Cranberry Bogs: The effect of cultivation and restoration on habitat distribution, benthic invertebrate communities, and food webs in stream ecosystems

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Abstract

Cranberry farming changes the land in many ways, and these changes influence habitat distribution, benthic invertebrate communities, and food webs in stream ecosystems. To understand the variation in these dynamics between cultivated, restored and natural streams, I classified habitat along transects and analyzed benthic invertebrate samples. Stable isotope analyses clarified the relationships between dominant food sources, benthic invertebrates, and organisms of higher trophic levels. The dominant habitats varied from sand in cultivated streams to gravel and leaf pack in less-impacted streams. These habitat changes affected benthic invertebrate populations which were larger, but less diverse, in streams surrounded by cranberry bogs. One or two species were dominant in cultivated streams, perhaps because the loss of sensitive invertebrate species resulted in reproductive advantages and the loss of predation pressure. The presence of a riparian forest influenced the dominant primary producer in a stream: where a riparian forest was present, terrestrial leaves were a main food source; where the canopy was not fully closed, aquatic vegetation was more important; and when no riparian forests were present, algae/detritus formed the base of the food web. This indicates that when restoring streams, attention should be paid to the condition of the riparian forest and the quality of substrate in the stream.

***Keywords**: riparian zones, agriculture, habitat distribution, benthic invertebrates, food web, stream restoration*

Introduction

Land use changes around streams cause dramatic changes within them. Pesticides and herbicides introduce toxins, and fertilizers increase nutrient levels in the soil. The clearing of land and regular tilling also decreases water retention, and the resultant runoff loads nearby watersheds with nutrients, toxins, and sediment. In Massachusetts, cranberry cultivation is a primary form of agriculture in riparian areas. Cranberry farmers alter streams by adding sand, leveling the land, flooding seasonally, and using trenches and culverts to control water flow (Clark and Sandler 1992).

As humans continue to convert the world's forests and wetlands into cities and farms, communities are starting to value species conservation (Harding et al. 1998). In Cape Cod, reforestation and stream restoration are occurring as agriculture becomes less important to the economy and some communities try to revive biotic diversity and fish populations.

In this study, three rivers with similar geological histories were examined – the Mashpee, Quashnet and Coonamessett Rivers (Figure 1). The Mashpee River – a groundwater-fed, forested stream – was a marker of what natural conditions in a river should be. The Quashnet River was an active cranberry bog until 1954, when Hurricane Carol flooded the bogs with salt water. Since then, a committee from *Trout Unlimited* has worked on restoring the river by planting red maple trees, adding pea-sized gravel, building overhangs, and inserting deflectors. All of these efforts were geared towards changing the physical structure of the Quashnet to make it a more desirable habitat for brook trout, herring, and striped bass (Schwarzman 2002). The Coonamessett River has been actively cultivated for about as long as the Quashnet River. Since 1972, it has been owned by Falmouth and leased to a farmer. In 1998, authorities found EDB in the river water from the Massachusetts Military Reservation and destroyed the crop of cranberries (Schwarzman 2002). In 2003, the town embarked on a process to develop a restoration plan for the Coonamessett River. Until the plans are finalized, the bogs are sitting fallow and undergoing passive restoration. The goal of restoration efforts on both rivers is to make the Quashnet and Coonamessett more like natural rivers and to foster fish populations that used to thrive there.

Benthic macroinvertebrates are a key component of stream ecosystems. They act as decomposers, recycle nutrients, and provide a primary source of food to other species in an ecosystem (Hauer and Resh 1996). Invertebrates are strongly influenced by abiotic factors like sediment grain size, water quality, current velocity, and stream depth – all of which are impacted by agricultural practices (Ingersoll and MacDonald 2002). Because macroinvertebrates have species of varying degrees of tolerance to changes, they are good bioindicators of stream health (Linke et al. 1999). If an ecosystem has a very diverse benthic invertebrate population, then it is healthy. In stressed ecosystems, one or two species tend to dominate (Harding et al. 1998).

By developing an understanding of the benthic invertebrate populations across three rivers (the Coonamessett, Quashnet and Mashpee – henceforth referred to as a *restoration gradient*), and understanding the types of vegetation and substrata (*microhabitats*) that they live in, this study will explore the ways that agriculture impacts stream ecosystems. The benthic invertebrate populations and river habitats will be quantified, and a combination of species composition, habitat distribution, a stable isotope analysis, and information from literature will allow stream food webs to be generated. Hopefully, an understanding of benthic invertebrates, the microhabitats they prefer to live in, and their trophic links to other organisms, will reveal what restoration techniques have been successful at the Quashnet and what efforts should be pursued on the Coonamessett.

Methods

At each stream, a 200-300m reach that included representative riffles, pools, and riparian vegetation was selected. Transects were set up every 10m along the reach, and microhabitat was classified every 10cm using the transect-point intercept technique (Resh, Myers and Hannaford 1996). Microhabitats were grouped into five primary categories - sand, gravel, organic matter, leaf pack and aquatic vegetation. This data was used to determine the percentage of each microhabitat available to benthic invertebrates.

Three invertebrate samples were collected from each microhabitat using a Surber sampler with an area of 930cm^2 and a collection net with a mesh size of 500µm (Surber 1937, Hauer and Resh 1996, Harding et al. 2006). Within the Surber sampler's metal frame, overlying gravel, organic matter, leaves or vegetation were removed, stored in Ziplock bags, and taken back to the lab. The underlying sediment was also disturbed to a depth of about 2cm, the water was allowed to clear, and the process was repeated. The sediment and invertebrates collected in the net were also stored in Ziplock bags and returned to the lab. In the lab, invertebrates were extracted from the sediment, counted, and identified to the lowest possible taxa - usually the Family or Genus level. Representative invertebrates were preserved in 100% ethanol for further use in isotopic analysis (Stanley and Doyle 2002).

Total invertebrate density for each river was calculated as shown below:

$$D_w = (H_1 * A_1) + (H_2 * A_2) + (H_3 * A_3) + (H_4 * A_4) + (H_5 * A_5)$$

where D_w represents the weighted density of invertebrates in a river (# invertebrates/m^2), the five H_n terms represent the percentage of each microhabitat (%), and the five A_n terms represent the total invertebrate abundance in each microhabitat (# invertebrates/m^2).

The taxa found in Surber samples were also classified as tolerant (T), somewhat sensitive (F) or sensitive (S), according to guidelines from Earth Force ("Benthic Analysis Instructions" 2006). This data was used to develop an EPT water quality index. Streams with no "S" taxa and a score less than 11 were considered poor; and streams with at least 4 "S" taxa and a score more than 22 were rated excellent. These results were compared to results from a 2004 study to evaluate whether the water quality of the rivers has improved with restoration efforts (Kingsland 2004).

To evaluate site-specific differences in the river habitat classified as gravel, the sediment collected in the Surber samplers was dried in a 60^{o}F drying oven for two days. Six metal sieves (10mm, 4mm, 2mm, 1mm, 0.5mm, 0.25mm) were weighed individually prior to adding the sediment sample. The sieves were stacked, the sediment was poured in, and the stack was shaken from side-to-side for 5-10 minutes to promote separation. To determine the size distribution of the sediment sample, the metal sieves were re-weighed with the sediment after separation took place. Sediment weights were converted into percentages to make comparisons across sites.

To determine the amount of light reaching the water at each site, a Li-cor 6200 was used. An unforested area was used to calibrate the Li-cor 6200, and a total of 9 measurements were taken over a 100-meter section of the reach to generate an average value for each site.

Samples of submerged aquatic vegetation, terrestrial leaf litter, organic matter, and representative benthic invertebrates from each river were prepared for a stable isotope analysis of carbon and nitrogen. All samples were dried over several hours in aluminum weighing boats, ground using a mortar and pestle, and stored in 20mL glass scintillation vials. Isotopic values for other plants, fish and eels not sampled for each river, were obtained from other studies (Kumai 2006, Kingsland 2004). A stable isotope analysis for carbon and nitrogen on plants, organic matter, and benthic invertebrate samples made it possible to determine how benthic invertebrates' diets are influenced by nearby cranberry cultivation.

Results

The average width and depth of the three rivers varied. The Coonamessett and Mashpee Rivers were shallower and wider than the Quashnet River (Figures 2, 3); however, the Mashpee exhibited the greatest range of widths for the reaches examined (Figure 4).

Sand was the primary substrate in the Coonamessett River, making up 52% of the river bottom. Algae and submerged aquatic vegetation like Vallisneria, Quillwort and water-starwort made up 26% of the bottom. 14% of the substrate was classified as organic matter, and 8% was considered gravel. Leaf pack and logs contributed by riparian forests were not observed in the Coonamessett River (Figure 5).

In the Quashnet River, submerged aquatic vegetation (Vallisneria and water-starwort) was the most prevalent microhabitat (53%). Gravel and sand were also abundant, making up 19% and 13% of the bottom, respectively. Leaf pack and organic matter only made up 10% and 5% of the bottom, but were frequently observed in microhabitats classified as submerged aquatic vegetation (Figure 5).

In the Mashpee River, gravel was the most abundant microhabitat (52%). Leaf pack was also prevalent (23%). Sand, organic matter and submerged aquatic vegetation were the least common microhabitats, making up 11%, 10% and 4% of the bottom, respectively (Figure 5).

The percentage of organic matter was relatively constant between the rivers; however, the percentages of leaves, sand, gravel and submerged aquatic vegetation showed clear trends along the restoration gradient. The Coonamessett, the most recently cultivated stream, had a much larger percentage of sand than the other sites; the Quashnet had more submerged aquatic vegetation than the other rivers; and the Mashpee had the highest percentage of gravel and terrestrial leaf inputs (Figure 6).

The leaf area indices for the Coonamessett, Quashnet, and Mashpee rivers were 0, 1.2, and 1.8-2.1μmol quanta m^{-2} s^{-1}, respectively (Kumai 2006).

Across the three rivers, total invertebrate density and diversity showed strong differences. The Coonamessett had the highest invertebrate density, but the lowest diversity, and the Mashpee had the lowest invertebrate density and the highest diversity (Figures 7, 8).

Eleven taxa of macroinvertebrates were found in the Coonamessett River (Figure 8). Invertebrate density was the highest in submerged aquatic vegetation; however, more prevalent microhabitats like sand also showed fairly high invertebrate densities (Figure 9). The most abundant taxon in the Coonamessett River was scuds (*Gammarus fasciatus*), which made up 67% of the invertebrate population. Sow bugs (*Caecidotea communis*) were also abundant (21%), and three species of snails, collectively, made up 8% of the population. No other taxa were present to this magnitude in the Coonamessett River (Figure 10).

The Quashnet River had a more diverse invertebrate population than the Coonamessett. It supported 17 taxa of macroinvertebrates across all microhabitats; however, invertebrate density was highest in submerged aquatic vegetation (Figures 8, 9). Like the Coonamessett River, scuds (55%) and sow bugs (38%) were the most abundant taxa (Figure 11). More taxa were collected in the Quashnet than in the Coonamessett, although their percent densities were smaller (less than 1%).

The Mashpee River had 20 taxa of macroinvertebrates (Figure 8). Invertebrate diversity was similar in four microhabitats – submerged aquatic vegetation, gravel, organic matter, and leaf pack – although percent invertebrate density was highest in leaf pack (33%) and submerged aquatic vegetation (31%). Like the Coonamessett and Quashnet Rivers, the most abundant invertebrate taxon was scuds; however, caddisflies (*Trichoptera*), fingernail clams (*Bivalvia Sphaeriidae*), sow bugs, aquatic earthworms (*Annelida Oligochaeta*), and biting midges (*Diptera Ceratopogonidae*) each made up at least 5% of the benthic invertebrate population (Figure 12).

To determine why invertebrate density and number of taxa varied across the gravel microhabitats, the sediment grain size distribution was determined. Graphs reflect the percent of the sediment retained by a particular sieve; thus, a high percentage of sediment in the 0.5mm column suggests that this percentage of sediment has a grain size between 0.5 and 1mm (the previous sieve size). In the Coonamessett River, the most prevalent grain size was between 0.5 and 1mm – in the range of sand (Figure 15). Sediment samples taken from the Quashnet River were not consistent at the top and bottom of the reach. At the top, the most prevalent grain size was greater than 4mm; whereas at the bottom of the reach, it was between 0.5 and 1mm like the Coonamessett River (Figure 16). In the Mashpee River, most of the sediment was at least 4mm, and a large percentage was greater than 10mm. This trend was consistent across all sampling sites in the Mashpee (Figure 17).

Water quality ratings for all three rivers have improved compared to 2004. The Coonamessett was classified as poor in 2004, and because it has one "S" taxon, it is now considered "good." The Quashnet and Mashpee Rivers were considered "good" in 2004, but have improved dramatically. The Quashnet River still has "good" water quality since it has only 3 "S" taxa. But the Mashpee River has six "S" taxa and a score of 41, suggesting that it now has "excellent" water quality (Figure 13).

To compare the trophic roles of organisms in the ecosystem, all organisms were classified into five feeding groups (filterers, shredders, predators, grazers and gatherers) according to diet information in literature (Delong and Brusven 1998, Voshell 2002, Merritt and Cummins 1996). All streams had 3 filterers; however, while snails and clams were dominant filterers in the Coonamessett River, caddisflies were primary filterers in the Quashnet and Mashpee Rivers (Table 1). Along the restoration gradient, the number of taxa classified as shredders, grazers and gatherers increased. The Quashnet River contained the most predators, and the Mashpee River had the most shredders and gatherers (Figure 14).

In the Coonamessett River, detritus forms the base of the food web. Algae and aquatic vegetation (Vallisneria and water-starwort) were both components of this detritus, but were not consumed directly (Figure 18). Sow bugs, caddisflies and amphipods fed primarily on detritus, while crayfish, eels, darters, leeches and other fish ate invertebrates. The top carnivores in the Coonamessett River were large mouth bass.

In the Quashnet River, detritus, composed primarily of terrestrial leaves, and aquatic vegetation were important sources of food (Figure 19). Some algae were observed, however, they were not important for invertebrate populations. Leeches and caddisflies were supported by the detrital pathway, and amphipods, stoneflies, and darters were supported primarily by aquatic vegetation. Sow bugs and alderflies fed on a mix of detritus and aquatic vegetation. Larger fish were not caught in this experiment, and the top carnivore sampled was an American Eel.

Detritus, composed of terrestrial leaves, was also the central food source in the Mashpee River (Figure 20). Craneflies, mayflies, amphipods and stoneflies fed on detritus, and populations of these invertebrates supported sow bugs, eels, leeches and fish. Brook trout and large mouth bass were the top carnivores in the Mashpee River.

Many species showed different isotopic signals in different rivers (Table 3). The Quashnet River consistently showed the lowest nitrogen signal of the three rivers, and the Coonamessett had the highest. Variations in the carbon signals were species-specific, and a general trend was not evident.

Discussion

Habitat Assessment

Streams are naturally composed of many different microhabitats; however, some microhabitats are more desirable than others. In the Coonamessett River, six taxa of benthic invertebrates lived in the sand. Due to the extreme abundance of sand from the cranberry bogs, tolerant benthic organisms were probably forced to live in that microhabitat. But in the Mashpee and Quashnet, where many other habitat choices were available, fewer benthic organisms lived in the sand (4 taxa in the Mashpee and none in the Quashnet). In contrast, submerged aquatic vegetation, organic matter and leaf litter, when present, were consistently very densely and diversely-populated microhabitats.

Leaf Area Index

To understand why certain microhabitats were more prevalent, it is essential to understand where the Quashnet and Coonamessett Rivers are in their restoration processes. In the 1890's, the forests around both rivers were cleared to build the cranberry bogs (Schwarzman 2002). Since the bogs around the Coonamessett have only recently (within the last two years) become fallow, the riparian vegetation has not changed. In contrast, since red maple trees were planted around the Quashnet in the 1970's, when restoration work began, the forest canopy is starting to close.

Since leaf area indices were taken in late autumn after most leaves had fallen, the values do not accurately reflect the amount of light coming through the canopy at the peak of a growing season. However, the trend in values reflects a larger trend across sites, showing the maturity of the canopy over the river. In the Coonamessett, where the LAI is 0 μmol quanta m^{-2} s^{-1}, the river receives full sunlight and there are no forests. At the Quashnet, where a young forest has started to develop around the river, the LAI is slightly higher, and at the Mashpee, surrounded by a mature forest, the LAI is the highest, suggesting that the Mashpee River receives the least amount of sunlight. As shown by the way that different microhabitats dominate in these rivers, the maturity of the riparian forest determines the ability of aquatic vegetation to grow and the amount of organic matter inputs the river receives – factors that influence the benthic invertebrate community.

Gravel Quality

At every stream, some habitat area was classified as gravel. At the Mashpee, gravel was a dominant and productive microhabitat. However, gravel at the Quashnet and Coonamessett Rivers was not nearly as productive. Sediment grain size measurements indicated that there were distinct differences between gravel in each of the three rivers.

In gravel from the Coonamessett, a sediment grain size of 0.5 to 1mm (the grain size of sand) was most abundant. As a result, gravel and sand had similar percent invertebrate densities (9% and 7%) and equal numbers of taxa (6) in the Coonamessett. Increased sediment load to the Coonamessett as a result of cultivation likely occupied the pore spaces between larger substrates in the stream and, over time, covered these habitats completely (Snyder et al. 2003).

In the Quashnet River, two sediment grain sizes (one large, and one comparable to sand) were prevalent; thus, gravel showed a slightly higher percent invertebrate density (1%) than sand (0%) and had 4 taxa of invertebrates. Although there was more gravel on the Quashnet, the smaller, more prevalent gravel did not seem to be attractive – benthic invertebrate densities were lower on the Quashnet than on the Coonamessett.

The most productive gravel was in the Mashpee River, where gravel was a more densely-populated microhabitat (19%) than sand (2%). In this habitat, the primary sediment grain size was greater than 10mm, suggesting that gravel in the Mashpee had much larger pore spaces. Caddisfly populations seemed to prefer this gravel size because, as case makers, they need substantial rocks to build their cases on, and larger pore spaces to move easily and escape the current.

Macroinvertebrates

In all rivers, scuds were present in every microhabitat as the dominant taxon of benthic invertebrates. In the Coonamessett River, Surber samples contained about seven times as many scuds per square meter (11000) as the Mashpee (1600) and Quashnet

(1500). Scuds also made up 67% of the total invertebrate population in the Coonamessett, suggesting that the river is still a stressed ecosystem (Harding et al. 1998). The absence of key predators in this system and the ability of scuds to thrive in any microhabitat could explain why they can survive particularly well in the Coonamessett.

In comparison to the Coonamessett, the Quashnet River has improved, but still shows signs of being stressed. Scuds are still the dominant invertebrate taxon, but 6 additional invertebrate taxa are also present, three of which are sensitive and indicate good water quality. The abundance of submerged aquatic vegetation, a preferred microhabitat for benthic invertebrates, clearly contributes to the increase in benthic invertebrate diversity seen in the Quashnet River.

In the Mashpee River, scuds are still the dominant benthic invertebrate, but only by a small majority. Many other taxa – clams, caddisflies, aquatic earthworms, and mayflies – are also prevalent in the ecosystem. This supports findings that in a natural, healthy stream, no one species should dominate (Harding et al. 1998, Delong and Brusven 1998).

Feeding Groups

Although invertebrate diversity is one indicator of a healthy system, streams are only healthy when invertebrates play certain functional roles (Callisto, Moreno and Barbosa 2001). In comparing the balance of filterers, grazers, shredders, predators and gatherers along the restoration gradient, some key differences were evident. The number of shredders, grazers and gatherers increased as the riparian forest matured because these taxa were more important in a stream receiving terrestrial leaf inputs (Hagen, Webster and Benfield 2006). Likewise, as the percentage of sand decreased, the number of invertebrate taxa classified as filterers remained constant. However, the population of filterers changed – while three taxa in the Coonamessett were solely filterers, one taxon in the Mashpee and two taxa in the Quashnet were generalists.

The number of taxa classified as predators varied across sites. The Coonamessett River had the lowest number of predators, which could be one reason why invertebrate density was so high in that stream. Predator-taxa were the most abundant in the Quashnet River, which might explain why invertebrate density was lower in this stream than in the Mashpee. Further research on the dominant role of generalists in an ecosystem would shed further light on what functional roles may be lacking in cultivated streams and what is necessary to bring them back.

Stable Isotope Analysis

A stable isotope analysis showed that none of the invertebrates sampled in the Coonamessett River fed directly on algae, detritus or vegetation. Amphipods and sow bugs were feeding on a mixture of detritus and Vallisneria, and caddisflies were feeding on detritus and algae. Crayfish, eels, leeches, and fish fed on a mixture of invertebrates.

In the Quashnet River, aquatic vegetation was a staple of the food web. The presence of riparian forests was evident in the food web – terrestrial leaves contributed to detritus, which was the dominant food source for caddisflies. Like the Coonamessett River, many invertebrates like amphipods, sow bugs and alderflies fed on water-starwort and detritus.

Isotope values for the Mashpee River showed that the primary food source for invertebrates was terrestrial-derived detritus. Aquatic vegetation and algae did not play large roles in the structure of this food web. Eels and brook trout fed on invertebrates like amphipods, craneflies, mayflies and stoneflies; however, the top carnivore, large mouth bass, also depended on other food sources.

Although the Coonamessett, Mashpee and Quashnet Rivers contain many similar taxa, the isotopic signals for all sampled taxa varied across rivers. The Coonamessett and Mashpee Rivers are each in the vicinity of houses and businesses whose septic tanks may have contributed to the higher background nitrogen we measured. The Quashnet is not surrounded by these developments and samples from this river had lower d^{15}N values.

Conclusion

A Recommendation for Restoration

Comparing the Mashpee, Quashnet and Coonamessett Rivers has been a valuable way to understand the effects of agriculture on the habitat distribution, benthic invertebrate communities and food webs in stream ecosystems. But the results of this comparison also shed light on important factors to consider in the restoration of a cultivated stream.

It is evident that planting trees around the Quashnet River has led to significant improvements. Although the canopy is not closed, trees surrounding the river have already begun to restore terrestrial organic matter inputs. In the Mashpee, leaf pack is an ideal habitat for benthic invertebrates and supports the largest variety of taxa. Increasing the prevalence of this microhabitat should improve the diversity of the benthic invertebrate population at the Quashnet. Thus, the forests around the Coonamessett River should be restored, as they are on the Quashnet.

In addition to the riparian vegetation, restoration efforts should focus on improving the benthic invertebrate community in the Quashnet. These invertebrates are an important food source for many fish species (Ingersoll and MacDonald 2002). Currently, restoration crews have taken a top-down approach to restoration – working to revive brook charr populations by rebuilding elements of their habitat. This habitat analysis suggested that their efforts have started to recreate desirable habitats for benthic invertebrate communities. However, the community at the Quashnet was still not as diverse as in the Mashpee and seemed to have too many predator-taxa, and not enough gatherers and shredders. The most significant physical differences between the Quashnet and Mashpee are in the amount of submerged aquatic vegetation/leaf pack, the type of gravel, and the dimensions of the stream channel.

Since the abundance of submerged aquatic vegetation and leaf pack are influenced by the state of the riparian vegetation, they will probably change naturally once the forest canopy closes over the river. But by bringing in larger gravel, which is more appealing to caddisfly populations, restoration crews could bring back populations of benthic organisms that are missing from the river. Recreating more natural microhabitats at the Quashnet and Coonamessett will probably involve mimicking the Mashpee's physical qualities and reevaluating whether the overhangs and flow deflectors already inserted at the Quashnet are helping to achieve these goals more quickly.

In a Larger Context

In stream ecosystems, aquatic vegetation and benthic invertebrates influence nutrient cycling and decomposition rates. Rates of nutrient uptake can help to determine the extent to which nutrients added upstream will reach estuaries and potentially cause eutrophication (Robins 2006). Through trophic interactions, benthic invertebrates are an important food source for fish, and habitat structure plays a key role in the ability of fish to hide from predators and reproduce. Examining three stream ecosystems from these perspectives revealed that riparian forests are essential in controlling water temperature and terrestrial organic matter inputs (Kumai 2006). Increased sedimentation rates due to cranberry cultivation alter the microhabitats present in an ecosystem – preventing submerged aquatic vegetation from growing, and filling the pore spaces in gravel where invertebrates live. Gravel is an important substrate – both for fish and for invertebrates; however, the two populations require different sizes of gravel. As shown by restoration efforts at the Quashnet, spawning brook trout prefer pea-sized gravel; whereas invertebrates like caddisflies require slightly larger gravel to build their cases and provide sufficient pore space. Bringing back both of these populations involves bringing back the types of habitats and food sources they need.

But it is critical to remember that there is no single recipe for river restoration. Restoration efforts are driven by a variety of human goals – for instance, bringing back aesthetic beauty or reviving failing fish populations. Depending on the nature of these goals, different courses of action must be taken. It is equally important to understand the way in which desired species interact with species that are present, since predator-prey interactions may have adverse effects on restoration efforts. All of these variables must be considered when embarking on a river restoration project.

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Appendix

Table 1. The common names, scientific names, and functional feeding groups of all taxa collected from the Coonamessett, Mashpee and Quashnet Rivers. (FI = filterer, SH = shredder, PR = predator, GR = grazer or scraper, and GA = gatherer).

Coonamessett River

Common Name	Scientific Name	Functional Groups				
Leech	*Annelida Hirudinea*			PR		
Sow Bugs	*Caecidotea communis*		SH	PR		GA
Scuds/Sideswimmers	*Gammarus fasciatus*		SH	PR		GA
Aq. Earthworm	*Annelida Oligochaeta*					GA
Common Netspinner Cfly	*Trichoptera Hydropsychidae*	FI				
Flatworm	*Turbellaria Dugesia*			PR	GR	GA
Bithyniid	*Prosobranchia Bithyniidae*	FI				
Viviparid	*Prosobranchia Viviparidae*					GA
Planorbid	*Planorbella campanulata*				GR	
Mayflies	*Ephemeroptera Ephemerellidae*		SH			GA
Fingernail Clams	*Bivalvia Sphaeriidae*	FI				

Mashpee River

Common Name	Scientific Name	Functional Groups				
Leech	*Annelida Hirudinea*			PR		
Sow Bugs	*Caecidotea communis*		SH	PR		GA
Scuds/Sideswimmers	*Gammarus fasciatus*		SH	PR		GA
Aq. Earthworm	*Annelida Oligochaeta*					GA
No-See-Ums	*Diptera Ceratopogonidae*			PR		GA
Trumpetnet Caddisfly	*Trichoptera Polycentropodidae*	FI		PR		
Northern Caddisfly	*Trichoptera Limnephilidae*		SH		GR	GA
Common Netspinner Cfly	*Trichoptera Hydropsychidae*	FI				
Saddlecase Maker Cfly	*Trichoptera Glossosomatidae*				GR	
Stoneflies	*Plecoptera Perlidae*			PR		
Dragonfly	*Anisoptera Aeshnidae*			PR		
Flatworm	*Turbellaria Dugesia*			PR	GR	GA
Riffle Beetles	*Coleoptera Elmidae*				GR	GA
Alderflies	*Megaloptera Sialidae*			PR		
Mayflies	*Ephemeroptera Heptageniidae*					GA
Mayflies	*Ephemeroptera Ephemerellidae*		SH			GA
Soldier Flies	*Diptera Stratiomyidae*					GA
Craneflies	*Diptera Tipulidae*		SH			
Snails	*Prosobranchia Viviparidae*					GA
Fingernail Clams	*Bivalvia Sphaeriidae*	FI				

Quashnet River

Common Name	Scientific Name	Functional Groups				
Leech	*Annelida Hirudinea*			PR		
Sow Bugs	*Caecidotea communis*		SH	PR		GA
Scuds/Sideswimmers	*Gammarus fasciatus*		SH	PR		GA
Aq. Earthworm	*Annelida Oligochaeta*					GA
No-See-Ums	*Diptera Ceratopogonidae*			PR		GA
Craneflies	*Diptera Tipulidae*		SH			
Trumpetnet Caddisfly	*Trichoptera Polycentropodidae*	FI		PR		
Common Netspinner Cfly	*Trichoptera Hydropsychidae*	FI				
Saddlecase Maker Cfly	*Trichoptera Glossosomatidae*				GR	
Soldier Flies	*Diptera Stratiomyidae*					GA
Stoneflies	*Plecoptera Perlidae*			PR		
Dragonfly	*Anisoptera Aeshnidae*			PR		
Flatworm	*Turbellaria Dugesia*			PR	GR	GA
Giant Water Bug	*Belostomatidae Lethocerus*			PR		
Riffle Beetles	*Coleoptera Elmidae*				GR	GA
Non-Biting Midges	*Diptera Chironomidae*	FI		PR	GR	GA
Alderflies	*Megaloptera Sialidae*			PR		

Table 2. The density of invertebrates in each of the microhabitats at the Coonamessett, Quashnet and Mashpee Rivers.

	Density of Invertebrates (# individuals/m2)				
	SAV	Gravel	OM	Sand	Leaf
Coonamessett	11458	1403	2290	1224	-
Quashnet	2429	29	309	0	-
Mashpee	1450	958	678	86	1564

Table 3. How isotopic signals for carbon and nitrogen differ across rivers.

	Coonamessett		Quashnet		Mashpee	
	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
Water-Starwort	**-32.3**	**8.9**	**-33.0**	**5.8**	**-30.1**	**7.2**
Organic Matter	**-29.5**	**6.2**	**-29.1**	**2.6**	**-28.2**	**4.8**
Amphipods	**-27.8**	**9.1**	**-32.5**	**6.8**	**-24.9**	**7.4**
Sow Bugs	**-28.5**	**8.5**	**-31.1**	**7.2**	**-25.4**	**9.1**
Caddisflies	**-30.5**	**9.8**	**-28.2**	**5.7**	**-29.7**	**9.1**
Leeches	**-27.0**	**13.6**	**-27.6**	**8.4**	**-24.8**	**11.7**
Craneflies	**-33.1**	**9.8**	**-37.2**	**5.9**	**-26.5**	**5.9**
American Eel (S)	**-29.0**	**13.3**	**-29.3**	**9.5**	**-26.2**	**10.7**

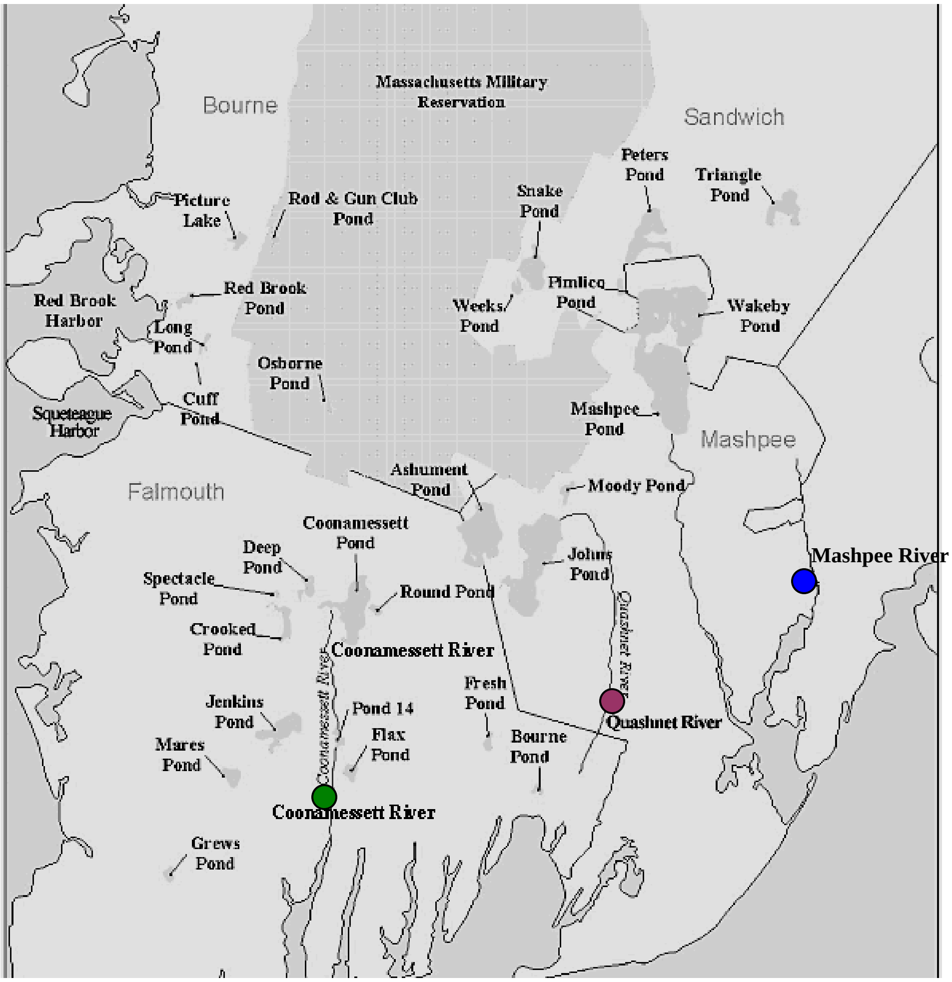

Figure 1. Map of sampling sites on the Coonamessett (green), Quashnet (purple) and Mashpee (blue) Rivers.

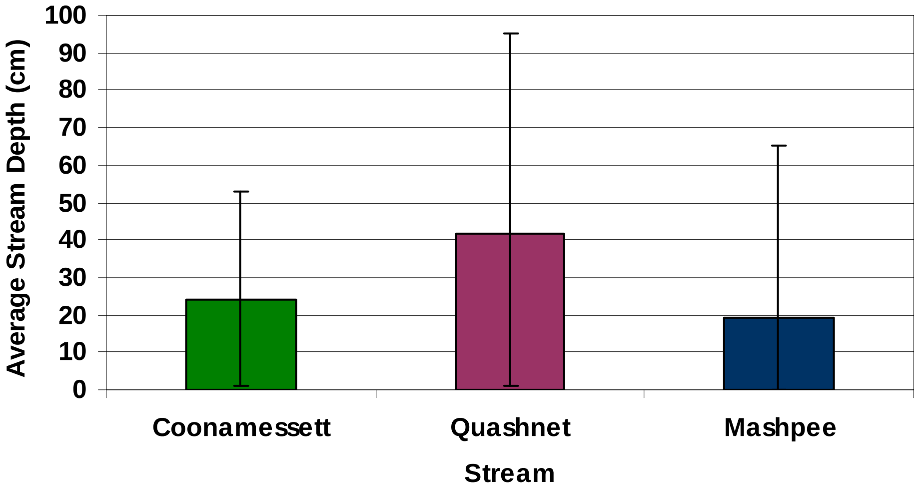

Figure 2. The average depth of the Coonamessett, Quashnet and Mashpee rivers. Transects were set up every 10m along the reach, and depth measurements were taken every 10cm along each transect. Error bars shown represent maximum and minimum depths observed along reach.

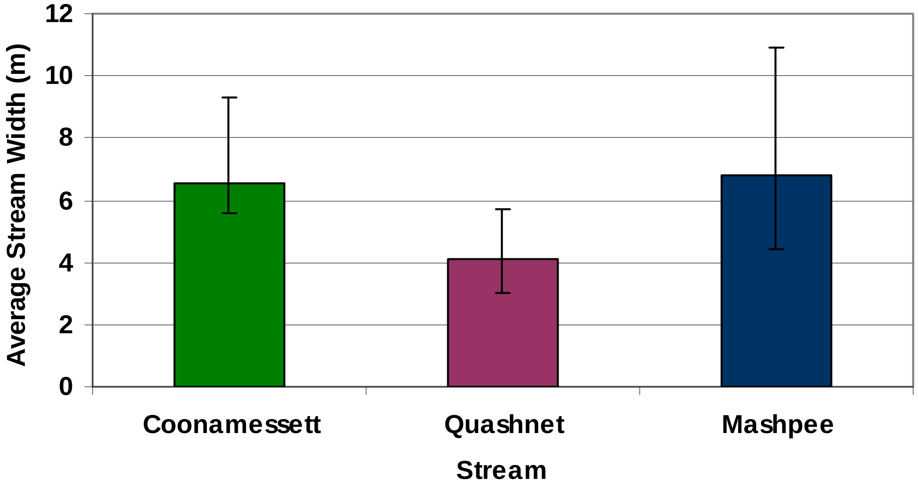

Figure 3. The average width of the Coonamessett, Quashnet and Mashpee rivers. Width measurements were taken at each transect every 10m along the reach. Error bars shown represent maximum and minimum widths observed along reach.

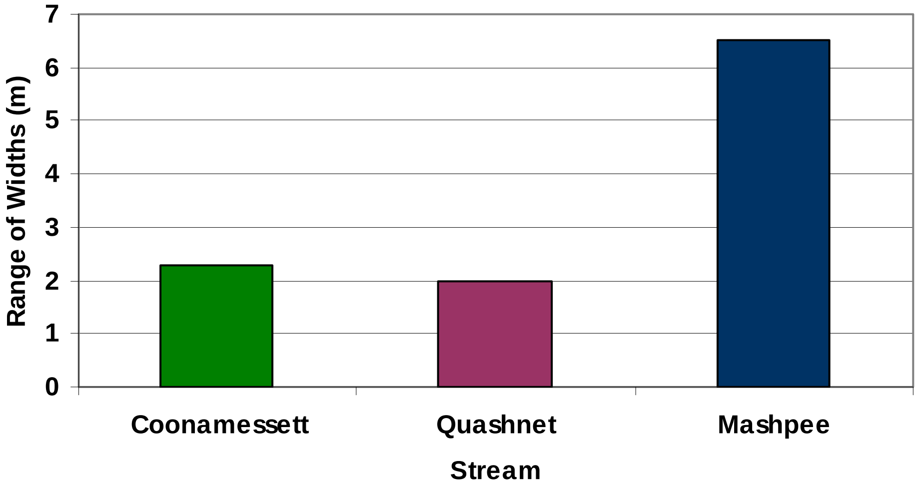

Figure 4. The range of widths of the Coonamessett, Quashnet and Mashpee rivers.

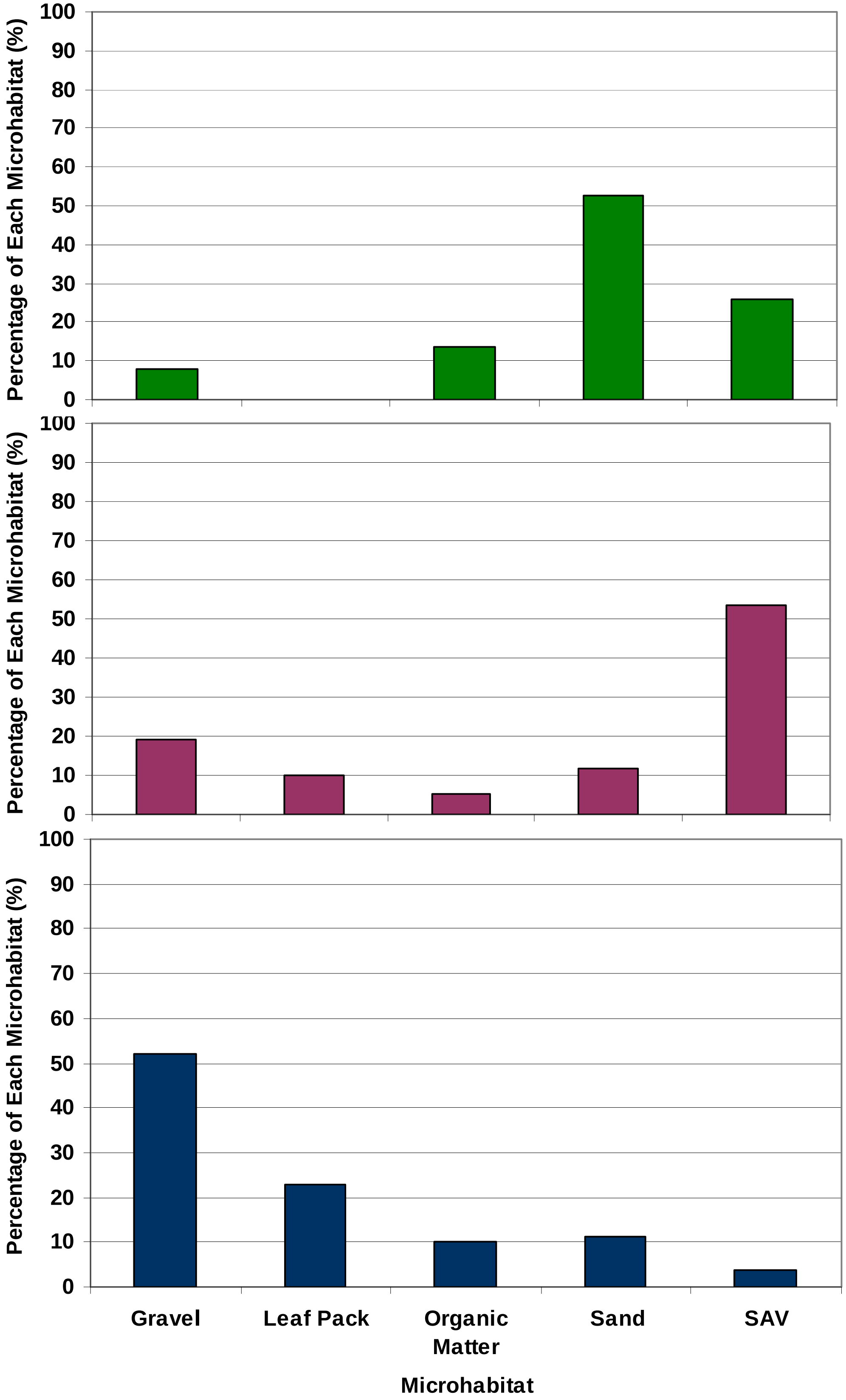

Figure 5. The percent distribution of microhabitats on the Coonamessett (top), Quashnet (middle), and Mashpee (bottom) rivers. Transects were set up every 10m along a reach, and microhabitat was classified every 10cm along the length of each transect.

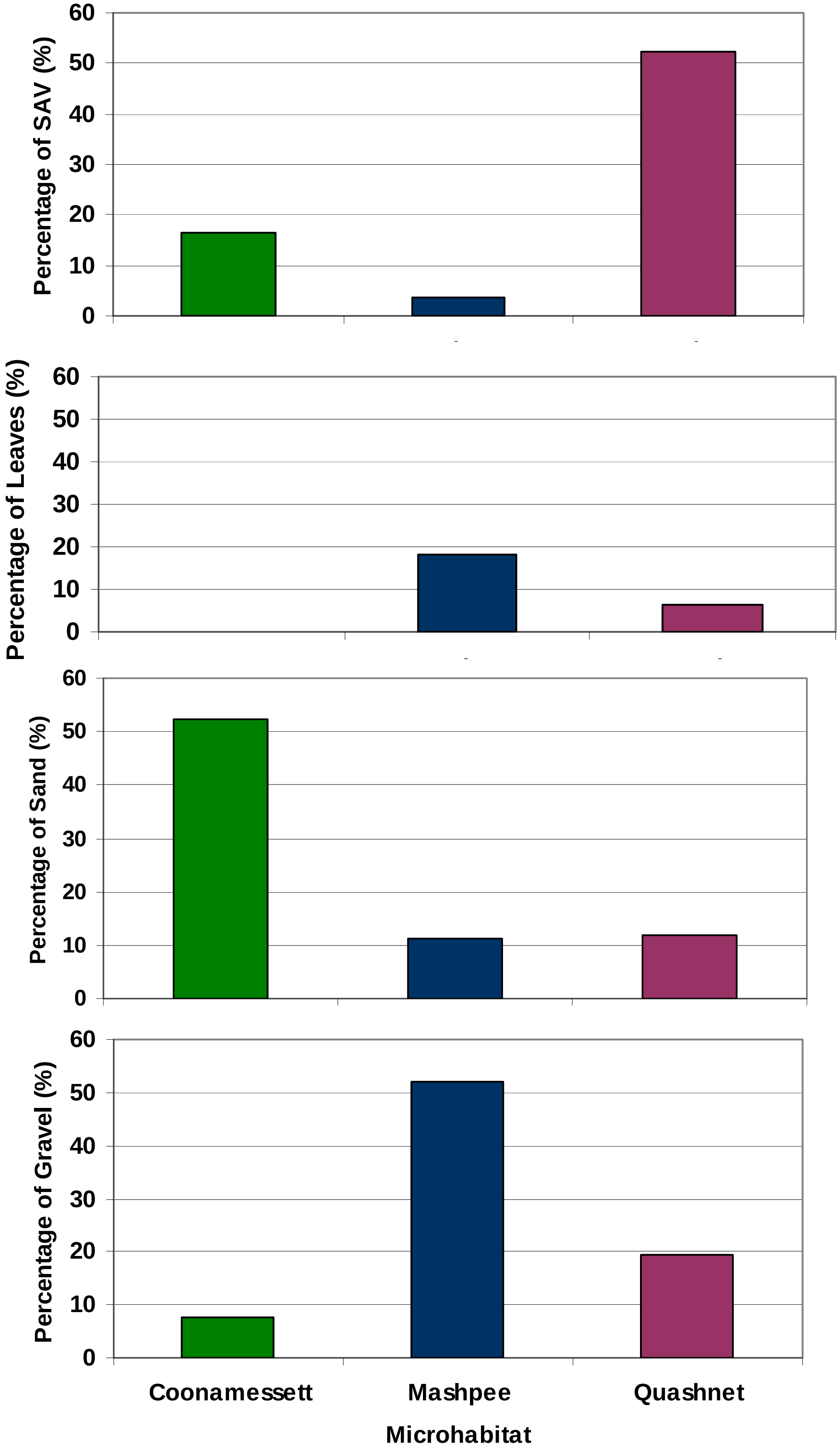

Figure 6. The percentage of submerged aquatic vegetation, terrestrial leaves, sand and gravel in reaches on the Coonamessett, Mashpee and Quashnet Rivers. Percentages determined from point-transect data.

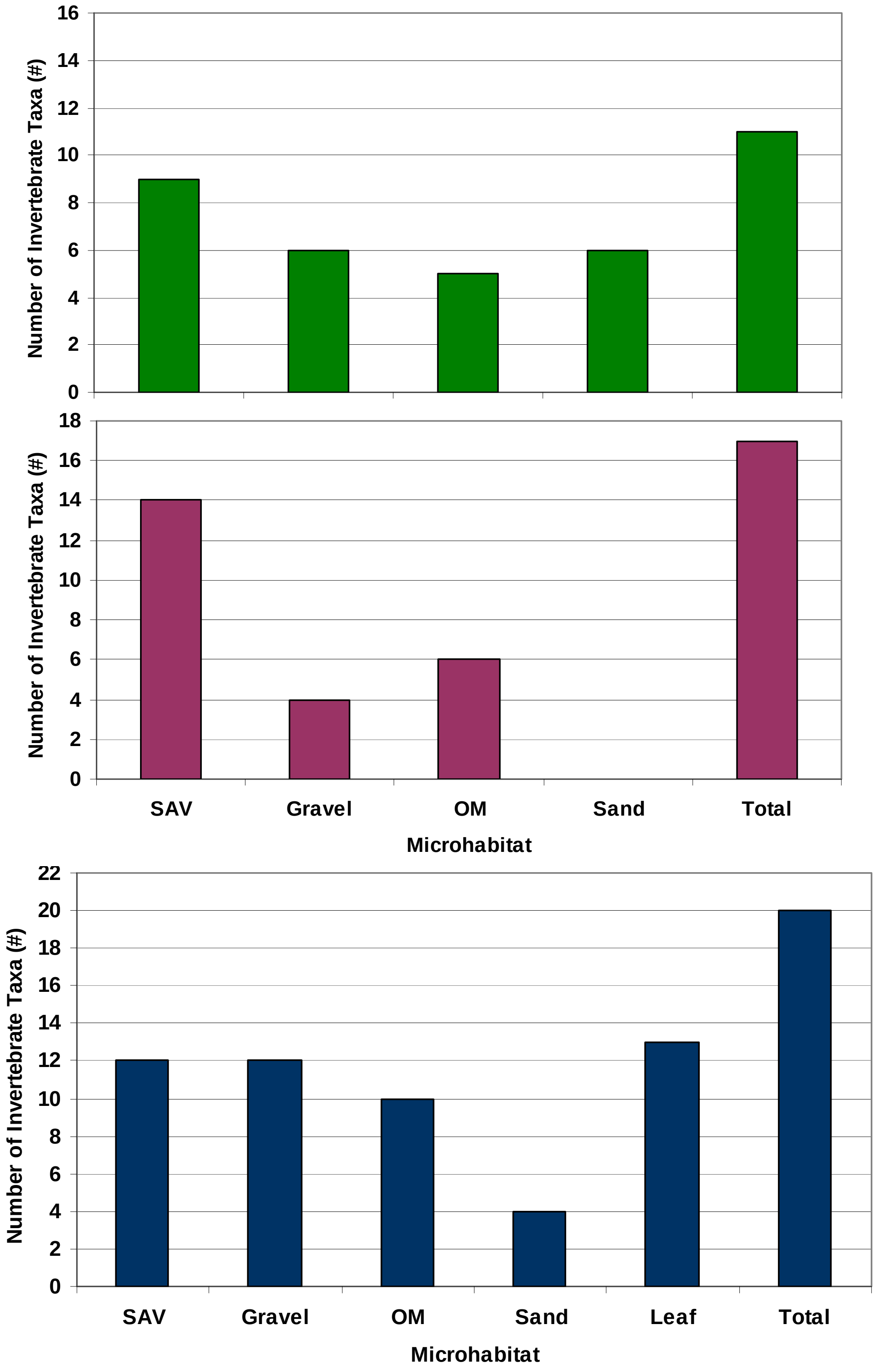

Figure 7. The number of invertebrate taxa found in Surber samples from each microhabitat. (Coonamessett River (top figure), Quashnet River (middle figure), Mashpee River (bottom figure)). The leaf microhabitat was only sampled in the Mashpee River.

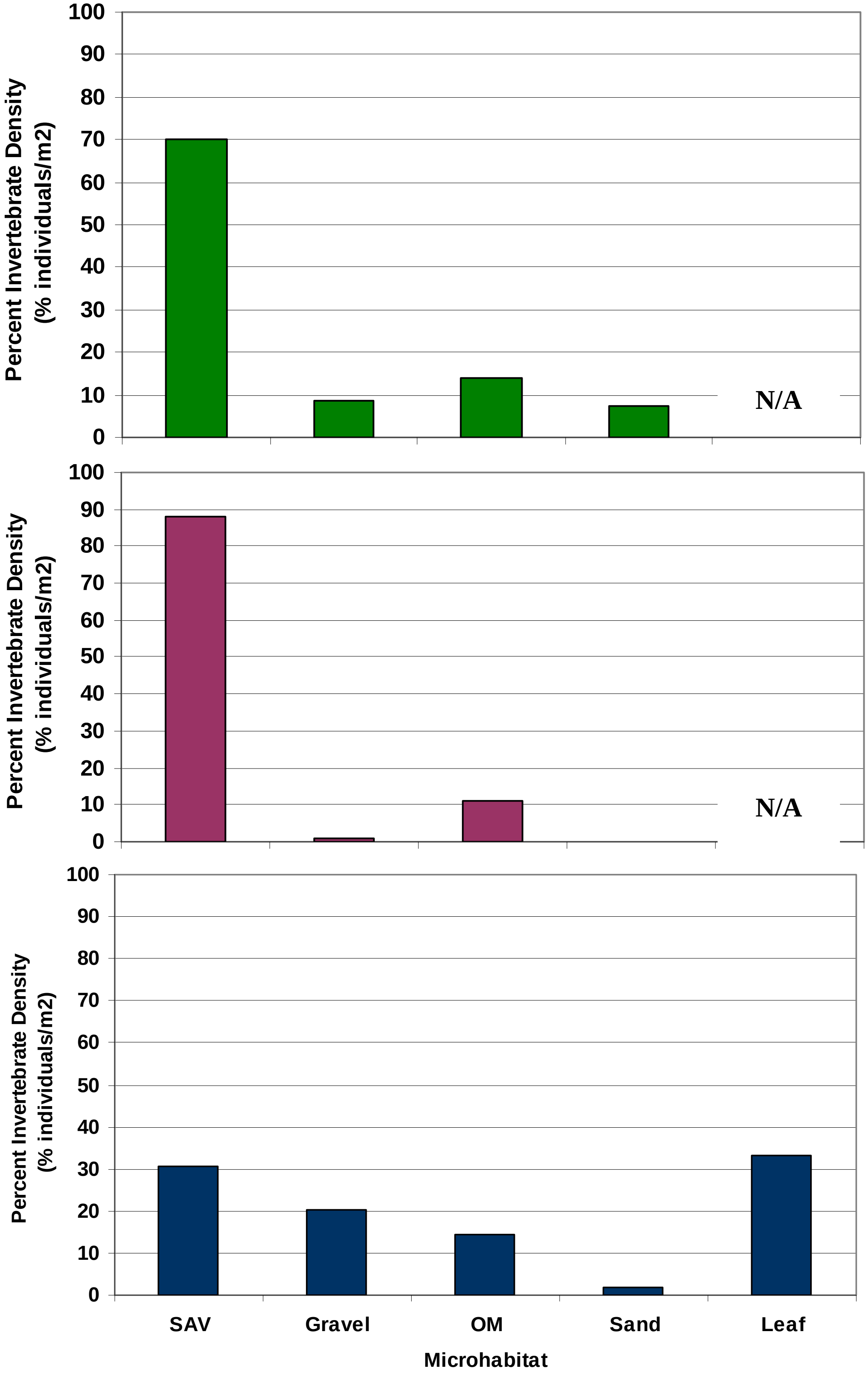

Figure 8. How percent invertebrate density changes across microhabitats and rivers. (Coonamessett River (top figure), Quashnet River (middle figure), Mashpee River (bottom figure)).

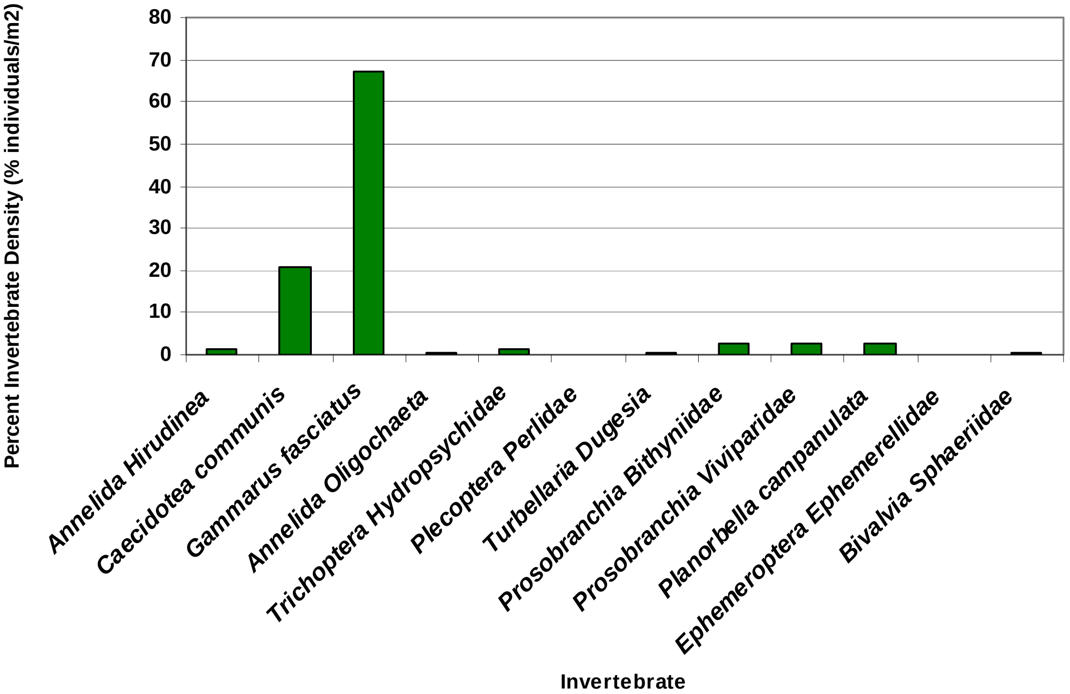

Figure 9. Invertebrate taxa found in all Surber samples and their percent density for the Coonamessett River.

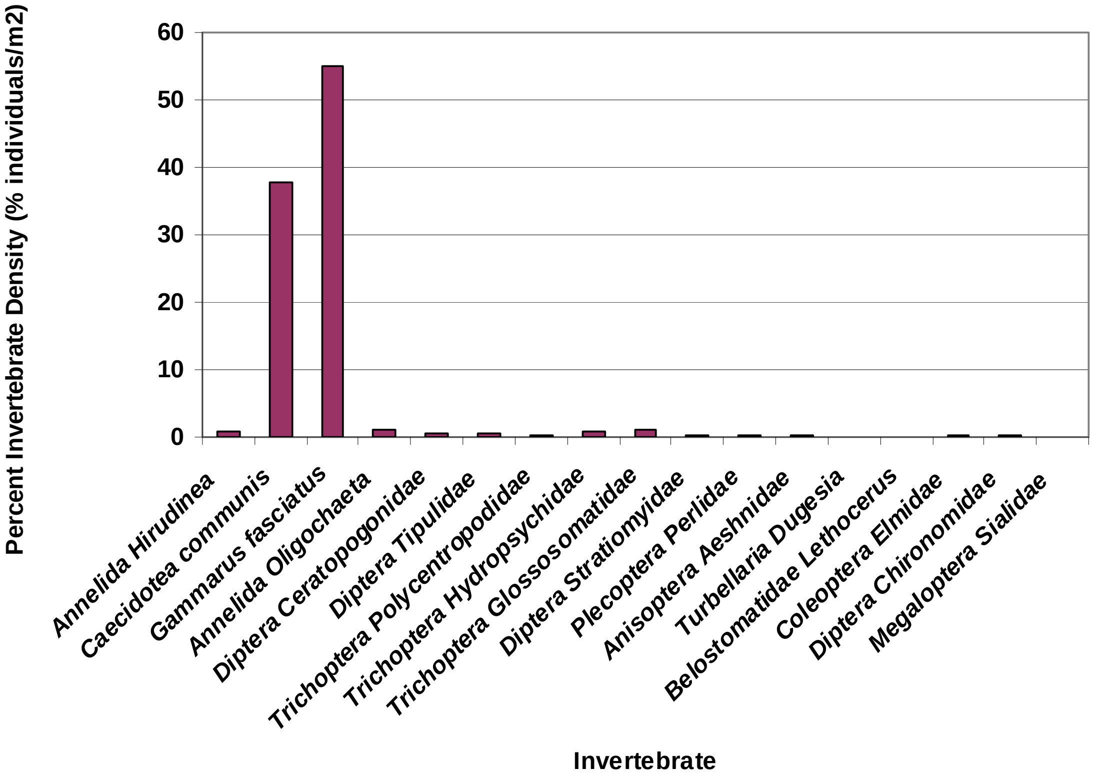

Figure 10. Invertebrate taxa found in all Surber samples and their percent density for the Quashnet River.

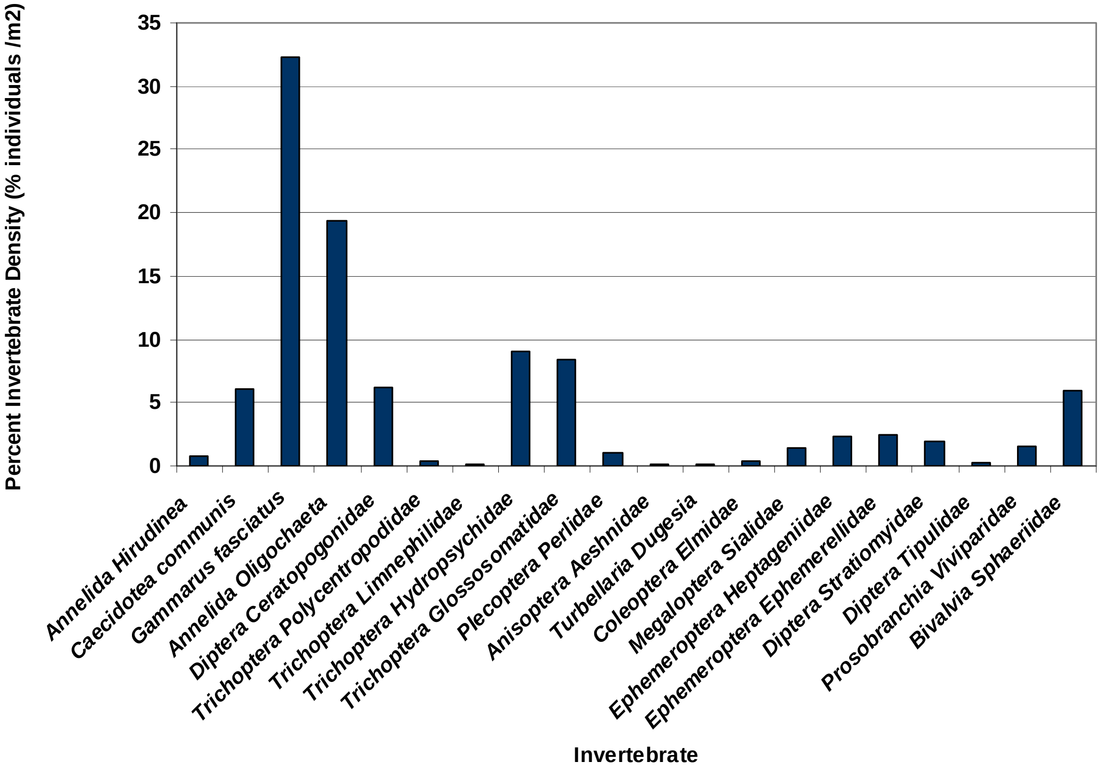

Figure 11. Invertebrate taxa found in all Surber samples and their percent density for the Mashpee River.

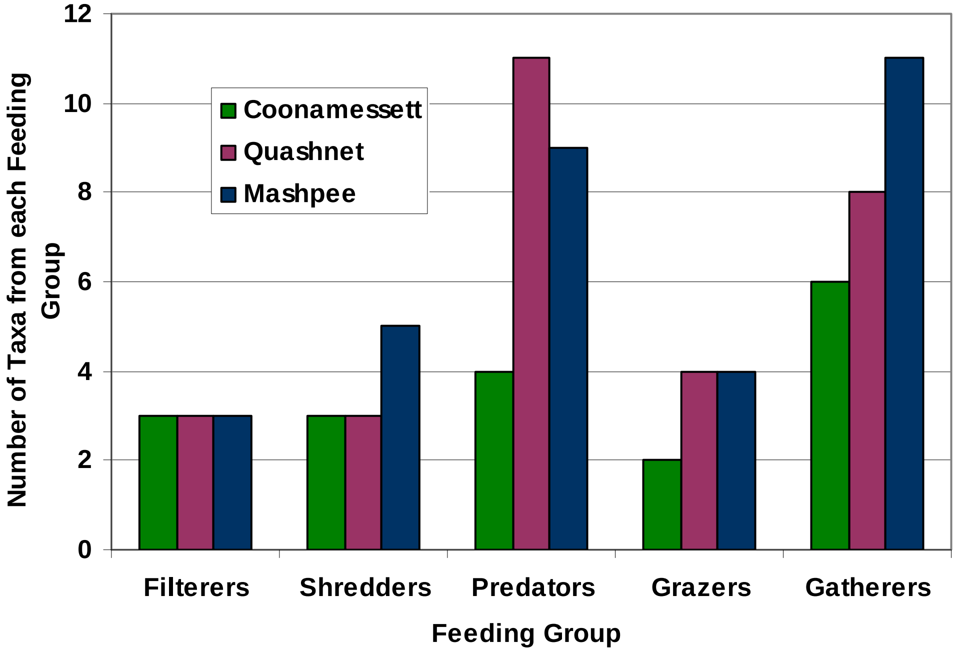

Figure 12. The number of taxa from each feeding group collected in Surber samplers across all microhabitats in the Coonamessett, Mashpee and Quashnet rivers.

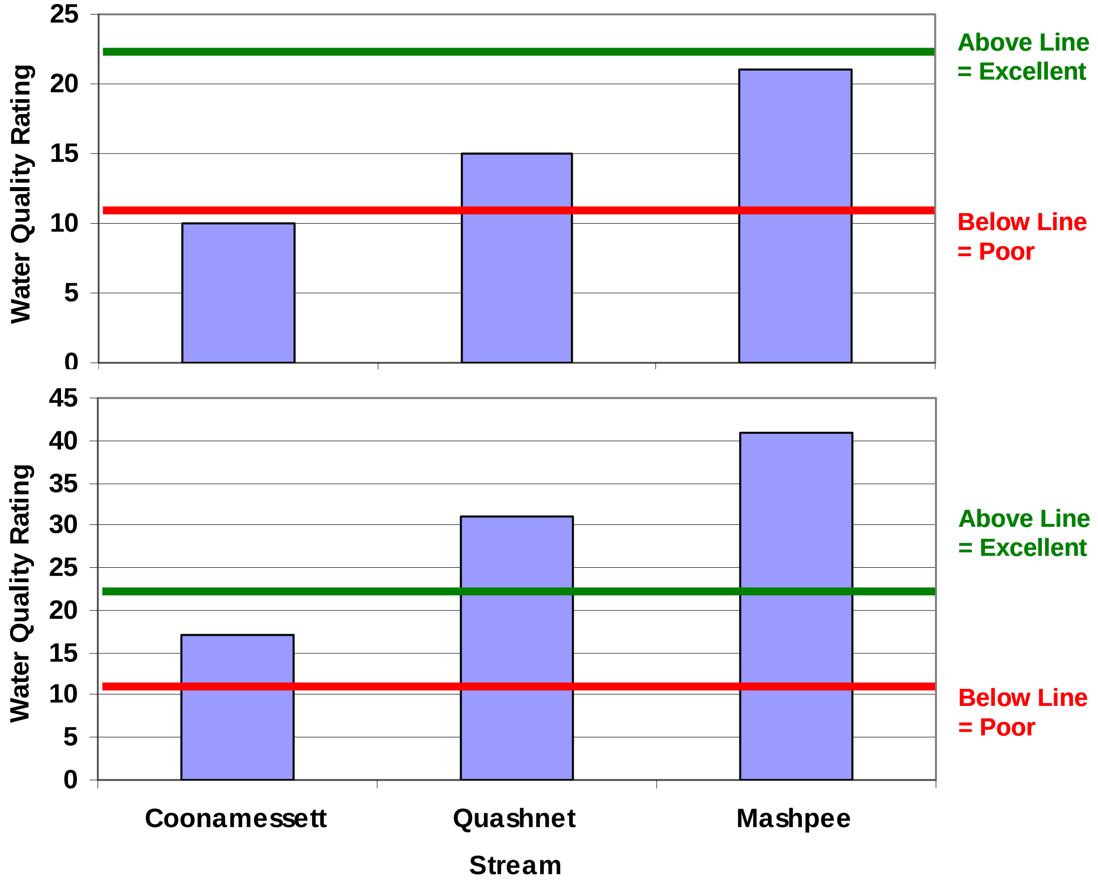

Figure 13. The EPT index of water quality for the Coonamessett, Quashnet and Mashpee rivers. Upper figure (2004 results from Kingsland), bottom figure (2006 results).

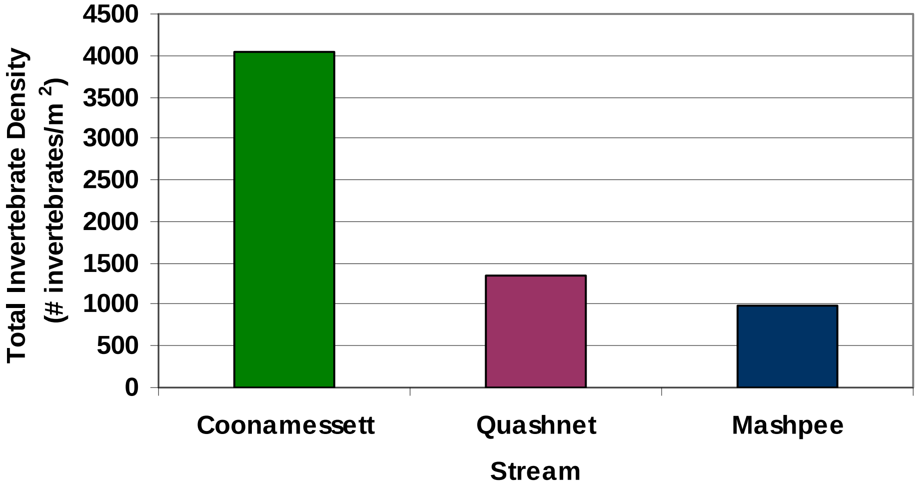

Figure 14. The density of invertebrates in the Coonamessett, Quashnet and Mashpee rivers. Invertebrate density is a weighted average across all microhabitats calculated from point-transect and Surber sample data.

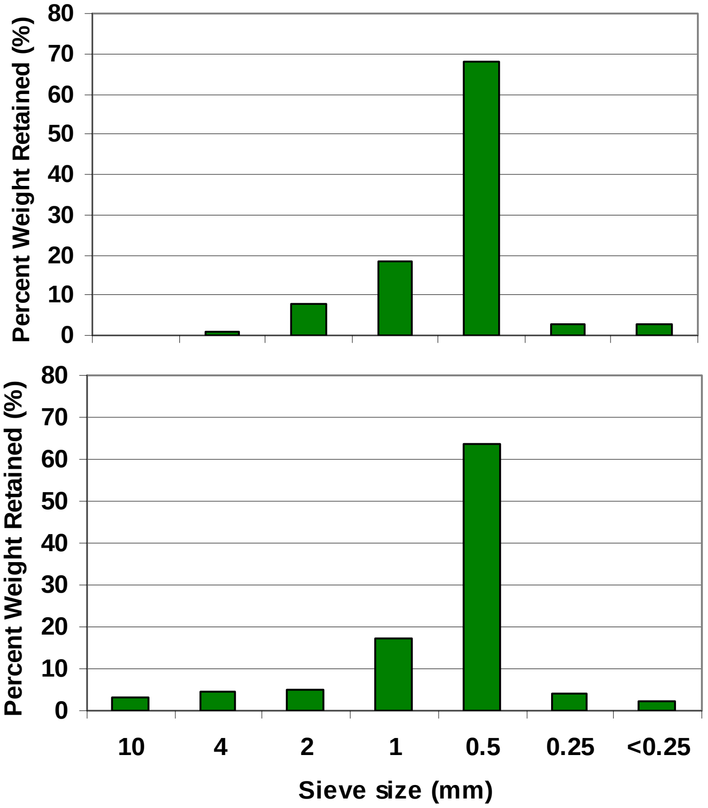

Figure 15. The percent weight of sediment retained in six sieves for Coonamessett River sediment samples taken at the upper (top figure) and lower (bottom figure) section of the reach.

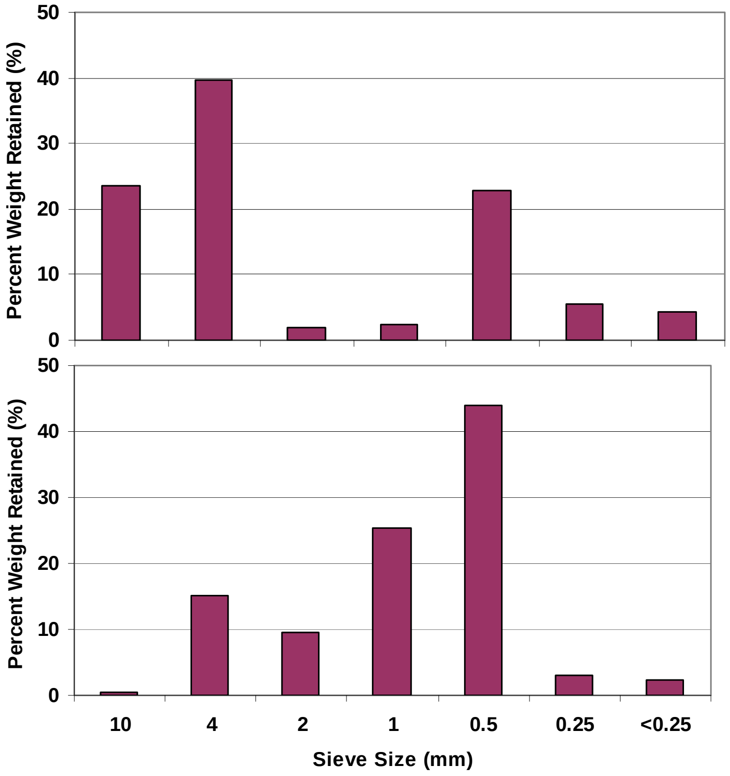

Figure 16. The percent weight of sediment retained in six sieves for Quashnet River sediment samples taken at the upper (top figure) and lower (bottom figure) section of the reach.

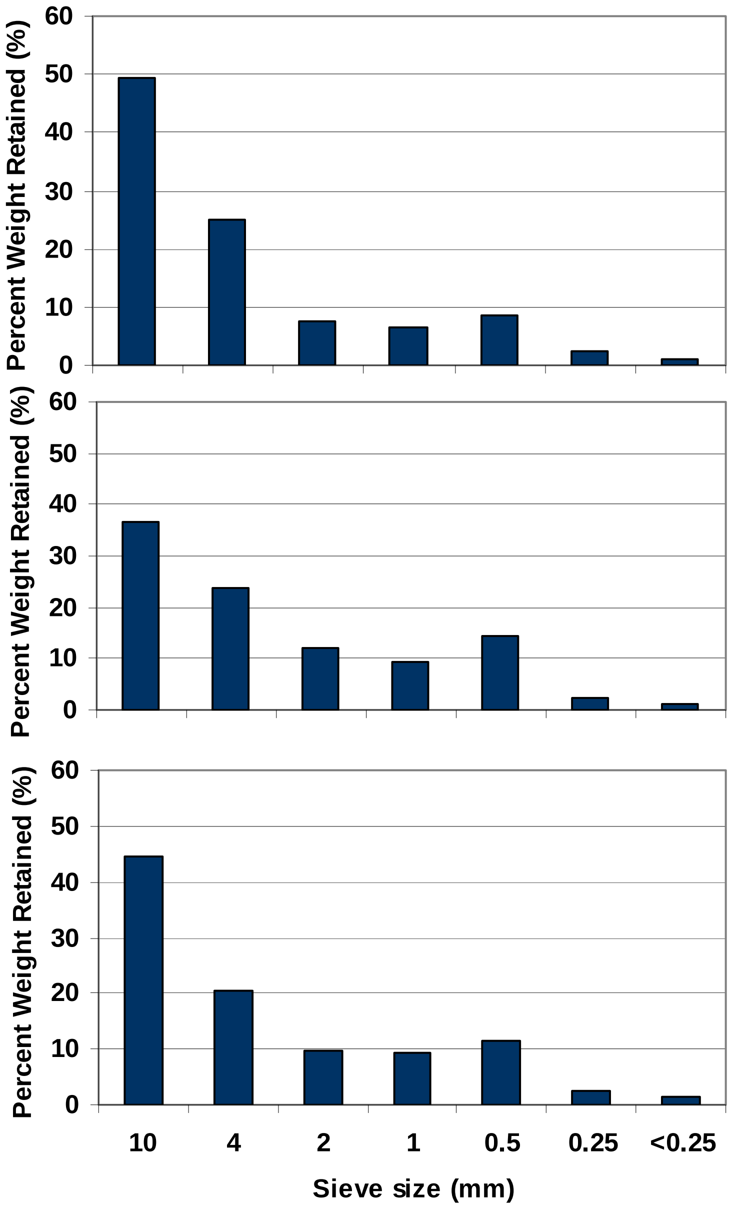

Figure 17. The percent weight of sediment retained in six sieves for Mashpee River sediment samples taken at the upper (top figure), middle (center figure) and lower (bottom figure) sections of the reach.

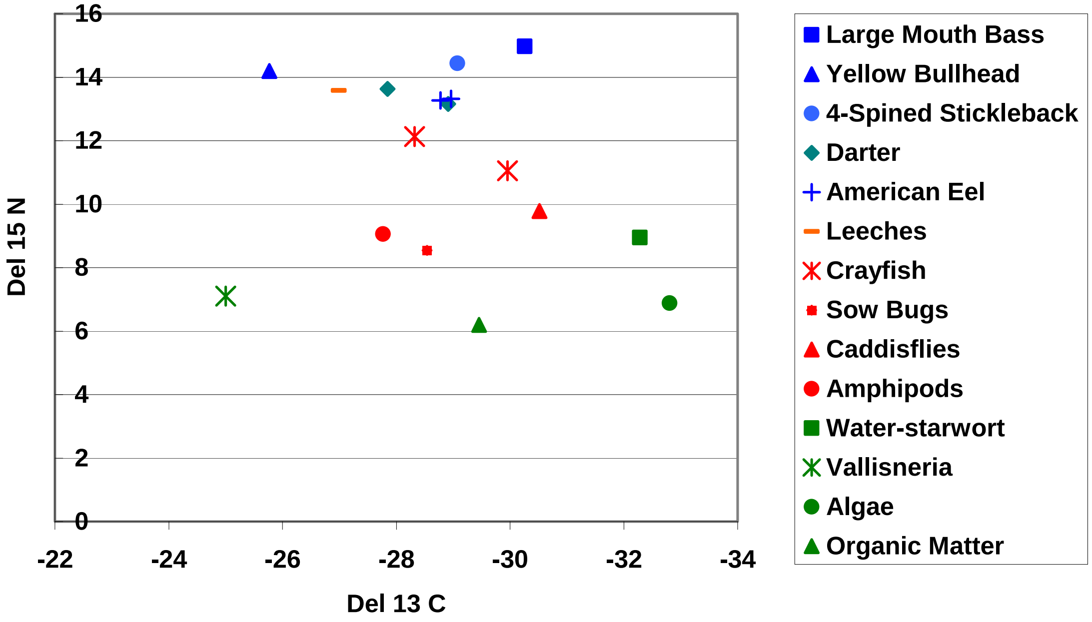

Figure 18. Stable isotope values for plants, invertebrates and fish from the Coonamessett River.

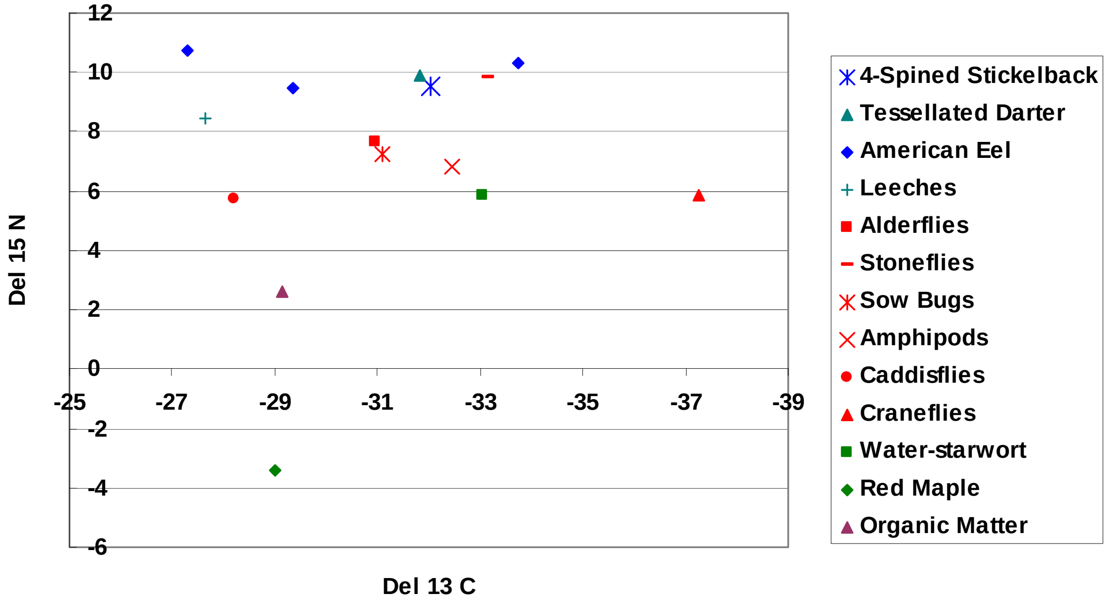

Figure 19. Stable isotope values for plants, invertebrates and fish from the Quashnet River.

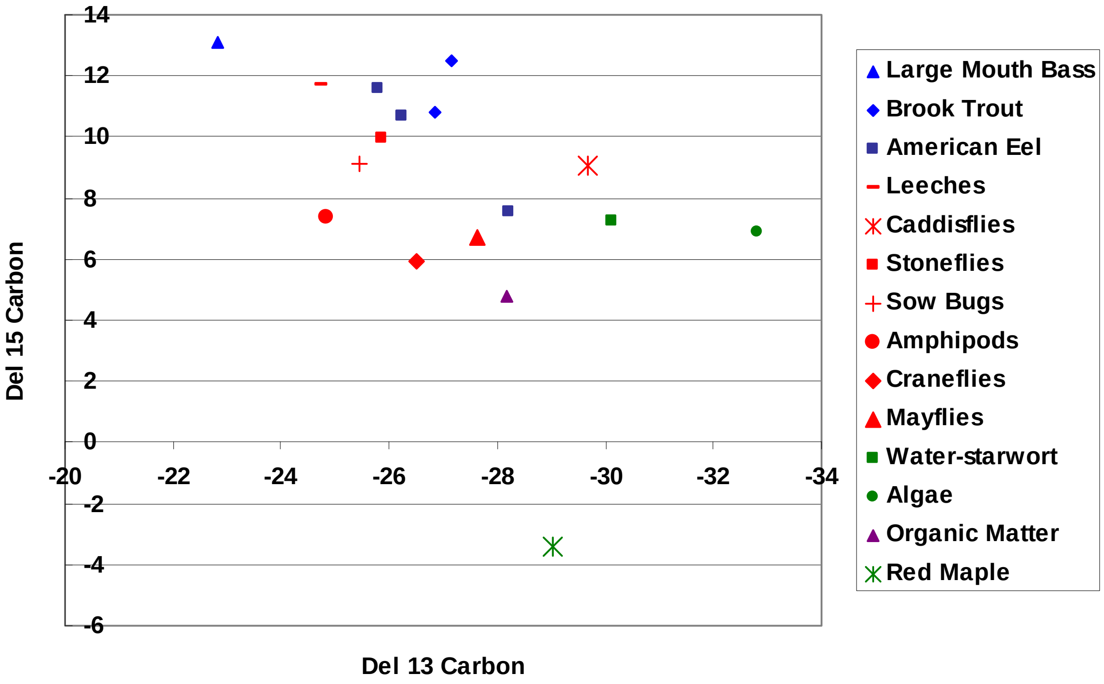

Figure 20. Stable isotope values for plants, invertebrates and fish from the Mashpee River.