How Fish Communities Differ Across Stream Restoration Intensities

Andrew Miano\textsuperscript{1}
Mentor: Linda Deegan\textsuperscript{2}
Collaborators: Sam Stewart\textsuperscript{3}, Audrey Seiz\textsuperscript{3}, Lena Weiss\textsuperscript{3}

\textsuperscript{1} Department of Biology, Connecticut College, New London, CT, 06320
\textsuperscript{2} The Ecosystems Center, Marine Biological Laboratory, Woods Hole MA, 02543
\textsuperscript{3} Semester in Environmental Science, Marine Biological Laboratory, Woods Hole MA, 02543
Abstract

Cape Cod freshwater stream ecosystems provide a variety of ecosystem services for humans. Unfortunately, stream ecosystems have been highly degraded through the process of cranberry bog agriculture in the last decade. In recent years there has been a push to return these degraded streams back to their natural states and restore the services they provide. Fish communities are one important indicator of a healthy stream. On Cape Cod restoring brook trout populations is the goal of many restoration projects as they have been diminished throughout the east coast. Stream restoration can be carried out in a variety of methods ranging from monitoring to constructing a new river channel. This project examined how fish communities differed with varying levels of restoration intensity. Methods included a two pass seining method and three pass electroshocking method to sample fish. Stream characteristics such as temperature and large debris counts were also used to compare how both the physical and biological characteristics of a stream affect fish populations. It was found that increasing connectivity, habitat structure and riparian zone vegetation are the three most important aspects of stream restoration that influence these important cold-water species.

Key words/phrases:
Fish Communities, Brook Trout, Stream Restoration, Habitat Complexity

Introduction

Freshwater stream ecosystems provide humans with a variety of important ecosystem services. Humans rely on stream to filter our water, giving us healthier useable water (Kashuba, 2011). In addition they also provide flood and water control for human populations (Kashuba, 2011). They are also an important economic driver because they attract people for recreational uses such as hiking, fishing and aesthetic appeal (Kashuba, 2011). From an ecological standpoint they also promote biodiversity, as they are unique ecosystems for many species (Kashuba, 2011). Unfortunately humans have degraded streams more than almost any other type of ecosystem (Lake et al, 2007). In particular streams around Cape Cod have been degraded since the 1800’s through the inputs of dams and cranberry bog agriculture (Hurley, 2007). These disturbances have straightened streams while reducing the important riparian zones that provide shade and terrestrial inputs into the stream. This also makes the streams flow at higher rates and warmer temperatures leading to a loss of their ecosystem services. Increasingly, the loss of these vital stream ecosystems throughout Cape Cod has prompted a push to return streams back to their natural function. This is known as stream restoration. Unfortunately, ecological concepts can be left out during stream restoration (Lake et al, 2007). This is in part due to the fact that ecologists still do not know all of the ecological drivers that promote natural stream function. For example ecologists still don’t know how biodiversity relates to stream ecosystem function and which species are most critical
One theory suggests that for many streams all of the native species of the stream are needed to promote and restore stream function (Lake et al, 2007).

Fish communities are a particularly important indicator of the health of a stream. They are also an important part of stream function as they promote biodiversity and many species of fish can fill different niches within the stream ecosystem. For example, some fish can be important primary consumers in stream ecosystems while others provide significant top down controls on herbivorous organisms. Streams around Cape Cod are primarily cold-water streams because they are groundwater fed. One of the most important species in Cape Cod streams is the Brook Trout, *Salvelinus fontinalis*. Brook trout are a native cold-water fish to Cape Cod but are generally not found in water above 20°C (Hartel et al. 2002). Brook trout not only provide important top down controls on algae consumers but also promote fisheries tourism (Lake et al, 2007). In addition they are good indicators of excellent water quality as they are cannot survive in areas with lots of pollution (Hartel et al. 2002). There is a special type of brook trout on Cape Cod that spend part of their lives in salt water and then return to the stream. These “salters” have adapted to swim in salt water as adults making them larger than typical brook trout (Hurley, 2007). This type of brook trout has not been seriously studied and much is still unknown about them (Hartel et al. 2002). Unfortunately, brook trout as a species are only present in 5% of their former habitats (Hurley, 2007). In addition there are currently only nine known streams that support sea run populations (Winders, 2009). For this reason brook trout, in particular sea-run brook trout, are the target species in many stream restoration projects around Cape Cod. It will be increasingly more important to restore streams that promote and restore fish communities as human influences degrade more and more of these natural and important ecosystems.

These fish communities rely on a variety of factors within stream ecosystems. These include both physical characteristics such as temperature and dissolved oxygen but also biological characteristics such as organic matter and habitat complexity. The three most important factors for Cape Cod streams are temperature, connectivity and habitat structure. Temperature is important because it can influence the types of fish that can live in a particular stream. Temperature can be affected by the shading of the riparian zone, which is also an important input of food in the form of organic matter (Lake et al, 2007). Connectivity is also important as dams and other water control structures can hinder fish migration and affect water flow. Habitat complexity such as woody structures and undercut banks are important because they can alter stream characteristics and provide areas for fish to live.

This project will examine how varying intensities of stream restoration affect these important fish communities on Cape Cod. I hypothesize that restoration intensities will affect fish communities differently and this will be based on how well the physical and biological components of the stream are affected.

**Methods**

*Site Description*

Fish communities can be thought of as the abundance and types of fish within a stream community. To answer how varying stages of stream restoration affect fish communities I will sample four different streams around Cape Cod. I will sample one
reference stream that has not been disturbed and three streams that have been disturbed by cranberry bog agriculture and undergone restoration in different ways. These streams are primarily groundwater-fed and are similar sized. Because of these similarities it can be assumed that if they were all in “pristine” condition they would be similar to the reference stream. The reference stream I will look at is the Mashpee River. This is a coastal river that has not been disturbed and therefore has not needed restoration (The Trustees of Reservation, 2008). Due to the lack of disturbance it has a largely intact riparian zone and a high degree of habitat complexity. For this project I will consider the Mashpee River to be an example of a “pristine” river and the best possible scenario for a stream community on Cape Cod.

Conversely the other three streams have been disturbed by cranberry bogs and have undergone some type of restoration. For this project we will restoration compared to the fish communities within the streams. The first stream is the Coonamessett River. This stream has been naturally restoring for 5 years. It has an under vegetated riparian zone, a low degree of habitat complexity and water control structures impeding river flow. These characteristics give the river warmer temperatures and a sandy bottom. This system will represent the lowest possible restoration intensity among the four streams. The next stream is Red Brook, which was restored two years ago. Unlike the Coonamessett it has undergone a medium level restoration intensity through the addition of woody habitat materials and removal of structures inhibiting natural water flow (Division of Ecological Restoration, 2009). This stream has had time to re-grow its riparian zone and has a high degree of habitat complexity due to the addition of woody structures. Red Brook will act as a middle level intensive strategy for restoring streams. The last stream I will look at is the Eel River. This river was completely restored last year by using heavy machinery to carve a new riverbed and install large habitat structures (Inter-fluve and Underwood Associates, 2010). This stream has a high degree of habitat complexity but not a fully intact riparian zone as it has not had much time since is restoration. Eel River will represent a high intensity strategy for restoring streams.

**Sampling Methods**

In order to sample fish communities in each stream a 150 meter reach was set up in each stream by establishing a transect every 15 meters of the stream (Stewart, 2011). Both physical and biological components of each stream were taken in order to accurately compare not just how the fish communities differ but also how different stream characteristics affect them.

One important factor that relates to fish community structure in stream ecosystems is habitat complexity. Habitat complexity was estimated across the four stream restoration gradients using three methods. First, physical parameters of each stream such as dissolved oxygen, salinity and specific conductivity were taken of using a Hydrolab. Water temperature data was also obtained for the Mashpee River, Eel River and Red Brook during the 2011 summer through Steve Hurley at the Massachusetts Division of Fisheries & Wildlife. 2011 summer water temperature data was also obtained for the Coonamessett River through Chris Neill at the Coonamessett River Trust. In addition LAI measurements were taken at each stream (Stewart, 2011) Secondly, habitat complexity in each stream was determined using
a habitat assessment field data sheet developed by UCDAVIS. This method gave quantitative measurements of habitat complexity based on cover densities, pool and riffle variability, sinuosity, riparian zone type and other important factors (UCDAVIS, 2011). Using this method of assessing habitat complexity allowed the streams to be quantitatively compared across restoration intensities. Lastly, a more comprehensive assessment of large debris in each stream system was taken. To do this the number of large woody debris over 25 cm in diameter and large rocks within the 150 meter reach of each the stream were counted using field observations and compared (USEPA, 2011).

Fish communities in the four streams were characterized over the sampling reach of 150 meter in each ecosystem. Fish were captured and their populations estimated by two methods. The first method was a two-pass depletion method using seine and dip nets (Lockwood et al, 2000). To conduct this method within the reach, a 15 meter section with a representative pool was blocked off using one seine net at the upstream end and two seine nets at the downstream end of the section (figure 1). Dip nets were then used to scare fish into the first downstream net where they could be captured in the seine net or using dip nets. The first downstream seine net was then removed and any fish captured were held in buckets. The stream was left undisturbed for up to ten minutes to try and get any fish in the reach to come out from hiding. Fish were then again scared into the second downstream seine net and collected. Each fish from each pass was then measured for both length and weight. This seine and dip net two-pass depletion method was then repeated for another 15 meter section within the reach that had a representative run. The number of fish captured was then converted to the total abundance in a representative pool and representative run section of each stream using equation 1:

\[
N = \frac{C_1^2}{(C_1 - C_2)}
\]

Equation 1: Taken from Lockwood et al, 2000.

Where \(N\) = The population estimate
\(C_1\) = Number of fish caught in first pass
\(C_2\) = Number of fish caught in second pass

If all the fish were caught in the first pass then it was assumed the population was equal to the total number of caught. If more fish were captured in the second pass then the abundance was assumed to be 1.5 times the total number of fish caught, rounded down to the nearest whole number.

To scale up fish abundances to the 150 reach the percentage of pools and runs within the given reach were estimated. This was done by using transect data collected every 15 meters (Stewart 2011). Each transect within the reach was determined to either contain a run or a pool. Using this data the number of each fish species could be scaled up by their corresponding areas. This gave a total number of fish within the 150 meter reach. This data could then be used to calculate biomass by multiplying each type of fish by their respective average weights. Both abundance and biomass was then normalized to a 100 meter section.
In addition to the seine and dip net depletion method, triple pass electroshocking data was also used to compare all the streams. Unfortunately it was not possible to electroshock streams that have brook trout, as they tend to spawn in November when sampling occurred. Fortunately triple pass raw data was obtained from Steve Hurley at the Massachusetts Division of Fisheries & Wildlife (Hurley 2011). These data sets included the Mashpee River 2001, Red Brook 2001, and Eel River 2011. In addition to obtaining previously sampled data, triple pass electroshocking data was conducted in the Coonamesset River with the help of Steve Hurley. Block nets were set up on either side of a 100 meter section. A smith root model 12-B electrofisher (400 volts -500 volts, 15 switch setting) was used to conduct sampling in the upstream direction. Three passes were done at 1465, 1227 and 1150 second respectively. Each fish was measured and weighed and at the end of the third run they were returned to the stream.

The number of fish captured was then converted to the total abundance using the program MicroFish (Deventer, 2006). If all the fish were caught in the first pass then it was assumed the population was equal to the total number of caught. If fish were not captured in a descending order then the abundance was assumed to be 1.5 times the total number of fish caught, rounded down if .5.

From the information obtained from the seine and dip net two-pass depletion method and the triple pass electroshocking method species biodiversity was characterized across the restoration intensities. Using this information functional groups were established among the streams. Functional groups of fish were categorized into warm-water, cold-water and estuarine species in order to compare how the types of fish differ across the streams (Armstrong and David, 1999).

Another part of this study was to determine fresh and salt water influences on the diets of top trophic level fishes in each stream. To do this, fin clips were taken from brook trout caught in the Mashpee River, Eel River and Red Brook. A representative sample of largemouth bass was taken from the Coonamesset River as a reference. Carbon and nitrogen stable isotopes analysis was then run on the tissue samples to determine fresh and salt water influences on their diets (Weiss, 2011).

Results

All of these streams were restored in different intensities differ in both physical and biological characteristics. As part of this project both stream characteristics and fish communities were examined. Furthermore these factors were determined to relate to each other. All of the streams had similar salinities, dissolved oxygen levels and specific conductivities (table 1). Conversely summer temperature varied greatly between the four streams. The reference stream was the least variable between June and September with an average temperature below 20°C (figure 2). Likewise the medium intensity stream also had a low degree of variability and had an average temperature below 20°C, although it still fluctuated more than the reference stream (figure 2). Both the high and low intensity streams were much more variable then the reference stream and had average temperatures above 20°C (figure 2). In addition average summer temperature decreased with the increasing leaf area index of a stream (figure 3).
Another important stream characteristic is the presence of large structures within the stream. The reference, medium and high intensity streams all had similar amounts of large structures within the 150 meter reach (figure 4). Interestingly, the high intensity stream had large rocks present that were not present in any of the other streams (figure 4). The low intensity stream had much lower numbers of large structures present in the stream (figure 4). The habitat assessment score was highest in the reference stream and lowest in the low intensity restoration stream (figure 5). The medium restoration intensity stream was closest to the reference stream with the high intensity stream being the intermediate (figure 5).

Total fish abundances in the stream varied both between the streams themselves and the two methods used. Using both methods the low intensity stream has the highest number of fish per 100 meters of stream (figure 6). Using the electroshocking method the reference stream showed the second highest abundance of fish followed by the high intensity and then the medium restoration intensity stream (figure 6). Conversely, the seine method showed the medium intensity stream had the second highest fish abundance followed by the high intensity stream and then the reference stream (figure 6). Interesting brook trout abundance showed a different trend. Both the seine and the electroshocking method showed that the reference stream had the highest brook trout abundance per 100 meters (figures 7 and 8). The medium intensity stream was most like the reference stream in brook trout abundance followed by the high restoration intensity stream (figures 7 and 8). The low intensity stream did not have any brook trout over a 100 meters of stream (figures 7 and 8). It should be noted that the electroshocking was much more effective at catching brook trout then the seining method, although the seining method did show the same general trend as the electroshocking method (figure 7 and 8).

Fish biodiversity also differed between all of the streams. Total fish biodiversity was similar for the reference, low and medium restoration intensity streams, while the high restoration intensity stream had the lowest (figure 9). The reference stream had the most cold-water species and was most uniform between the numbers of species in the three functional groups (figure 9). The medium and high restoration intensity streams had the same number of cold-water species (figure 9). The low and high intensity streams had the highest number of the warm-water species compared to total biodiversity (figure 9). The percent of each functional group in the total fish abundance also differed between each stream. Electroshocking data showed that the both the reference and medium restoration intensity streams were heavily dominated by cold-water species (figure 10). The low and high restoration intensity streams were much more dominated by warm-water species with the low intensity stream having no cold-water species (figure 10). Similarly the seine method showed that the reference stream was dominated by cold-water species while the low and high intensity streams were warm-water dominated (figure 10). Conversely the seine method showed that the medium restoration intensity stream was estuarine dominated (figure 10). Fish biomass over 100 meters followed a similar trend as fish abundance. The low intensity stream had the highest biomass but it was mostly warm-water dominated (figure 11). The reference stream had the next highest biomass, and was dominated by cold-water species. The third highest biomass was found in the high intensity stream, which was also mostly cold-water dominated (figure 11). The medium intensity stream had the lowest biomass and was mostly dominated by estuarine species (figure 11).
Average summer temperature had a moderate correlation with fish functional groups (figure 12). In general, as temperature increased the number of warm-water species increased. Likewise as temperatures decreased the number of cold-water species increased (figure 12). In addition to temperature there is a correlation with increasing the number of large structures and the number of brook trout within a 150 meter reach (figure 13). Along with large structures the habitat assessment score is strongly correlated with brook trout abundance over the 150 meters reach (figure 14).

Lastly stable isotope analysis from eastern brook trout and largemouth bass showed differences between the restoration intensities. In the reference stream brook trout had the highest delta 15 nitrogen value and was intermediate in delta 13 carbon values between the medium and high intensity brook trout (figure 15). The medium intensity stream brook trout was intermediate in its delta 15 nitrogen values and had the lowest delta 13 carbon value (figure 15). The high intensity stream brook trout had the lowest delta carbon 13 values and the lowest delta 15 nitrogen values (figure 15). The largemouth bass from the low restoration intensity stream was intermediate in both its delta 13 carbon and delta 15 nitrogen values (figure 15).

Discussion

Both the physical and biological characteristics of Cape Cod streams are important to understanding the fish communities within them. All of these streams are groundwater fed and are similar sizes. These similarities attribute to the fact that they all have similar physical parameters such as dissolved oxygen, salinity and specific conductivity. There are many factors that affect fish communities within stream ecosystems. One of the most important factors within stream ecosystems is temperature. Stream temperature can be controlled by a variety of factors. Along with air temperature, cold groundwater is the driving force that keeps many streams cold (Taque et al, 2007), particularly on Cape Cod. Another important factor that can affect stream temperatures is riparian zone vegetation. This vegetation lowers temperature by shading streams and diminishing the warming of water by direct sunlight (Taque et al, 2007). This trend of riparian zone shading can be seen across all of the stream sampled. The high and low restoration intensity streams had both the warmest summer water temperatures and the least leaf area cover (figures 2 and 3). In contrast both the reference and medium intensity streams both had the lowest summer water temperatures and the greatest leaf cover (figures 2 and 3). Temperature, however, is not the only factor that influences stream ecosystems. Connectivity is also an important factor in New England stream ecosystems. Dams and water control structures can have negative impacts on migrating fish species such as sea run brook trout and estuarine species (Winders, 2009). Another important factor that affects fish communities in streams is habitat complexity. Habitat complexity can be thought of as a combination of structures and riparian zone characteristics that provide habitat for fish and other organisms. Restoration can affect habitat complexity by both the addition of large debris into the stream and restoring the riparian zone. The numbers of large structures within the streams were very similar for the medium, high and reference stream. This means that when active restoration is done it is effective at installing habitat for fish to live. Other factors that can influence habitat complexity include the riparian zone and channel characteristics as well as sediment deposition and
sinuosity. Using the UCDAVIS habitat assessment sheet it was shown that the medium restoration intensity stream was most like the reference stream in habitat complexity. This is because the stream was allowed to grow its riparian zone while still getting the benefits of restoration in the form of large woody debris. The high intensity stream had a slightly lower habitat complexity because it has not yet had time to fully grow its riparian zone. In addition the high intensity stream was slow moving and deep, in part by the manmade ponds as part of the restoration effort. The low intensity stream was shown to have the least habitat complexity. This is because the stream has not had time to grow its riparian zone as it has just been monitored and has not had the benefits of active restoration.

Interestingly, the trend in habitat complexity does not reflect total fish abundances. It was shown that the low intensity stream had the highest abundance of fish. Although this may seem contradictory it doesn’t tell the whole story of the fish communities within the stream. Further investigation shows that the low intensity stream had not only had no brook trout but also no cold-water fish present. In fact it was an extremely warm-water fish dominated stream. This is because it does not have a developed riparian zone to both provide shade and habitat for fish to live. It also does not have many large structures within the stream that can give brook trout places to live. The low intensity stream also has various water control structures that can impede estuarine related and important cold-water fish. The combination of increased temperatures, decreased habitat complexity and the presence of water control structures makes the stream much more dominated by smaller warm-water fish as opposed to larger cold-water fish.

This is much different than the reference stream. This stream has not had any disturbances that have negatively affected the stream. Because of this lack of disturbance the stream has a fully developed riparian zone. This is important for several reasons. First, the vegetative cover provides shade and decreases temperature in the stream. In addition the riparian zone increases habitat complexity through the inputs of woody debris into the stream. The stream also does not have any water control structures that can impede fish migration. For all of these reasons the reference stream has the highest abundances and biodiversity of cold-water species. Although it may have less abundance then the low restoration intensity stream it has the highest abundance and biomass of brook trout and other cold-water species. Furthermore, stable isotope analysis suggests that the brook trout from the reference stream have a combination of fresh and marine influences in their diet. This may mean that these fish are the rare sea run form that are known to be present in this particular river. This is important because it is the goals of these restorations to return the streams to their natural state, which means bring back these important cold-water species.

The medium restoration intensity stream is most similar in abundance and biodiversity to the reference stream. This stream has had time to partly develop a riparian zone that decreases temperatures by increasing shade. The riparian zone is not developed enough to have a significant impact on contributing large woody debris to the stream. Fortunately restoration has added large woody debris into the stream, which has increased habitat complexity for these fish to live. This stream has benefited both from a semi-developed riparian zone and the addition of woody structure. In addition the stream also has had water control structures removed so important cold-water and estuarine fish.
migration is not impeded. These reasons have allowed cold-water fish to come back to the stream. Although the stream has a lower abundance than the reference and low intensity stream it is biologically similar to the reference stream. The stream has a high abundance percentage of cold-water species and has the highest number of brook trout out of all the restored streams. It should be noted that the electroshocking data is from 2001, which is before the major restoration had occurred, although there was prior restoration that included the addition of woody debris. We would expect fish abundances to be higher than the data suggests but with the abundance of functional groups being in the same proportions. Furthermore, stable isotope suggests that the brook trout in this stream have a combination of fresh and marine influences in their diet. This may mean that these fish are the rare sea run form that was the goal of the restoration. The medium restoration intensity stream is most like the reference stream because of an increase in habitat complexity, lower temperatures and a high degree of connectivity.

The high restoration intensity stream has fish abundances that are intermediate between the medium and low restoration intensity streams. This stream has benefited from not only the addition of large structures within the stream but also a new, sinuous river channel. This is important for promoting habitat complexity for fish to live. Unfortunately the riparian zone of the stream has been both disturbed by cranberry bog agriculture and the high intensity restoration of remaking the river channel. The riparian zone has not had enough time since these disturbances and has not developed significantly. This means that the riparian zone does not shade the stream, leading to a increase in water temperature. In addition the riparian zone is not a significant source of habitat complexity for the stream. These factors have greatly influenced fish abundances within the stream. The stream does have a small brook trout population present, although it is probable they move out of the area in warmer months. The high intensity stream still has water control structures between the reach sampled and the ocean. This could impede migration of important cold-water and estuarine related fish. Furthermore, Stable isotope data suggests that these trout are feeding only on freshwater sources and are not the sea run form. In addition the high restoration intensity stream has a higher abundance of warm-water fish and lower abundance of cold-water fish then the medium intensity and reference stream. The combination of increased habitat complexity, but warmer water temperatures and a low degree of connectivity have lead to a more warm-water fish dominated system which can still support cold-water fish in small abundances at certain points in the year.

Throughout this study it has been shown that connectivity, temperature and habitat complexity are important factors for determining the abundance and types of fish present in stream ecosystems.

Conclusion:

 Restoration through increasing habitat complexity, connectivity and riparian zone vegetation is the most effective way to return important cold-water species to streams on Cape Cod. Further studies would benefit by looking at other types of stream restoration and their respective fish communities.
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References:


Appendix: Figures and Tables
Figure 1: Up and Downstream nets in the seining two-pass depletion method
Temperature Among Restoration Intensities

Figure 2: Average summer temperature across stream restoration intensities
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Figure 4: Number of large structures in a 150 meter section across each stream restoration intensity.
Figure 5: Habitat Assessment Score (UCDAVIS, 2011) across each restoration intensity
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Figure 9: Fish biodiversity across restoration intensities
Figure 10: Percent of functional groups in fish abundances.
Figure 11: Fish biomass across restoration intensities. Estimated using a seine and dip net two-pass depletion method.
Figure 12: Number of cold and warm water species compared to average summer temperatures of stream restoration intensities.
Figure 13: Brook trout abundance vs number of large structures in 150 meters of stream across stream restoration intensities
Figure 14: Brook trout abundance vs habitat assessment score in 150 meters of stream across stream restoration intensities.
Figure 15: Carbon and Nitrogen stable isotope values of top trophic level fishes for each restoration intensity.
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Table 1: Dissolved oxygen, salinity and specific conductivity across restoration intensities