FINAL REPORT

State: **NEW HAMPSHIRE** **Grant**: **F-61-R-25/F22AF00514**

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, 2019 - December 31, 2023

ABSTRACT

Between January 1, 2019 and December 31 2023, the New Hampshire Fish and Game Department conducted one investigation per year 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. During the reporting period of January 1, 2019 to December 31, 2023, a total of 7,372 Rainbow Smelt (*Osmerus mordax*)(902 in Oyster River, 2,755 in Squamscott River, and 3,715 in Winnicut River) were caught using fyke nets. The highest annual catch between 2019 and 2023 for each river was 349 smelt in 2019 at the Oyster River, 989 smelt in 2021 at the Squamscott River, and 1,907 smelt in 2022 at the Winnicut River. The highest recapture rate was in the Oyster River (4%), followed by the Winnicut River (3%), and the Squamscott River (2%). The highest CPUE was at the Oyster River in 2019 (23.79 smelt per day), followed by the Winnicut River in 2022 (17.99 smelt per day), and the Squamscott River in 2020 (17.69 smelt per day). A male-skewed sex ratio continues to be observed in all rivers, a likely result of differences in spawning behavior between sexes. Age distribution weighted by percent-at-age for age-1 fish was highest in 2022, age-2 fish in 2021, age-3 fish in 2020, age-4 fish in 2021, and age-5+ fish in 2020. Most water quality measurements (temperature, dissolved oxygen, specific conductivity) were within or near acceptable ranges for smelt spawning and egg incubation and development;

however, pH was below the 6.5 pH threshold on all rivers for multiple days at the beginning of sampling in 2023. Turbidity was above the threshold in the Oyster River for the majority of days monitored and multiple days for the Squamscott and Winnicut rivers.

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 Rainbow 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, extreme 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 sampling fyke nets for this project were constructed with 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 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 moved approximately 2,000 feet upstream in 2013, after the removal of the Winnicut Dam.

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. 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 at low tide for three nights each week when possible during the spawning run when conditions allowed. On the next low tide, samplers hauled the net and randomly distributed the contents 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 beginning and end of the sampling period.

Over the course of the spawning run, scale samples for ageing were collected 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 making 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. Annuli were identified along with a "shiny line" scar (Mckenzie 1958). The two individuals aged each scale sample without prior biological information 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).

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, 2019 and December 31, 2023, the New Hampshire Fish and Game Department conducted one investigation per year to monitor the Rainbow Smelt resource using fishery independent techniques during spawning runs in the Great Bay Estuary and possibly implement strategies to restore and maintain populations of Rainbow Smelt to historic levels. A total of 7,372 Rainbow Smelt (902 in Oyster River, 2,755 in Squamscott River, and 3,715 in Winnicut River) were caught in the fyke nets from 2019 to 2023 (Table 1.2-1). The highest catches between 2019 and 2023 were in 2019 at the Oyster River (349), 2021 at the Squamscott River (989), and 2022 at the Winnicut River (1,907). Between 2019 and 2023, the highest recapture rate was in the Oyster River (4%, n=40), followed by the Winnicut River (3%, n=127), and the Squamscott River (2%, n=56). 74 sampling trips occurred at the Oyster River, 75 at the Squamscott River, and 96 at the Winnicut River. The highest CPUE during the five-year period was at the Oyster River in 2019 (23.79 smelt per day), followed by the Winnicut River in 2022 (17.99 smelt per day), and the Squamscott River in 2020 (17.69 smelt per day). A male-skewed sex ratio continues to be observed in all rivers (Appendix Tables 1.2-1 through 1.2-5).

The number of smelt scale samples aged during the project period ranged from 182 samples in 2021, to 419 samples in 2022 (Table 1.2-2). Lengths of Rainbow Smelt increased with age, ranging from a minimum length of 79 mm at age-1 to a maximum length of 290 mm at age-6 (Table 1.2-2). The highest percent-at-age for each age class was; age-1 smelt in 2022, age-2 in 2021, age-3 in 2020, age-4 in 2021, and age-5+ in 2020 (Tables 1.2-3). The 2021 year-class shows preliminary signs of being a strong cohort reflected in the age-1 and age-2 distributions in the five-year period (Table 1.2-4). In contrast, the 2020 year-class can be identified as the weakest year-class from the five-year period, as shown by proportional percent at age being consistently lower than the mean in all rivers as the cohort is tracked through subsequent sampling seasons.

During the reporting period, bycatch consisted primarily of Threespine Stickleback (*Gaserosteus aculeatus*) and Fourspine Stickleback (*Apeltes quadracus*) at the Oyster River; White Sucker (*Catastomus commersonii*) and Fourspine Stickleback at the Squamscott River; and Fourspine Stickleback and Mummichog (*Fundulus heteroclitus*) at the Winnicut River (Table 1.2-5). The Oyster and Squamscott rivers had the highest bycatch diversity with 24 unique species, followed by the Winnicut River with 14 species.

Temperature measurements during the reporting period ranged from -0.14°C to 14.83°C and were generally similar between rivers (Appendix Figure 1.2-1). Specific conductivity measurements ranged from 0.16 to 0.72 mS/cm, and were generally lower in the Oyster and Squamscott rivers, and higher in the Winnicut River (Appendix Figure 1.2-2). pH measurements ranged from 5.99 to 8.24, and generally were more variable in the Oyster and Squamscott rivers when compared to the Winnicut River (Appendix Figure 1.2-3). Dissolved oxygen measurements ranged from 9.48 to 15.55 mg/L (Appendix Figure 1.2-4). Dissolved oxygen saturation measurements ranged from 85.3% to 113.4% (Appendix Figure 1.2-5). Turbidity measurements ranged from 0.13 to 19.63 NTU, and were generally highest in the Oyster River (Appendix Figure 1.2-6).

Egg tile sampling within the reporting period indicated that relative egg density was greatest at the Winnicut River in 2019 and in the Squamscott River in 2021 (Table 1.2-6).

DISCUSSION

Data included in this report prior to 2013 were collected under a federal grant from NOAA Fisheries and are included 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 (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 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 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 egg tiles at the Squamscott River in 2014 having a mean of 0.55 eggs/tile per day; however, no smelt were caught in the fyke net during sampling that year (Table 1.2-1). 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.

Both catches in number of fish and CPUE have shown considerable variability between years and between locations within years. Annual catches throughout the time series have ranged from 0 to 989 smelt in the Squamscott River, 9 and 402 smelt in the Oyster River, and 10 to 1,907 smelt in the Winnicut River (Table 1.2-1). For the 2019 to 2023 sampling period, the mean annual catch was highest at the Winnicut River at 743 smelt, followed by the Squamscott River at 551 smelt, and the Oyster River at 180 smelt. In 2022, the Winnicut River had a time series high of 1,907 total smelt captured. A CPUE time series high of 23.79 smelt per day occurred at the Oyster River in 2019. 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 the spawning survey were heavily male-skewed in all rivers during the reporting period (Appendix Tables 1.2-1 through 1.2-5). 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, on the other hand, 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 where 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 a year. During the 2019 to 2023 sampling period, 97% 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 have been found to increase the survival of larvae in Atlantic Herring *Clupea harengus* (Blaxter and Hempel 1963), which may support 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). The results of the survey during the 2019 to 2023 period support these findings. The proportion of age-1 smelt sampled was near or above the historic mean of that year class, excluding 2021. (Table 1.2-3). Rainbow Smelt 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 age composition data to 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 2017 produced a strong year-class; indicative by each year class (age-1 through age-4) being consistently above the historic mean in each successive years' fyke net sampling (Table 1.2-3). In contrast, the 2020 year-class was a weak cohort. However, the reliability of cohort strength estimates should be supported with large sample sizes.

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). Most water quality measurements during the five-year project period were within or near acceptable ranges for viable smelt spawning and egg incubation and development (Appendix Figures 1.2-1 through 1.2-6). Parameters that were beyond the respective acceptable thresholds included pH and turbidity. pH was in acceptable range throughout the five-year project period, except for several days in all rivers in 2023. High turbidity readings were observed periodically throughout the reporting period at all rivers, but to a lesser extent in 2020. The Oyster River showed consistently high turbidity levels, where the 1.7 NTU acceptable threshold was exceeded on 89% of sampling days. 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 as high levels linger throughout the egg incubation period.

In conclusion, Rainbow Smelt fyke net catches remain variable during this reporting period. Annual CPUE time-series highs were recorded at all rivers (2019 at the Oyster River, 2020 at the Squamscott River, and 2022 at the Winnicut River). The sex ratio in all rivers were male-skewed. 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. However, 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 be limiting, most water quality parameters recorded at monitored New Hampshire spawning streams during this five-year project period are not believed to be negatively effecting egg survival, with the exception of turbidity and possibly pH.

REFERENCES

Blaxter, J.H.S., and G, Hempel. 1963. The influence of egg size on herring larvae, Clupea harengus (L.). J. Cons. Perm. Int. Explor. Mer. 28:211-240.

Buckley, J.L. 1989. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic); Rainbow Smelt. U.S. Fish and Wildlife Service Biological Report 82(11.106). U.S. Army Corps of Engineers, TR EL-82-4. 11pp.

Chase, B.C., and A.R. Childs. 2001. Rainbow Smelt (*Osmerus mordax*) spawning habitat in the Weymouth-Fore River. Massachusetts Division of Marine Fisheries, Technical Report TR-5. Gloucester, MA.

Clayton, G.R. 1976. Reproduction, first year growth, and distribution of anadromous Rainbow Smelt, Osmerus mordax, in the Parker River and Plum Island Sound estuary, Massachusetts. Master's Thesis. University of Massachusetts, Amherst, Massachusetts.

Clayton, G.R., C.F. Cole, S.A. Murawski, and J.D. Parrish. 1978. Common marine fishes of coastal Massachusetts. University of Massachusetts, Amherst, Massachusetts.

Collette, B.B., and G. Klein–MacPhee. 2002. Bigelow and Schroeder's Fishes of the Gulf of Maine. Smithsonian Institution Press, Washington, D.C.

Enterline, C.L., B.C. Chase, J.M. Carloni, and K.E. Mills. 2012a. A Regional Conservation Plan For Anadromous Rainbow Smelt in the U.S. Gulf of Maine. Maine Deptartment of Marine Resources. 96 pp.

Enterline, C.L., A. Simpson, S. Elzey, and J. Fischer. 2012b. Improving methods to accurately age Rainbow Smelt (*Osmerus mordax*) *in* Fourth North American Workshop on Rainbow Smelt: Extended Abstract Proceedings. Wood C. H., C. L. Enterline, K. Mills, B. C. Chase, G. Verreault, J. Fischer, and M. H. Ayer (eds.). Massachusetts Division of Marine Fisheries, Technical Report TR-51. Gloucester, MA. 88 pp.

Enterline, C.L. 2013. Understanding Spawning Behavior and Habitat Use by Anadromous Rainbow Smelt (*Osmerus Mordax*) Using Passive Integrated Transponder Systems and Telemetry. Master's thesis. University of New Hampshire, Durham, New Hampshire.

Flagg, L.N. 1974. Distribution, food habits, and management of Striped Bass and Rainbow Smelt in Maine coastal waters. Completion report AFS-4, Maine Department of Marine Resources.

Geffen, A.J. 1990. Response of Rainbow Smelt, *Osmerus mordax*, eggs to low pH. Journal of Fish Biology 37:865-871.

Kendall, W.C. 1926. The Rainbow Smelts. Bulletin of the Bureau of Fisheries, Vol. XLII, Doc. No. 1015.

Kircheis, F.W., and J.G. Stanley. 1981. Theory and practice of forage-fish management in New England. Transactions of the American Fisheries Society 110:729-737.

Kirn, R.A. 1986. Assessment of Rainbow Smelt *(Osmerus mordax)* as forage in Lake Champlain. Master's thesis. University of Vermont, Burlington.

Lawton, R., P. Brady, C. Sheehan, S. Correia, and M. Borgatti. 1990. Final report on spawning sea-run Rainbow Smelt (Osmerus mordax) in the Jones River and impact assessment of Pilgrim Station on the population, 1979-1981. Pilgrim Nuclear Power Station Marine Environmental Monitoring Program, Report Series No. 4, 72 pp.

Marcotte, A., and J.L. Tremblay. 1948. Notes sur la biologie de l'éperlan (*Osmerus mordax* Mitchell) de la Province de Québec. Sta. Biol. Saint-Laurent, Que. Contrib. 18:107 pp.

McKenzie, R. A. 1958. Age and growth of Rainbow Smelt, *Osmerus mordax* (Mitchill), of the Miramichi River, New Brunswick. Journal of the Fisheries Research Board of Canada, 15(6), pp. 1313-1327.

McKenzie, R.A. 1964. Rainbow Smelt life history and fishery of the Miramichi River, New Brunswick. Journal of the Fisheries Research Board of Canada, Bulletin 144.

Murawski, S.A., and C.F Cole. 1978. Population dynamics of anadromous Rainbow Smelt *Osmerus mordax*, in a Massachusetts river system. Transactions of the American Fisheries Society 107:535–542.

Murawski, S.A., G.R. Clayton, R.J. Reed, and C.F. Cole. 1980. Movements of spawning Rainbow Smelt, *Osmerus mordax*, in a Massachusetts Estuary. Estuaries 3(4):308-314.

O'Gorman, R., R. Bergstedt, and T.H. Eckert. 1987. Prey fish dynamics and salmonine predator growth in Lake Ontario 1974-1984. Canadian Journal of Fisheries and Aquatic Sciences 44(Supplement 2):390-403.

Rupp, R.S. 1968. Life history and ecology of the Rainbow Smelt (Osmerus mordax) in the inland waters of Maine. Maine Department of Inland Fish Game, Federal Aid in Fish Restoration, Project F-10-R, Final Report.

Stewart, D.J., J.F. Kitchell, and L.B. Crowder. 1981. Forage fishes and their salmonid predators in Lake Michigan. Transactions of the American Fisheries Society 110:751-763.

Whaley, R.A. 1991. An Improved Technique for Cleaning Fish Scales. North American Journal of Fisheries Management 11:234-236

Wyatt, L.H., A.L. Baker, and D.L. Berlinsky. 2010. Effects of sedimentation and periphyton communities on embryonic Rainbow Smelt, Osmerus mordax. Aquatic Sciences 72:361–369.

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, 2008–2023.

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
	2022	3/15 – 4/14/2022	15	183	8	3	7.96
	2023	3/21 – 4/20/2023	15	90	2	0	2.66
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
	2022	3/15 – 4/14/2022	15	701	14	0	7.16
	2023	3/21 – 4/20/2023	15	46	0	0	1.41

Table 1.2-1 (Continued)

River	Year	Haul dates	Number of sampling trips	Number of smelt caught[a]	Number of smelt recaptured[b]		CPUE
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
	2022	3/9 – 4/14/2022	18	1,907	94	0	17.99
	2023	2/14 – 4/20/2023	27	855	21	0	4.40

[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, 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, 2019–2023.

		Age-1	Age-2	Age-3	Age-4	Age-5	Age-6
Number smelt aged	2019	130	178	24	5	0	1
	2020	121	154	86	25	3	0
	2021	19	113	32	17	1	0
	2022	218	121	60	19	1	0
	2023	125	107	13	1	0	0
Mean length (mm)	2019	104	178	190	226	N/A	290
	2020	118	169	202	222	239	N/A
	2021	110	172	201	220	258	N/A
	2022	111	147	200	217	220	N/A
	2023	116	179	200	221	N/A	N/A
Min length (mm)	2019	80	142	154	222	N/A	290
	2020	91	98	157	181	230	N/A
	2021	94	111	150	194	258	N/A
	2022	82	101	161	199	220	N/A
	2023	79	131	183	221	N/A	N/A
Max length (mm)	2019	131	224	233	234	N/A	290
	2020	138	209	237	247	249	N/A
	2021	120	214	230	239	258	N/A
	2022	157	214	226	232	220	N/A
	2023	155	211	219	221	N/A	N/A

Table 1.2-3. Age distribution of Rainbow Smelt, weighted by total catch from Rainbow Smelt scale samples collected during fyke net sampling with all sampled rivers combined in New Hampshire, 2010–2023.

Year	Percent at age					N
	Age-1	Age-2	Age-3	Age-4	Age-5+	
2010[a]	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[a]	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
2022	68.60	23.10	6.20	2.00	0.00	419
2023	50.81	43.50	5.28	0.41	0.00	246
Mean	32.8	45.2	19.1	2.8	0.1	317

[a] Squamscott River did not have samples due to low catch in 2010 and 2014.

Table 1.2-4. Age distribution of Rainbow Smelt, weighted by total catch collected during fyke net sampling with in the Oyster, Squamscott, and Winnicut rivers in New Hampshire, 2010–2023.

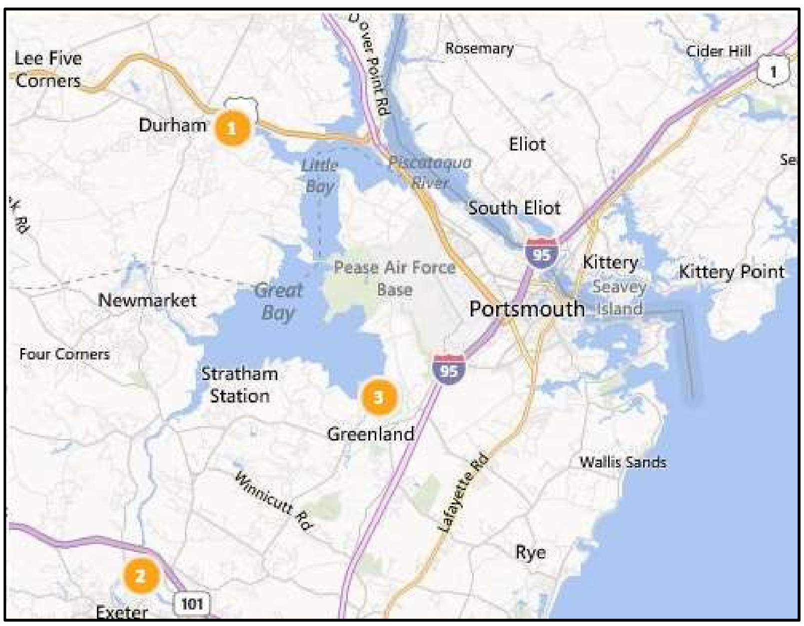
River	Year	Percent at age					N
		Age-1	Age-2	Age-3	Age-4	Age-5+	
Oyster	2010	64.9	25.6	8.1	1.5	0.0	177
	2011	10.2	74.6	15.0	0.1	0.0	192
	2012	25.1	52.2	21.6	1.2	0.0	162
	2013	35.8	41.7	17.5	5.0	0.0	17
	2014	67.9	25.0	7.1	0.0	0.0	28
	2015	0.0	42.9	42.9	14.3	0.0	7
	2016	65.0	31.0	3.3	0.7	0.0	226
	2017	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
	2022	72.5	26.4	1.2	0.0	0.0	94
	2023	62.7	35.8	1.5	0.0	0.0	67
	Mean	38.9	47.2	12.2	1.7	0.0	91
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
	2022	58.5	36.6	3.6	1.4	0.0	146
	2023	68.6	28.6	2.9	0.0	0.0	35
	Mean	24.5	50.0	22.4	3.1	0.1	141
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
	2022	72.1	17.6	7.8	2.5	0.1	179
	2023	41.0	50.7	7.6	0.7	0.0	144
	Mean	27.2	51.6	18.5	2.6	0.1	105

Table 1.2-5. Geometric mean bycatch from Rainbow Smelt fyke net sampling in the Oyster, Squamscott, and Winnicut rivers, New Hampshire, 2019-2023.

Common name	Scientific name	Oyster River # of fish per day						Squamscott River # of fish per day						Winnicut River # of fish per day					
		2019	2020	2021	2022	2023	Mean	2019	2020	2021	2022	2023	Mean	2019	2020	2021	2022	2023	Mean
Alewife	*Alosa pseudoharengus*						0.00	0.16	0.20		0.10	0.21	0.13						0.00
American Eel	*Anguilla rostrata*	0.26	0.26	0.15	0.29	0.46	0.28	0.12		0.90		0.24	0.21	0.20		0.08		0.05	0.06
Atlantic Silverside	*Menidia menidia*		0.11	0.05	0.05		0.04						0.00					0.07	0.02
Atlantic Tomcod	*Microgadus tomcod*	0.90	1.12	0.38	2.15	2.18	1.24		0.34				0.07						0.00
Banded Killifish	*Fundulus diaphanus*				0.10	0.13	0.04		0.10				0.02	0.05	0.03	0.54	0.19	0.82	0.33
Black Crappie	*Pomoxis nigromaculatus*	0.06	0.11	0.10	0.10	0.26	0.13	0.06	0.04		0.13	0.10	0.06						0.00
Blueback Herring	*Alosa aestivalis*					0.05	0.01		0.04			0.08	0.02						0.00
Bluegill	*Lepomis macrochirus*	0.06	0.36	0.15			0.11					0.18	0.03						0.00
Brook Trout	*Salvelinus fontinalis*						0.00		0.04		0.13		0.03	0.10		0.05			0.02
Brown Bullhead	*Ameiurus nebulosus*						0.00	0.25	0.08	0.10	0.05	0.20	0.13			0.05			0.01
Brown Trout	*Salmo trutta*						0.00				0.05		0.01						0.00
Chain Pickerel	*Esox niger*				0.13		0.02	0.55	0.36	0.18	0.15		0.23						0.00
Common Shiner	*Luxilus cornutus*				0.10		0.02	0.51	0.32	0.10	0.29	0.13	0.25	0.05		0.05	0.04		0.02
Cunner	*Tautogolabrus adspersus*					0.05	0.01						0.00						0.00
Fallfish	*Semotilus corporalis*						0.00					0.20	0.04						0.00
Fourspine Stickleback	*Apeltes quadracus*	6.34	9.68	5.51	4.75	2.26	5.30	0.55	1.36	1.34	15.86	4.37	2.85	53.83	0.75	2.31	2.90	19.74	6.72
Golden Shiner	*Notemigonus crysoleucas*					0.05	0.01	0.06	0.21	0.24	0.05	0.20	0.15						0.00
Little Sculpin	*Myoxocephalus aenaeus*	0.30			0.05		0.05						0.00						0.00
Mummichog	*Fundulus heteroclitus*	6.89	0.61	8.15	4.82	5.07	4.03		0.04	0.46		0.24	0.14	1.28	0.19	2.37	0.94	3.98	1.54
Ninespine Stickleback	*Pungitius pungitius*		0.23				0.05						0.00	1.70	0.07	0.11		0.25	0.28
Pumpkinseed	*Lepomis gibbosus*	0.12	0.04	0.05	0.05	0.05	0.06	0.23	0.37	0.36	0.40	0.33	0.34		0.03				0.01
Sea Lamprey	*Petromyzon marinus*	0.14		0.05	0.10		0.05	0.35	0.29	0.98	0.20	0.40	0.42						0.00
Smooth Flounder	*Pleuronectes putnami*	1.28	1.19	0.24	0.72	0.36	0.70						0.00						0.00
Striped Bass	*Morone saxatilis*						0.00						0.00						0.00
Striped Killifish	*Fundulus majalis*	0.73	1.16	4.42	1.72	0.37	1.40			0.13	0.10	0.08	0.06	0.51	0.59	2.23	0.19	3.71	1.26
Threespine Stickleback	*Gasterosteus aculeatus*	1.57	7.00	40.85	2.79	4.60	6.44	0.26	0.29	0.46	0.05	0.10	0.22	0.39	0.34	1.03	0.43	0.18	0.41
White Perch	*Morone americana*	0.67	1.71	0.57	0.28	1.08	0.83	0.39	1.17	0.84	0.33	0.20	0.58		0.26	0.15		0.05	0.09
Winter Flounder	*Pseudopleuronectes americanus*	0.06	0.04	0.10		0.10	0.06						0.00						0.00
White Sucker	*Catostomus commersonii*	0.06	0.13		0.05	0.08	0.06	2.01	3.97	3.14	4.71	1.69	3.03			0.05		0.03	0.01
Yellow Bullhead	*Ameiurus natalis*						0.00	0.23			0.05		0.04						0.00
Yellow Perch	*Perca flavescens*	0.06			0.13	0.10	0.05	4.57	0.82	0.47	0.50	1.09	1.06						0.00

Table 1.2-6. Geometric mean number of eggs per day collected on egg tiles set daily during fyke net sampling in the Oyster, Squamscott, and Winnicut rivers, New Hampshire, 2019–2023.

	Oyster	Squamscott	Winnicut
2019	0.24	2.22	10.82
2020	0.19	0.82	1.09
2021	0.04	3.00	1.63
2022	0.14	0.20	0.46
2023	0.01	0.16	0.09



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.