DISTRIBUTION AND ABUNDANCE OF FISHES IN RELATION TO BARRIERS: IMPLICATIONS FOR MONITORING STREAM RECOVERY AFTER BARRIER REMOVAL.

By
Cory Gardner

A THESIS
Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science
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Thesis Co-Advisors: Stephen M. Coghlan Jr. and Joseph Zydlewski

An Abstract of the Thesis Presented
In Partial Fulfillment of the Requirements for the
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in Wildlife Ecology
December 2010

Dams are ubiquitous in coastal Maine, and have altered both instream habitats and the distribution and abundance of fishes in these habitats. These impacts are caused mainly by a disruption of the natural hydrology, temperature regime, and habitat connectivity due to physical barriers; the subsequent fragmentation limits the movement of resident fishes, and prevents anadromous fishes from reaching historic spawning habitat. Dam removal has become a common method for restoring streams to a more natural state, but often the response of the fish community is not monitored rigorously.

Sedgeunkedunk Stream, a small tributary to the Penobscot River (Maine, USA) has been the focus of a restoration effort, which includes the removal of two dams (at 0.6 and 5.3 km upstream of the Penobscot confluence). Currently sea lamprey (*Petromyzon marinus*) is the only anadromous species known to spawn successfully in the system.
In this study we quantified fish community metrics, by conducting electrofishing surveys, along a headwaters-to-mouth gradient in Sedgeunkedunk Stream, establishing pre-removal baseline conditions and variability. We also described the distribution and abundance of spawning of sea lamprey in Sedgeunkedunk Stream, in anticipation of potential range expansion after the completion of the dam removals. Sea lampreys, and their nests, were censused using daily stream surveys and a mark-recapture model.

Over three years prior to dam removal (2007-2009), the fish community in Sedgeunkedunk Stream showed consistent trends in species richness and abundance, with metrics always highest downstream of the lowest dam (minimums of 14 species and 2.7 fish/m²), always lowest immediately upstream of that dam (minimums of 5 species and 0.9 fish/m²), and generally recovering upstream towards the headwaters. Although seasonal and annual variation in metrics within each site were substantial, patterns across all sites were remarkably consistent regardless of sampling episode. Immediately after dam removal, we saw significant decreases in richness and abundance (10 species, 0.7 fish/m²) below the former dam site and a corresponding increase in fish abundance at the upstream site (5 species, 5.0 fish/m²), and for the first time, anadromous Atlantic salmon were found upstream of the former dam site. No such changes were obvious in a reference stream.

In 2008 forty-seven sea lamprey entered the stream, and constructed 31 nests; all fish received PIT tags, which allowed us to identify and follow movements of individuals. Individuals that arrived early in the run were active in the system longer, and used more nests, than did late migrants. Sea lamprey *frequently* ascended to the first dam encountered before swimming back downstream and beginning nest construction. Nests
were distributed from head-of-tide to the lowermost dam; no spawners or nests were
observed in the tidally-influenced zone or upstream of this dam.

Our results show that by quantifying baseline conditions in a small stream before
restoration, the effects of stream restoration efforts on fish communities can be monitored
successfully. Based on the observed movements in the system, and the range of their
habitat use, we anticipate that spawning sea lamprey will re-colonize formerly
inaccessible habitat
Funding for this project was provided by NOAA’s National Marine Fisheries Service, the Maine United States Geological Survey Cooperative Fish and Wildlife Research Unit, the University of Maine, and the Maine Agriculture and Forestry Experiment Station. We also thank R. Cope, G. Goulette, D. Kircheis, T. Liebech, K. Mueller, J. Murphy, B. Perry, K. Ravana, D. Skall and T. Trinko for assistance in sampling. We thank our field technicians Silas Ratten, Jacob Kwapiszeski, Ryan Haley, Scott Ouellette, Anthony Feldpausch, Michael Picard, Meghan Nelson, and many others who helped out along the way (University of Maine) for their hard work, and Rory Saunders (NOAA) for sparking our interest in the role of sea lamprey in Sedgeunkedunk Stream. Mention of trade names does not imply endorsement by the United States government.
# TABLE OF CONTENTS

ACKNOWLEDGMENTS........................................................................................................... ii
LIST OF TABLES.................................................................................................................. v
LIST OF FIGURES................................................................................................................ vi

Chapter

1. DISTRIBUTION AND ABUNDANCE OF STREAM FISHES IN RELATION TO BARRIERS: IMPLICATIONS FOR MONITORING STREAM RECOVERY AFTER BARRIER REMOVAL................................................................. 1
   Introduction......................................................................................................................... 1
   Methods............................................................................................................................... 6
      Study Area....................................................................................................................... 6
      Study Design.................................................................................................................. 7
      Fish Surveys................................................................................................................... 8
      Abundance Estimates................................................................................................. 9
      Community Assessment............................................................................................. 10
   Results............................................................................................................................... 11
   Discussion......................................................................................................................... 15

2. DISTRIBUTION AND ABUNDANCE OF ANADROMOUS SEA LAMPREY 
(Petromyzon marinus) SPAWNERS IN A DAMMED STREAM: CURRENT STATUS AND POTENTIAL RANGE EXPANSION
   FOLLOWING BARRIER REMOVAL.................................................................................. 24
Introduction ................................................................. 23

Methods .............................................................................. 28

Study area ........................................................................... 28

Sea lamprey population estimate and behavioral evaluation ....... 28

Nest surveys and abundance estimation .................................. 29

Results .................................................................................. 30

Discussion ............................................................................. 33

REFERENCES ........................................................................ 37

BIOGRAPHY OF THE AUTHOR ............................................. 46
LIST OF TABLES

Table 1.1. Occurrence of species, before the removal of the Mill Dam, in study sites in Sedgeunkedunk Stream and Johnson Brook, Penobscot Co., Maine. 2007-2009. .................................................................11

Table 1.2. Shannon Wiener diversity index values for fish community composition in sites in Sedgeunkedunk Stream and Johnson Brook, Penobscot Co. ME. 2009. ……12

Table 1.3. Sorenson’s Similarity Index values comparing fish community composition between sites in Sedgeunkedunk Stream and Johnson Brook, Penobscot CO. ME. 2009. .........................................................13

Table 2.1. Number of live sea lamprey captured for the first time on each day of the sampling period, the mean water temperature of that day and the mean number of days observed active in the river, and mean number of total nests sea lamprey that entered on that day used before they died, Sedgeunkedunk Stream, Penobscot Co., ME 2008. ...............................................................31

Table 2.2. Smallest, largest and mean sizes of sea lamprey nests, and the maximum number of sea lamprey observed on them in Sedgeunkedunk Stream, Penobscot Co. ME. 2008. .................................................................33
LIST OF FIGURES

Figure 1.1. Study sites on Sedgeunkedunk Stream (S1-S5) and Johnson Brook (J1-J3), Penobscot Co. ME. 2007-2009. …………………………………………………6

Figure 1.2. Species richness at sampling sits along stream gradient in Sedgeunkedunk Stream and Johnson brook, Penobscot Co. Maine 2008-2009. ……………12

Figure 1.3. Fish density (#/m2) at sites along stream gradient of Sedgeunkedunk Stream and Johnson Brook, Penobscot Co. Maine. 2007-2009………………..14

Figure 1.4. Blacknose dace density (#/m2) at sites along stream gradient of Sedgeunkedunk Stream and Johnson Brook, Penobscot Co. Maine, 2007-2009. …………………………………………………………14

Figure 1.5. Length frequency distribution of blacknose dace at sites below and above removed dam in Sedgeunkedunk Stream, Penobscot Co. Maine. 2009. ……15

Figure 1.6. Net gain of blacknose dace within size classes at site S1 and S2 following dam removal in Sedgeunkedunk Stream, Penobscot Co. Maine. 2009. ……15

Figure 2.1. Location of Sedgeunkedunk Stream, Fields Pond, and the dams that were removed during the Sedgeunkedunk Stream restoration. Penobscot Co. Maine, USA. ………………………………………………………………………28

Figure 2.2 The cumulative proportion of sea lamprey entering Sedgeunkedunk Stream, Penobscot Co. Maine. 2008. …………………………………………………30

Figure 2.3. Frequency of the number of nests individual male, and female sea lamprey were observed using during the duration of their activity in Sedgeunkedunk Stream, Penobscot, Co., Maine. 2008. …………………………………………31
Figure 2.4. Distribution sea lamprey nests, and percentage of substrate made up fines (smaller than 2mm) along the stream gradient of Sedgeunkedunk Stream, Penobscot Co., Maine. 2008.
Chapter 1

DISTRIBUTION AND ABUNDANCE OF STREAM FISHES IN RELATION TO
BARRIERS: IMPLICATIONS FOR MONITORING STREAM
RECOVERY AFTER BARRIER REMOVAL.

Introduction

Resilience is defined as the ability of an ecosystem to return to a natural state following a disturbance (Holling 1973). Often, resilience is dependent upon sufficient species diversity persisting so that functional groups necessary to restore a natural state remain (Elmqvist et al. 2003). Ecosystems which are subject to disturbances that occur over large spatial and temporal scales are more sensitive to a lack of diversity (Elmqvist et al. 2003). The temporal, and spatial, variability in species-specific responses to disturbance are likewise important to maintaining ecosystem resilience (Elmqvist et al. 2003). Without a sufficient amount of species diversity the post-disturbance community may attain different stable states than the one that preceded disturbance (Gunderson 2000).

Since the arrival of European settlers on the east coast of North America, human population growth and development have led to myriad disturbances in most terrestrial and aquatic ecosystems (Ehrlich and Holden 1971; Vitousek et al. 1997). Of interest here
is the construction of dams. For centuries, dams have been built to control flows, create water supplies, and generate electricity in the coastal watersheds of New England and elsewhere (Benke 1990). Dams caused changes in hydrology, sediment loading, temperature regimes, and connectivity within and among ecosystems (Koster et al. 2007; Petts 1980). Dams building was also associated with increases in industrial pollution. While the physicochemical effects of dams on streams have been well documented, the impact of dams on fish communities has not (Baldigo and Warren 2008; Quinn and Kwak 2003). There has been great recent emphasis on restoring stream ecosystems perturbed by dams; however, it is unknown if these ecosystems have the ecological resilience to return to a state that resembles preindustrial conditions after centuries of chronic disturbance.

Dams may impact the distribution and abundance of fish communities by the disrupting the natural hydrologic and thermal regimes and fragmenting habitat (Winston et al. 1991). Impoundments convert lotic habitats to lentic (Martinez et al. 1994), and may decrease sediment loading and increase water temperature downstream (Kinsolving and Bain 1993; Ligon et al. 1995). Habitat fragmentation can prevent resident fish species, which make relatively short movements, from accessing habitats that are necessary in completing their life history (Schmetterling and Adams 2004) or maximizing energy balance during critical periods (Hall 1972), thus disrupting energy and material flows in the stream (Hall 1972).

Anadromous fishes are likely to suffer a greater impact from fragmentation (Benke 1990) than would freshwater residents. Historically, many rivers and ponds in Maine harbored spawning runs of numerous migratory species, such as Atlantic salmon.
(Salmo salar), alewife (Alosa pseudoharengus) sea lamprey (Petromyzon marinus) and rainbow smelt (Osmerus mordax) (Saunders et al. 2006). In the Pacific Northwest, anadromous fish such as Pacific salmon (Oncorhynchus spp.) can transport marine derived nutrients and energy into otherwise oligotrophic freshwater ecosystems and increase primary productivity and microbial decomposition rates of detritus (Brock et al. 2007; Durbin et al. 1979; Wipfli et al. 1998). Such increased productivity, in turn, facilitates growth in resident fish species (Bilby et al. 1996; Scheuerell et al. 2007; Wipfli et al. 2003). It is likely that some of these relations exist, or existed, in systems on the Atlantic coast as well. As dams have severed this marine-freshwater connectivity, anadromous species have experienced worldwide decline (Limburg and Waldman 2009) and freshwater systems have become more oligotrophic (Stockner et al. 2000). This connection between anadromous communities and the resilience resident communities in a perturbed system is poorly characterized.

Abundance, richness, and ultimately diversity of stream fishes increase along the gradient from headwaters to mouth in a small, non-fragmented stream, due to predictable increases in the availability and diversity of habitats (Sheldon 1968) and the species pool of potential colonizers in nearby rivers (Smith and Kraft 2005). These metrics can ebb and flow upstream and downstream over time in response to discharge and resultant velocity barriers to potential colonizers from downstream reaches (Grossman et al., 2010). Ultimately, stream discharge and other physicochemical conditions driven by landscape changes along this longitudinal gradient lead to patterns of energy and nutrient flow to which stream ecosystems respond dynamically yet predictably (Vannote et al., 1980), although interruptions in the continuum evince marked changes in the stream biota.
In coastal streams, anadromous fish may penetrate relatively far into headwaters, and the subsidies of marine-derived nutrients and energy associated with these migrants provides another gradient to which resident fishes may respond (Mitchell and Cunjak 2007). If the presence of a dam alters these natural gradients, then the structure and function of fish communities should shift as well.

Sedgeunkedunk Stream, a small tributary of the Penobscot River below head-of-tide (Figure 1.1), typifies small streams in Maine impacted by dams. Current restoration efforts offer an opportunity to assess the resilience of the structure and function of this fish community when released from habitat fragmentation caused by multiple dams. Runs of anadromous fishes in Sedgeunkedunk Stream have either disappeared or were reduced substantially after the building of three dams on the stream. Recent declines in anadromous fishes in Sedgeunkedunk Stream mirror those in the entire Penobscot watershed, which contains over 100 known dams; however, because Sedgeunkedunk Stream flows into the Penobscot River below the lowermost mainstem dam (Veazie Dam), it is one of only three major tributaries that could receive anadromous fishes before they encounter a relatively large, mainstem dam. Currently, Atlantic salmon in Sedgeunkedunk Stream and most of the Penobscot watershed are listed as a federally-endangered species (74 Fed. Reg. 29344; June 19, 2009), and alewife, sea lamprey, and rainbow smelt are at historic low levels of abundance throughout Maine watersheds (Saunders et al. 2006).

As part of a collaborative restoration project, fish passage has been created or restored in Sedgeunkedunk Stream at the location of two former dam sites between Fields Pond and the confluence with the Penobscot River (Figure 1.1). The lowermost dam...
(Mill Dam) was removed in August 2009, and the middle dam (Meadow Dam) was bypassed in August 2008 by a rock-ramp fish-way that allows fish passage while maintaining current water levels in Fields Pond and adjacent wetlands. Thus habitat connectivity for migrating anadromous and resident fishes has been restored throughout most of the Sedgunkedunk watershed.

This study began in 2007, two years prior to removal of the lowermost dam, as a long term monitoring effort directed toward the effects of this restoration on the fish community in the Sedgunkedunk watershed. While the reversion towards a more historic species composition is desired or expected following dam removal, there is often an initial decline in abundance of resident species until the geomorphology of the stream is stabilized (Catalano et al. 2007; Doyle et al. 2005). In small streams the physical recovery from the immediate disturbance of a dam removal can take as little as a year, if high water events move the sediment from the impoundment downstream quickly (Burroughs et al. 2009), but the response of the fish community may be protracted (Hart et al. 2002), illustrating the importance of long term monitoring to characterize biotic response. Many small streams are characterized by a great deal of variability at different scales, both spatially (e.g., longitudinally and within short reaches) and temporally (e.g., both annually and seasonally), which could make the detection of community changes difficult (Baldigo and Warren 2008; Jackson et al. 2001, Moyle and Vondracek 1985). In this study the data collected before the removals are used to quantify the baseline conditions and variability in this altered system, and a neighboring reference system.

Specifically, our objectives were to: 1) Quantify the baseline distribution and abundance, and the associated variability, of fish species in Sedgunkedunk Stream...
before final dam removal; 2) Quantify the distribution and abundance of fish species in Sedgeunkedunk Stream immediately following removal of the lowermost dam; 3) Determine if the temporal and spatial variability in fish community metrics will allow us to detect changes in response to dam removals. This work represents the first step in assessing the long term research goal of characterizing resilience and recovery in small coastal systems.

**Methods**

**Study Areas**

Sedgeunkedunk Stream is a third-order tributary of the Penobscot River, **Penobscot Co. Maine**. The stream flows out of Fields Pond at 44°44’05”N and 68°45’56”W and debouches into the Penobscot River (at river km 36, which is approximately at head-of-tide) at 44°46’08”N and 68°47’06”W. The stream drains 5400 hectares including Brewer Lake and Fields Pond (Figure 1.1). The lowermost Mill Dam, which was removed in August 2009, was located just 600 meters upstream of the stream’s confluence with the Penobscot River. The middle Meadow Dam, which was located at stream km 5.3 upstream from the Penobscot confluence, was replaced by a rock-ramp fishway in August 2008. The removal of these two barriers provides for presumably unimpeded access from the Atlantic.
Ocean into Fields Pond, via the lower Penobscot River and then Sedgeunkedunk Stream. The uppermost Brewer Lake Dam, located between Fields Pond and Brewer Lake, will remain intact, and continue to block passage further upstream in the watershed.

For future monitoring following the dam removal, our study incorporated a Before-After-Control-Impact design (BACI; Stewart-Oaten et al. 1986), which accounts for naturally-occurring temporal and spatial variation so that we can attribute differences in Sedgeunkedunk Stream fishes to restoration efforts irrespective of background noise. A BACI design requires that pre-impact conditions and variability are known, which we established by sampling for one year before the restoration project began, and two years before the lowermost dam removal took place. We also monitored a reference system, Johnson Brook, which is a tributary of the Penobscot River located in Orrington, Maine (Figure 1). The stream flows out of Swetts Pond at 44°42’18”N and 68°47’10”W and debouches into the Penobscot River (at river km 24) at 44°42’08”N and 68°49’50”W. This system includes a natural barrier (Clark’s Falls, at stream km 2.2) and a dam at the outlet of Swetts Pond (at stream km 5.5); these barriers to passage are analogous to the dams located in Sedgeunkedunk Stream.

Study Design

Five 100-m sampling locations were selected along Sedgeunkedunk Stream (Figure 1.1). Site S1 is located at stream km 0.45-0.55, immediately downstream of the former Mill Dam, and was the only site accessible to anadromous fish. Site S2 is located immediately upstream of the Mill Dam site at stream km 0.62-0.72. Site S3 is located approximately halfway between the Mill Dam and Meadow Dam sites at stream km 2.5-
2.6. Site S4 is located immediately downstream of the Meadow Dam / Fishway site at stream km 5.2-5.3. Site S5 is located in upstream of Brewer Lake; because the Brewer Lake Dam is not scheduled for removal, this site will remain unaffected by the restoration project and serve as a reference site within Sedgeunkedunk Stream.

Three 50-m sampling locations were selected along Johnson Brook in order to compare with sites on Sedgeunkedunk Stream before and after barrier removal (Figure 1). These sites were limited to 50 m due to access problems and the presence of beaver dams and their associated impoundments, which would have limited our ability to sample 100-m long reaches effectively, but likely did not impede fish passage. Site J1 is located immediately downstream of Clark’s Falls at stream km 3.62-3.67. Site J2 is located immediately upstream of Clark’s Falls at stream km 3.71-3.76. Site J3 is located immediately downstream of the dam at the outlet of Swetts Pond at stream km 7.3-7.8.

Fish surveys

Each location was sampled in August of 2007. In 2008 and 2009, each location was sampled twice per year, once in the spring (usually late May) as soon as spring runoff subsided and again in late summer (usually mid August) during low-flow conditions. The Meadow Dam was removed after sampling was completed in 2008. The Mill Dam was removed immediately before the second sampling of 2009. Fish abundance at each site was estimated by conducting three-pass depletion estimates (Zippin 1958) using backpack electrofishers, except for spring 2007 when we conducted 2-pass depletions. Electrofisher settings were 30-60Hz, 20% duty cycle, and ~300-500V, depending on measured ambient conductivity, and were optimized for maximum power.
transfer (Reynolds 1996). Each site was closed to immigration and emigration during the survey using 3mm-mesh blocking nets. All fish caught were identified to species, and the first 300 individuals of each species at each site were measured (total length; mm) and weighed (wet mass; 0.1 g). Except for incidental mortality (<2% for all sampling events), fish were returned to the stream alive. This repeated electrofishing probably did not influence the fish community measurably (e.g., Latimore and Hayes 2008). In summer 2008 all sampling was completed before the removal of the Meadow Dam. In 2009 the summer round of sampling took place within 7 days after the removal of the Brewer Dam. We sampled Site S1 three days after the dam removal, as soon as that stream had cleared of suspended sediment enough for us electrofish effectively. We note that although American eel were present and abundant at all sites at all times, our catchability was extremely low for small elvers (< 100 mm TL), so we limit analysis of eel data to qualitative, rather than quantitative, measures (i.e., presence / absence).

**Abundance Estimates**

At each sampling reach, stream width was measured at ten locations and the area estimated as the product of reach length and mean width. This sampling area was used in our estimates of total fish density (# of fish / m²), with associated variances, for each sampling location (with the exception of American eel, as described above). Differences in density among reaches and over time were assessed by inspecting overlap of 95% confidence intervals, which is a conservative estimate (Simpson et al., 1961). This method does not allow us to assume “no significant difference” when there is an overlap.
however it does allow us to assume a significant difference (at $\alpha = 0.05$) when there is no overlap (Payton et al., 2003).

*Community Assessment*

Temporal and longitudinal changes in the fish assemblages were characterized using four methods. First, species richness was determined by noting presence/absence of each species. Comparisons of species richness among sites, and over time, were made using a Friedman test and Tukey multiple comparisons (Zar, 1984). Presence/absence was also used to describe species distribution before barrier removal, in order to monitor species movement and colonization after removal. Second, we used a Shannon–Wiener species diversity index (Krebs, 1989);

$$H' = -\sum P_i \ln P_i$$

for each site over time, where $P_i$ is the proportion of the population belonging to species $i$. Third, we used a Sorensen’s Similarity Index (Krebs, 1989);

$$QS = \frac{2c}{(a + b)}$$

where $c$ is the number of common species, and $a$ and $b$ are the total number of species in the two sites respectively. In this index of similarity the results range from 0 (no similarity) to 1 (identity).

Differences between mean length and mean mass of species found at all sites were detected using a two-way ANOVA, with site and sampling time as the main effects. Lengths of each species were used to construct length frequency histograms, and by finding natural breaks in the size distribution which separate age classes, we determine size and age structure for three common species at each site. A Kolmogorov-Smirnov test was used to find differences between length frequency distributions.
Results

Over the course of this study we encountered 22 species and 26,873 individual fish (Table 1.1). In 2007, we captured 4,760 fish in Sedgeunkedunk Stream. In 2008, we captured 7,872 fish in Sedgeunkedunk Stream and 3,693 fish in Johnson Brook. In 2009, we captured 8,516 fish in Sedgeunkedunk Steam and 2,032 in Johnson Brook. The dominant species in both streams was eastern blacknose dace (*Rhinichthys atratulus*). In Sedgeunkedunk Stream species richness, diversity, and the density of total fish was highest below the Mill Dam and lowest above the dam. These metrics then increased along the gradient with increasing upstream from the dam, but then declined in the isolated headwater site (S5).

Table 1.1. Occurrence of species, before the removal of the Mill Dam, in study sites in Sedgeunkedunk Stream and Johnson Brook, Penobscot Co., Maine. 2007-2009.

<table>
<thead>
<tr>
<th>Species</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>J1</th>
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<td>Atlantic salmon</td>
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<td>Eastern brook trout</td>
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<td>White sucker</td>
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<td>Yellow perch</td>
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<tr>
<td>Alewife</td>
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<tr>
<td>Rainbow smelt</td>
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<tr>
<td>Sea Lamprey</td>
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- ○ density ≥ 0.1 fish/m²
- ● density ≥ 0.01 fish/m²
- ◆ density < 0.01 fish/m²
- * no density estimated

Comment [SC1]: Check with the formatting desired by the graduate school, but usually figures and tables are given their own pages, rather than snuggled nest to text. Same comment applies throughout.
sampling, and 7 species present in each summer sampling. Immediately after removal of the Mill Dam the species richness at site S1 decreased from 14 to 10, and the richness at the sites upstream were similar to that found in previous samplings. Species that were no longer found at site S1 following the dam removal were: northern redbelly dace (*Phoxinus eos*), finescale dace (*Phoxinus neogaeus*), fathead minnow (*Pimephales promelas*), and ninespine stickleback (*Pungitius pungitius*). In Johnson Brook, the species richness at site J1 (downstream of Clark’s Falls) ranged from 8-11. This decreased to 4-6 species at site J2 (upstream of Clark’s Falls). Richness was always highest at site J3 (downstream of Swett’s Pond Dam, ranging from 10-13 species.

Prior to the removal of the Mill Dam, Atlantic salmon were encountered only at site S1. In the fall of 2008 one Atlantic salmon parr was captured (TL = 152mm), and in the spring of 2009, one Atlantic salmon fry (TL = 30 mm) was captured. After the removal of the Mill Dam in 2009, Atlantic salmon parr were captured at site S2 (5 individuals, mean TL = 83 mm), and 55 were captured at site S3 (55 individuals, mean

| Table 1.2. Shannon Wiener diversity index values for fish community composition in sites in Sedgeunkedunk Stream and Johnson Brook, Penobscot Co. ME. 2009. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | May-08          | May-09          | May-08          | May-09          | May-09          |
| May-08          | 1.63            | 1.40            | 1.40            | 1.88            | 1.88            |
| Aug-08          | 1.22            | 0.77            | 0.77            | 0.56            | 0.56            |
| May-09          | 1.40            | 0.43            | 0.41            | 0.77            | 0.77            |
| Aug-09          | 1.44            | 0.82            | 0.69            | 0.56            | 0.56            |

**Figure 1.2.** Species richness at sampling sites along stream gradient in Sedgeunkedunk Stream and Johnson Brook, Penobscot Co. Maine 2008-2009.
Species diversity in Sedgeunkedunk Stream was always highest at sites S1 and S5 (Table 1.2). Before the removal of the Mill Dam, sites S1, S4, and S5 had high (i.e., QS > 0.70) pairwise similarity values, but were less similar to sites S2 and S3; sites S2 which were highly similar (Table 1.3). In Johnson Brook the diversity was highest at site S3 and lower at site S1 and S2. Total fish density in Sedgeunkedunk Stream was highest at site S1 and lowest at site S2 during all sampling occasions before the removal of the Mill Dam (Figure 1.3a). Densities followed a pattern along the stream gradient of increasing at site S3 and site S4, but decreasing at site S5. Total fish density in Johnson Brook showed a consistent pattern at all sampling events. Density was higher at site J1, than at sites J2 and J3 (Figure 1.3b).

The community structure in Sedgeunkedunk Stream changed following the removal of the Mill Dam. There was an increase in diversity at site S2 (Table 1.2). All of the sites in Sedgeunkedunk stream became more similar (Table 1.3). Fish density at site S1 showed a significant decline, while the density at site S2 increased more than five-fold (Figure 1.3a). The density also increased at site S3 and site S4, but the density at site S5 did not change significantly. There was no change in the pattern in Johnson Brook over this time period (Figure 1.3b).

Table 1.3. Sorenson’s Similarity Index values comparing fish community composition between sites in Sedgeunkedunk Stream and Johnson Brook, Penobscot CO, ME, 2009. Values range from 0 (no similarity) and 1 (identity). Values above the dashed line are from before the dam removal. Values below are from after the dam removal.

<table>
<thead>
<tr>
<th>a. Sedgeunkedunk Stream</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
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<tr>
<td>S1</td>
<td>-</td>
<td>0.53</td>
<td>0.80</td>
<td>0.73</td>
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<tr>
<td>S2</td>
<td>0.67</td>
<td>-</td>
<td>0.80</td>
<td>0.53</td>
<td>0.57</td>
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<tr>
<td>S3</td>
<td>0.78</td>
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<td>-</td>
<td>0.78</td>
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<tr>
<td>S4</td>
<td>0.84</td>
<td>0.71</td>
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<td>-</td>
<td>0.94</td>
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<tr>
<td>S5</td>
<td>0.82</td>
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<td>0.93</td>
<td>0.88</td>
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<table>
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<tr>
<th>b. Johnson Brook</th>
<th>J1</th>
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<th>J3</th>
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<tr>
<td>J1</td>
<td>-</td>
<td>0.53</td>
<td>0.67</td>
</tr>
<tr>
<td>J2</td>
<td>0.67</td>
<td>-</td>
<td>0.47</td>
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<tr>
<td>J3</td>
<td>0.82</td>
<td>0.59</td>
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</table>
Three species were ubiquitous spatially and temporally in Sedgeunkedunk stream: eastern blacknose dace, fallfish (*Semotilus corporalis*), and white sucker (*Catostomus commersoni*). Blacknose dace was, often by an order of magnitude, the most abundant species at all sampling locations and times, and mirrored the pattern seen in overall fish density. After the removal of the Mill Dam the density of blacknose dace at site S1 decreased significantly, whereas the density at site S2 more than tripled (Figure 1.4a). The density rose significantly at site S3 and site S4 while the density at site S5 remained statistically unchanged. Blacknose dace density in Johnson Brook also showed a
consistent pattern at all sampling events, with density higher at site J1 than at sites J2 and J3 (Figure 1.4b).

The mean length and mass of blacknose dace, and all other common species, differed among all sites at each sampling occasion (all p < 0.05), but did not show any consistent spatial or temporal pattern. The same was true of the size distribution of blacknose dace, but there was a noticeable pattern. Before the removal of the Mill Dam, the size distribution of blacknose dace lengths was similar among sites S1, S3, and S4, but skewed towards smaller individuals at site S2. Immediately following the removal of the Mill Dam the length distribution in site S1 was truncated, while the size distribution at site S2 appears to expand and resemble the distribution in other sites prior to removal (Figure 1.5). The net losses at site S1 and the net additions at site S2 of blacknose dace within size classes appear to correspond to each other (Figure 1.6), especially assuming some growth in length over the

Figure 1.5. Length frequency distribution of blacknose dace at sites below and above removed dam in Sedgeunkedunk Stream, Penobscot Co. Maine. 2009.

Figure 1.6. Net gain of blacknose dace within size classes at site S1 and S2 following dam removal in Sedgeunkedunk Stream, Penobscot Co. Maine. 2009.
Discussion

In the two years of sampling that preceded the removal of the Mill Dam and the completion of the restoration project in Sedgeunkedunk Stream, we documented consistent patterns in the distribution and abundance of fishes. These patterns and the low variability associated with them give us confidence in our ability to detect any long-term changes that may occur in the system, as does our ability to detect short-term differences in these patterns that immediately followed the removal of the Mill Dam.

The presence of the Mill Dam in Sedgeunkedunk Stream influenced the composition, and size structure, of the fish community along the stream gradient. Each study site along the stream showed a consistent pattern over time, prior to dam removal. The site directly below the dam (S1), although affected by the hydrological disturbances associated with a dam, most likely represented the natural habitat condition of the stream most closely, and was the only site readily accessible to fishes migrating from the Penobscot River and the Atlantic Ocean. This connectivity to the larger aquatic ecosystems can allow for the increased species richness and diversity (Lyons and Schneider 1990; Smith and Kraft 2005); migratory species, like Atlantic salmon and nine-spine stickleback, as well as resident species from the Penobscot River, could enter this section of stream. Connectivity also increased habitat availability, due to access to parts of the Penobscot, and increased thermal variability, due to the presence of a tidal zone near the mouth of the stream that could create a thermal refuge.
The study site located directly above the dam (S2) was a straight, slow moving, impoundment. The riparian zone consisted of grasses that had colonized the sediment that had been deposited above the dam, replacing the normal forest cover along the stream. The combination of the exposure, channel straightening, and siltation resulted seemingly in habitat homogeneity. Because of this, and the lack of connectivity caused by the dam, this section of stream had fewer fish, and lower species richness and diversity, than all other sites. The community also contained more large bodied species like fallfish and white sucker, which could use deeper pools caused by the impoundment (Petts 1980; Swink and Jacobs 1983). Populations of small-bodied minnows, like blacknose dace, were dominated by smaller fish. All species found in this site could be found at other sites as well. While these decreases in abundance and diversity are to be expected as part of the natural process as one moves up a stream gradient (Sheldon 1968), the differences between these sites were drastic and occurred over a distance of less than 100 meters.

Species richness, diversity, and the density of total fish increased along the gradient from moving upstream from the dam. This probably represents a decreasing impact of the dam on the fish community as it moves upstream from the disturbance caused by the dam (Kinsolving and Bain 1993; Phillips and Johnston 2004), and shows that the community at the site directly above the dam represents an interruption of a natural stream gradient (Sheldon 1968). The fish communities at sites S3 and S4 became more similar to site S1, corresponding to a gradual recover from the interruption caused by the Mill Dam. The relatively low fish density at site S5, located much further upstream in the watershed, was probably caused by two factors. Connectivity to
downstream reaches and the Penobscot River is reduced by another dam and two lakes, as well as a comparatively long distance from a large pool of potential migrants or colonizers (e.g., Smith and Kraft 2005). More importantly, this headwaters reach is located in a steeper, more heavily forested section of the watershed, and is characterized by lower temperatures and conductivity than in downstream sites. It is also characterized by shallower pools. Thus, overall production potential of fishes is probably reduced here (Schlosser 1982). The community at this site is what would be expected in a stream section higher up in the watershed, and probably is representative of a lightly-impacted headwaters reach not influenced strongly by anadromous fishes.

The pattern in Johnson Brook was similar to the longitudinal pattern that we found in Sedgeunkedunk Stream, although the differences above and below the impassible barrier were not as dramatic, and the distinct changes associated with the Mill Dam removal was not present here. The site below the impassible falls (J1) showed higher species richness and diversity than the site directly above the falls (J2), which is probably a function of habitat disconnectivity, similar to the effect of the Mill Dam in Sedgeunkedunk Stream. However, there were differences between the site above the falls in Johnson Brook (J2) and the site above the Mill Dam in Sedgeunkedunk (S2). While the waterfall acted as a barrier to upstream migration, it was not associated with a deforested, channelized and sedimented impoundment, like in Sedgeunkedunk Stream, so it did not harbor a community dominated by larger bodied species. Despite this we still observed a decline in fish density and species richness above the waterfall in Johnson Brook analogous to what occurred above the Mill Dam in Sedgeunkedunk. Species that were found at S1 and J1, and not at S2 or J2 include: fathead minnow, golden shiner

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(Notemigonus crysoleucas), northern redbelly dace, and ninespine stickleback. Creek chub (Semotilus atromaculatus) was the only species found at site S1, J1 and J2, but not found at S2. This could imply that it was the impoundment in Sedgeunkedunk that led to the absence of creek chub, while it was the lack of habitat connectivity that led to the absence of the previous species. While the farthest upstream site in Johnson Brook (J3) contained lower fish densities than the site below the falls, it did show an increase in species richness, most likely due to its location below an old low-head dam located at the outlet of Swett's Pond. This site often included species normally associated with a lentic environment that had probably been washed downstream during floods in the spring and had persisted in a few pools located within the site, associated with a road crossing, which do not exist in the analogous site in Sedgunkedunk Stream (S4). These species include brown bullhead Ameiurus nebulosus, chain pickerel Esox niger, and white perch Morone americana. Predation by these species might explain the very low density of small-bodied fishes like blacknose dace.

The fact that the fish community in Johnson Brook also showed consistent trends along the stream gradient over time, similar to those that we found in Sedgeunkedunk Stream up until dam removal, will allow us to use the BACI design to detect future changes. During the continued monitoring of the recovery of Sedgeunkedunk Stream, comparing the changes in the fish community of Sedgeunkedunk Stream to what happens in Johnson Brook in the context of a BACI design will help isolate changes that are attributable to restoration from those due to natural variability. This is possible because the close proximity of the streams should make other regional environmental factors constant. Over the course of this study longitudinal and temporal patterns in
Sedgeunkedunk Stream, before the removal of the Mill Dam, and Johnson Brook were consistent. This consistency allowed us to detect the immediate effects of the disturbance that took place after the removal of the Mill Dam.

Three days after the removal of the Mill Dam on August 14, 2009, we began post-removal sampling at site S1. The removal of the dam caused a large amount of sediment to move through the system; immediately downstream of the former dam site, the stream was very turbid and the substrate became covered in a layer of silt. The immediate response to these changes was a decline in species richness and fish density below the former dam location. Fish mortality can be expected during these types of events of increased flow and turbidity (Doeg and Koehn 1994). In this case though, some of the observed decline in density could be caused by movement and not mortality. While there was not an increase in species richness above the dam site, there was a dramatic increase in fish density. This is evidence that the species that were common in the stream were able to move upstream of the disturbance.

The changes in the size structure of blacknose dace show that some of the decline in fish density below the former dam site could be explained by fish moving upstream. The length distribution of blacknose dace at site S1 and S2 immediately following the removal of the Mill Dam show that while site S1 lost a majority of the larger fish during the disturbance, site S2 showed gains in larger fish. The net gains for each site show that the losses at site S1 correlate with the gains at site S2, especially if summer growth is assumed to have taken place. There is still evidence of some mortality associated with the disturbance, but it is clear that in the larger size-classes of blacknose dace (> 40mm) many of the fish were able to move upstream. While successful colonization of former
dam impoundments by downstream fish species has been shown (Catalanato et al. 2007), this would have occurred very quickly in our study. Fish densities at sites S3 and S4 reached their highest levels in the study after the dam removal. Small stream fishes like blacknose dace can move over 1 km in a day (Albanese et al. 2003), which makes the colonization of site S3 and S4 by fish that previously occupied reaches below the dam possible. Even if individuals did not migrate all the way up to site S4 it is possible that there could have been a cascading effect of displacement pushing fish upstream as densities increased in sites upstream of the former dam. In sites that were not affected by the removal of the Mill Dam, site S5 in Sedgeunkedunk Stream and all of the sites in Johnson Brook, we did not detect any deviations from the dominant patterns in abundance or community structure.

Another possible effect of the dam removal was the colonization of previously unavailable stream sections by juveniles of anadromous Atlantic salmon. Prior to dam removal we usually encountered one juvenile Atlantic salmon every time we sampled below the dam. We were unsure if this was the result of spawning activity in the lower stream reaches, or if these were individuals who had strayed from elsewhere in the Penobscot watershed. In the sampling that took place following the dam removal we captured 5 age 0+ Atlantic salmon parr directly above the former dam site and 55 parr at site S3. It is possible that adults spawned in Sedgeunkedunk Stream below the Mill Dam, and that resultant parr moved upstream in response to the disturbance caused by dam removal. It is also possible that these salmon were juvenile landlocked Atlantic salmon, but no spawning of landlocked Atlantic salmon has been documented in the lower Penobscot watershed. Both of these explanations seem unlikely because we
captured only one fry in the spring of 2009, but otherwise the presence of Atlantic salmon upstream of the dam immediately after its removal is unexplained and natural recolonization of formerly inaccessible habitat is the most parsimonious explanation.

In order to detect the response of Sedgeunkedunk Stream to dam removal it is important to know what the baseline conditions and variability were before the dam removal. Prior to dam removal we found consistent patterns in space and over time, which will allow us to detect the changes that take place following the restoration project. The only deviation from this pattern occurred at the two sites immediately adjacent to the dam immediately after removal, and our sampling allowed us to detect these changes. Continued monitoring will allow us to show how the stream fishes below the dam site recover from the disturbance, and how the entire stream fish community responds to a more natural hydrology and increased connectivity to large river and marine ecosystems.

Dams have been in place in New England watersheds, for centuries. Every year more and more dams are being removed in this country in with the goal of river restoration (Heinz Center 2003). This is often done without a clear idea of what that restoration means ecologically and without any plan to monitor the response (Bernhardt et al. 2005). If there is monitoring it is often directed towards a target fish species of interest (Doyle et al. 2005) rather than a community response.

Dam removals in this country are an expensive undertaking. This money is often spent without ever really knowing what the results of the efforts are. The preferred method of implementing a dam removal requires adaptive management. This form of management involves constant scientific feedback, so that the effects of previous...
decisions are known and can inform future actions. This is impossible without effective, well planned, monitoring (Heinz Center 2003).

Palmer et al. (2005) presented five criteria for successful restoration projects: a guiding image of the restored system, indicators of ecosystem recovery are improved, resilience is increased, there is no lasting harm, and that an ecological assessment is completed. Monitoring is necessary if the project is to be deemed successful.

Sedgeunkedunk Stream provides a model of small coastal stream restoration throughout Maine and elsewhere. The results of the monitoring here will inform adaptive management within this system, the Penobscot River watershed, and other restoration projects in the region.

This type of monitoring can be useful in detecting the response of fish communities in dammed streams as dam removals become a more popular restoration effort in Maine and beyond. This restoration project is notable because it takes place downstream of the anticipated Penobscot River Restoration Project, in which two large main-stem dams are to be removed, and fish passage installed or improved at two other dams (PRRT 2009). We view the Penobscot River, structurally and functionally as thousands of Sedgeunkedunk–sized tributaries, and thus this small scale restoration project is the first step/...
Chapter 2

DISTRIBUTION AND ABUNDANCE OF ANADROMOUS SEA LAMPREY
(Petromyzon marinus) SPAWNERS IN A DAMMED STREAM: CURRENT
STATUS AND POTENTIAL RANGE EXPANSION
FOLLOWING BARRIER REMOVAL

Introduction

Many rivers and ponds in Maine once harbored spawning runs of anadromous fish species, such as Atlantic salmon (Salmo salar), alewife (Alosa pseudoharengus) sea lamprey (Petromyzon marinus) and rainbow smelt (Osmerus mordax), (Saunders et al. 2006). These fish likely transported marine derived nutrients and energy (MDNE) into otherwise oligotrophic freshwater ecosystems, that could stimulate primary productivity and microbial decomposition of detritus (Brock et al. 2007; Durbin et al. 1979; Wipfli et al. 1998). MDNE subsidies from Pacific salmon increase productivity and growth of resident fish species in many Pacific Northwest watersheds (Bilby et al 1996; Scheuerell et al. 2007; Wipfli et al. 2003), and historically, anadromous fishes in Maine probably provided similar subsidies (Saunders et al., 20056). As dams have severed this marine-freshwater connectivity in Maine and elsewhere, anadromous species have experienced worldwide decline (Limburg and Waldman 2009) and freshwater systems have become more oligotrophic (Stockner et al. 2000).

Sedgeunkedunk Stream, a small tributary of the Penobscot River below head-of-tide (Figure 2.1), typifies small streams in Maine impacted by dams. Current restoration efforts offer an opportunity to assess how the structure, function, and resilience of the fish
community responds to long-term disturbance by, and then relief from, habitat fragmentation from multiple dams. Runs of anadromous fishes in Sedgeunkedunk Stream either disappeared or were reduced substantially after the building of three dams on the stream (at 0.6, 5.3 and 8.0 km upstream of the confluence with the Penobscot River; “stream km”). The downstream dam has been there, in some form, for over two centuries (S. Shepard, Aquatic Science Associates, personal communication). Declines in anadromous fishes in Sedgeunkedunk Stream mirror those in the entire Penobscot watershed, which contains over 100 known dams; because Sedgeunkedunk Stream is one of only three major tributaries that could receive anadromous fishes before they encounter a relatively large, mainstem dam on the Penobscot River (i.e., Veazie Dam), restoration of anadromous fishes here should precede that in tributaries farther upstream in the watershed when the mainstem dams are removed or bypassed. Currently, Atlantic salmon in Sedgeunkedunk Stream and most of the Penobscot watershed are listed as a federally-endangered species (74 Fed. Reg. 29344; June 19, 2009), and alewife, sea lamprey, and rainbow smelt are at historic low levels of abundance (Saunders et al. 2006).

As part of a collaborative restoration project, fish passage has been created or restored in Sedgeunkedunk Stream at the location of two former dam sites between Fields Pond and the confluence with the Penobscot River (Figure 2.1). The lowermost dam (Mill Dam) was removed in August 2009, and the middle dam (Meadow Dam) was bypassed in August 2008 by a rock-ramp fish-way that allows fish passage while maintaining current water levels in Fields Pond and adjacent wetlands. Thus habitat
connectivity for migrating anadromous and resident fishes has been restored throughout most of the Sedgunkedunk watershed.

Currently, Sedgeunkedunk Stream receives a small run of anadromous sea lamprey, the only anadromous fish known to spawn in the stream reliably. Adult sea lampreys are parasitic in the ocean and return to freshwater after two to seven years to spawn (Beamish 1980). Unlike many anadromous species, sea lamprey do not home to natal streams (Bergstedt and Seyle 1995; Waldman et al. 2008), and may select spawning streams based on flow, temperature (Andrade et al. 2007), or the presence of chemical compounds released by both ammocoetes and sexually-mature males (Li et al. 2002; Vrieze et al. 2010). This should allow for faster expansion and colonization into new habitats than for anadromous species with strong homing tendencies, like Atlantic salmon. The rapid expansion of sea lamprey throughout the upper Great Lakes is strong evidence of their ability to colonize suitable and accessible streams (Smith and Tibbles 1980). Their capacity for rapid range expansion makes sea lamprey likely to benefit immediately from restoration efforts in Sedgeunkedunk Stream.

In North America, research on sea lamprey is dominated by Great Lakes issues, where the species is invasive upstream of Niagara Falls but probably native throughout the watersheds of Lakes Ontario and Champlain (Waldman et al. 2004, 2006; but see Eshenmeyer 2009). Sea lamprey invasion has been devastating for economically-valuable recreational and commercial fisheries (Christie 1973). Because of their highly-visible parasitism on popular sport fish, sea lamprey have acquired a negative public image not only in the Great Lakes region, but also within their native range.
Recolonization and recovery of sea lamprey may be a critical step in the restoration of native anadromous fish assemblages in Maine. Sea lamprey are an ecologically significant member of stream ecosystems, both as spawning adults and in the larval form. They are semelparous, dying in early summer after spawning, making the adults potential sources of MDNE in otherwise oligotrophic streams – a potentially important combination of time and place for nutrient subsidies in Maine (Nislow and Kynard 2009). Adults build nests in shallow riffles or the tails of pools, by moving cobbles and pebbles into mounds located downstream of a pit. Spawning occurs in the pit and includes tail and body flexions and vibrations on or near the substrate. Both nest building and spawning activities appear to clear away fine sediments from the coarse substrate on a local scale (Kircheis 2004), perhaps reducing substrate armoring and embeddedness, similar to the effects seen from Pacific salmon aggregations (Montgomery et al. 1996). Thus it has been suggested that sea lamprey nest building activities may “condition” potential spawning habitat for Atlantic salmon (Kircheis 2004; Saunders 2006). Finally, ammocoetes are a potential prey base for other resident species and act as filter feeders actively trapping nutrients from the water column (Applegate 1950).

This study provides a baseline assessment of the status of sea lamprey in Sedgeunkedunk Stream, where restoration efforts should make the watershed more accessible to anadromous fishes. Specifically, our objectives are to: 1) quantify the abundance and movements of sea lamprey in Sedgeunkedunk Stream before the removal of the Mill Dam 2) quantify the distribution and abundance sea lamprey nests in Sedgeunkedunk Stream before the removal of the Mill Dam 3) Assess the likelihood of...
colonization of sea lamprey into new habitats made accessible following the removal of the Mill Dam. This work represents the first step in a long term monitoring of the response of sea lamprey to this restoration, and the influence of their presence on the Sedgeunkedunk Stream ecosystem.

Methods

Study Area

Sedgeunkedunk Stream is a third-order tributary of the Penobscot River, flowing through the Town of Orrington and the City of Brewer, Maine. (Figure 2.1). The Jowermost Mill Dam, which was removed in August 2009, was located just 700 meters upstream of head of tide, near the stream’s confluence with the Penobscot River, and
limited access for anadromous species farther upstream. The removal of this barrier provides for presumably unimpeded access from the Atlantic Ocean into Sedgeunkedunk Stream, via the lower Penobscot River. The uppermost Brewer Lake Dam, located between Fields Pond and Brewer Lake, will remain intact, and continue to block passage further upstream in the watershed.

Sea lamprey population estimate and behavioral evaluation

We captured sea lamprey in an Indiana-style trap-net that spanned the entire width of the Sedgeunkedunk Stream, 90 m upstream of the confluence with the Penobscot River (river km 36), approximately at head-of-tide. Net dimensions included a 3 mm square mesh, 1.3m x 1.6m rectangular mouth, 1m diameter circular cod end, 2.5 m length, and wings that extended the width of the stream (4.0 m at time of deployment). We deployed the net from 15 May to 1 July, 2008. At deployment the thalweg depth was 0.8m, but water depth varied with stream discharge and tidal cycle. During the first five sampling days (18-22 June) high water rendered this net ineffective. During this time period we captured sea lamprey easily with hand nets during stream surveys. The lack of deep pools and instream structure, combined with low turbidity, facilitated capture of sea lamprey in the stream. We tagged each captured sea lamprey with both an internal Passive Integrated Transponder (PIT) tag and an external floy tag. Mass, length, and sex were recorded for each sea lamprey before release.

During the sea lamprey run, stream surveys were conducted daily. We surveyed the 610-m reach from the trap net to the Mill Dam, and 2 km above the Mill Dam, and identified observed fish using a portable PIT tag reader, thus obviating the need to handle
fish repeatedly (Hill et al. 2006). We captured any non-tagged sea lamprey with a hand net and processed them accordingly. At each encounter with a sea lamprey the following were recorded: whether it was alive or dead, the location in the stream, whether or not it was found on a nest, and if so which nest and what other individuals were in the nest.


**Nest surveys and abundance estimation**

Daily nest surveys were also conducted throughout the duration of the sea lamprey spawning run. Each nest location recorded and marked on the stream bank with flagging. Maximum length, width, and depth were recorded for both the upstream depression and the downstream mound of each nest, and any sea lamprey occupying nests were identified. Abundance of nests was estimated using a Cormack-Jolly-Seber mark-recapture method in MARK. The 610 meters of accessible stream below the Mill Dam was divided into 61 10-meter sections and lamprey nest abundance was recorded for each section. We also recorded substrate size along a random transect, running perpendicular to the stream bank, in each stream section. Substrate was sampled by walking heel to toe along the transect and measuring the size of the substrate component at each step.

![Figure 2.2 The cumulative proportion of sea lamprey entering Sedgeunkedunk Stream, Penobscot Co. Maine. 2008.](image-url)
Results

In 2008, the spawning run of sea lamprey in Sedgeunkedunk Stream began on 18 June and ended on 27 June. During that period a total of 47 sea lamprey (21 female and 26 male) was captured and tagged. The mark-recapture model estimated total abundance (N ± 2SE) of 47 ± 0. Of the 47 lamprey caught only 16 were captured using the trap net. Of those sea lamprey that evaded the trap net, the mean point of capture was 345 ± 52 m upstream of the net, and 5 sea lamprey were captured initially in the pool directly downstream of the Mill Dam. No lamprey were observed above the Mill Dam. Males and females were similar in size (males mean length was 625 ± 23cm and mean mass was 750 ± 100g, females mean length was 612 ± 22cm and mean mass was 700 ± 100g). There was not a detectable pattern in size or sex of a sea lamprey and the arrival of it to the stream. Sea lamprey entered the stream at a relatively steady rate throughout the period (Figure 2.2).

Individual sea lamprey were active in the stream for an average of 2.5 ± 0.5 days (range 1 – 6 days),

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<tr>
<th>Date entered</th>
<th>Total</th>
<th>Males</th>
<th>Females</th>
<th>Water temp. (°C)</th>
<th>Days active</th>
<th>Nests used</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/18</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>16.9</td>
<td>4.4±1.0</td>
<td>1.8±1.2</td>
</tr>
<tr>
<td>6/19</td>
<td>9</td>
<td>5</td>
<td>4</td>
<td>16.5</td>
<td>3.5±1.0</td>
<td>2.0±0.7</td>
</tr>
<tr>
<td>6/20</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>16.9</td>
<td>4.0±2.0</td>
<td>3.3±1.3</td>
</tr>
<tr>
<td>6/21</td>
<td>7</td>
<td>4</td>
<td>3</td>
<td>18.8</td>
<td>2.1±0.5</td>
<td>1.4±0.7</td>
</tr>
<tr>
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<td>4</td>
<td>2</td>
<td>2</td>
<td>19.5</td>
<td>3.0±2.2</td>
<td>2.8±1.7</td>
</tr>
<tr>
<td>6/23</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>19.5</td>
<td>1.4±0.8</td>
<td>0.8±0.6</td>
</tr>
<tr>
<td>6/24</td>
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<td>2</td>
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<td>3.3±0.3</td>
</tr>
<tr>
<td>6/25</td>
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<td>1</td>
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<td>0.2±0.2</td>
</tr>
<tr>
<td>6/26</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>20.8</td>
<td>1.0</td>
<td>0.3±0.3</td>
</tr>
<tr>
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<td>0</td>
<td>21.9</td>
<td>1.0</td>
<td>0.0</td>
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<tr>
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<td>1</td>
<td>1</td>
<td>-</td>
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<tr>
<td><strong>Total</strong></td>
<td>47</td>
<td>26</td>
<td>21</td>
<td>-</td>
<td>2.5±0.5</td>
<td>1.4±0.4</td>
</tr>
</tbody>
</table>

Table 2.1. Number of live sea lamprey captured for the first time on each day of the sampling period, the mean water temperature of that day and the mean number of days observed active in the river, and mean number of total nests sea lamprey that entered on that day used before they died, Sedgeunkedunk Stream, Penobscot Co., ME 2008. Means are presented with ±2SE.

Figure 2.3. Frequency of the number of nests individual male, and female sea lamprey were observed using during the duration of their activity in Sedgeunkedunk Stream, Penobscot, Co., Maine. 2008
and were observed on average 2.3 ± 0.4 times (range 1 – 5 observations). Average linear distance traveled, based on successive observations of individuals, was 103 ± 48 m (not including individuals observed only once); minimum and maximum daily means were 89 ± 55 m, and 138 ± 50 m. Daily distances ranged from 0 m (i.e. individuals found on the same nest on consecutive days, n = 3 ) to 255 m. Every lamprey was observed alive; of these 47 live fish captured, we observed the carcasses of 17 individuals. All observed carcasses were observed in the wetted stream channel. Carcasses were found, on average, 116 ± 71 m downstream of the point of last live observation. We did not observe any additional downstream movement of carcasses after first sighting.

While sea lamprey entered the stream everyday from June 18-June 27, we did not observe any live sea lamprey after June 27. Mean water temperature increased everyday during the run starting at 16.9° C and reaching 21.9°C on the last day. Sea lamprey that arrived in the stream earlier, regardless of sex, were able to spend more days in the stream and, on average, were associated with more total nests before death (Table 2.1). Females were more likely to be observed on only one or two nests than were males, whereas males were less likely to be observed associated with a nest or be seen on 3 or more nests, than were females (Figure 2.3).

During stream surveys, 31 nests were identified. There were no nests identified above the Mill Dam.

Figure 2.4. Distribution sea lamprey nests, and percentage of substrate made up fines (smaller than 2mm) along the stream gradient of Sedgeunkedunk Stream, Penobscot Co., Maine. 2008.
The mark-recapture model estimated total nest abundance (N ± 2SE) of 31 ± 0. Sea lamprey nests were present in 39% (24 of 61 stream sections) of the stream available to them. These nests were distributed throughout the stream upstream of head-of-tide to immediately downstream of the Mill Dam, where the substrate had a low percentage of fine sediment (<2mm) (Figure 2.4). Sea lamprey nests were present in 87% of the stream sections characterized by less than 20% fine sediment. No nests were found below head-of-tide or above the dam. Mean nest dimensions included a pit that was 75cm long, 56cm wide and 20cm deep, and a mound that was 62cm long, 57cm wide and 8cm deep (Table 2.2). Nests as attendance ranged from 0 to 6 sea lamprey at one time, never with more than 2 males or 4 females on any one nest, with a mean number

<table>
<thead>
<tr>
<th></th>
<th>Pit length</th>
<th>Pit width</th>
<th>Pit depth</th>
<th>Pile length</th>
<th>Pile width</th>
<th>Pile depth</th>
<th>Max. # of sea lamprey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smallest</td>
<td>42±11</td>
<td>40±9</td>
<td>23±23</td>
<td>37±37</td>
<td>35±11</td>
<td>11±11</td>
<td>0</td>
</tr>
<tr>
<td>Largest</td>
<td>126±12</td>
<td>101±10</td>
<td>23±23</td>
<td>128±128</td>
<td>101±9</td>
<td>9±1</td>
<td>6</td>
</tr>
<tr>
<td>Mean</td>
<td>75±11</td>
<td>56±9</td>
<td>20±20</td>
<td>62±14</td>
<td>57±8</td>
<td>8±1</td>
<td>1.8±0.4</td>
</tr>
</tbody>
</table>

Table 2.2. Smallest, largest and mean sizes of sea lamprey nests, and the maximum number of sea lamprey observed on them in Sedgeunkedunk Stream ,Penobscot Co. ME. 2008. Measurements are in cm. Mean of the maximum number of sea lamprey for all nests is shown with ±2SE. Smallest and largest nests determines by area.

Discussion

In 2008, lamprey arrived in Sedgeunkedunk Stream later than in most streams in the lower Penobscot watershed (Oliver Cox, Maine Department of Marine Resources, personal communication). In Maine, sea lamprey spawning occurs in late May and early June when the water temperature reaches 17-19° C (Kircheis 2004). By the time the sea lamprey arrived the mean daily water temperature in Sedgeunkedunk Stream had

Comment [SC9]: Very awkward. “Females shared nests with, on average, more male partners than did males” or something like that

Deleted: There was significantly different between males

Deleted: and females in the number of other males occupying the dame nest

Females shared nests with, on average, more male partners than did males (two sample paired means t-test  p < 0.0004, df = 15)
exceeded 20° C for most of early June. The sea lamprey run might have been triggered by the temperatures dropping below 17° C on June 17, and then increasing back up to 20°C over 9 days (Binder and McDonald 2008). This decrease in temperature coincided with an increase in discharge, which has been shown to initiate migration (Almeida et al. 2002). This period of lower temperatures was short, so individuals who arrived early had more opportunity to take advantage of a brief period of favorable spawning conditions.

We saw no evidence of nest fidelity in either male or female sea lamprey. In fact we observed that sea lamprey moved often in the system and used multiple nests, with individuals using as many as 5 nests and travelling as much as 255m between nest sites in consecutive days. This is consistent with what has been observed in other lamprey species (Moser et al. 2007). Thus, a single sea lamprey may modify the substrate in several reaches of the same stream, and multiple sea lampreys may build and expand upon on a communal nest. Males initiate nest building (Kircheis 2004), and typically were associated with multiple nests. Males were more likely to be observed away from a nest than were females, which could be caused by their tendency to move among multiple nests, possibly in order to avoid sharing nests with other males.

Despite the relatively short reach of Sedgeunkedunk Stream accessible to anadromous fishes, sea lampreys did spawn there in modest numbers. Our methods of capture and survey for both sea lamprey and their nests were successful, and our models of abundance indicated that we were able to capture every sea lamprey in the system and record every nest location. The use of PIT packs was also very successful in identifying individuals without any observable disruption of their behavior and we were able to record the location and activity of individuals on a daily basis.
Historic abundances of sea lamprey in Maine are unknown (Kircheis 2004). Therefore, we do not know whether 47 sea lamprey in Sedgeunkedunk Stream represents a run of spawners that is persistent in the system, despite the limited habitat available to them, or one that is in decline. During 20 year study on the Fort River (which is similar in size to Sedgeunkedunk Stream), Massachusetts, there was a mean of 80 spawners per year entering the stream (Nislow and Kynard 2009). Tributaries of Lake Ontario with less than 1km of available stream below a dam support runs of up to 800 sea lamprey (Binder et al. 2010). Now that the dams on Sedgeunkedunk have been removed, what happens next will help us to determine the viability of the sea lamprey spawning run in the stream. In Portugal, sea lamprey have been shown to use previously-inaccessible habitat after connectivity is restored (Almeida et al. 2002). It is likely that there will be an immediate expansion of sea lamprey spawning range in Sedgeunkedunk Stream now that the Mill Dam has been removed. Many sea lamprey swam to the Mill Dam on the first day they entered the stream before moving downstream to other nesting habitats. Also, sea lamprey nests were distributed throughout the available stream below the dam. We found nests in almost all of the reaches that were not dominated by fine sediment. This makes us believe that the only factor preventing spawning by sea lamprey further upstream was the Mill Dam.

Sea lamprey potentially provide important ecological functions in the stream communities, particularly ones that have lost other anadromous components. Their semelparous life history make them a potential source of MDNE. We only observed 17 carcasses in the stream, which suggests that the other sea lamprey left before death, the carcasses were transported somewhere that we could not see it, either by the current or
Terrestrial scavengers, or the carcass was washed out of the system. Most sea lamprey carcasses decompose within 1-2 weeks (Nislow and Kynard 2009), such that MDNE addition occurs in Sedgeunkedunk Stream before high discharge events wash the carcasses into the Penobscot River. We did not observe downstream movements of intact carcasses, but did witness rapid disintegration following carcass deposition.

The nest building behavior of sea lamprey has the potential to act as a substrate conditioner for Atlantic salmon, especially in a system that does not currently support reliable salmon spawning. The mean length of sea lamprey nests in the stream was 1.37m, and even the smallest nests that we observed were nearly a meter long; nests of this size could have a potentially important impact on the substrate of a stream that is often less than 4 meters wide. If the abundance and distribution of the spawning run increases with restoration, as we expect, this creates a large potential for sea lamprey to affect the substrate of a large portion of Sedgeunkedunk Stream. The synergism between a suite of anadromous species could be an important factor in each species’ recovery (Saunders et al. 2006). If the numbers of spawning sea lamprey using Sedgeunkedunk Stream increase following dam removals it could potentially impact the ecology of other anadromous species through nutrient addition and substrate modification.
REFERENCES


American Benthological Society. 9:77-88.


BIOGRAPHY OF THE AUTHOR

Cory Gardner was born in Bangor, Maine on September 13, 1978. He was raised in Orono, Maine and graduated from Orono High School in 1997. He attended the University of Maine and graduated in 2007 with a Bachelor’s degree in Wildlife Ecology. Cory is a candidate for the Master of Science degree in Wildlife Ecology from The University of Maine in December, 2010.
The biotic responses to dam removals usually are not monitored (Bernhardt et al. 2005), or the research is focused on a target fish species (Doyle et al. 2005), rather than a community response, like we have done in this study. Because we do not know what the abundances and size structure of fish species was before the construction of the dams, it is important to know what the baseline conditions and variability were before the restoration. Prior to dam removal we found consistent patterns in space and over time, and low variability, which will allow us to detect the changes that take place following the restoration project. The only deviation from this pattern occurred at the two sites immediately adjacent to the dam immediately after removal, and our sampling allowed us to detect these changes. Continued monitoring will allow us to show how the stream fishes below the dam site recover from the disturbance, and how the entire stream fish community responds to a more natural hydrology and increased connectivity to large river and marine ecosystems.

This type of monitoring can be useful in detecting the response of fish communities in dammed streams as dam removals become a more popular restoration effort in Maine and beyond. This restoration project is notable because it takes place downstream of the anticipated Penobscot River Restoration Project, in which two large main-stem dams are to be removed, and fish passage installed or improved at two other dams (PRRT 2009). We view the Penobscot River, structurally and functionally as thousands of Sedgeunkedunk–sized tributaries, and thus this small scale restoration project is the first step towards rehabilitation of a major river system.