The effects of riparian alterations on stream food webs

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ABSTRACT

Alterations made to rivers in order to create cranberry bogs change the plant species composition and the physical structure of the river's ecosystem. These changes can have a large impact on the species composition of the animals living in the ecosystem, thus changing the food web. Fish, and macroinvertebrates were collected and the habitat was assessed for an active cranberry bog, a restored cranberry bog, and a natural river ecosystem in order to develop food webs for all three sites. The active bog had little available fish cover, no indicators of good water quality, was dominated by small-bodied fish, algae, and amphipods, and had a simplified food web. The restored bog had substantial fish cover, brook trout and other indicators of good water quality, several large-bodied fish species, and a more complex food web. These results indicate that restoring the bog returned the river to more natural conditions, and thus restoring cranberry bogs is worth the cost and effort.

INTRODUCTION

Human alterations of ecosystems alter the physical structure of the ecosystem and the plants that are present in the ecosystem. Plants form the base of food webs, and by changing the plants in an ecosystem humans change the species composition of other organisms living in that ecosystem and the food webs that connect them. Stressed ecosystems like this tend to have fewer species present. Stressed ecosystems can also become dominated by one or two species that can thrive in the changed conditions. And the changes caused at the base of the food web can lead to a simplified food web.

On some streams and rivers in Massachusetts the natural riparian vegetation was removed and the physical structure of the land was converted for the cultivation of cranberries. In-stream riparian vegetation slows the flow of water through the river, and draws nutrients like nitrogen out of the water. Macroinvertebrates live in and feed on in-stream vegetation, and many fish species eat the invertebrates and also use the vegetation for cover. Riparian vegetation also contributes to the detritus that collects in the bottom of rivers, which influences the detrital food pathway. Now these rivers have been diverted, the water level and flow are controlled by man, and there is little to no detrital input from other plants surrounding the rivers. Fertilizers and pesticides are added to the cranberry crops and ends up in the rivers adding nutrients to the water, which may increase nutrient loading in the estuaries that connect these rivers to the ocean. The pesticides may kill insects that also play a role in the river ecosystems.

Does conversion of the riparian vegetation in an ecosystem to a cranberry bog negatively affect riparian food webs? If so, would restoring the bog to a more natural riparian plant cover improve conditions for fish species? I addressed these questions by assessing the habitat and comparing abundances and composition of macroinvertebrate and fish species of rivers with actively-farmed and restored cranberry bogs to those of a natural river.

METHODS

Three rivers, the Coonamessett, Quashnet, and Mashpee (Figure 1), were studied to determine the effects of varying levels of human disturbance on stream food webs. A large portion of the Mashpee River has been set aside as reserved land (Schwarzman 1977). The river is relatively undisturbed, has not had any of its riparian vegetation removed, and so is the most natural of the three rivers even though it receives elevated nitrogen inputs from the upper reaches of its watershed. The site on the Mashpee river is just south of Route 28 where it is tidal freshwater. The site on the Quashnet River (Section 6) has recently been restored to serve as habitat for brook trout. Several years ago Trout Unlimited and other volunteer groups constructed baffles and undercut banks, and planted trees along the river in order to help the river return to more natural conditions. No further restoration work has been done on this section of the river since this initial work. The site is north of Route 28 (off Martin Road) and had been used as a cranberry bog until it was flooded with salt water from hurricane Carol and subsequently abandoned in 1954. The site on the Coonamessett River is currently owned by the town of Falmouth and leased to a farmer for cranberry farming (Schwarzman 1977). Currently there is an ongoing debate as to whether or not the town of Falmouth should restore the cranberry bogs on the Coonamessett to more natural conditions in order to restore habitat for fish and other wildlife.

Habitat quality was assessed using ten or more transects at each site. We measured total river width, length of overhanging vegetation and undercut banks, and water depth with cover and sediment type at ten points in the main channel of the river. This data was used to determine the amount of cover available to fish. Cover was defined as submerged aquatic vegetation, submerged rocks or logs, terrestrial leaf pack, emergent marsh plants, overhanging banks, overhanging tree branches one meter or less above the water surface, and water 30 cm or greater in depth. Substantial amounts of these cover types (enough for a fish about 20 cm long to hide in) had to be present in 50% or more of the 10cmX10cm area immediately surrounding a point, in order for the point to be classified as cover.

Fish were collected at each site using block netting and a generator-powered backpack electrofishing unit (Reynolds 1996). Seine nets were set up 25 metres apart from each other and held in place with wooden stakes and bricks. The electrofishing team consisted of myself with the backpack unit and anode net and two to three assistants each with a dip net and one with a bucket to hold the fish. Two passes were made with the electrofishing unit on each of two 25m sections at the Coonamessett and Quashnet sites, and one 28m section at the Mashpee site, (differences in fishing at the sites will be described further in the discussion section). The fish from each pass on each 25m section were brought to shore, sorted (using 50mg/L of Alpharma MS222 (Tricane Methane Sulphonate) mixed with water from the river to sedate the fish), counted and bagged to be brought back to the lab for further analysis, or released. A total of about ten fish of each species and/or size class was bagged and returned to the lab if ten or more fish were caught. If fewer than ten were caught all were returned to the lab. The exceptions to this rule were the threatened american brook lamprey (*Lampetra appendix*) all of which were released, brook trout (*Salvelinus fontinalis*) of which only one fish was returned to the lab from each of the two rivers they were caught on, and american eels (*Anguilla rostrata*) 40 cm or larger were also released. All fish that were released were measured for total length (TL) and mass using a ruler and a field portable mass balance.

One benthic invertebrate sample was collected from each site using a Surber sampler with an area of 929.03 cm^2, and a 500um sized net. All of the surface area sediment within the Surber sampler's metal frame was disturbed to a depth of about 2 cm, the water was allowed to clear and the sediment was disturbed a second time. The insects, gravel, and other materials collected in the net were stored in jars and other containers put on ice and returned to the lab. Representative samples of the dominant aquatic vegetation at each river were also collected, either in the Surber samples or separately for use in isotopic analyses.

In the lab TL and mass were measured for all fish collected to determine average length and mass for each species at each site. Further, more tedious identification methods were used to determine the species present at each site, including the determination of large and small-bodied species. Small-bodied species were defined as species with an average adult TL of about 10 cm or less. Large-bodied species had average adult TL of more than 10 cm. Gut contents of representative individuals of each species and/or size class from each site were also examined.

The benthic invertebrates collected from each river were separated from the sand and vegetation, identified down to the Order or Family level, and counted. An EPT Water Quality Rating was used to assess the water quality for each river. In the assessment each invertebrate type present in a river was listed and given a score of one through three (as determined by the key used) and the score of all of the invertebrates present in the river were added together to get the total river score. Each river was then given a water quality rating based on the total river score. Poor water quality was defined as a river with a total score of less than 11 and no invertebrates with a score of 3(or "S" taxa). Rivers with fair water quality had a total score of 11-16 or at least one "S" taxa, rivers with good water quality had a total score of 17-22 or at least 2 "S" taxa, and rivers with a total score of more than 22 or at least 4 "S" taxa were rated excellent.

Representative fish, invertebrates, and submerged aquatic vegetation from each site were selected and prepared for stable isotope analysis. Fish large enough to fillet had muscle tissue extracted whereas several of the smaller fish and all invertebrates were placed together. The plant material was washed with tap water and had invertebrates visually removed from the samples. All of the isotope samples were dried over several hours in aluminum weighing boats and then ground using a mortar and pestle, and placed in 20mL scintillation vials for isotopic analysis. Isotopic values for other plants present, but not sampled for each river were obtained from previous studies in the Semester in Environmental Science program. These values were compared to the values of the plants and animals that were analyzed for each river.

Food webs were developed for each river based on the fish, invertebrates, and aquatic vegetation present, observations from gut content analyses, information from literature about fish and invertebrate diets and stable isotope analyses.

RESULTS

The main substrate present in the Coonamessett River was bare sediment (either sand or mud) which made up 70% of the river bottom (Figure 2). Algae was the dominant type of submerged vegetation present in the river making up 12% of the bottom. Vallisneria was also present in the river and combined with the small areas of emergent marsh vegetation made up 13% of the bottom types measured. No areas of terrestrial inputs (leaf pack or tree branches) were found in the Coonamessett.

Bare sediment made up 59% of the bottom in the Quashnet River (Figure 3), however no algae was found there, vascular plants made up a larger portion of the bottom (22%) and 4% of the bottom was covered with leaves or wood. Bare sediment was only present on 20% of the bottom in the Mashpee River (Figure 4). No algae was found there, but vascular plants and terrestrial inputs made up 42% and 30% of the bottom respectively.

85% of the Coonamessett River consisted of open areas (areas not classified as cover) (Figure 5), while only 16% of the Quashnet and 4% of the Mashpee rivers were open. 15% of the measured area in the Coonamessett would provide suitable cover for fish (Figure 6). 84% of the Quashnet River could be used for cover, and 96% of the Mashpee was cover.

The Coonamessett also had the fewest types of cover available in the three rivers with four (Figure 7) whereas the Quashnet had nine, and the Mashpee had eleven.

A total of 8 types of macroinvertebrates were found in the Coonamessett River (Figure 8), the most abundant type were amphipods, 50 of which were counted but more were present in the sample. 7 types of invertebrates were present in the Quashnet River but none were found in large numbers (Figure 9). 11 types of invertebrates were present in the Mashpee River and again there weren't large numbers of any type (Figure 10).

The Coonamessett had a total of 764 invertebrates per m^2 (226 without scuds (Table 1)), while the Quashnet had 183 invertebrates per m^2 (140 without scuds), and the Mashpee had 646 invertebrates per m^2 (463 without scuds).

None of the invertebrates found in the Coonamessett River were classified as "S Taxa", while two invertebrates from the Quashnet (caddisfly larvae and stonefly nymph) and three invertebrates from the Mashpee (caddisfly larvae, mayfly nymph, and stonefly nymph) were classified as "S Taxa" (Figures 8-10). The Coonamessett River had a total EPT Water Quality Rating score of 10, the total score for the Quashnet River was 14, and the total score for the Mashpee River was 21 (Figure 11).

Six species of fish were caught in the Coonamessett River, eight fish species were caught in the Quashnet, and nine fish species were caught in the Mashpee (Table 2). A total of 424 fish were caught in Coonamessett, 170 in the Quashnet, and 276 in the Mashpee (Figure 12). Dividing these totals by the total length of the sections fished on each river the Coonamessett River yielded 8.48 fish/m, the Quashnet had 3.4 fish/m, and the Mashpee had 11.04 fish/m (Figure 13).

Of the fish resident species (Table 2) present in each river only two (40%) of the species in the Coonamessett River were large-bodied (Figure 14). Four (57%) of the resident fish species in the Quashnet River were large-bodied, and six (75%) of the resident species in the Mashpee were large-bodied.

The three most abundant resident fish species in the Coonamessett River were the tessellated darter (*Etheostoma olmstedi*), four-spined stickleback (*Apeltes quadracus*), and american eel (Figure 15). The most abundant resident fish species in the Quashnet River were tessellated darter, american eel, four-spined stickleback, and white sucker (*Catostomus commersoni*) (Figure 16). The most abundant resident fish species in the Mashpee River were american eel, mummichog (*Fundulus heteroclitus*), brook lamprey, and white sucker (Figure 17).

The stable isotope analyses revealed that the four-spined sticklebacks, tessellated darters, and american eels in the Coonamessett River were all feeding, for the most part, from the vallisneria-grazing or detritus pathway (Figure 18). The four-spined sticklebacks, tessellated darters, and medium american eels in the Quashnet River were feeding from the potomogeton-grazing or detritus pathway, the brook trout and small american eels were feeding from the red maple-grazing or detritus pathway, and the white suckers were feeding from the vallisneria-grazing or detritus pathway (Figure 19). The three-spined sticklebacks (*Gasterosteus aculeatus*), and brook trout in the Mashpee River were feeding from the red maple-grazing or detritus pathway, the white suckers were feeding from the vallisneria-grazing or detritus pathway, and the small American eels were feeding from a mix of the vallisneria and spiky plant-grazing or detritus pathways (Figure 20).

DISCUSSION

Habitat Assessment

85% of the Coonamessett River was not qualified as suitable cover for fish. Algae is the dominant submerged vegetation in the river which is characteristic of a stressed river ecosystem.

The four types of cover available in the Coonamessett are vallisneria, some emergent marsh vegetation, one small overhanging bank, and a few spots had depths over 30cm. While 59% of the Quashnet River's bottom is bare sediment many of those areas have depths of 30cm or more, which also serves as cover and is the main reason that 84% of the Quashnet river could be used for cover. The Quashnet also has two types of submerged vascular plants, which serve as cover, as well as man-made baffles, overhanging banks and tree branches which are ideal sources of cover for several fish species especially brook trout. 96% of the Mashpee River qualified as cover, which was pretty evenly distributed among submerged vascular plants, and leaf pack, and many of the areas that had bare sediment had depths 30cm or deeper and qualified as cover. The Quashnet and Mashpee Rivers have habitat characteristics of healthy, natural river ecosystems.

Macroinvertebrates

The dominant type of macroinvertebrate present in the Coonamessett River were amphipods, and no other invertebrates were present in large numbers. The Quashnet River had fewer types of invertebrates present, but none of them were present in large numbers. The Mashpee River had the most types of invertebrates present without any of them dominating the ecosystem. Even though the Coonamessett had more types of invertebrates present than the Quashnet River, the Quashnet had two invertebrate types present that are considered indicators of good water quality "S Taxa" and the Coonamessett had zero of these invertebrate types. That is why the Coonamessett had a score of 10 which means it has poor water quality. The Quashnet and Mashpee River fall into the good to excellent water quality ranges with scores of 14 and 21 respectively. It should be noted that the EPT test that I used to make this assessment was designed for use in freshwater ecosystems in Pennsylvania, but I cannot find any reason as to why it would not be accurate in the rivers that I studied for this project.

Fish

The most important thing to notice about all of the different fish species captured in all three rivers is that brook trout were only caught in the Mashpee and Quashnet rivers. When brook trout are present in a river it is considered an indicator of good water quality. Another important fact to notice is that no herring were caught during the fishing sessions in the Quashnet River. This was the last of the three rivers fished, and herring had been observed in the Quashnet on previous trips there. We did not observe herring in either the Coonamessett or Mashpee rivers after fishing in the Quashnet so we assumed they had migrated out of the rivers for the winter. Herring were not a major part of the food web analysis as they are migratory fish and were probably not spending sufficient time in the rivers to contribute to the food web, or consume many of the resident invertebrate species.

The total number of fish caught in each river was most likely affected by the amount of cover present in the rivers. The Coonamessett yielded the highest total number of fish caught, but remember the Coonamessett had almost no cover present in the river. So the vast majority of the fish that were stunned by the electrofishing unit could easily be seen, and were caught. The Quashnet River had the lowest total catch, and lowest abundance of fish per linear meter of river fished. This was most definitely affected by the presence of many areas of deep water, several baffles and overhanging banks, and areas of dense potomogeton present in the two sections of the river that we fished. These things made it much more difficult to see fish that were stunned by the electrofishing unit. It was virtually impossible to see any fish that may have been underneath of the overhanging banks. In the Mashpee River the areas of submerged aquatic vegetation, and leaf pack were very dense and more than likely prevented us from seeing many fish that may have been hiding below these areas. The Mashpee also had large areas with partially submerged shrubs in the water that we could not get back into to catch fish; some fish definitely retreated to these areas when we attempted to shock them. However, none of the data presented in this paper had been altered to account for the fact that many fish were lost in the Quashnet and Mashpee rivers due to lowered visibility.

As stated in the results section, the only species of large bodied fish that was present in large numbers in the Coonamessett River was the american eel. The only other large-bodied species present in the Coonamessett was the bluegill (*Lepomis macrochirus*), and all four of them were juveniles. Bluegills in this river would most likely not reach adult size, and these juveniles most likely came from Flax Pond, which is connected to the Coonamessett. Four species of large-bodied fish were caught in the Quashnet River, american eels and white sucker were both present in substantial numbers. Six species of large-bodied fish were caught in the Mashpee River, and american eels, white suckers, and brook lamprey were present in large numbers. These differences also suggest that the Coonamessett cannot support as many large-bodied fish species as the other two rivers.

Stable Isotope Analysis

The stable isotope analysis for the Coonamessett River shows that none of the animals sampled were feeding directly on algae, the dominant plant species in the river. Amphipods and leaf bugs (an unidentified type of beetle larvae) were feeding on a mix of algae and vallisneria. The four-spined sticklebacks, medium, and small american eels were feeding on invertebrates that were not sampled but were feeding on mainly vallisneria and some algae. The tessellated darters were feeding on invertebrates that feed on vallisneria and possibly some of an unidentified spiky plant. The fact that the dominant plant in the ecosystem (algae) does not contribute to the food web is another indication that the Coonamessett is a stressed ecosystem.

The fish and invertebrates in the Quashnet feed on a wide variety of food sources. The Quashnet River stable isotope analysis shows that the three invertebrates sampled were feeding on potomogeton or another plant with a slightly more negative $d^{13}C$ value. Medium american eels, four-spined sticklebacks, and tessellated darters were all feeding on invertebrates that were feeding off of potomogeton, brook trout were probably feeding on a mix of invertebrates that eat potomogeton and invertebrates that eat red maple leaf detritus, small american eels were probably eating a mix of invertebrates that feed on red maple detritus and vallisneria, and white suckers were feeding on invertebrates that feed on vallisneria.

Fish and invertebrates in the Mashpee River were also in several feeding pathways. Amphipods and mayfly larvae were feeding on a mixture of potomogeton and red maple detritus. The stonefly larvae were feeding on another invertebrate that feeds on red maple detritus, the caddisfly larvae were feeding on a mixture of red maple detritus and vallisneria. The brook trout and three-spined stickleback were probably feeding on a mixture of stonefly and caddisfly larvae, the white suckers and small american eels were feeding on an invertebrate that was feeding on vallisneria.

The food web for the Coonamessett River (Figure 21) is relatively simple. The river has a few types of plants that are either directly grazed or contribute to the detritus food pathway, a few invertebrate species feeding off of the plants, and a few fish species that feed on the invertebrates. At the most the Coonamessett has four trophic levels, with large american eels as the only tertiary carnivore present. The food web for the Quashnet River (Figure 22) is more complex than that of the Coonamessett. It has more types of plants available at the base of the food web, and while it has one invertebrate less than the Coonamessett, one of the invertebrates present in the Quashnet is carnivorous. The Quashnet also has more fish species present which makes it more difficult to determine what each species feeds on. The Mashpee River's food web (Figure 23) is the most complex of the three. With several types of plants forming the base of the food web, and many invertebrate and fish species that make it more difficult to determine what animals are feeding from which food pathways. The most important quality to notice about the food webs is that the Coonamessett has a relatively simplified food web, which is another characteristic of stressed ecosystems. Another point to notice is that all three food webs have no more than four trophic levels, and so there cannot be a correlation between the number of trophic levels and the level of alterations to the ecosystem.

Previous research at a total of nine sites on these three rivers by Gocke (2003) did not yield as many total fish or quantitatively assess cover available to fish but did find some fish species not found in this project. Fishing further stretches of each river may yield a few more species in the Quashnet and Mashpee rivers, but I would not expect to find many more species in the Coonamessett River.

CONCLUSION

The lower cranberry bog on the Coonamessett River has many of the characteristics of a stressed ecosystem. The dominant plant species in the river is algae, which does not play a major role in the food web of the river, which makes for a relatively simple food web. One type of invertebrate, the amphipods, is present in abundance. Amphipods are a type of invertebrate that are known to thrive in stressed aquatic ecosystems. The most abundant species of fish are small-bodied fish that are usually considered baitfish. The Coonamessett has very little cover available for large-bodied fish species, and does not have any brook trout, caddisfly, mayfly, or stonefly larvae which all indicate good water quality when present in a river.

On the other hand Section 6 of the Quashnet River is much more similar to a natural river ecosystem. While it still has a lot of bare sediment on its bottom the Quashnet does not have any algae present, and has more types of plants, and fish present, which make its food web a bit more complex. The Quashnet also has a lot of suitable habitat for large-bodied fish species to use, such as overhanging banks, and deep water. The Quashnet also has brook trout, caddisfly larvae, and stonefly larvae present which are all indicators of good water quality. This all suggests that the restoration project on this section of the Quashnet River has had the desired effect of making the former cranberry bog to more natural conditions. There is still some data from this project that can be analyzed in order to make further comparisons between all three rivers, and I'm sure that more interesting results will be found when that data is analyzed.

ACKNOWLEDGMENTS

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The Town of Falmouth Board of Selectmen for approving our research on the Coonamessett River, and Steve Hurley for allowing us to use his boat, cooler, and fish cage, granting us access to the Quashnet River, and his advice. They were all a joy to have worked with.

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FIGURES AND TABLES

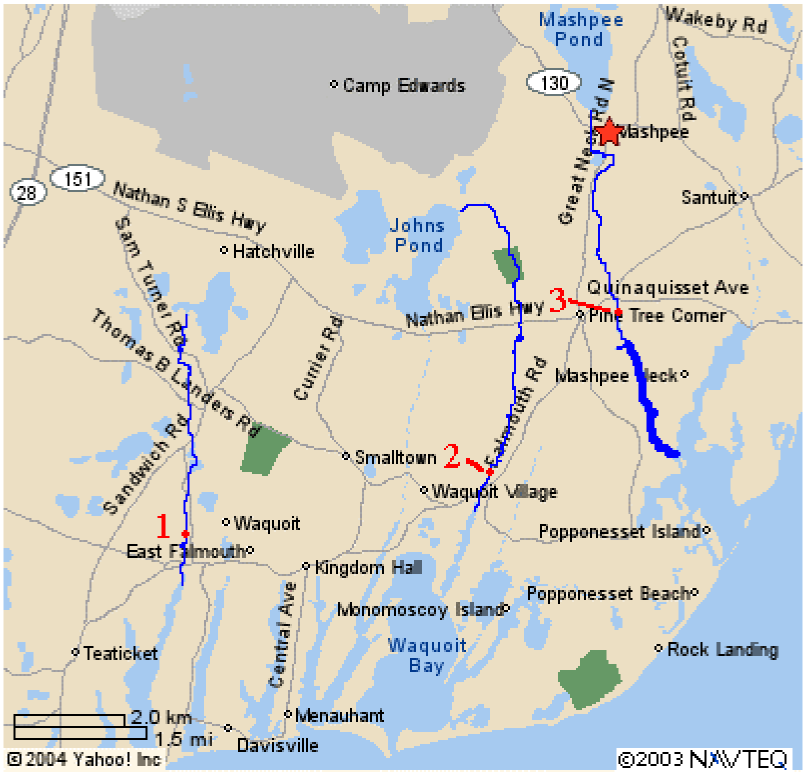

Figure 1.) Map of sampling sites on the Coonamessett (Site 1), Lower Quashnet (Site 2), and Lower Mashpee (Site 3) rivers.

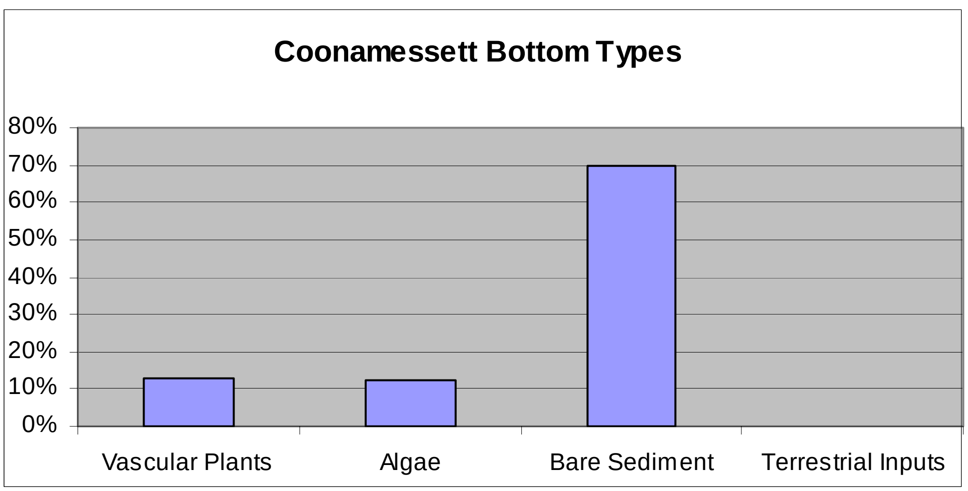

Figure 2.) Percent of river substrate consisting of vascular plants (emergent marsh and submerged aquatics), algae, bare sediment, and terrestrial inputs (leaves and wood).

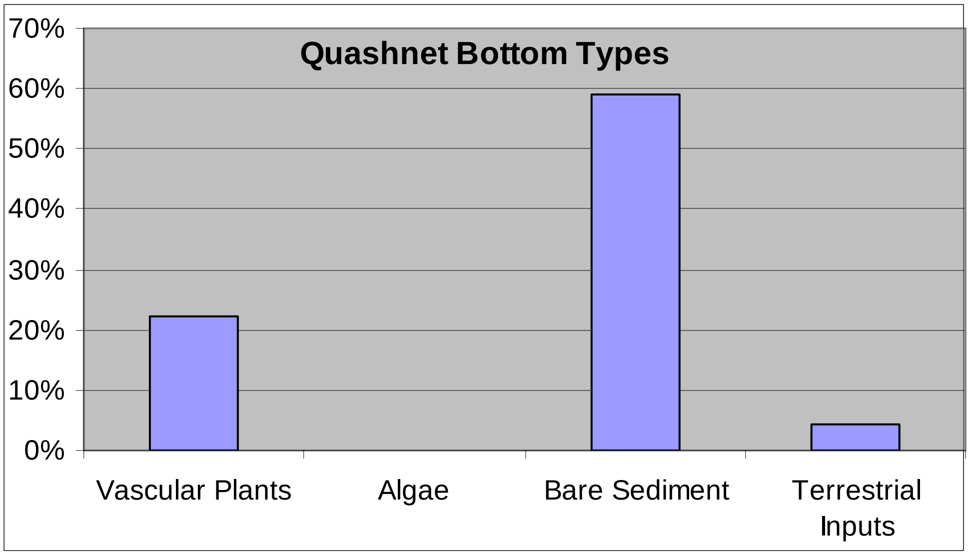

Figure 3.) Percent of river substrate consisting of vascular plants (emergent marsh and submerged aquatics), algae, bare sediment, and terrestrial inputs (leaves and wood).

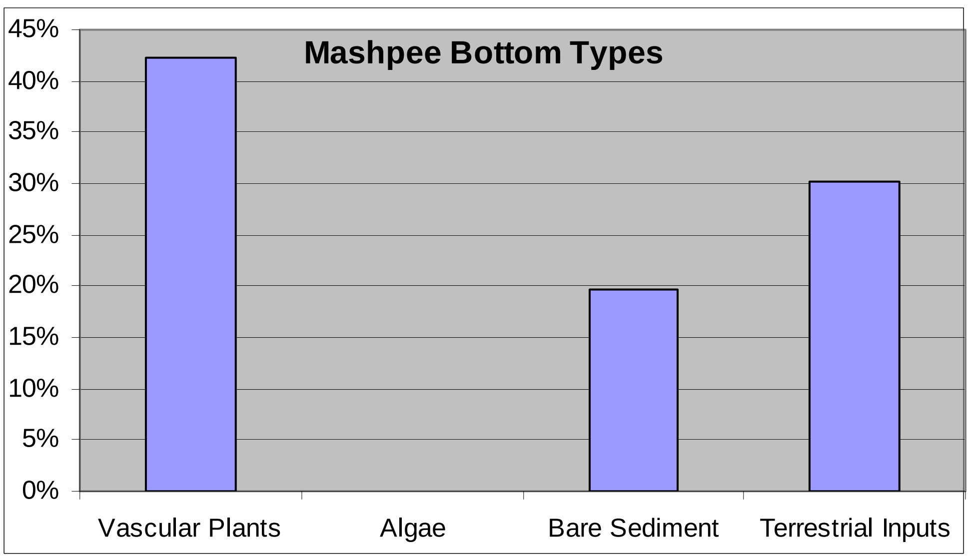

Figure 4.) Percent of river substrate consisting of vascular plants (emergent marsh and submerged aquatics), algae, bare sediment, and terrestrial inputs (leaves and wood).

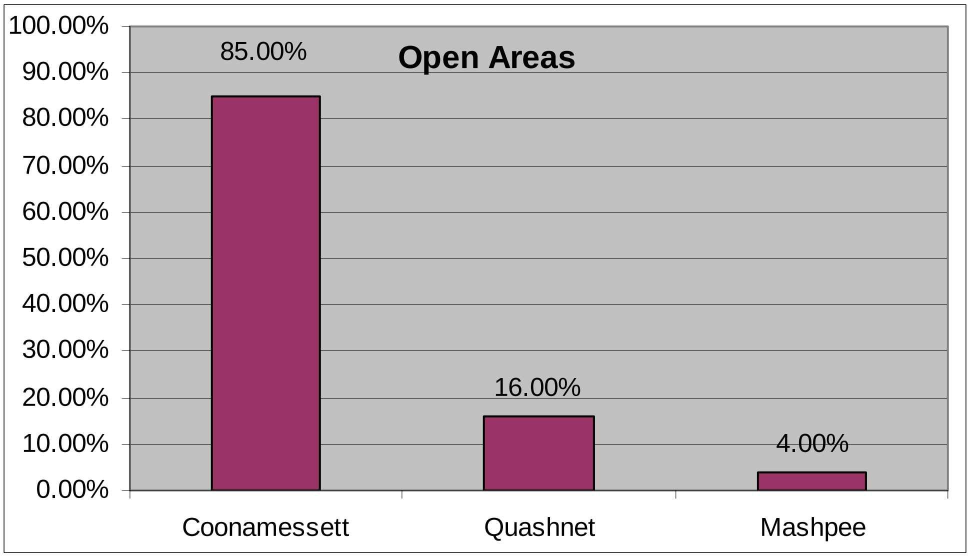

Figure 5.) Percent of river with bare sediment or algae.

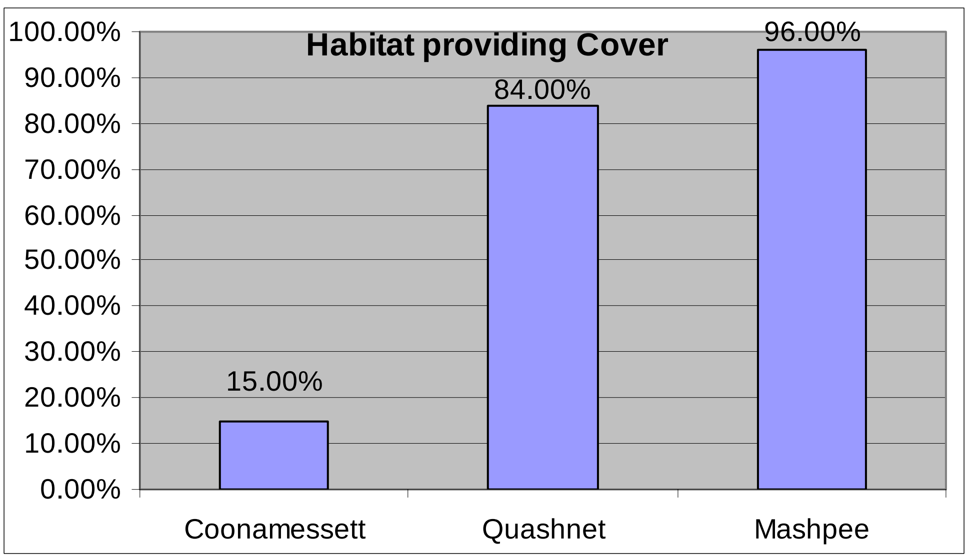

Figure 6.) Percent of river with cover suitable for a large-bodied fish.

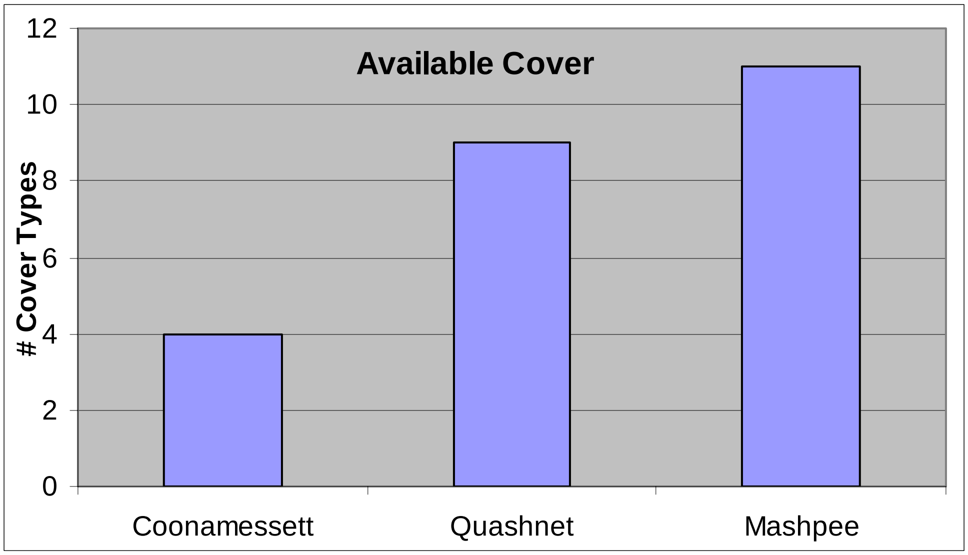

Figure 7.) Number of cover types available for fish.

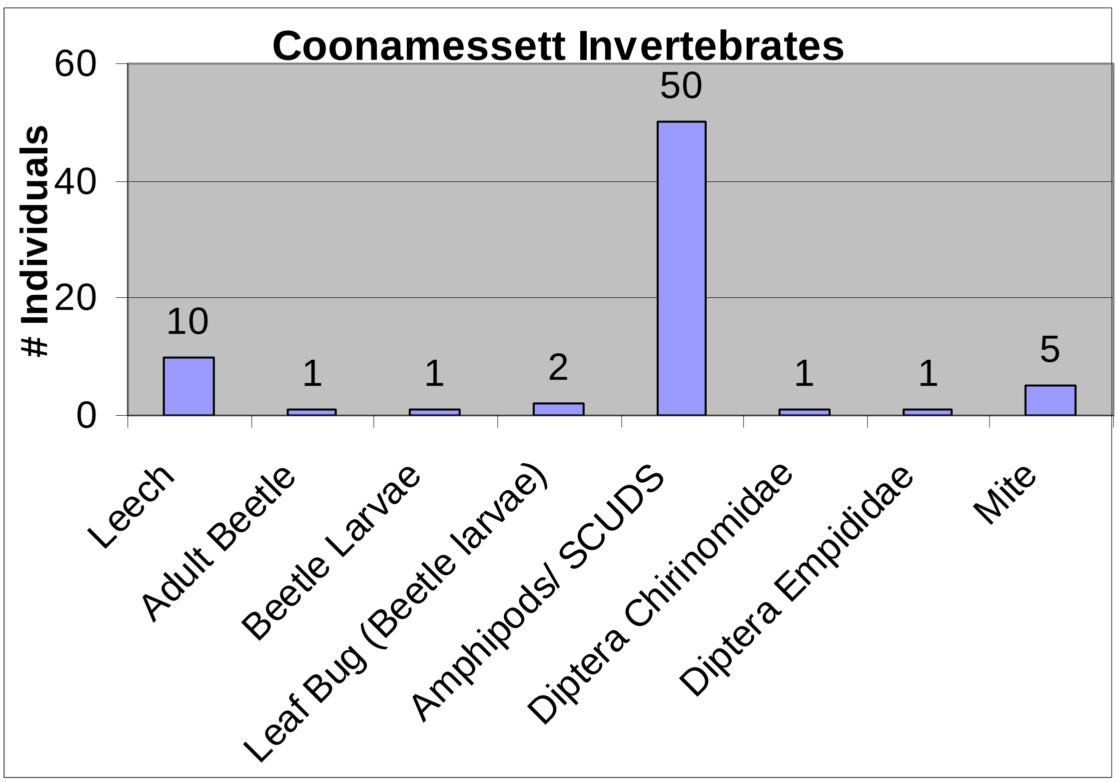

Figure 8.) Number of individual macroinvertebrates caught in one benthic sample.

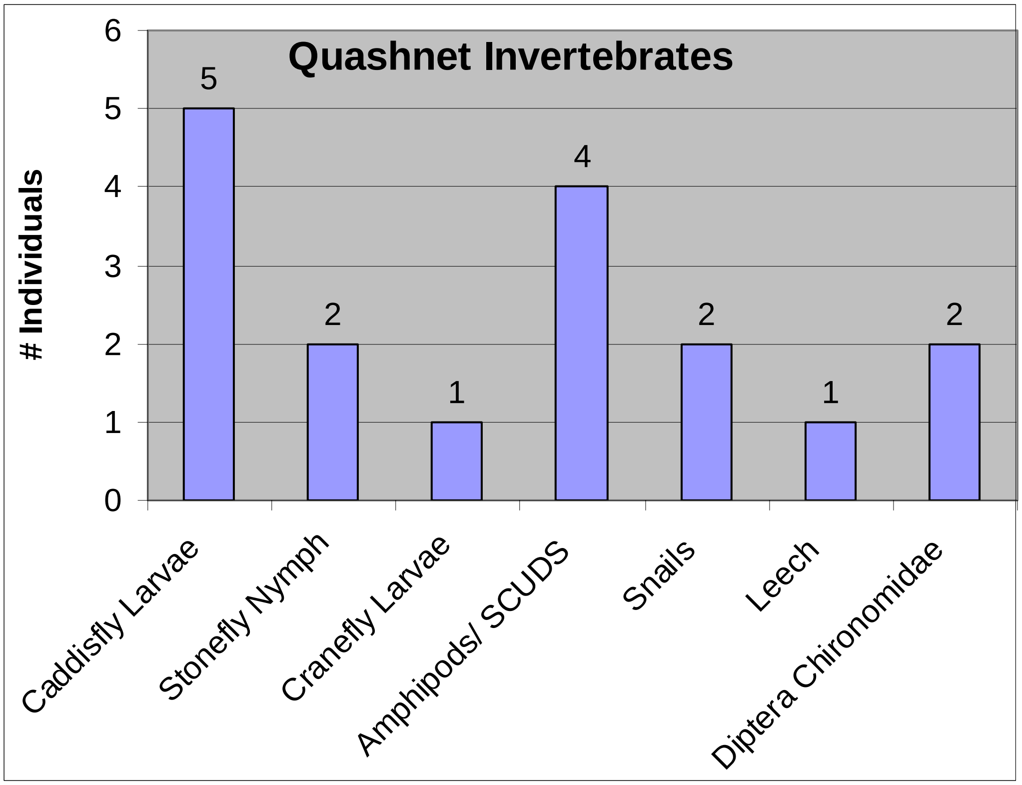

Figure 9.) Number of individual macroinvertebrates caught in one benthic sample.

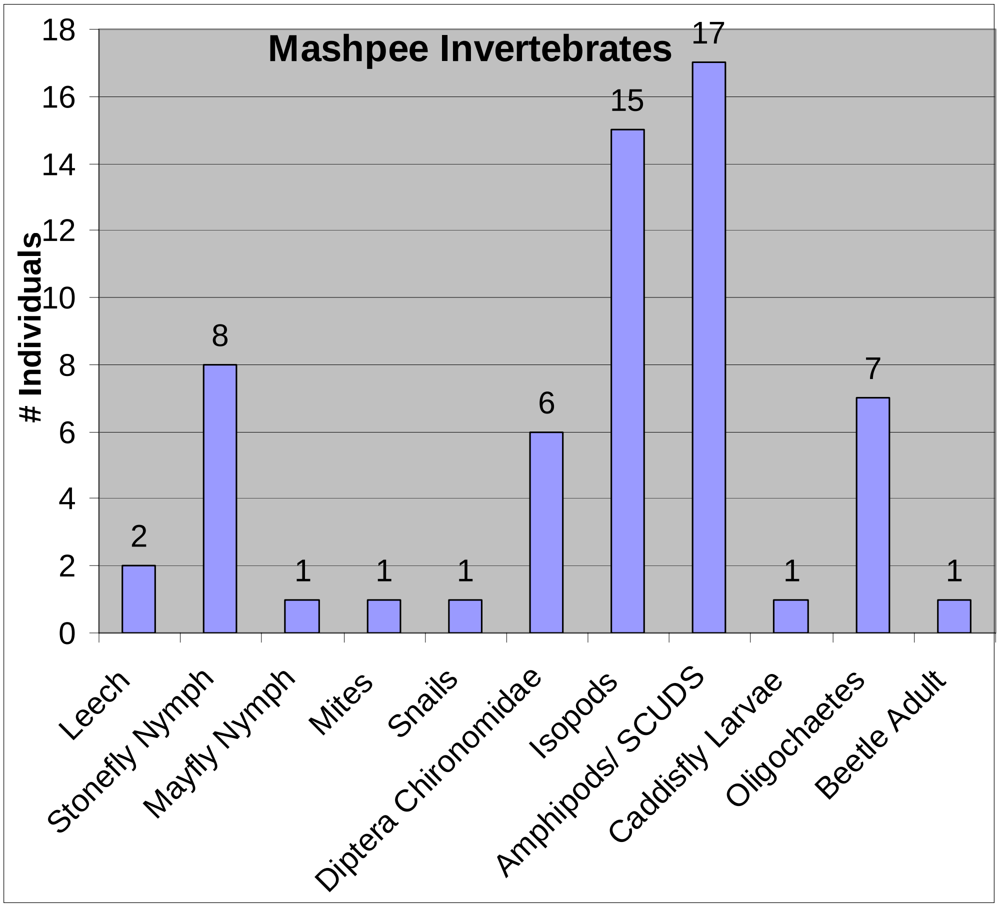

Figure 10.) Number of individual macroinvertebrates caught in one benthic sample.

RIVER	Total Invertebrates /m^2	Totals Without Scuds
Coonamessett	764	226
Quashnet	183	140
Mashpee	646	463

Table 1.) Total number of invertebrates caught in Surber sampler scaled-up to an area of one m^2, and the total number without including amphipods.

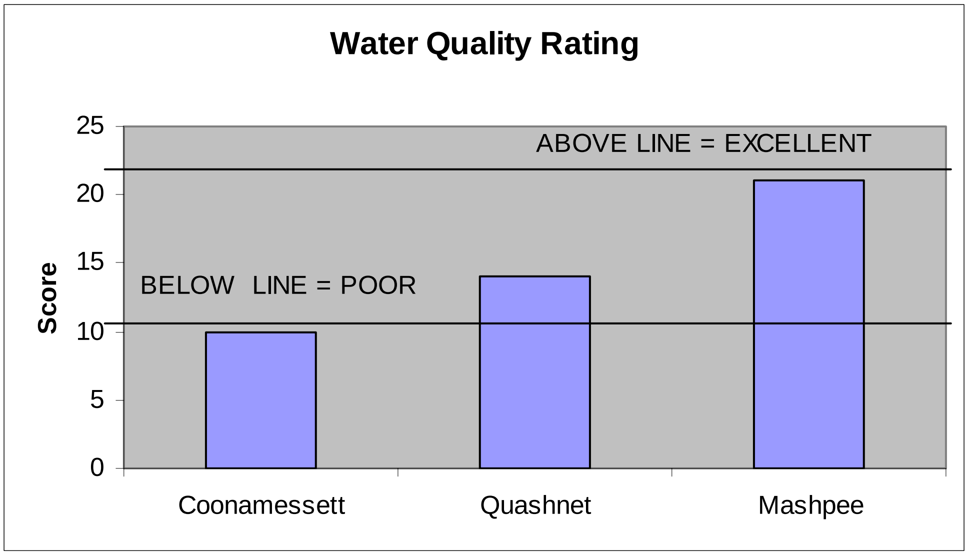

Figure 11.) EPT Water Quality Rating score. Poor line = 11, Excellent line = 22.

			Coonamessett	Quashnet	Mashpee
RESIDENT					
Small adult size < 10 cm)					
	3-Spined Stickleback				*x*
	4-Spined Stickleback		x	x	
	9-Spined Stickleback			x	
	Mummichog				*x*
	Tessellated Darter		x	x	
	Banded Killifish		x		
Large Adult size (> 20 cm)					
	Bluegill		x		x
	Brook Lamprey				x
	Brook Trout			x	x
	Brown Bullhead				x
	Golden Shiner			x	
	American Eel		x	x	x
	White Sucker			x	x
MIGRATORY					
	Herring		x	(x)	x
	TOTAL SPECIES		**6**	**8**	**9**

Table 2.) All fish species caught in all three rivers and total number of species in each river.

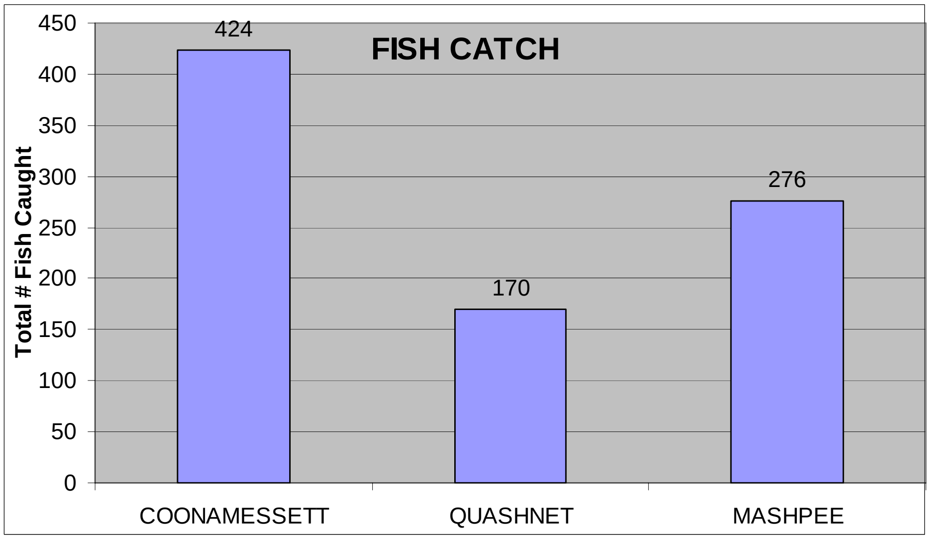

Figure 12.) Total number of fish caught in each river.

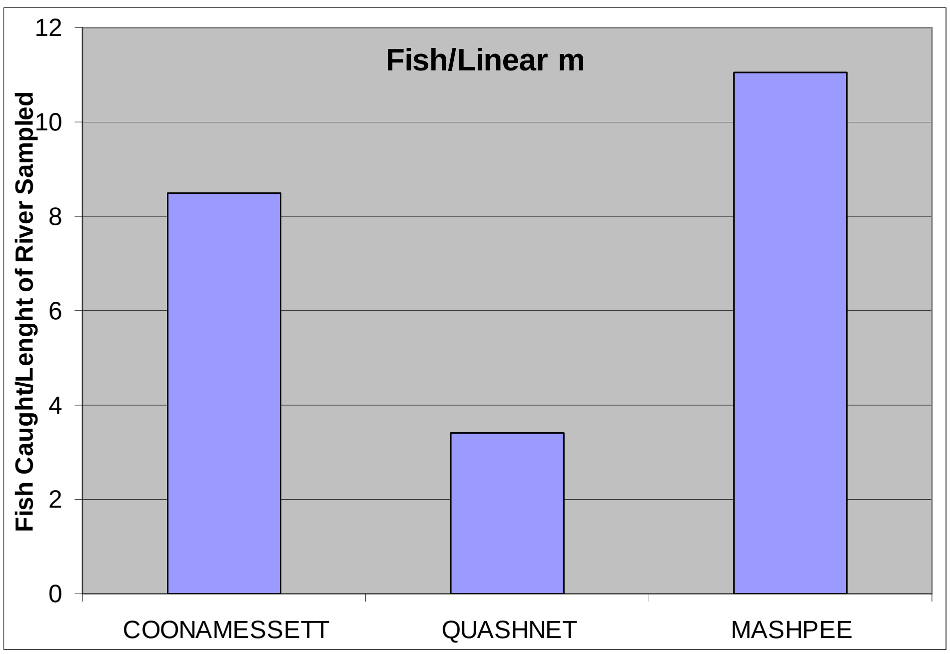

Figure 13.) Total number of fish caught in each river divided by total river length fished.

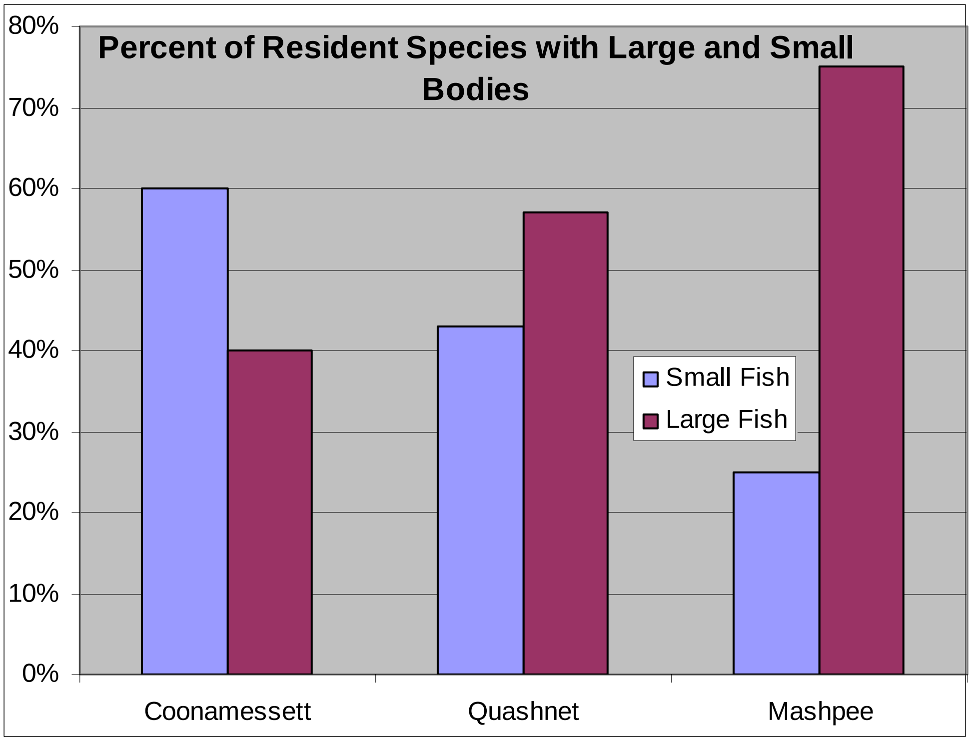

Figure 14.) Percentage of resident fish species with small or large adult body size

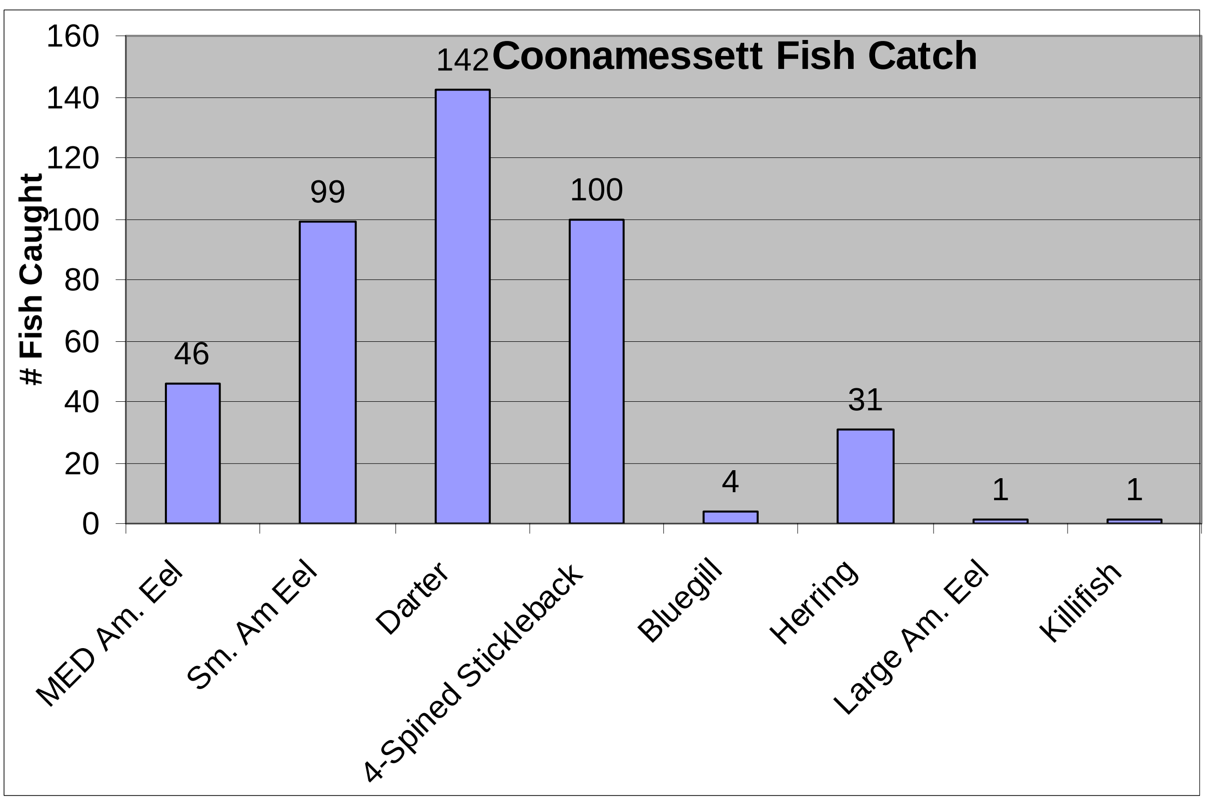

Figure 15.) Number of individual fish caught for each size-class and/or species.

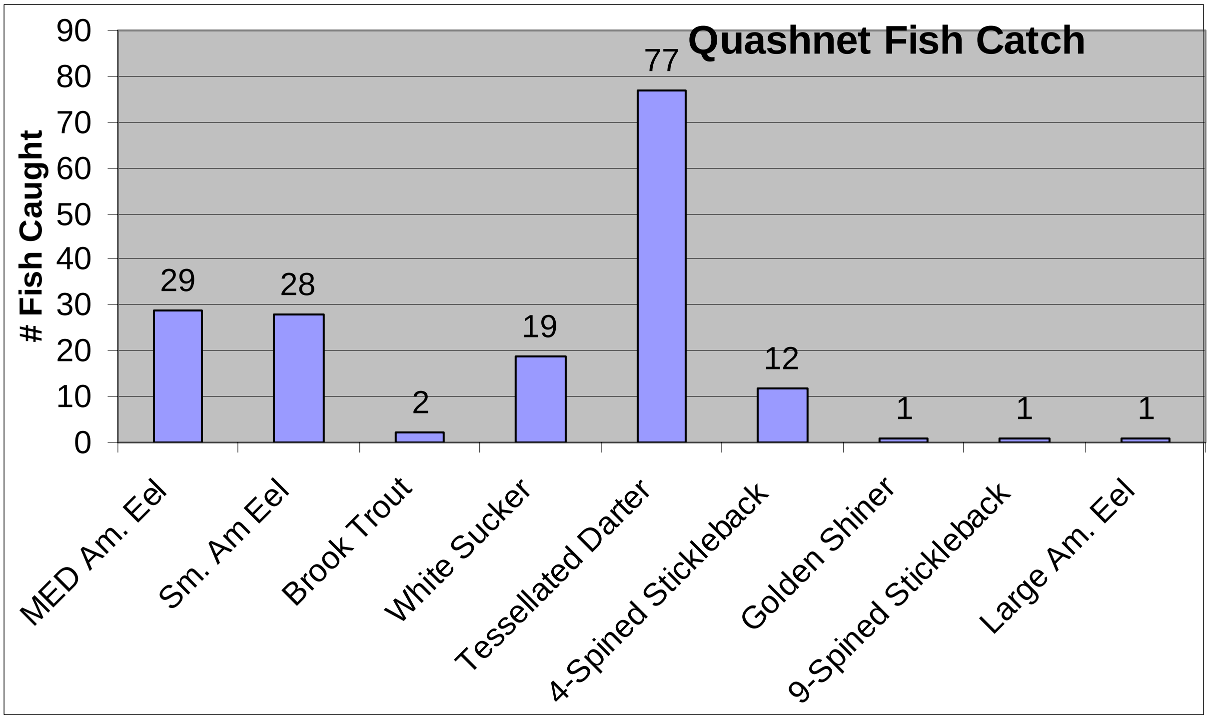

Figure 16.) Number of individual fish caught for each size-class and/or species.

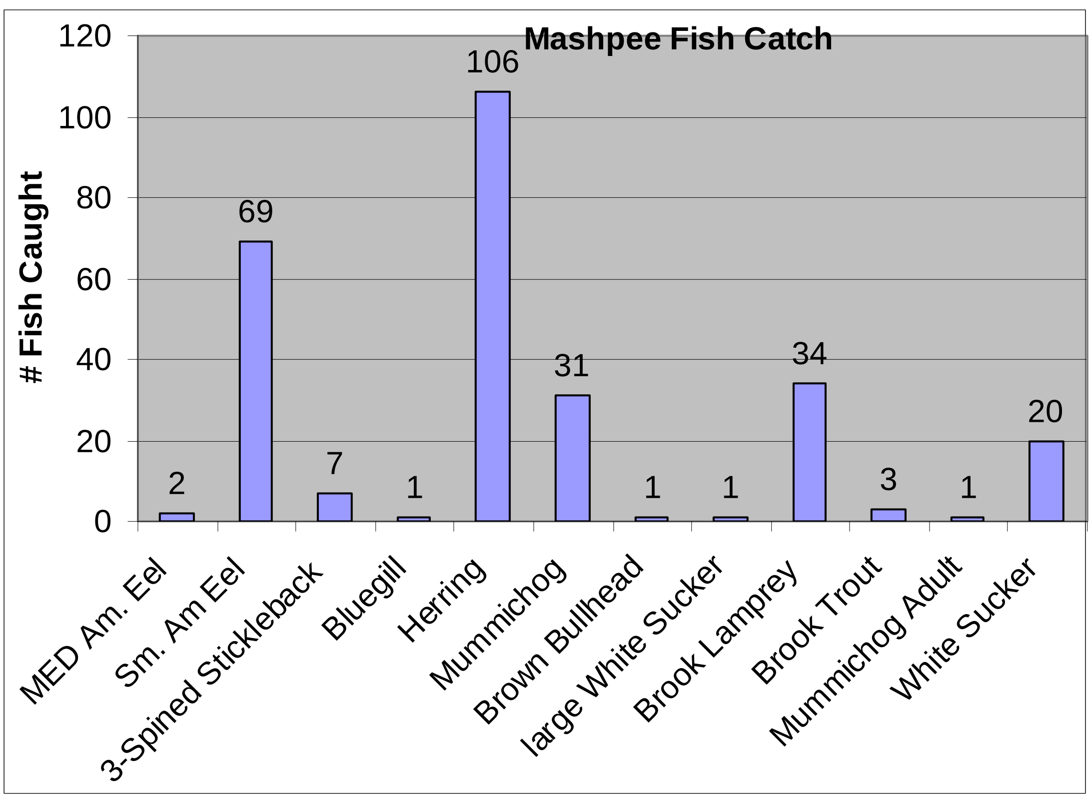

Figure 17.) Number of individual fish caught for each size-class and/or species.

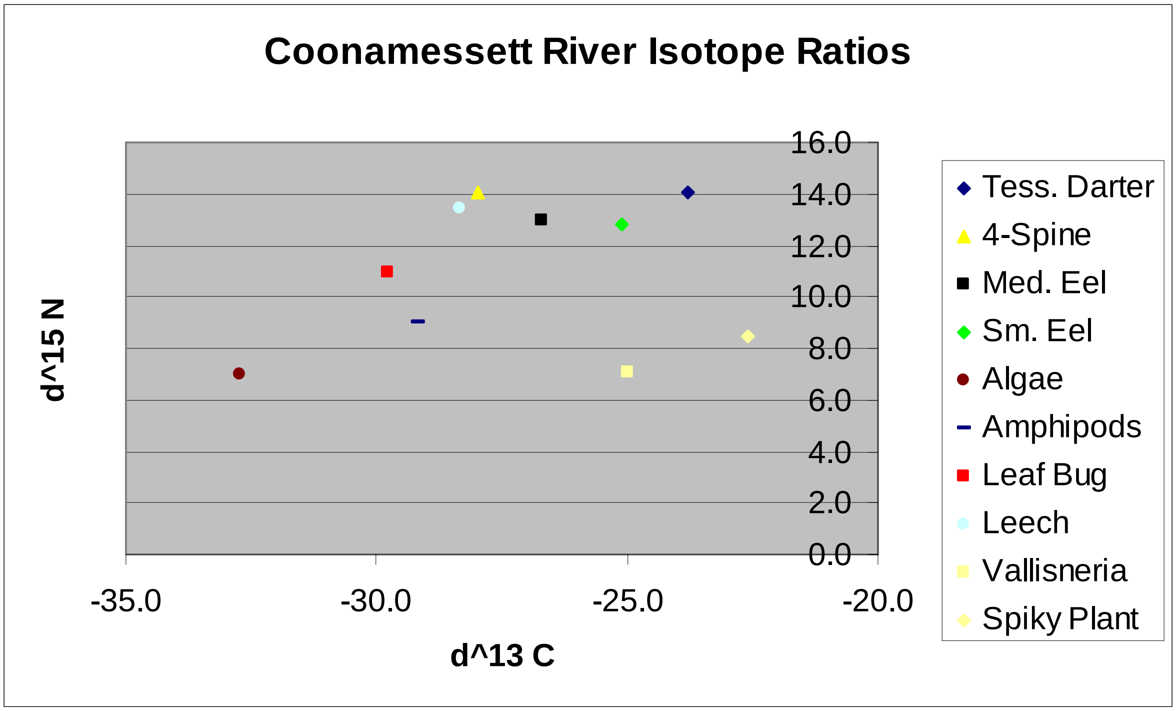

Figure 18.) Stable isotope values for fish, invertebrates, and plants sampled. Values not sampled in this project are peach-colored.

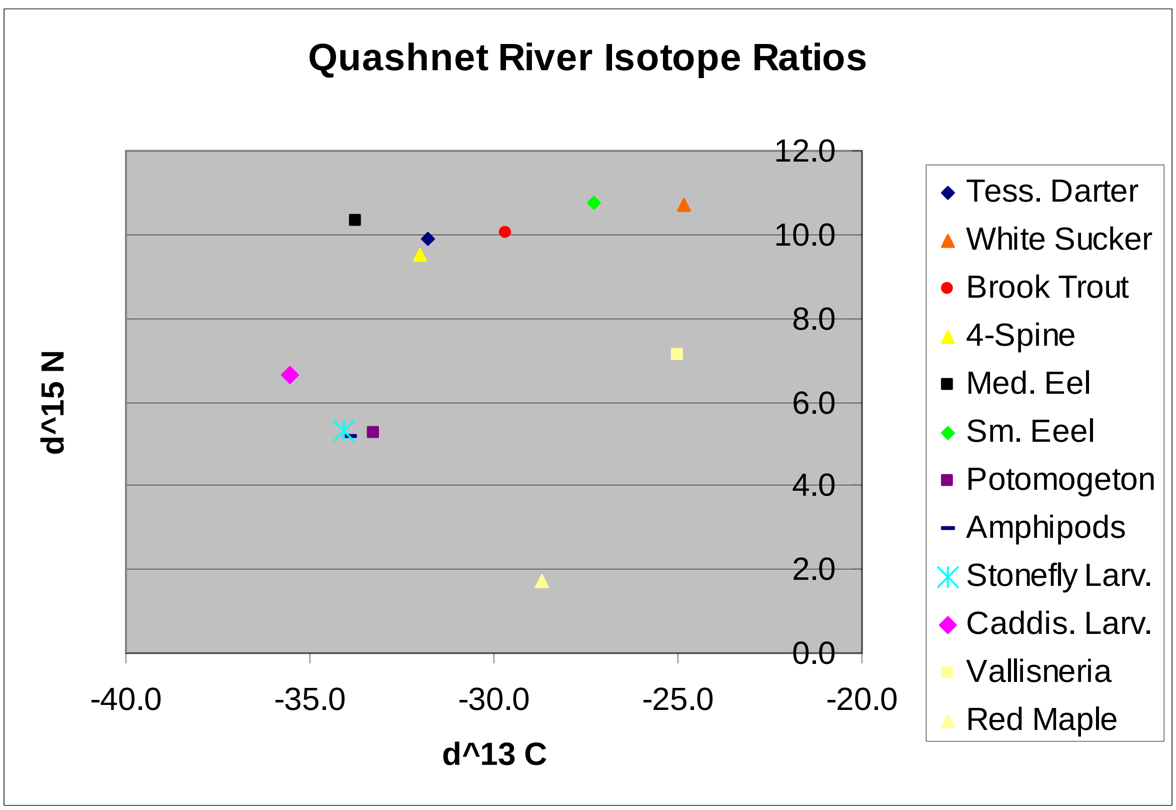

Figure 19.) Stable isotope values for fish, invertebrates, and plants sampled. Values not sampled in this project are peach-colored.

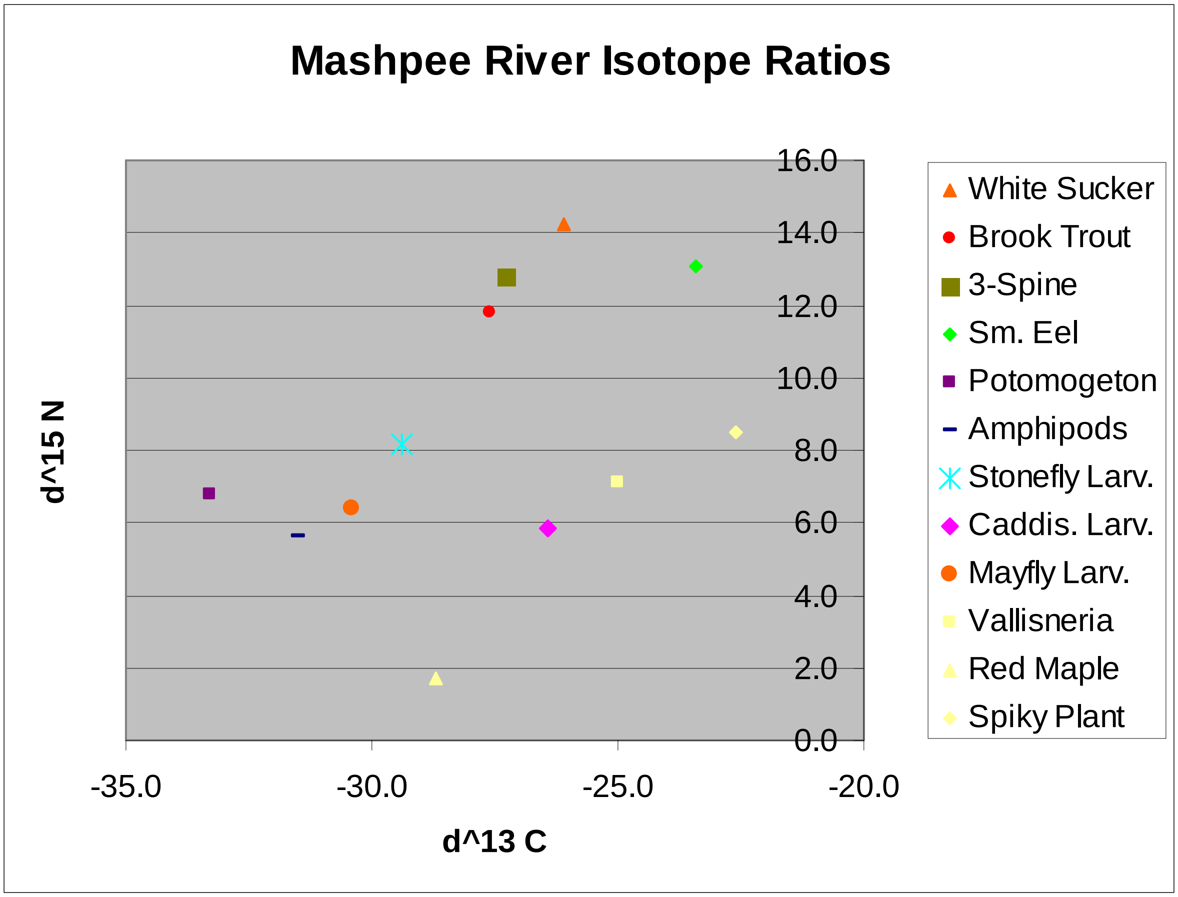

Figure 20.) Stable isotope values for fish, invertebrates, and plants sampled. Values not sampled in this project are peach-colored.

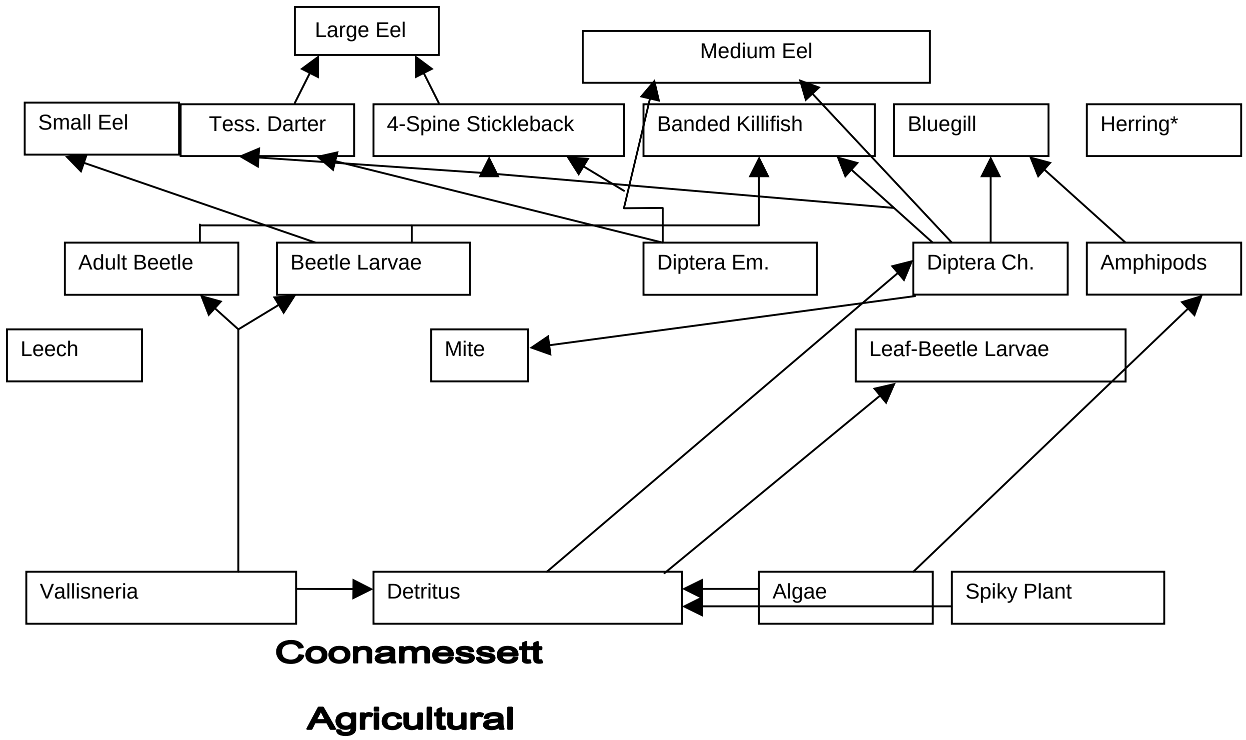

Figure 21.) Food web developed using literature information, gut content analyses, and stable isotope analyses.

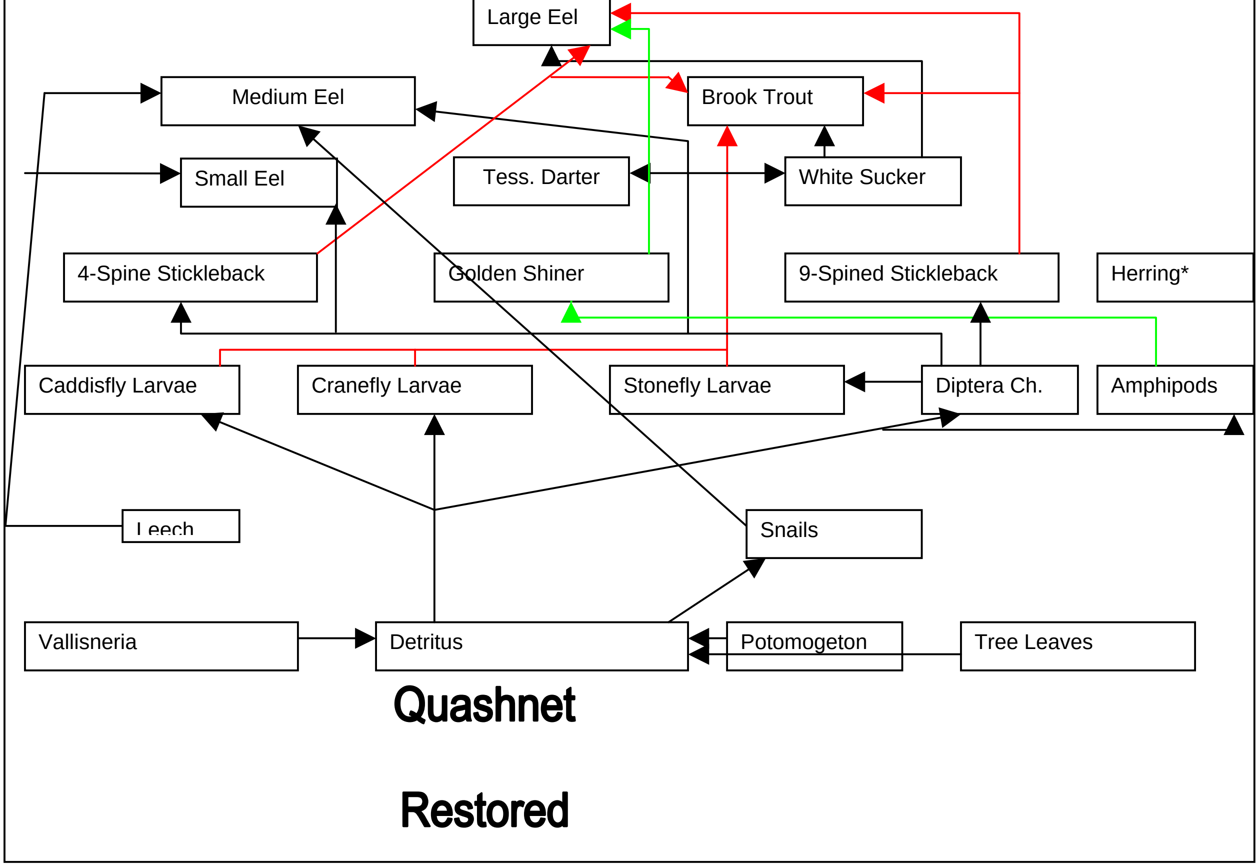

Figure 22.) Food web developed using literature information, gut content analyses, and stable isotope analyses.

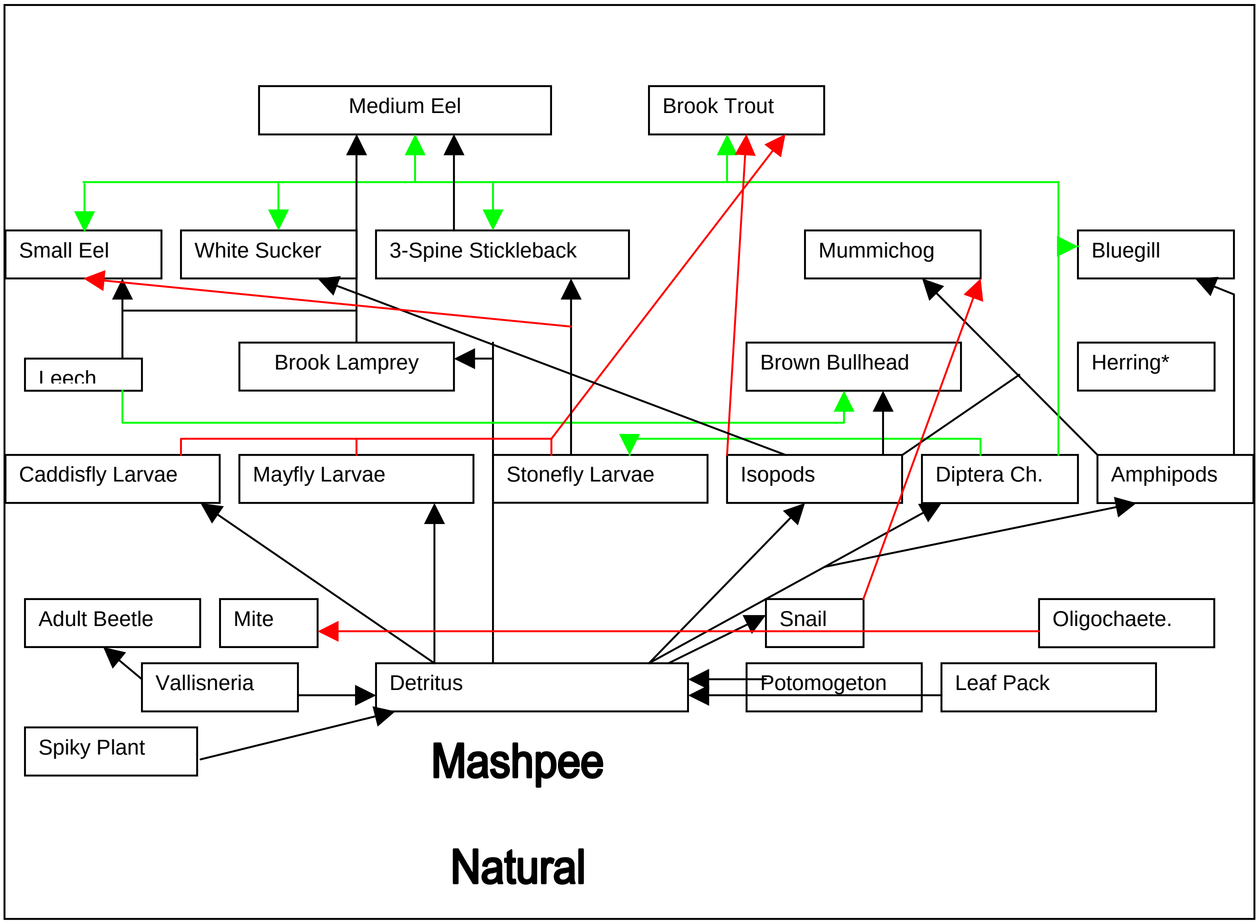

Figure 23.) Food web developed using literature information, gut content analyses, and stable isotope analyses.