Technical Report

Massachusetts Division of Marine Fisheries
Technical Report TR-33

An Evaluation of the Use of Egg Transfers and Habitat Restoration to Establish an Anadromous Rainbow Smelt Spawning Population

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An Evaluation of the Use of Egg Transfers and Habitat Restoration to Establish an Anadromous Rainbow Smelt Spawning Population

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Abstract: **Rainbow smelt (*Osmerus mordax*) eggs were transferred from donor populations to the Crane River, Massachusetts, and a passage impediment to spawning habitat was removed in order to establish an anadromous spawning run. Smelt populations in Massachusetts declined sharply in the 20th century and growing public concerns warrant the development of restoration practices to address the problem. The Crane River was identified as having high restoration potential for smelt among coastal rivers in Massachusetts Bay because of the presence of 2,000 m^2 of suitable spawning habitat upstream of a former mill sluiceway. Smelt eggs were transferred to the Crane River for three seasons and the egg deposition of returning adults was monitored for five seasons. The project was successful in establishing a small spawning run of smelt to the Crane River and allowing access to previously unattainable spawning habitat. However, the total estimate of age-2 adult smelt recruited to the Crane River spawning run from three years of egg transfers was only 256 fish, and very low numbers of smelt eggs were encountered during monitoring. The egg transfer project was evaluated in terms of eggs collected, egg survival, Crane River recruitment, water quality and project costs. Based on these results, we conclude that egg transfers are not an efficient approach for population restoration because the method is labor intensive relative to recruitment benefits and present donor populations yield few surplus eggs. We recommend that a more efficient approach would be the use of hatchery incubation to achieve higher egg survival at locations with concurrent restoration efforts to improve water quality, and spawning and migratory habitats.**

Introduction

Rainbow smelt (*Osmerus mordax*) are a native anadromous species that ranges on the Atlantic coast of North America from Labrador to Virginia (Bigelow and Schroeder 1953). Landlocked populations also naturally occur and have been introduced as forage species in freshwater lakes in eastern North America and the Great Lakes. Anadromous smelt mature in coastal waters and estuaries, then ascend coastal rivers on springtime spawning runs. Spawning occurs at night during flood tide and eggs are broadcast to shallow, freshwater riffles upstream of tidal influence (Clayton 1976, Murawski et al. 1980). Fertilized eggs are negatively buoyant and adhere to riffle substrata where incubation occurs for 1-3 weeks depending on water temperature (McKenzie 1964). Upon hatching, larvae are immediately transported downstream into the tidal zone where feeding on zooplankton begins. By age-2, smelt are mature and fully recruited to local fisheries and spawning runs. In New England, smelt have traditionally supported popular sportfisheries, small commercial fisheries and are valued as important prey for many fish and wildlife species (Kendall 1926, Bigelow and Schroeder 1953, and Collette and Klein-MacPhee 2002).

Smelt populations in Massachusetts have declined sharply from historic references although the magnitude of decline is uncertain because no assessments are conducted on smelt fisheries or populations. Observations elsewhere in the Gulf of Maine (Collette and Klein-MacPhee 2002, Grout and Smith 2004, and NOAA 2004) and in the St. Lawrence River region of Quebec (Trencia 1999) point to a similar trend of smelt population and fisheries decline in the 20th century. Causal factors for the decline have not been previously investigated, although watershed alterations such as obstructions to passage and spawning habitat degradation are suspected influences (Squires et al. 1976, and Chase 2006). Concern over the status of smelt continues to grow as evident by their designation as a federal Species of Concern by the National Marine Fisheries Service under their Endangered Species Act review process (NOAA 2004). The designation was based on the criteria of significantly decreased landings records and apparent truncation of smelt distribution.

Increasing concern over the status of smelt populations have prompted interest in population and spawning habitat restoration techniques. The only smelt restoration method commonly used during the 20th century was the transferring of smelt eggs from a productive smelt run to a river targeted for population enhancement. Fertilized smelt eggs were collected on trays placed at spawning riffles in

donor runs and transported to spawning riffles in depleted runs where hatching would occur from the trays. It was assumed that the river receiving smelt eggs had suitable conditions (spawning substrata and water chemistry) to support egg survival, and the transferred eggs would provide adult recruitment that could sustain a viable spawning run. Smelt egg stocking was first recorded in 1877 in Maryland and the earliest record for Massachusetts is 1910 (Fried and Schultz 2006). Smelt egg transfers were successfully used to establish smelt in the Great Lakes in the early 20th century (Van Oosten 1937), and were used for much of the 20th century in New England to establish landlocked populations in freshwater lakes and to enhance coastal anadromous spawning runs (Bigelow and Schroeder 1953, Reback and DiCarlo 1972, Chesmore et al. 1973, and Grout and Smith 1994). After decades of smelt egg transfer projects in Massachusetts, Reback and DiCarlo (1972) state the success of these efforts is unknown. Overall, the documentation on this practice is limited and no evaluations have been conducted on the effectiveness of egg transfers to establish an anadromous smelt run.

In response to concerns over declining smelt populations and strong interest from the sportfishing community to conduct smelt egg transfers, the Massachusetts Division of Marine Fisheries (DMF) conducted an evaluation on the efficiency of egg transfers in a control river where smelt were not present. Our goal was to evaluate the methodology and success of egg tray transfers in order to develop restoration strategies for smelt. Smelt spawning habitat monitoring identified the Crane River as one of the best candidates on the Gulf of Maine coast of Massachusetts for conducting an evaluation of egg transfers (Chase 2006). The Crane River was selected because no smelt eggs were documented during three years of monitoring, and suitable spawning habitat was available upstream of a modest passage barrier. Ongoing projects with smelt culture and restoration in Quebec (Pouliot and Verreault 2001, and Trencia and Langevin 2003) indicated that hatchery incubation had potential as an alternative approach to egg stocking with egg trays. We conducted pilot smelt culture efforts prior to this study (B.Chase, DMF, unpublished data) that supported this potential, and included egg survival experiments in the evaluation to confirm the suitability of Crane River water quality for incubation and to compare egg survival for in-river and hatchery incubation.

Objectives. (1) Establish a spawning population of smelt by transferring three million eggs per year for three years.

(2) Restore access to spawning habitat by removing an impediment to passage.

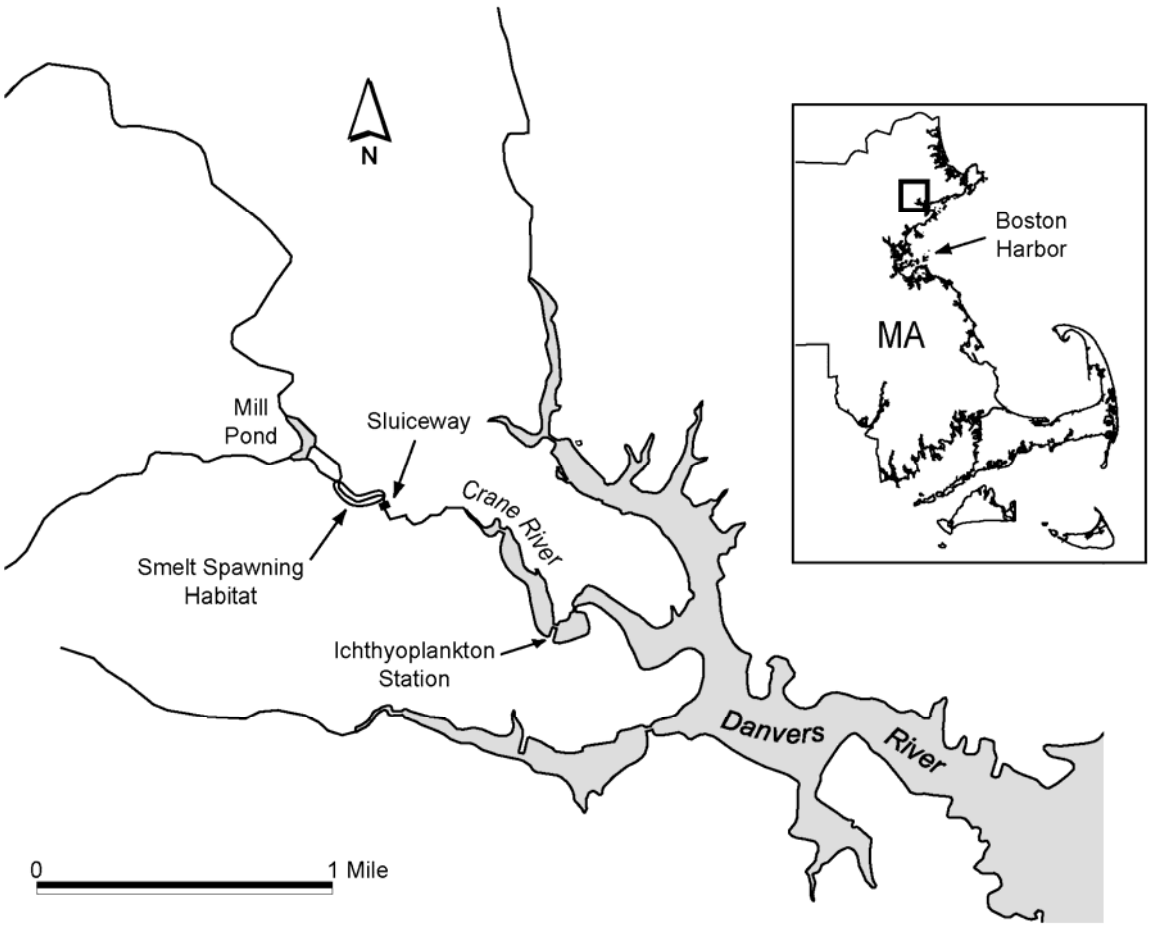
(3) Evaluate the egg transfer method in terms of water quality, egg survival rates in the field and laboratory, estimated recruitment to the spawning run, and project cost.

(4) Monitor the Crane River for five seasons to document the success of egg transfers and spawning habitat use by returning adult smelt.

(5) Develop recommendations for future smelt enhancement efforts using egg tray transfers or alternative methods.

Study Area. The Crane River is a small, freshwater tributary to the Danvers River estuary located in the Town of Danvers in the North Shore Coastal Drainage Basin of Massachusetts (Figure 1). The drainage area of the Crane River is 14.8 km^2 (Wandle 1984). No streamflow gauge stations were located on the Crane River. The origin of Crane River discharge is two small tributaries (Crane Brook and Beaver Brook) in the Town of Danvers that enter a two hectare pond named Mill Pond. The river runs for 0.5 km from Mill Pond to a former mill outlet pond (<0.5 hectare). A tannery operated on the mill site for over 100 years until closing in 1984. The tannery discharged its wastewater directly to Crane River prior to connecting to the municipal sewer in 1975. The sluiceway that drains the outlet pond created an elevation rise of 0.3 to 0.5 m, depending on discharge. The outlet pond sluiceway is located less than 100 m upstream of the tidal interface of the Danvers River estuary. The Crane River possesses approximately 2,000 m^2 of potential spawning

Figure 1. Location of the study site at Crane River, Danvers, Massachusetts, USA.



substrate upstream of the former mill sluiceway that blocked smelt passage, and 350 m^2 of spawning substrate in two riffles between the sluiceway and the tidal zone. No smelt eggs were found upstream or downstream of the sluiceway during 1988-1990 spawning habitat monitoring (Chase 2006). No records were found that identify the Crane River as a former smelt run. However, given the presence of smelt spawning runs elsewhere in the Danvers River estuary and suitable spawning habitat in close proximity to the estuary, it is likely that a smelt run was present prior to the creation of the outlet mill pond.

Methods

Egg Collections. Smelt eggs were collected by placing rectangular egg trays in spawning riffles of rivers with productive smelt runs. The trays consisted of wooden frames containing sphagnum moss that served as the collection surface for eggs. The frames were weighted on the bottom with steel bars and wire mesh held the tightly packed moss. This type of collection tray type has been used for decades by DMF and provides a good attachment substrate for adhesive smelt eggs (Lawton et al. 1990). Three sizes of egg trays were used: 1538 cm^2, 1627 cm^2, and 1858 cm^2. The wire mesh

size was 6.45 cm^2 (1.0 in^2), resulting in 238, 252, and 288 mesh cells for the respective egg trays. Egg trays were deployed at prime spawning riffles for overnight sets in smelt runs in the Boston Harbor region (Figure 1). The trays were allowed to set for additional nights until adequate numbers of eggs were collected. The Back River, Weymouth, was the primary donor river and the Fore River, Braintree, and Town Brook, Quincy, were used as back-up donor runs. Once retrieved, egg trays were covered with wet towels and driven directly to the Crane River (one hour travel time). Egg trays were deposited in potential spawning riffles in the Crane River and initial egg counts were made to estimate the total number of transferred eggs.

Stratified random sampling was used to estimate the number of eggs transferred because smelt spawning events and the spawning substrata where egg trays were deployed were heterogeneous. Each transfer date was treated as separate strata and egg counts were randomly made in 5% of the cells in every tray. Stratum weights were considered equal because the same size egg trays were used for each deployment and egg deposition in spawning riffles was unpredictable.

For each tray, the total number of eggs counted was divided by number of cells counted to estimate mean eggs per cell . The stratified mean, stratified variance and confidence intervals were calculated for each stratum as follows:

$$\overline{Y}_{st} = \sum \left[\overline{y_i}\right] / T_h$$

$$V(\overline{Y}_{st}) = \sum N_i (N_i - n_i) S_i^2 / n_i$$

$$s\left(\overline{Y}_{st}\right) = \sqrt{V\left(\overline{Y}_{st}\right)}$$

where h indicates the stratum,

i the unit within the stratum,

$\overline{Y}_{st}$ is the stratum mean,

T_h is the number of collection trays,

N_i is the total no. of cells in collection tray,

$V\left(\overline{Y}_{st}\right)$ is the stratified variance, and

$s(\overline{Y}_{st})$ is the standard error (Cochran 1977).

The stratified mean was multiplied by the total number of cells in all trays to calculate the total number of eggs for a transfer date. Confidence intervals were calculated for stratified egg totals for each transfer date (t = 1.645, α = 0.1, df = Σn_{hi} -1) (Cochran 1977).

Water Chemistry. Water chemistry measurements were made at the egg transfer station in the Crane River, at donor rivers and during laboratory egg survival trials. Temperature, salinity, pH, dissolved oxygen, and specific conductivity were measured using a Hydrolab Surveyor II that was calibrated daily. Measurements were made at donor populations during each visit to deploy or retrieve collection trays. Measurements were made in the Crane River and in laboratory egg survival trial tanks at the start of each egg transfer or egg survival trial and every third day following. Biweekly stream flow velocity and discharge measurements were made in the Crane River using a Teledyne Gurley 622-G current meter.

Smelt Egg Survival. Egg survival trials were conducted to evaluate the survival rates of transferred smelt eggs, the influence of Crane River water quality on hatching, and to provide a comparison of egg survival from traditional egg tray stocking with egg survival in a controlled hatchery setting. The trial tested the hypothesis that there would be no difference in survival between field and laboratory treatments. We also tested the hypothesis that there would be no difference in survival of eggs incubated in a low salinity treatment and eggs incubated in Crane River freshwater. Pilot investigations prior to this study indicated that low salinity water might discourage fungal growth and result in higher egg survival than freshwater incubation (B. Chase, DMF, *pers. observation*).

Test trays were deployed for overnight sets to collect eggs for the survival trials. The test trays were smaller versions (292 cm^2) of the egg collection trays. After collection, the test trays were monitored under the following treatments: placed in spawning riffles in the Crane River (F), placed in laboratory tanks with Crane River water (C), and placed in laboratory tanks with Crane River water adjusted to 6 ppt salinity (S). For each trial 15 test trays were collected with five trays randomly assigned to each treatment. For the laboratory trials, trays were placed in static 10 gal aquaria that were set in a 275 gal tank with flow-through seawater. Water was pumped from a saltwater impoundment to a tank outside the laboratory that was exposed to similar variations in air temperature as Crane River flows. Fifty percent of the aquaria water was changed weekly. Aquaria were supplied with aeration through two air stones and received no direct sunlight.

Total egg counts were made on the day of collection and every three days until hatching. Because hatching could not be confirmed in the free-flowing, Crane River, the last count of late-stage embryos prior to laboratory hatching was used as an estimate of maximum egg survival. Data on the percentage of eggs surviving on each test tray were transformed using the arcsine square root transformation because the data were proportions and to reduce the influence of unequal variance among treatment means. (Sokal and Rohlf 1969). Transformed survival data where tested for significant differences using the student t-test ($\alpha = 0.05$).

Recruitment to Adult Spawning Run. Did previous smelt egg transfer efforts enhance, restore or establish smelt runs? This is an important unanswered question related to the utility of smelt egg transfers. Most transfers in Massachusetts took place at existing, depleted smelt runs. With a run of unknown size present it was difficult to assess if future recruitment was related to the egg transfers and consequently, such evaluations were not made. We selected a river with no smelt present and estimated numbers of mature age-2 smelt that would be recruited to a Crane River spawning run from the transferred eggs using the following adult equivalent model (Goodyear 1978, and Boreman 1997).

$$N_a = \sum_{i=1}^{n} N_i \cdot S_i \quad .$$

Where N_a is the equivalent number of age group a, n is the number of ages or life stages between egg deposition and age-2 adults, N_i is the number surviving to each age group or life stage, and S_i is the survival probability from age i to age a. The model assigns survival probabilities to each age group up to the age of recruitment to the spawning stock. Survival rates for early life stages of rainbow smelt are not well-described. The most suitable survival rates were selected from published literature. An estimate for egg survival (S = 0.036 at the low density of 0.5 eggs/cm^2) was selected from McKenzie (1964) for New Brunswick rainbow smelt. Larval (S = 0.07) and age-1 (S = 0.132) survival rates were selected from Saunders (1981) who modeled Massachusetts Bay smelt population dynamics with assumed survival rates for these life stages. Adult smelt survival (S = 0.2815 for age 2 and 3) were estimated by Murawski and Cole (1978) for Parker River smelt in Massachusetts.

Monitoring of Smelt Egg Deposition. We monitored egg deposition for five years following the egg transfers to confirm the presence of returning adult smelt and assess egg densities. Early attempts to randomly measure egg density (eggs/m^2) were not successful because of sparse egg deposition over a large area of potential spawning habitat. An alternative approach was adopted where the time spent looking for eggs was recorded and the number of eggs found were counted and compared as eggs/hour. This approach allowed comparison to the 1988-1990 monitoring in Crane River when visits were made twice a week during March, April and May to document the presence of smelt eggs by manually inspecting the substrate by hand and with custom-crafted egg scoops (steel basket

attached to a broom handle). During each visit for the 1997-2001 monitoring, the two prime spawning riffles upstream and downstream of the mill sluiceway were inspected. The time spent searching was recorded and total smelt eggs were counted during monitoring, except when 100 or more eggs were counted at one of the four riffles. In this case, counting would cease at 100 and monitoring would resume at the next spawning riffle. The first year of expected spawning run recruitment after initial egg transfers was 1997. Weekly visits were made during the peak spawning period of April and some additional visits were made in late-March and early-May.

Ichthyoplankton. Ichthyoplankton samples were collected to detect the presence and timing of smelt larvae in Crane River tidal waters downstream of the egg transfer location. A rectangular plankton net (0.14 m^2) with 0.505 mm mesh, was used to sample the ebb flow of surface water shortly after high tide. Samples were collected during daylight at a railroad bridge upstream of the confluence of the Crane River to the Danvers River estuary (Figure 1). A 2030-R General Dynamics flowmeter attached to the net frame was used to measure water velocity (m/sec) and volume (m^3). Samples were preserved in 5% phosphate buffered formalin and returned to the laboratory for sorting and microscopic analysis. Fish eggs and larvae were measured to the nearest 0.1 mm and identified with the aid of manuals by Colton and Marak (1969), Scotton et al. (1973), Martin and Drewry (1978), and Elliot and Jimenez (1981).

Project Costs. Project costs were recorded in order to evaluate the project success relative to costs and for future management decisions on transferring smelt eggs or on alternative means for smelt population restoration. Labor and supplies costs were recorded for actual 1995-1997 expenditures in US dollars.

Results

Smelt Egg Transfers. Smelt eggs were transferred from donor rivers to the Crane River on 17 occasions during 1995-1997 (Table 1). The objective of transferring three million eggs annually was not met, as the stratified mean estimate for all three years was 2.74 million eggs (± 81,706 eggs with 90% CI). Over two million eggs were collected during 1995 when high densities of smelt eggs were found in the Back River. The higher densities of eggs collected in 1995 were not encountered again. The number of transfer attempts was increased in 1996 and 1997 and egg trays were deployed at alternative donor rivers to increase egg collections. The spawning events that produced the higher egg deposition in 1995 were not evident in any of the smelt spawning runs throughout the region during 1996 and 1997.

Smelt Egg Survival Trials. Two attempts to estimate egg survival failed in 1995 because too many eggs were caught on test trays to accurately count and monitor, and two early season attempts in 1996 failed because too few eggs were caught. Two successful egg survival trials were made in April and May, 1996, when suitable densities of eggs were collected on 15 test trays and initial egg counts were compared to eyed egg counts before hatching. Test trays for the first trial were collected on April 17th after one night in the Back River with an average density of 0.5 eggs/cm^2 (Table 2). Hatching was first noted in the laboratory tanks on April 25th (8 days after collection and 9 days after trays were deployed in the Back River). The last egg count before hatching was made on April 23rd (6 days after collection). The mean water temperature during this period was 12.1 ºC in the Crane River and 13.1 ºC for both laboratory treatments (Table 3). The mean estimates for maximum egg survival were 24.4% (FA), 89.4% (CA), and 73.3% (SA). Transformed egg survival data for all treatments in both trials were found to have equal variances (F-test). The survival of eggs in both laboratory treatments were significantly higher than the field treatment survival ($df = 8$, $P \leq 0.001$). The survival of eggs in the two laboratory treatments were not significantly different ($df = 8$, $P = 0.091$).

Test trays for the second trial were collected on May 17th after four nights in the

Table 1. Smelt egg transfers from donor rivers to the Crane River during 1995-1997. Stratified estimates were made of egg density, total eggs per transfer and confidence intervals (CI).

Date	River	Trays (No.)	Egg Density (eggs/cm^2)	Strat. Mean (eggs/cell)	SE	Total Eggs
3/31/95	Back	33	14.5	93.5	29205	777,546
4/14/95	Back	6	2.0	12.9	1776	22,349
4/18/95	Back	25	28.7	185.1	37820	1,332,781
3/28/96	Back	13	0.4	2.4	1383	9,072
4/16/96	Back	22	8.9	57.2	12104	317,142
4/18/96	Back	12	0.7	4.4	833	15,235
4/25/96	Back	5	0.6	4.1	342	4,879
4/30/96	Back	13	2.2	14.4	3323	53,128
5/2/96	Back	10	1.6	10.4	1522	26,444
5/7/96	Back	8	0.3	2.2	481	4,774
5/17/96	Town	8	0.5	3.0	645	6,912
4/9/97	Back	16	1.2	7.5	1800	34,532
4/15/97	Back	16	0.7	4.5	1254	18,170
4/21/97	Fore	8	1.9	12.2	2180	27,995
5/1/97	Fore	18	0.8	4.9	1129	21,016
5/5/97	Town	15	1.8	11.7	2353	50,429
5/13/97	Fore	14	0.6	4.1	1004	13,661
Egg Sum						2,736,065
90% Upper CI						2,817,771
90% Lower CI						2,654,359

Table 2. Smelt egg survival trial conducted in April, 1996. Smelt eggs were collected on April 17th in the Back River after a one night set. The last count prior to hatching was made on April 23rd.

Treatment	No.	Initial Egg Count	Density (eggs/cm^2)	Last Egg Count	Survival (%)
Crane River	FA1	195	0.7	60	30.8
Crane River	FA2	238	0.8	74	31.1
Crane River	FA3	124	0.4	39	31.5
Crane River	FA4	159	0.5	30	18.9
Crane River	FA5	171	0.6	17	9.9
Mean			0.6		24.4
Laboratory	CA1	153	0.5	129	84.3
Laboratory	CA2	97	0.3	89	91.8
Laboratory	CA3	107	0.4	96	89.7
Laboratory	CA4	164	0.6	135	82.3
Laboratory	CA5	170	0.6	168	98.8
Mean			0.5		89.4
Laboratory	SA1	53	0.2	39	73.6
Laboratory	SA2	150	0.5	126	84.0
Laboratory	SA3	82	0.3	40	48.8
Laboratory	SA4	53	0.2	78	94.0
Laboratory	SA5	56	0.2	37	66.1
Mean			0.3		73.3

Table 3. Water chemistry measurements for Crane River smelt egg survival trials. Field measurements were grab samples taken a minimum of every three days (April 17- 26th; and May 17- 23rd). Laboratory data are the means from five aquaria replicates taken a minimum of every three days.

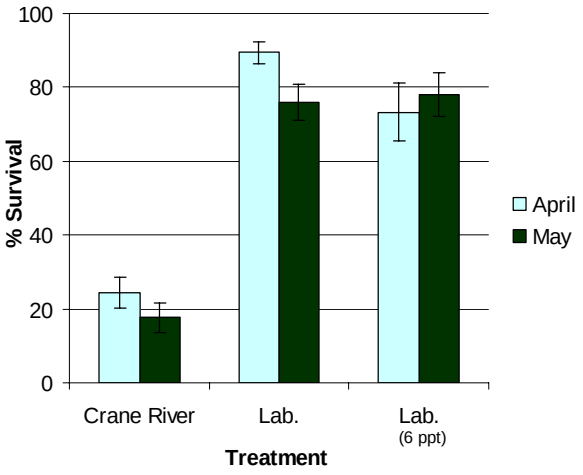
April - 1996		Crane River (FA)			Laboratory (CA)			Laboratory (SA)		
Parameter	N	Mean	Start	End	Mean	Start	End	Mean	Start	End
Water Temp. (ºC)	4	12.1	7.5	14.5	13.1	10.0	15.5	13.1	10.1	15.5
D.O. (mg/L)	4	10.7	11.3	10.1	9.8	11.0	9.3	9.6	10.4	9.1
pH	4	7.0	6.9	7.0	7.8	7.7	7.9	7.6	7.5	7.6
Sp. Cond (mmho/cm)	4	0.707	0.569	0.829	1.031	1.029	1.016	11.42	12.40	10.58
Salinity (‰)	4	0.0	0.0	0.0	0.0	0.0	0.0	6.0	6.5	5.5
May - 1996		Crane River (FM)			Laboratory (CM)			Laboratory (SM)		
Parameter		Mean	Start	End	Mean	Start	End	Mean	Start	End
Water Temp. (ºC)	3	18.4	12.6	21.1	18.0	15.8	20.1	17.9	15.9	20.2
D.O. (mg/L)	3	8.9	10.0	8.5	9.1	9.9	8.6	8.8	9.4	8.3
pH	3	7.0	6.7	7.1	7.7	7.6	7.9	7.6	7.5	7.6
Sp. Cond (mmho/cm)	3	0.701	0.573	0.768	0.820	0.807	0.893	12.01	12.64	10.82
Salinity (‰)	3	0.0	0.0	0.0	0.0	0.0	0.0	6.3	6.7	5.6

Table 4. Smelt egg survival trial conducted in May, 1996. Smelt eggs were collected May 17th in the Town River after a four night set. The last count prior to hatching was made on May 20th.

Treatment	**No.**	**Initial Egg Count**	**Density** (eggs/cm^2)	**Last Egg Count**	**Survival** (%)
Crane River	FM1	40	0.1	3	7.5
Crane River	FM2	47	0.2	9	19.1
Crane River	FM3	62	0.2	18	29.0
Crane River	FM4	59	0.2	6	10.2
Crane River	FM5	48	0.2	11	22.9
Mean			0.2		17.7
Laboratory	CM1	60	0.2	50	83.3
Laboratory	CM2	44	0.2	29	65.9
Laboratory	CM3	53	0.2	44	83.0
Laboratory	CM4	40	0.1	34	85.0
Laboratory	CM5	48	0.2	30	62.5
Mean			0.2		75.9
Laboratory	SM1	46	0.2	31	67.4
Laboratory	SM2	34	0.1	27	79.4
Laboratory	SM3	47	0.2	35	74.5
Laboratory	SM4	42	0.1	42	100.0
Laboratory	SM5	32	0.1	22	68.8
Mean			0.1		78.0

Town Brook with an average density of 0.2 eggs/cm^2 (Table 4). Hatching was first noted in the laboratory during the afternoon of May 20th (3 days after collection, and 8 days after trays were deployed in Town Brook). Only one egg count was made after the initial May 17th count on the morning of May 20th. The mean water temperature during this period was 18.4 ºC in the Crane River and approximately 18.0 ºC for both laboratory treatments (Table 3). The mean estimates for maximum egg survival were 17.7% (FM), 75.9% (CM), and 78.0% (SM). The survival of eggs in both laboratory treatments were significantly higher than the field treatment survival (df = 8, $P \leq 0.001$). The survival of eggs in the two laboratory treatments were not significantly different (df = 8, P = 0.618). Both egg trials had the consistent results of high survival for laboratory treatments and relatively low survival for the Crane River treatment (Figure 2).

Figure 2. Crane River smelt egg survival trials, 1996. The bars indicate mean survival at the last egg count (+/- 1 SE).



Spawning Habitat Monitoring. The Crane River smelt spawning habitat was monitored during 1997-2001 to document egg deposition from returning adult smelt and to evaluate passage improvement following the sluiceway removal by the Town of Danvers in 1996. The removal of the sluiceway lowered the outlet pond's elevation resulting in open passage to upstream habitat and created a new spawning riffle at the upstream inlet of the pond. The first year that age-2 adult smelt would be expected to return was 1997. Five smelt eggs were found on April 3rd, the first monitoring date in 1997, about 50 m downstream of the modified sluiceway. Zero to five eggs were found downstream of the modified sluiceway with each visit in 1997, except on April 21st when 50 eggs were found 75 m upstream of the sluiceway in the newly formed riffle. Several of these eggs were hatched out in the laboratory and identified as smelt larvae.

Smelt eggs were found in the Crane River during each of the five years of monitoring except in 1999 when none were found during seven trips (Table 5). The low densities of observed smelt eggs indicated that very few adults participated in the smelt run during these years. Low densities of smelt eggs were found at four shallow riffles located from 75 m downstream of the sluiceway to 100 m upstream of the sluiceway at the base of a

Table 5. Monitoring of smelt egg deposition in the Crane River, 1997-2001.

Year	Monitoring Period	Egg Deposition Period	Trips (No.)	Effort (Hrs.)	Eggs (No.)	CPUE (Eggs/hr)
1997	April 3rd - May 8th	April 3rd - May 1st	6	5.2	60	12
1998	March 25th - April 30th	March 25th - April 16th	5	4.7	48	10
1999	April 1st - May 12th	none found	7	3.8	0	0
2000	March 9th - May 11th	March 28th - May 4th	11	7.3	150	21
2001	March 29th - Apr. 30th	March 29th - April 24th	5	2.7	127	47

cobble riffle. A total of 120 m of river length and 513 m^2 of spawning substrate (wetted perimeter) were found to contain smelt eggs. The potential spawning habitat in the Crane River estimated prior to this study was 2,170 m^2 of substrate along 547 m of river length (Chase 2006). The temporal range of smelt egg presence during the five years was March 25th to May 4th. On two dates (April 27, 2000 and March 29, 2001) greater than 100 eggs were found at in one riffle. In both cases it was a shallow, gravel riffle 50 m downstream of the sluiceway.

Recruitment to Adult Spawning Run. Life stage survival values from smelt literature were used to determine a theoretical estimate for potential recruitment from the egg transfers. The eggs transferred in 1995 would first recruit age-2 adult smelt to the spawning run in 1997. The mean estimate for total smelt eggs transferred during 1995 was 2.133 million (Table 1). The adult equivalent estimate for this amount of eggs is 200 age-2 smelt (Table 6). The estimate of age-2 smelt returning in 1998 from the 1996 egg stocking was 41 smelt, along with 56 age-3 adults from the 1995 age class. The estimate for smelt returning from 1997 egg stocking was 15 age-2 smelt in 1999, along with 12 age-3 smelt from the 1996 year class. Under the assumption of no survival after age-3, there would be four age-3 smelt returning for the 2000 smelt run to complete the initial production from egg transfers. The total estimate of smelt recruited to the Crane River from the three years of egg transfers was 256 age-2 and 72 age-3 smelt.

Water Chemistry. Field measurements of water chemistry resulted in similar mean values at the Crane River and donor rivers for most of the parameters measured (Table 7). Only specific conductivity had large differences in mean values: the Crane River had higher specific conductivity than two donor rivers. The Back River had six pH measurements that violated Massachusetts surface water quality standards for support aquatic life (< 6.5) (MDEP 1996). The only other violations of water quality standards were low dissolved oxygen measurement in the Back River in early May 1995 caused by alewives crowding in the river channel where smelt spawned. Overall, the water chemistry values for these parameters were supportive of smelt egg survival in the donor rivers and Crane River.

Ichthyoplankton. Ichthyoplankton collections were made on 10 dates in both 1995 and 1996 from March 30th to June 4th (Table

Table 6. Estimated recruitment to adult smelt spawning run in the Crane River. Annual columns show the estimated recruitment to each life stage produced by egg transfers during 1995-1997 (Table 1).

		1995	1996	1997	Total
Eggs Transferred		2,132,676	437,586	165,803	2,736,065
Life Stage	**Survival**				
egg	0.0360	76776	15753	5969	
larva	0.0700	5374	1103	418	
age-1	0.1320	709	146	55	
age-2	0.2815	200	41	15	256
age-3	0.2815	56	12	4	72

Table 7. Mean water chemistry measurements made during April and May at the Crane River and egg donor rivers, 1995-1997. Discharge in the Crane River was measured biweekly (N = 16). Back and Fore river discharges were estimated from Chase (2006) and recorded for Town Brook from a U.S. Geological Service gage station (#01105585).

River	Sample (N)	Temp. (ºC)	pH	D.O. (mg/L)	Sp. Cond. (mmho/cm)	Discharge (m^3/s)
Crane River	38	12.9	7.1	10.7	0.726	0.33
Back River	4	10.4	6.5	9.7	0.400	0.95
Fore River	18	13.6	6.9	10.5	0.339	1.40
Town Brook	5	12.3	6.7	10.5	0.679	0.29

8). Smelt larvae were caught on three dates, May 1st, 1995 and May 2nd and 8th, 1996. Detrital smelt eggs were caught on one occasion, April 18, 1995. These dates coincide well with transfer dates and expected hatching. All smelt were yolk-sac larvae except for one 15 mm larvae on May 1st, 1995 that could have migrated into the Crane River from other spawning locations. Ten other species of marine fish were represented in the eggs and larvae collected, including sand lance, the most frequently caught species.

Project Costs. The total project cost for 1995-1997 was estimated as US $39,179 (Table 9). The highest individual cost was the principal investigator labor which came to over $24,000 with fringe and indirect costs. The next highest cost was $9,575 for technicians. A Sweetwater Trust grant of $8,000 paid for technician salaries in 1995 and 1996. Materials and equipment costs were low ($5,550) because DMF possessed all necessary instrumentation for laboratory and field measurements, and most egg collection trays were constructed for previous egg transfer projects. Total hours during 1995-1997 were 1,665.5 for staff and 105 for volunteers. No attempt was made to assess the amortized value of project equipment that was purchased previously. The costs for 1998-2001 monitoring were also not included because these brief visits were made during the field operations of a new project. The inclusion of previously purchased equipment and post-1997 monitoring would raise the project cost to the range of $50,000-$60,000.

Discussion

The sluiceway alteration provided access

Table 8. Ichthyoplankton samples collected during 20 sample dates at the railroad bridge upstream of Rt. 35 on the Crane River, 1995-1996. Sizes are average total length for larvae and diameter for eggs. Larvae density is the absolute density for the total sample volume (2,242 m^3).

Species		Type	FOC (No.)	Period	No.	Size (mm)	Density (No./100 m^3)
sand lance	*Ammodytes americanus*	larva	7	3/30 - 5/17	22	10.7	1.0
Atlantic silverside	*Menidia menidia*	larva	4	5/17 - 6/4	23	6.0	1.0
rainbow smelt	*Osmerus mordax*	larva	3	5/1 - 5/8	7	7.5	0.3
Atlantic cod	*Gadus morhua*	larva	3	3/30 - 4/4	7	17.1	0.3
grubby	*Myoxocephalus aenaeus*	larva	3	3/30 - 4/4	7	7.2	0.3
Atlantic herring	*Clupea harangus*	juvenile	2	4/4 - 4/18	2	37.5	0.1
winter flounder	*Pleuronectes americanus*	larva	2	4/26 - 5/1	2	4.0	0.1
fourbeard rockling	*Enchelyopus cimbrius*	larva	2	5/30 - 6/4	3	4.3	0.1
radiated shanny	*Ulvaria subbifurcata*	larva	1	6/4	4	4.7	0.2
L-L group	*Labridae-Limanda*	egg	3	5/17 - 5/31	11	1.0	0.5
P-S group	*Paralichthys-Scopthalmus*	egg	1	5/31	2	0.9	0.1
rainbow smelt	*Osmerus mordax*	egg	1	4/18	5	1.1	0.2

Table 9. Crane River smelt restoration project costs and effort, 1995-1997.

Source	Effort (hr.)	Wage ($/hr.)	Salary ($)	Fringe ($)	Indirect ($)	Purchases ($)	Total ($)
Biologist	796.5	20	15,930	3,664	4,460		24,054
Technician (97)	102.0	13	1,326	305			1,631
Technician (95/96)	662.0	12	7,944				7,944
Volunteers	105.0						
Transportation						1,050	1,050
Field Supplies						2,500	2,500
Laboratory Supplies						2,000	2,000
Total	1,665.5		25,200	3,969	4,460	5,550	39,179

to approximately 2,000 m^2 of upstream spawning habitat and three seasons of smelt egg transfers to the Crane River resulted in the presence of a smelt spawning run. This is the first documentation in Massachusetts of the establishment of an anadromous rainbow smelt spawning run following egg transfers and habitat restoration. The declaration of a successful restoration project does come with several caveats. Without a mark-recapture effort, there is no way to confirm that the returning adults in 1997-2001 originated from the transferred eggs. The possibility of smelt colonizing Crane River from nearby smelt runs cannot be eliminated, although the timing of the returns and the absence of smelt prior to the project strongly imply the transfers produced returning adults. Secondly, the numbers of smelt eggs transferred were much lower than the project objective and represent the equivalent of a very small spawning run. Finally, the few smelt eggs found during 1997-2001 monitoring confirmed smelt spawning but approached the lower limit of detection. These concerns point towards a restoration project with limited success in terms of population recruitment. However, additional benefits were realized with improved passage for smelt and American eel (*Anguilla rostrata*), and information to support future smelt restoration and management efforts.

Smelt Egg Survival. Smelt egg survival for both treatments were higher than expected natural survival. The average "maximum egg survival" of the two Crane River egg survival trials was 21% (Tables 2 and 4). The proportion of embryos surviving to late-stage in the Crane River trials was much higher than published smelt egg survival rates (Rothschild 1961, McKenzie 1964, and Rupp 1965). The higher level in the Crane River trials certainly does not account for additional mortality that occurs in the next day or two before hatching. The application of a 21% egg survival rate to the adult equivalency model resulted in the estimated recruitment of 1,495 age-2 adults. The uncertainty over survival after the last egg count led us to adopt the conservative egg survival rate of 3.6% from McKenzie (1964). Our high egg survival during laboratory trials with Crane River water was encouraging and reduced concerns over negative influences of Crane River water quality on egg incubation.

The high survival rate may also have been enhanced by the optimal incubation surface provided by the sphagnum moss. The natural substrate of the Crane River was degraded by sedimentation in some locations and excessive periphyton growth throughout the habitat. It is possible that the improved substrate of the egg trays increased egg survival over the 2-4% range from published experiments. This feature of egg tray transfers could be a benefit in term of increasing hatching survival over that occurring naturally at degraded spawning substrate. This advantage of using artificial substrate incubators has been demonstrated for lake trout (*Salvelinus namaycush*) restoration (Bronte et al. 2002).

Smelt Egg Monitoring. Our efforts to record random observations of egg deposition in terms of spawning substrate densities (eggs/ m^2) failed because of sparse egg deposition. Smelt eggs were found at only a few specific locations in four riffles that represented only 20% of the potential river length where spawning could occur. The lack of a quantitative measure of egg deposition limits our evaluation of the spawning run produced by the egg transfers. We then adopted a qualitative approach of counting observed eggs per hour at the two primary riffles upstream and downstream of the modified sluiceway. This approach documented the presence of spawning smelt in the Crane River: finding smelt eggs on the first day of monitoring during the first year that age-2 recruitment was expected. The monitoring efforts of five seasons indicated that very few adult smelt were participating in the spawning run. Approximately 385 smelt eggs were found during about 24 hours of egg monitoring (16 eggs/hour). This is an improvement over finding no smelt eggs in the Crane River over approximately 20 hours of monitoring during 1988-1990 (Chase 2006).

The smelt eggs observed in the Crane River were low relative to the reproductive capacity of smelt and the available spawning habitat in the Crane River. McKenzie (1964) investigated egg survival at various density levels in the Miramichi River, New Brunswick, finding that the lowest egg densities (0.6 eggs/ cm^2) produced the highest survival and the lowest survival occurred at very high densities (nearly 200 eggs/cm^2). The egg densities collected on the transfer trays from the Back River averaged 4.8 eggs/cm^2, with a range of 0.3 to 29 eggs/cm^2 (Table 1). If Crane River had egg densities equal to the minimum found at the Back River we would expect that each scoop of gravel would produced at least a dozen smelt eggs. This condition was not observed in five years of monitoring.

Population Recruitment. Our evaluation of recruitment gains to the Crane River spawning run is qualitative in the absence a marking process to confirm that returning adults originated from the egg transfers. The life stage survival model used in Table 6 estimated a modest return of 256 age-2 and 72 age-3 smelt from the three years of egg transfers. This estimate of few returning adults is consistent with the low densities of eggs found during spawning habitat monitoring.

Potential recruitment can be considered by using the perspective of back-calculating the numbers of female smelt that could have produced the number of eggs transferred. A large majority of adult smelt in measured in recent Massachusetts Bay smelt runs have been age-2 fish (Lawton et al. 1990, and Chase 2006). Clayton (1976) derived a length-fecundity equation for smelt in the Parker River, Massachusetts, that estimated a modal fecundity of 31,400 eggs for age-2 female smelt. The mean estimate for total smelt eggs transferred during 1995-1997 was 2.74 million, which would approximate the production of 87 age-2 females. This value is in a similar range as the estimated 256 age-2 smelt (both sexes) recruited from egg transfers, and further illustrates the minor contribution from egg transfers relative to the potential of natural production.

Summary

Although the establishment of a smelt run in the Crane River is encouraging and provides insight on future restoration efforts, the results of this project imply that egg transfer methods are not an efficient or cost effective approach. The goal of transferring nine million smelt eggs total was based on a practical estimation of potential yield given the status of donor populations and project resources. If successful, the estimated production of age-2 smelt (using Table 6 survival rates) returning from the initial egg transfers of nine million eggs would have been 843 smelt. This would represent a very small smelt run and minor returns for the cost expended. Despite substantial efforts, the smelt runs selected as the most suitable donor runs on the Gulf of Maine coast in Massachusetts produced less than three million eggs in three years.

Given the poor status of donor populations in Massachusetts and modest recruitment benefits from the Crane River egg transfers, it is recommended that alternative approaches to egg transfers be considered. High survival rates (80-90%) for smelt eggs collected from spawning runs and hatched in controlled settings have been reported in New England (Akielaszek et al. 1985, Grout and Smith 1994, and Ayer et al. 2005). Trencia and Langevin (2003) report high egg survival using hatchery methods to aid smelt run production in a tributary to the St. Lawrence River, Quebec. For 2000-2003 spawning seasons, they had egg survival between 90-95% for 25 to 37 million smelt eggs at a low-cost facility located along the spawning run. The deployment of such hatchery methods along with habitat restoration efforts to reduce the degradation from sedimentation, eutrophication and passage impediments could produce substantial returns for similar costs as the Crane River egg transfer project. For example, the 1995 egg tray transfers of 2.13 million eggs produced an estimated 200 age-2 adults, whereas 90% egg survival in a hatchery mode would raise that estimate to 2,644 age-2 smelt.

Future evaluations will need to separate the effect of habitat restoration from stocking contributions by employing improved measures of habitat and spawning run responses. In our project we believe that observed smelt egg deposition during 1997-2001 originated from the egg transfers, but the potential that smelt colonized Crane River following the 1996 sluiceway modifications cannot be tested. Mark and recapture techniques will be needed to confirm actual spawning run contributions. The important issues of smelt genetics, homing and spawning site fidelity were not part of this evaluation. Concern over mixing genetic stocks may be limited because smelt appear to display less fidelity to natal streams than other anadromous fish species. These topics have not been fully addressed for smelt; however, but the potential for isolated genetic stocks of smelt in Massachusetts Bay is low given the results of tagging studies (Murawski et al. 1980), genetic analyses that found no differences in Gulf of Maine smelt (Bernatchez 1997), and many egg transfer efforts in Massachusetts dating back to the early 20th century.

Conclusions

The modification of the sluiceway and smelt egg transfers resulted in the establishment of a rainbow smelt run in the Crane River. The approach of transferring smelt eggs on collection trays was labor intensive and costly relative to the low numbers of returning adult smelt to the Crane River. Given the present poor status of donor populations in Massachusetts we do not recommend that smelt egg transfers are used as a restoration method for anadromous rainbow smelt runs. Instead, we recommend a more efficient approach of combining habitat restoration methods with the benefits of hatchery incubation. Improvements to water quality, spawning substrate and migration habitats followed by hatchery production should allow a cost effective approach for establishing a sustainable rainbow smelt run.

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