since the late 1800s to mid-1900s (Enterline et al. 2012a). While recreational fisheries for smelt continue, declining catches have been noted by anglers, particularly since the 1980s. A winter creel survey has been conducted in NH since 1978 and while fishing effort (angler hours) fluctuates on an annual basis, it has been generally declining since 2003 (See Project II-1).

The National Oceanic and Atmospheric Administration (NOAA) listed Rainbow Smelt as a federal Species of Concern in 2004 as a result of over-harvest, water quality and habitat degradation, inaccessibility to spawning grounds, and possible disease issues. New Hampshire also lists anadromous smelt as a Species of Special Concern. Although smelt population declines have been widely documented, the causes are not well understood. In the federal listing of smelt, factors identified in MA as potential contributors included structural impediments to their spawning migration (such as dams and blocked culverts) and chronic degradation of spawning habitat due to storm water inputs that include toxic contaminants, nutrients, and sediment (Chase and Childs 2001).

Following NOAA's designation of Rainbow Smelt as a Species of Concern, the ME Department of Marine Resources received a six-year grant from NOAA's Office of Protected Resources to work in collaboration with the MA Division of

Marine Fisheries and NH Fish and Game Department to document the status of and develop conservation strategies for smelt (NA06NMF4720249). Standardized procedures for indexing the abundance of spawning smelt were developed. Four years of fyke net sampling (2008-2011) during spawning runs throughout the Gulf of Maine region 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 indicate that Gulf of Maine smelt populations are currently stressed.

Many threats to Rainbow Smelt spawning habitat were identified as part of the study. Obstructions such as dams and improperly designed culverts may physically impede smelt migration to appropriate spawning sites. Furthermore, 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 the regional project, pH, turbidity, nutrient levels, and dissolved contaminants warranted concern for water quality (Enterline et al. 2012a). Field observations also showed an association between nitrogen levels and periphyton growth at spawning grounds. Laboratory experiments demonstrated that high periphyton growth, higher than levels observed in the field, significantly impaired the survival of smelt embryos (Wyatt et al. 2010).

Further evidence of the decline of Rainbow Smelt can be derived from a survey of historically active spawning sites throughout ME, using a study from the 1970s (Flagg 1974) as a valuable baseline for comparison. A recent survey found that 13% of the historically active spawning streams no longer support smelt spawning, and most of the streams that remain active now support smaller runs than they did historically (Enterline et al. 2012a). The substantial decline in strong spawning runs warrants concern and attention.

Habitat use in marine waters is largely unknown but can be inferred through interviews with coastal harvesters and state trawl surveys. Rainbow 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 anglers 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 (Collette and Klein-MacPhee 2002). However, recent findings indicate that smelt may remain within estuaries and bays contiguous to their spawning sites for up to two months after spawning (Enterline 2013).

PROCEDURES

The fyke nets construction for this project have six hoops measuring 0.76 m in diameter attached to a box frame which measures 1.22 m by 1.22 m. Throats are attached to the second and fourth hoop inside the mouth. Soft wings (1.22 m by 4.88 m) with leads and floats are attached to both sides of the box frame mouth to increase the channel coverage.

To intercept the spawning movements of smelt that occur at night during the flood tide, the fyke nets were set at mid-channel in the intertidal zone below the downstream limit of Rainbow Smelt egg deposition. The fyke net opening faced downstream, and nets were hauled after overnight sets.

Fyke net stations were selected at the Oyster, Squamscott, and Winnicut rivers (Figure 1.2-1). The stations were chosen for suitability to maintain a fyke net in a known Rainbow Smelt spawning run and to represent a range of run sizes and watershed conditions. The station at the Winnicut River was changed in 2013, moved approximately 2,000 feet upstream, after the removal of the Winnicut Dam. In order to accurately characterize the peak of the smelt spawning activity, the fyke nets were deployed upon ice-out (generally middle to end of March) until the third Thursday in April. During previous conduct of this study, between 2008 and 2014, sampling continued until smelt were not captured during sampling for two consecutive weeks. However, a review of the distribution of catch over the sampling period indicated that sampling between ice-out and the third Thursday in April would capture 97%–100% of the run at the Squamscott River, 86%–100% of the run at the Winnicut River, and 82%–98% of the run at the Oyster River. Fyke net catches were assumed to be representative of the size and sex composition of the spawning run.

Fyke nets were deployed for three nights each week when possible during the spawning run at low tide when conditions allowed. On the next low tide, samplers hauled the net and emptied the contents randomly distributed into buckets or large coolers with aerators, depending on the size of the catch. Total lengths of up to 100 males and 100 females per day were measured to the nearest millimeter. All remaining smelt were enumerated and sexed. Beginning in 2013, all smelt were fin-clipped to track recaptures. Bycatch species were identified, enumerated, and up to 25 fish per species were measured per sample day.

Bycatch and smelt catch per unit effort (CPUE) values were calculated by dividing the total catch by the total soak time (hours) for all haul dates prior to 2015. Currently, the geometric mean of the catch per day of all haul dates is used as a more appropriate measure to reduce the influence of no catches during the tails of the sampling period.

Over the course of the spawning run, scale samples for each centimeter size class for each sex were collected from smelt to be aged. Based on recommendations from the Massachusetts Division of Marine Fisheries, the number of scale samples for each centimeter size class for each sex was reduced from 25 to 10 starting in 2019. Scales are covered by a semi-transparent mucous membrane that can obscure annuli and make it difficult to age, especially for higher ages. To remove the mucous membrane, scales were placed in 1.5 mL plastic micro-centrifuge tubes filled with 2% pancreatin solution and agitated using a sonicator (Whaley 1991). Rainbow Smelt scales were independently aged by two readers using a QImaging microscopy camera and Image-Pro software. The two individuals aged each scale with no prior information about the length or gender of the fish. If discrepancies occurred between the two readers and a consensus could not be reached among them, then a third reader assigned an age (Enterline et al. 2012b). Annuli were identified along with a "shiny line" scar (Mckenzie 1958).

Egg tiles were deployed at each site to measure the relative egg density as a potential predictor of future year class strength. Each site location had two strings of five egg tiles (0.30 m by 0.30 m) located below mean low tide. Tiles were checked daily during fyke net deployments and all eggs were counted on each tile. Tiles were wiped clean after eggs were counted and returned to the water for repeat sampling. Egg density by river was quantified as the geometric mean of eggs per tile per sample day; prior reports used the arithmetic mean.

A YSI 6920v2 (YSI, Inc. Yellow Springs OH) multiparameter data sonde was used to record a daily onsite snapshot of the pH, temperature, specific conductivity, dissolved oxygen, and turbidity at each site below the spawning riffle where the fyke nets were set. The data sonde was calibrated each week during the sampling period.

## RESULTS

Between January 1, 2021 and December 31, 2021, the New Hampshire Fish and Game Department conducted one investigation to monitor the Rainbow Smelt resource using fishery independent techniques during their spawning run in the Great Bay Estuary and possibly implement strategies that restore and maintain populations of Rainbow Smelt to historic levels.

A total of 1,389 Rainbow Smelt (140 in Oyster River, 260 in Winnicut River, and 989 in Squamscott River) were caught in the fyke nets in 2021 (Table 1.2-1 and Figure 1.2-2). Recaptures from 2021 included, five males in the Oyster River, three males in the Winnicut River, and twenty-eight males in the Squamscott

River. Fifteen sampling trips occurred in each of the three rivers. The CPUE in 2021 was highest in the Squamscott River with 8.27 smelt per day, followed by 4.68 smelt per day in the Oyster River, and the Winnicut River with 2.54 smelt per day. In 2021, the male:female sex ratio was highest in the Squamscott River at 12.5:1, followed by 10.2:1, in the Winnicut River, and the Oyster River at 6.1:1, (Table 1.2-2).

Mean length of Rainbow Smelt in 2021 increased with age, ranging from 110 mm at age-1 to 258 mm at age-5 (Table 1.2-3). A total of 182 smelt scales were aged with age-2 and age-3 dominating the weighted age distributions (Tables 1.2-4 and 1.2-5).

Bycatch consisted primarily of Threespine Sticklebacks *Gasterosteus aculeatus* and Mummichog *Fundulus heteroclitus* in the Oyster River; White Sucker *Catostomus commersonii* and Fourspine Sticklebacks *Apeltes quadracus* in the Squamscott River; and Fourspine Sticklebacks and Mummichog in the Winnicut River (Table 1.2-6). The Squamscott and Oyster rivers had higher species diversity (14 species) followed by Winnicut River (12 species).

Temperature measurements ranged from 0.5°C to 12.8°C (Figure 1.2-3). The specific conductivity measurements ranged from 0.18 and 0.41 mS/cm and were generally lower in the Squamscott River and higher in the Winnicut River. The pH measurements ranged from 6.74 to 7.77 and all pH measurements were within the acceptable threshold. The dissolved oxygen measurements generally followed the same trends between rivers. Turbidity measurements ranged from 0.67 and 19.6 Nephelometric Turbidity Units (NTU) and were consistently above the threshold in the Oyster River.

Egg tile sampling indicated that relative egg density was greatest in the Squamscott River during 2021, followed by the Winnicut and Oyster rivers (Table 1.2-7).

## DISCUSSION

Data included in this report prior to 2013 were collected under a federal grant from NOAA Fisheries and are included in this report for comparison purposes.

Relative catches of Rainbow Smelt will be affected by smelt abundance; however, fyke net efficiency plays a large role when comparing catch between rivers. Stream profiles of each river were conducted in 2010 to quantify the percent net coverage in relation to stream area at each site. The Squamscott River has the largest stream area of 125.82 $m^2$, followed by the Winnicut (34.00 $m^2$), and Oyster (29.05 $m^2$) rivers. The fyke net covers only 9% of the entire river at high tide at the Squamscott River, 33% at the Winnicut River, and 38% at the Oyster River. A fyke net efficiency study was conducted in the Fore

River, MA, during a similar smelt spawning sampling study. An efficiency net (a larger fyke net that spans the entire channel of the river) was set upstream of the standard sampling fyke net. The efficiency of the standard sampling fyke net averaged 4% catchability of the efficiency net. Large numbers of smelt that are caught in the efficiency net suggest smelt can actively avoid the standard sampling fyke net (B.Chase, Massachusetts Division of Marine Fisheries, personal communication). One important effect of low net efficiency on the accuracy of results is exemplified by the fact that although egg tile counts at the Squamscott River in 2014 had a mean of 0.55 eggs/tile, no smelt were caught in the fyke net during sampling (Tables 1.2-1 and 1.2-7).

The sampling fyke nets used in MA have 1.22 m fixed wings whereas the fyke nets in NH use 4.88 m soft wings, which have floats on the top and weights on the bottom. The use of the longer soft wings could potentially increase the efficiency of NH nets as they would increase the net coverage within the river channel during the tidal changes.

Both catches in number of fish and CPUE have shown considerable variability between years and between locations within years. Annual catches have ranged from 0 to 989 fish in the Squamscott River and between 9 and 402 fish in the Oyster River (Table 1.2-1). The Winnicut River had much lower catches and less variation between 2008 and 2015, with an annual average catch of 19 fish, but catches beginning in 2016 were considerably higher, with an annual average between 2016 and 2021 of 442 fish. The relative start date of sampling each year could explain some of the yearly variability in smelt catches; however, more analysis needs to be completed.

Sex distribution among Rainbow Smelt can greatly affect spawning populations. Sex ratios from smelt captured in this spawning survey were heavily male-skewed in all rivers in 2021 (Table 1.2-2). Marcotte and Tremblay (1948) found that males have a longer physiological spawning period and may return to spawning grounds multiple times within the same year. Furthermore, mark and recapture studies have observed the same male at different spawning sites within a given year (Rupp 1968; Murawski et al. 1980). Females rarely ascend to the spawning grounds more than once in a season, based on mark and recapture surveys (Enterline 2013; Marcotte and Tremblay 1948). Female smelt are broadcast spawners and their spawning is expected to occur in a single event, as most of their eggs are deposited in one night.

Fisheries-dependent data collected by creel surveys during the past twenty years in NH have shown that sex ratios of Rainbow Smelt caught varied from 0.3:1 to 1.8:1 males:females (R.Heuss, New Hampshire Fish and Game Department, personal communication). Variation in the sex ratios between the winter creel survey and following spring spawning fyke net sampling may be explained by males have a longer physiological spawning period and interannual repeat spawning behavior while the females generally spawn once in one year. During 2021, all of the recaptured smelt were males (Table 1.2-1).

Age distributions within populations can affect spawning success. Fecundity and egg diameter of Rainbow Smelt increases with length and weight, as described by Clayton (1976). As a result, a higher proportion of older Rainbow Smelt would be more desirable in the spawning population, as they are typically longer in length and weigh more than younger smelt. Larger eggs also have been found to increase the survival of larvae in Atlantic Herring *Clupea harengus* (Blaxter and Hempel 1963), which may support that larger and thereby older fish are desirable in the spawning run of this Species of Special Concern. Although it has been shown that few age-1 smelt participate in Canadian smelt runs (McKenzie 1964), higher numbers were found in MA, NH, and southern ME runs (Murawski and Cole 1978; Lawton et al. 1990; Enterline et al. 2012a). Recent spawning surveys conducted between 2008 and 2011 found that runs in the Gulf of Maine were dominated by age-2 smelt, with few older fish in MA, NH, and southern ME, whereas older ages were better represented on spawning habitat in midcoast and eastern ME (Enterline et al. 2012a).

Cohorts can be followed through time with the age composition data to help identify weak and strong year classes and monitor recruitment into the spawning population. Age composition data from captured smelt, for all rivers combined, suggest that conditions in 2015 produced a strong year class; indicative by being the most prevalent cohort (age-1 through age-2) in each successive years' fyke net sampling to date (Table 1.2-5). In contrast, the same dataset indicates that the 2016 year class was a weak cohort, as it had below average age composition for most ages (Table 1.2-5).

Following cohorts through time depends on collecting samples that are representative of the population, which is related to resource size. More accurate characterizations of population structure can be inferred when sample sizes are larger. For example, the 2014 year class had above or near average age composition for age-2, age-3, age-4, and age-5+; however, age-1 was below average. This inconsistency in the strength of the 2014 year class over time might be explained by the fact that very few fish were collected in 2015, when the 2014 year class was age-1. These small sample sizes likely do not provide enough information to accurately characterize the strength of cohorts in that particular year, therefore, estimates in years of high sample sizes (e.g., age-2 in 2016 and age-3 in 2017) should be considered better indications of that cohort's success. Following cohorts through time helps determine years of successful recruitment, but if the resource or sample size is low and sample period is shortened an accurate estimate of the year class is difficult to predict.

Water quality can greatly affect spawning success. Water temperature influences the onset of Rainbow Smelt spawning and the duration of egg incubation. Dissolved oxygen concentrations greater than 6.0 mg/L are necessary for embryonic survival and normal development of smelt (Enterline et al. 2012a). Low pH can disrupt respiration and embryo survival (Geffen 1990) and turbidity measurements greater than 1.7 NTU can negatively impact smelt survival (Enterline et al. 2012a). All of the water quality measurements in 2021 were within or near acceptable ranges for viable smelt spawning and egg incubation and development, except for turbidity (Figure 1.2-3). Although high turbidity in NH occurs annually, due to runoff of snow melt and heavy rains in early spring, it could be negatively impacting smelt survival. The Oyster River turbidity levels were primarily above the accepted threshold for the spawning season.

In conclusion, catches remain variable with the highest CPUE in 2021 in the Squamscott River and lowest in the Winnicut River, but net efficiency may play a significant role in this variation. Sex ratios in all rivers in 2021 were male-skewed for all rivers. However, a more accurate representation of the sex distribution in the smelt population may be determined by sampling the fishery during the winter months leading to spawning. The creel surveys in NH and other states show sex ratio much closer to 1:1 due to sampling a broader range of the population over time. Following cohorts through time can help identify weak and strong year classes and monitor recruitment into the spawning population, but when resource size is limited or sample period is shortened, it is difficult to obtain accurate estimates of age composition. While biological and environmental factors affecting Rainbow Smelt populations are numerous, and may currently be limiting, the water quality of spawning streams monitored this year are not believed to be negatively affecting egg survival, with the exception of turbidity.

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Table 1.2-1. Haul dates, total soak hours, number of sampling trips, total Rainbow Smelt caught, and CPUE (geometric mean of smelt per day) from the smelt fyke net sampling in the Oyster, Squamscott, and Winnicut rivers in New Hampshire, 2008–2021.

| River | Year | Haul dates | Number of sampling trips | Number of smelt caught[a] | Number of smelt recaptured[b] | | CPUE |
|---|---|---|---|---|---|---|---|
| | | | | | Male | Female | |
| Oyster | 2010 | 3/9 - 5/6/2010 | 20 | 300 | N/A | | 2.90 |
| | 2011 | 3/29 - 5/13/2011 | 21 | 402 | N/A | | 4.31 |
| | 2012 | 3/6 - 5/17/2012 | 33 | 240 | N/A | | 3.21 |
| | 2013 | 3/19 - 4/10/2013 | 11 | 22 | 1 | 0 | 1.24 |
| | 2014 | 4/4 - 4/18/2014 | 7 | 29 | 0 | 0 | 3.53 |
| | 2015 | 4/1 - 4/24/2015 | 11 | 43 | 1 | 0 | 1.53 |
| | 2016 | 3/1 - 4/14/2016 | 21 | 367 | 41 | 3 | 5.72 |
| | 2017 | 3/3 - 4/13/2017 | 11 | 63 | 0 | 0 | 3.53 |
| | 2018 | 3/6 - 4/12/2018 | 16 | 9 | 1 | 0 | 0.39 |
| | 2019 | 3/26 - 4/18/2019 | 12 | 349 | 12 | 0 | 23.79 |
| | 2020 | 3/4 - 4/9/2020 | 17 | 140 | 10 | 0 | 4.29 |
| | 2021 | 3/17 - 4/15/2021 | 15 | 140 | 5 | 0 | 4.68 |
| Squamscott | 2008 | 3/18 - 4/24/2008 | 18 | 101 | N/A | | 1.43 |
| | 2009 | 3/17 - 5/14/2009 | 28 | 151 | N/A | | 1.17 |
| | 2010 | 3/9 - 5/6/2010 | 20 | 2 | N/A | | 0.06 |
| | 2011 | 3/29 - 5/12/2011 | 21 | 755 | N/A | | 4.76 |
| | 2012 | 3/6 - 5/17/2012 | 32 | 469 | N/A | | 1.91 |
| | 2013 | 3/19 - 4/25/2013 | 18 | 118 | 1 | 0 | 1.64 |
| | 2014 | 4/11 - 4/24/2014 | 4 | 0 | 0 | 0 | 0.00 |
| | 2015 | 4/8 - 4/30/2015 | 11 | 11 | 0 | 0 | 0.74 |
| | 2016 | 3/1 - 4/14/2016 | 21 | 456 | 1 | 0 | 7.84 |
| | 2017 | 3/3 - 4/18/2017 | 8 | 198 | 0 | 0 | 6.93 |
| | 2018 | 3/16 - 4/17/2018 | 15 | 171 | 4 | 1 | 8.27 |
| | 2019 | 3/26 - 4/18/2019 | 12 | 90 | 0 | 0 | 5.54 |
| | 2020 | 3/4 - 4/9/2020 | 18 | 929 | 11 | 3 | 17.69 |
| | 2021 | 3/17 - 4/15/2021 | 15 | 989 | 28 | 0 | 8.27 |
| Winnicut | 2008 | 3/18 - 4/24/2008 | 19 | 14 | N/A | | 0.53 |
| | 2009 | 3/17 - 5/14/2009 | 27 | 16 | N/A | | 0.28 |
| | 2010 | 3/9 - 5/6/2010 | 21 | 10 | N/A | | 0.24 |
| | 2011 | 3/29 - 5/12/2011 | 21 | 34 | N/A | | 0.87 |
| | 2012 | 3/6 - 5/17/2012 | 33 | 17 | N/A | | 0.32 |
| | 2013 | 3/19 - 4/25/2013 | 18 | 10 | 0 | 0 | 0.22 |
| | 2014 | 4/4 - 4/24/2014 | 9 | 27 | 0 | 0 | 1.23 |
| | 2015 | 4/1 - 4/30/2015 | 14 | 25 | 0 | 0 | 0.62 |
| | 2016 | 3/1 - 4/14/2016 | 21 | 738 | 49 | 0 | 4.57 |
| | 2017 | 3/3 - 4/19/2017 | 19 | 241 | 0 | 0 | 3.59 |
| | 2018 | 3/6 - 4/17/2018 | 18 | 722 | 160 | 0 | 7.04 |
| | 2019 | 3/20 - 4/18/2019 | 15 | 405 | 4 | 0 | 8.46 |
| | 2020 | 2/26 - 4/9/2020 | 21 | 288 | 4 | 1 | 1.61 |
| | 2021 | 3/17 - 4/15/2021 | 15 | 260 | 3 | 0 | 2.54 |

[a] Includes possible recaptures.
[b] Rainbow Smelt were fin-clipped starting in 2013 to track the number of recaptured smelt.

Table 1.2-2. Mean length by sex, week, and season, and count (N) and standard error (SE) of Rainbow Smelt caught from the fyke net sampling in the Oyster, Squamscott, and Winnicut rivers in New Hampshire, 2021.

| River | Sex | Week | Mean length (mm) | N | SE |
|---|---|---|---|---|---|
| Oyster | Male | 3/15/2021 | 175.0 | 58 | 1.4 |
| | | 3/22/2021 | 164.2 | 44 | 3.8 |
| | | 3/29/2021 | 152.4 | 8 | 7.1 |
| | | 4/5/2021 | 131.8 | 6 | 17.0 |
| | | 4/12/2021 | N/A | N/A | N/A |
| | Female | 3/15/2021 | 185.5 | 11 | 2.7 |
| | | 3/22/2021 | 143.0 | 4 | 22.0 |
| | | 3/29/2021 | 191.7 | 3 | 24.0 |
| | | 4/5/2021 | 170.0 | 1 | N/A |
| | | 4/12/2021 | N/A | N/A | N/A |
| | Male | Season | 167.1 | 116 | 2.1 |
| | Female | | 176.7 | 19 | 6.9 |
| | Sex ratio | | 6.1:1 | | |
| Squamscott | Male | 3/15/2021 | 183.3 | 664 | 0.6 |
| | | 3/22/2021 | 175.3 | 215 | 1.0 |
| | | 3/29/2021 | 147.6 | 11 | 7.9 |
| | | 4/5/2021 | N/A | N/A | N/A |
| | | 4/12/2021 | N/A | N/A | N/A |
| | Female | 3/15/2021 | 189.1 | 57 | 3.0 |
| | | 3/22/2021 | 169.2 | 12 | 3.2 |
| | | 3/29/2021 | 141.0 | 2 | 36.0 |
| | | 4/5/2021 | N/A | N/A | N/A |
| | | 4/12/2021 | N/A | N/A | N/A |
| | Male | Season | 180.9 | 890 | 0.6 |
| | Female | | 184.4 | 71 | 2.9 |
| | Sex ratio | | 12.5:1 | | |
| Winnicut | Male | 3/15/2021 | 176.0 | 165 | 0.8 |
| | | 3/22/2021 | 167.1 | 8 | 3.5 |
| | | 3/29/2021 | 171.1 | 60 | 1.9 |
| | | 4/5/2021 | 158.0 | 1 | N/A |
| | | 4/12/2021 | N/A | N/A | N/A |
| | Female | 3/15/2021 | 179.8 | 21 | 2.5 |
| | | 3/22/2021 | N/A | N/A | N/A |
| | | 3/29/2021 | 178.5 | 2 | 6.5 |
| | | 4/5/2021 | N/A | N/A | N/A |
| | | 4/12/2021 | N/A | N/A | N/A |
| | Male | Season | 174.3 | 234 | 0.8 |
| | Female | | 179.7 | 23 | 2.3 |
| | Sex ratio | | 10.2:1 | | |
| All sites combined | Male | Season | 178.4 | 1,240 | 0.5 |
| | Female | | 182.1 | 113 | 2.2 |
| | Sex ratio | | 11.0:1 | | |

Table 1.2-3. Mean, minimum, and maximum lengths at age from Rainbow Smelt scale samples collected during fyke net sampling in the Oyster, Squamscott, and Winnicut rivers in New Hampshire, 2021.

| | N | Mean length (mm) | Min length (mm) | Max length (mm) |
|---|---|---|---|---|
| Age-1 | 19 | 110 | 94 | 120 |
| Age-2 | 113 | 172 | 111 | 214 |
| Age-3 | 32 | 201 | 150 | 230 |
| Age-4 | 17 | 220 | 194 | 239 |
| Age-5 | 1 | 258 | 258 | 258 |

Table 1.2-4. Age distribution[a] of Rainbow Smelt, weighted by total catch collected during fyke net sampling with in the Oyster, Squamscott, and Winnicut rivers in New Hampshire, 2010–2021.

| River | Year | Percent at age | | | | | N |
|---|---|---|---|---|---|---|---|
| | | Age-1 | Age-2 | Age-3 | Age-4 | Age-5+ | |
| Oyster | 2010 | 64.9 | 25.6 | 8.1 | 1.5 | 0.0 | 177 |
| | 2011 | 10.2 | 74.6 | 15.0 | 0.1 | 0.0 | 192 |
| | 2012 | 25.1 | 52.2 | 21.6 | 1.2 | 0.0 | 162 |
| | 2013 | 35.8 | 41.7 | 17.5 | 5.0 | 0.0 | 17 |
| | 2014 | 67.9 | 25.0 | 7.1 | 0.0 | 0.0 | 28 |
| | 2015 | 0.0 | 42.9 | 42.9 | 14.3 | 0.0 | 7 |
| | 2016 | 65.0 | 31.0 | 3.3 | 0.7 | 0.0 | 226 |
| | 2017 | 8.1 | 74.8 | 17.1 | 0.0 | 0.0 | 59 |
| | 2018 | 28.6 | 57.1 | 14.3 | 0.0 | 0.0 | 7 |
| | 2019 | 49.0 | 50.1 | 0.9 | 0.0 | 0.0 | 122 |
| | 2020 | 47.9 | 46.2 | 5.9 | 0.0 | 0.0 | 85 |
| | 2021 | 7.5 | 77.1 | 14.1 | 1.2 | 0.0 | 32 |
| | Mean | 34.2 | 49.9 | 14.0 | 2.0 | 0.0 | 93 |
| Squamscott | 2010 | No samples collected | | | | | 0 |
| | 2011 | 29.0 | 59.5 | 10.9 | 0.7 | 0.0 | 320 |
| | 2012 | 3.3 | 75.4 | 18.8 | 2.5 | 0.0 | 202 |
| | 2013 | 15.3 | 30.7 | 48.9 | 5.1 | 0.0 | 113 |
| | 2014 | No samples collected | | | | | 0 |
| | 2015 | 27.3 | 27.3 | 45.5 | 0.0 | 0.0 | 11 |
| | 2016 | 20.6 | 63.3 | 14.7 | 0.9 | 0.4 | 225 |
| | 2017 | 1.0 | 63.5 | 30.5 | 5.1 | 0.0 | 145 |
| | 2018 | 12.8 | 38.0 | 40.0 | 8.9 | 0.4 | 162 |
| | 2019 | 24.4 | 67.8 | 6.7 | 1.1 | 0.0 | 63 |
| | 2020 | 32.4 | 37.4 | 26.7 | 3.3 | 0.1 | 194 |
| | 2021 | 0.8 | 72.0 | 19.5 | 7.6 | 0.1 | 81 |
| | Mean | 16.7 | 53.5 | 26.2 | 3.5 | 0.1 | 152 |
| Winnicut | 2010 | 30.0 | 55.0 | 15.0 | 0.0 | 0.0 | 9 |
| | 2011 | 12.6 | 74.8 | 6.6 | 6.1 | 0.0 | 33 |
| | 2012 | 0.0 | 70.0 | 30.0 | 0.0 | 0.0 | 13 |
| | 2013 | 20.0 | 60.0 | 20.0 | 0.0 | 0.0 | 9 |
| | 2014 | 63.0 | 22.2 | 11.1 | 3.7 | 0.0 | 27 |
| | 2015 | 0.0 | 24.0 | 64.0 | 12.0 | 0.0 | 25 |
| | 2016 | 58.3 | 32.5 | 8.5 | 0.7 | 0.0 | 256 |
| | 2017 | 3.0 | 71.6 | 20.4 | 4.6 | 0.4 | 148 |
| | 2018 | 41.3 | 34.5 | 22.4 | 1.4 | 0.4 | 291 |
| | 2019 | 21.2 | 63.9 | 13.4 | 1.3 | 0.3 | 153 |
| | 2020 | 18.3 | 60.8 | 17.6 | 2.8 | 0.5 | 109 |
| | 2021 | 0.4 | 84.6 | 14.3 | 0.7 | 0.0 | 69 |
| | Mean | 22.3 | 54.5 | 20.3 | 2.8 | 0.1 | 95 |

[a] values have changed from those previously reported after correcting for recaptured fish.

Table 1.2-5. Age distribution[a] of Rainbow Smelt, weighted by total catch collected during fyke net sampling in all sampled rivers combined in New Hampshire, 2010–2021.

| Year | Percent at age | | | | | N |
|---|---|---|---|---|---|---|
| | Age-1 | Age-2 | Age-3 | Age-4 | Age-5+ | |
| 2010[b] | 63.57 | 26.70 | 8.34 | 1.40 | 0.00 | 186 |
| 2011 | 22.22 | 65.02 | 12.14 | 0.63 | 0.00 | 545 |
| 2012 | 11.89 | 66.08 | 20.11 | 1.92 | 0.00 | 377 |
| 2013 | 18.40 | 34.23 | 42.61 | 4.75 | 0.00 | 139 |
| 2014[b] | 65.45 | 23.64 | 9.09 | 1.82 | 0.00 | 55 |
| 2015 | 6.98 | 27.91 | 55.81 | 9.30 | 0.00 | 43 |
| 2016 | 47.91 | 41.82 | 9.37 | 0.76 | 0.14 | 709 |
| 2017 | 2.86 | 68.76 | 23.97 | 4.20 | 0.20 | 352 |
| 2018 | 34.75 | 35.50 | 26.31 | 3.08 | 0.36 | 460 |
| 2019 | 32.85 | 58.71 | 7.60 | 0.72 | 0.12 | 338 |
| 2020 | 30.92 | 43.27 | 22.74 | 2.90 | 0.18 | 388 |
| 2021 | 1.42 | 74.89 | 17.97 | 5.64 | 0.07 | 182 |
| Mean | 28.27 | 47.21 | 21.34 | 3.09 | 0.09 | 315 |

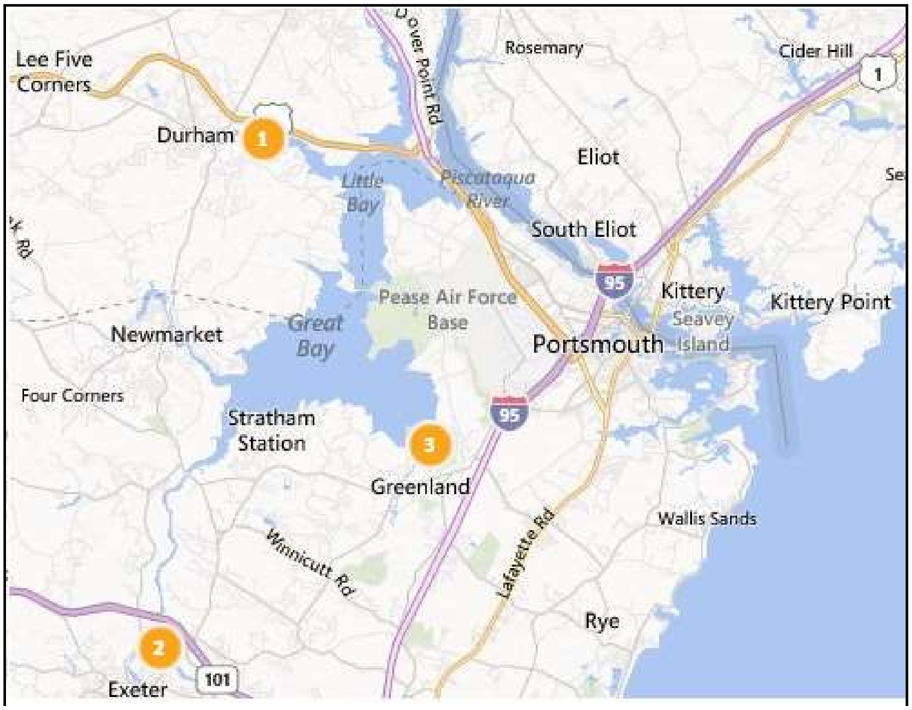
[a] values have changed from those previously reported after correcting for recaptured fish.
[b] Squamscott River did not have samples due to low catch in 2010 and 2014.

Table 1.2-6. Geometric mean bycatch from the Rainbow Smelt fyke net sampling in the Oyster, Squamscott, and Winnicut rivers in New Hampshire, 2017–-2021.

| Common name | Scientific name | Oyster River | | | | | | Squamscott River | | | | | | Winnicut River | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | # of fish per day | | | | | | # of fish per day | | | | | | # of fish per day | | | | | |
| | | 2017 | 2018 | 2019 | 2020 | 2021 | Mean | 2017 | 2018 | 2019 | 2020 | 2021 | Mean | 2017 | 2018 | 2019 | 2020 | 2021 | Mean |
| Alewife | *Alosa pseudoharengus* | 0.11 | | | | | 0.02 | 0.98 | | 0.16 | 0.20 | | 0.17 | | | | | | |
| American Eel | *Anguilla rostrata* | 0.25 | 0.17 | 0.26 | 0.26 | 0.15 | 0.21 | 2.09 | 0.05 | 0.12 | | 0.9 | 0.36 | 0.04 | 0.04 | 0.20 | | 0.08 | 0.06 |
| Atlantic Silverside | *Menidia menidia* | | | | 0.11 | 0.05 | 0.04 | | | | | | | 0.04 | | | | | 0.01 |
| Atlantic Tomcod | *Microgadus tomcod* | 0.07 | 0.60 | 0.90 | 1.12 | 0.38 | 0.60 | | | | 0.34 | | 0.08 | | | | | | |
| Banded Killifish | *Fundulus diaphanus* | | 0.09 | | | | 0.02 | | 0.38 | | 0.10 | | 0.10 | 0.54 | 0.32 | 0.05 | 0.03 | 0.54 | 0.27 |
| Black Crappie | *Pomoxis nigromaculatus* | 0.11 | 0.09 | 0.06 | 0.11 | 0.10 | 0.09 | 0.09 | 0.08 | 0.06 | 0.04 | | 0.05 | | | | | | |
| Blueback Herring | *Alosa aestivalis* | | | | | | | | | | 0.04 | | 0.01 | | | | | | |
| Bluegill | *Lepomis macrochirus* | 0.13 | 0.14 | 0.06 | 0.36 | 0.15 | 0.18 | 0.09 | | | | | 0.01 | 0.04 | | | | | 0.01 |
| Brook Trout | *Salvelinus fontinalis* | | | | | | | | | | 0.04 | | 0.01 | | | 0.10 | | 0.05 | 0.02 |
| Brown Bullhead | *Ameiurus nebulosus* | | | | | | | 0.74 | | 0.25 | 0.08 | 0.10 | 0.16 | | | | | 0.05 | 0.01 |
| Chain Pickerel | *Esox niger* | 0.07 | | | | | 0.01 | 0.57 | | 0.55 | 0.36 | 0.18 | 0.28 | | | | | | |
| Common Shiner | *Luxilus cornutus* | | 0.17 | | | | 0.04 | 0.09 | 0.29 | 0.51 | 0.32 | 0.10 | 0.26 | | | 0.05 | | 0.05 | 0.02 |
| Fallfish | *Semotilus corporalis* | | | | | | | | 0.05 | | | | 0.01 | | | | | | |
| Fourspine Stickleback | *Apeltes quadracus* | 2.28 | 1.06 | 6.34 | 9.68 | 5.51 | 4.19 | 2.28 | 0.61 | 0.55 | 1.36 | 1.34 | 1.09 | 2.48 | 1.22 | 53.83 | 0.75 | 2.31 | 3.28 |
| Golden Shiner | *Notemigonus crysoleucas* | 0.07 | | | | | 0.01 | 0.25 | 0.43 | 0.06 | 0.21 | 0.24 | 0.24 | | | | | | |
| Little Sculpin | *Myoxocephalus aenaeus* | 0.07 | | 0.30 | | | 0.06 | | | | | | | | | | | | |
| Mummichog | *Fundulus heteroclitus* | 1.99 | 0.70 | 6.89 | 0.61 | 8.15 | 2.39 | 0.09 | 0.10 | | 0.04 | 0.46 | 0.13 | 1.45 | 2.12 | 1.28 | 0.19 | 2.37 | 1.26 |
| Ninespine Stickleback | *Pungitius pungitius* | | | | 0.23 | | 0.05 | | | | | | | 0.04 | | 1.70 | 0.07 | 0.11 | 0.24 |
| Pumpkinseed | *Lepomis gibbosus* | 0.13 | 0.04 | 0.12 | 0.04 | 0.05 | 0.07 | 0.09 | 0.13 | 0.23 | 0.37 | 0.36 | 0.25 | 0.04 | | | 0.03 | | 0.02 |
| Sea Lamprey | *Petromyzon marinus* | 0.31 | 0.04 | 0.14 | | 0.05 | 0.09 | 0.36 | 0.15 | 0.35 | 0.29 | 0.98 | 0.40 | | | | | | |
| Smooth Flounder | *Pleuronectes putnami* | 0.48 | | 1.28 | 1.19 | 0.24 | 0.54 | | | | | | | | | | | | |
| Striped Bass | *Morone saxatilis* | | | | | | | | 0.14 | | | | 0.03 | | | | | | |
| Striped Killifish | *Fundulus majalis* | 0.18 | 1.14 | 0.73 | 1.16 | 4.42 | 1.29 | | | | | 0.13 | 0.03 | 1.88 | 2.33 | 0.51 | 0.59 | 2.23 | 1.35 |
| Threespine Stickleback | *Gasterosteus aculeatus* | 0.25 | 0.24 | 1.57 | 7.00 | 40.85 | 3.62 | | 0.05 | 0.26 | 0.29 | 0.46 | 0.22 | 0.32 | 0.38 | 0.39 | 0.34 | 1.03 | 0.45 |
| White Perch | *Morone americana* | 0.18 | 0.07 | 0.67 | 1.71 | 0.57 | 0.59 | 5.39 | 0.43 | 0.39 | 1.17 | 0.84 | 1.01 | 0.17 | 0.06 | | 0.26 | 0.15 | 0.13 |
| Winter Flounder | *Pseudopleuronectes americanus* | | 0.04 | 0.06 | 0.04 | 0.10 | 0.05 | | | | | | | | | | | | |
| White Sucker | *Catostomus commersonii* | | | 0.06 | 0.13 | | 0.04 | 0.98 | 0.73 | 2.01 | 3.97 | 3.14 | 2.12 | | 0.15 | | | 0.05 | 0.04 |
| Yellow Bullhead | *Ameiurus natalis* | | | | | | | 0.54 | | 0.23 | | | 0.09 | | | | | | |
| Yellow Perch | *Perca flavescens* | | | 0.06 | | | 0.01 | 1.94 | 1.66 | 4.57 | 0.82 | 0.47 | 1.43 | | | | | | |

Table 1.2-7. Geometric mean number of eggs per day collected on egg tiles set daily during the fyke net sampling in the Oyster, Squamscott, and Winnicut rivers, New Hampshire in 2014–2021.

| | Oyster | Squamscott | Winnicut |
|---|---|---|---|
| 2014 | 0.04 | 0.55 | 0.00 |
| 2015 | 0.08 | 0.19 | 0.05 |
| 2016 | 0.02 | 0.63 | 1.13 |
| 2017 | 0.00 | 1.06 | 1.14 |
| 2018 | 0.00 | 0.48 | 0.75 |
| 2019 | 0.24 | 2.21 | 10.82 |
| 2020 | 0.18 | 0.82 | 1.09 |
| 2021 | 0.04 | 3.00 | 1.63 |




1= Oyster River, 2= Squamscott River, 3= Winnicut River

Figure 1.2-1. Map of fyke net sampling locations in the Oyster, Squamscott, and Winnicut rivers, New Hampshire.

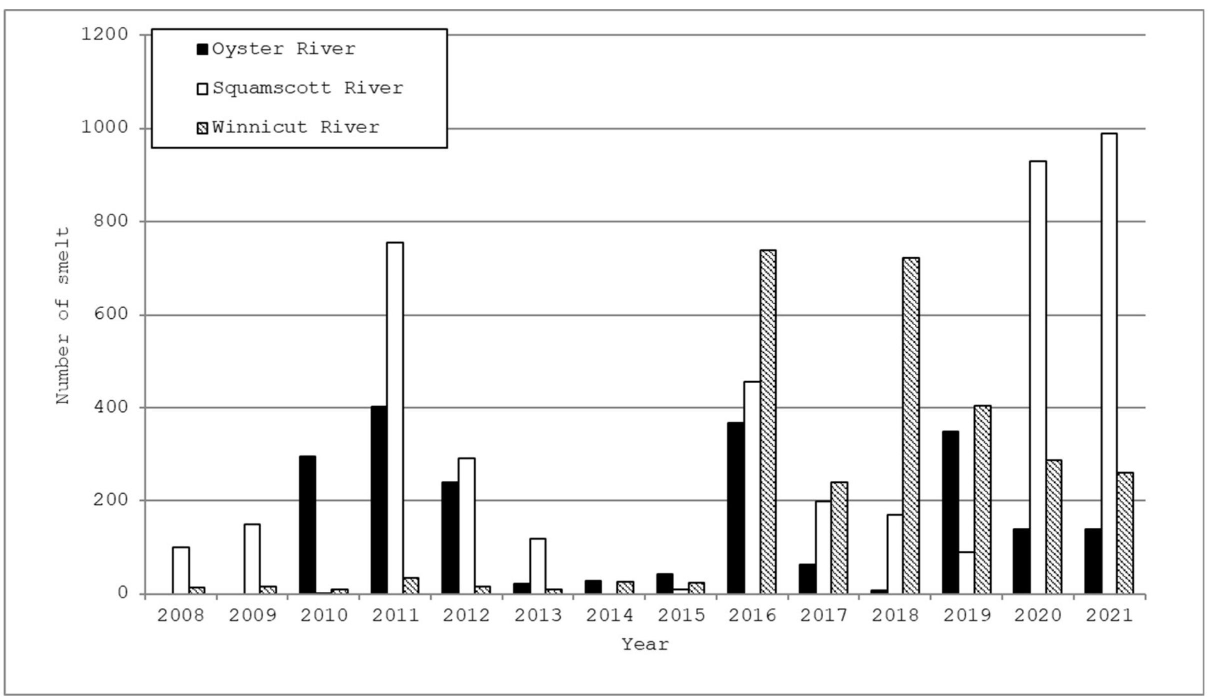



Figure 1.2-2. Rainbow Smelt catch from fyke net sampling in the Oyster, Squamscott, and Winnicut rivers, New Hampshire, 2008–2021.

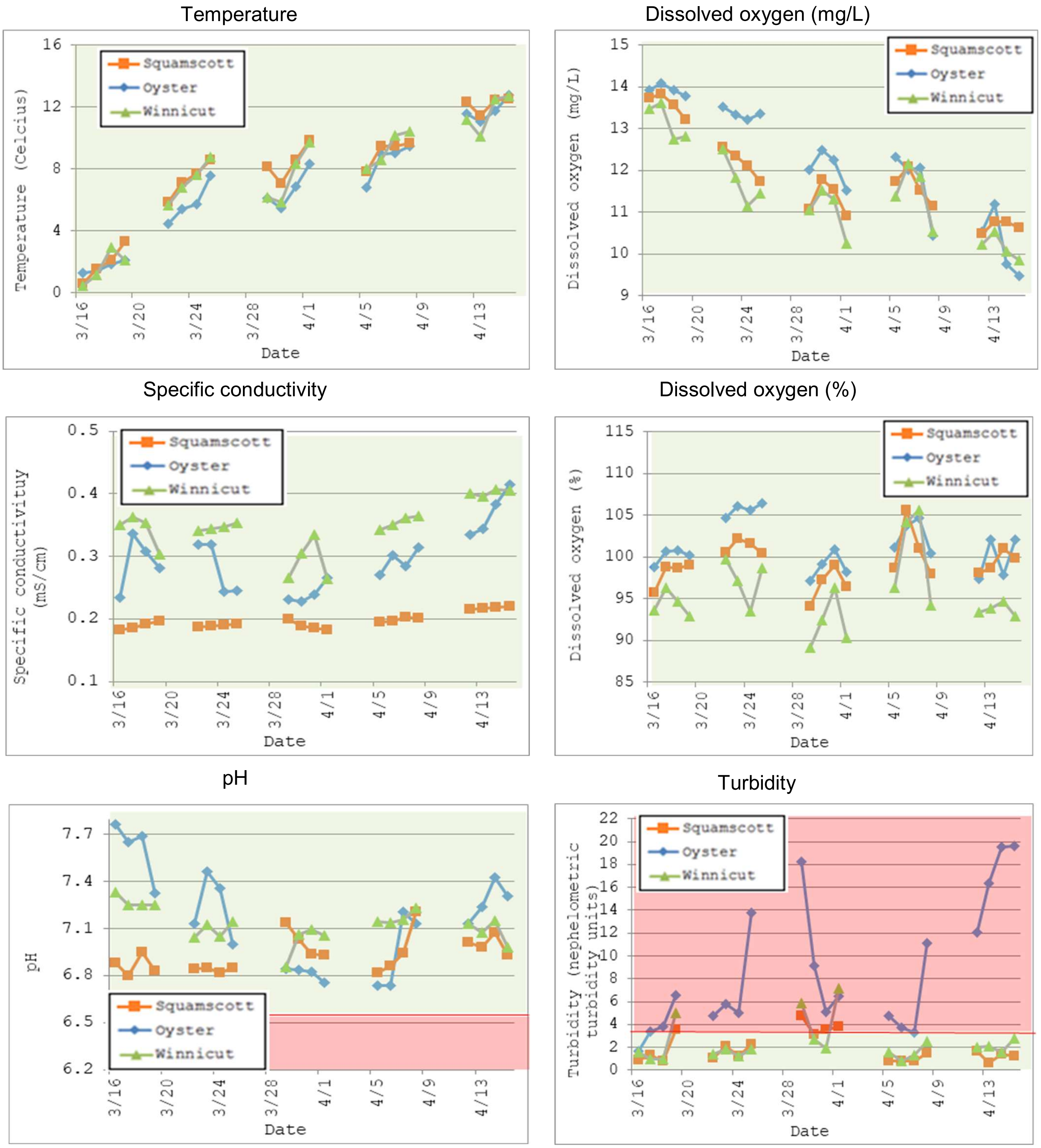



Figure 1.2-3. Daily mean measurements of water quality collected during the fyke net sampling in the Oyster, Squamscott, and Winnicut rivers, New Hampshire, 2021. Green area indicates within Rainbow Smelt threshold and red (dark shaded) area is outside of threshold.