Stream quality among active and restoring river-based cranberry bogs

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ABSTRACT

Some cranberry bogs on Cape Cod, MA rely on rivers to irrigate and flood them. The health of these rivers is potentially jeopardized by this practice, and the state of Massachusetts has purchased several of these sites for conservation and restoration. In this project, I assessed the quality and health of the streams in these bogs in comparison to the health of streams in active cranberry bogs and regions that have never been farmed for cranberries. My results for habitat complexity and in-stream invertebrate populations indicate that stream-quality increases with the amount of time the bog spents in natural restoration.

INTRODUCTION

Cranberry farming has been an important part of the Cape Cod economy for centuries (Cape Cod Cranberry Growers Association). Substantial plots of land in this region have been converted to bog platforms to support this industry. Traditionally, cranberry bogs are positioned around natural rivers and streams ("flow-through" bogs) to allow for easy irrigation and flooding of the bogs. There has been concern that flow-through bogs compromise the health of streams by impeding the migration routes of anadromouos fish, such as herring, and contributing to in-stream pollution and nutrient loading through fertilizer and pesticide usage (Buzzard's Bay National Estuary Program). Flow-through bogs further reduce stream quality by removing in-stream habitat for fish and invertebrate species. When the near-riparian land bordering the streams is cleared for the bog platform tree shading, root systems, and meanders are removed from the streams as well, diminishing their complexity and ability to support large food webs.

Flow-through bogs are grandfathered into Massachusetts state legislation, allowing older bogs that rely on natural waters to continue their operation, and this growing method now accounts for only 10-15% of cranberry agriculture on Cape Cod [2]. The State of Massachusetts has purchased several flow-through bogs and has been working to restore these stream and riparian habitats.

Restoration of disturbed lands can be approached through two different methods. The site can be actively restored, with man-made alterations being employed to encourage complexity and speed up development of the ecosystem, or the site can be naturally restored. In natural restoration the site is allowed to sit undisturbed and recover on its own, going through periods of succession until it reaches a stable state. For each of these restoration approaches there is the question of what the site will restore into. Will the system return to its original, undisturbed, pristine state, or will it reach an alternate, but still healthy, stable state? In this project I seek to address this question of succession and development within naturally restoring flow-through cranberry bogs.

Eight sites across the Cape Cod peninsula were investigated. Of these sites, two were flow-through cranberry bogs that were actively being used for agriculture, four were flow-through bogs in various stages of natural restoration, and two were natural rivers that had never been altered or used for cranberry production. I studied habitat complexity, invertebrate populations, fecal coliform contamination, and the potential for nutrient loading in an attempt to determine the health of the streams. My expectation was that the active bogs and younger restoration sites would have less healthy stream systems than the older restoration sites and the sites that were never used for cranberry farming.

METHODS

The eight sites studied spanned four different river systems. Five locations were situated along the Coonamessett River (Figure 1, Figure 2), one location was a tributary to one of the Coonamessett sites and was fed by Flax Pond (Figure 2), and one location was located on the south side of the Cape along the Mashpee River (Figure 3). The final location, Red Brook, was located on the west side of the Bourne Bridge in the Lyman Reserve in East Wareham, MA (Figure 4). Reservoir Bog and Middle Bog, along the Coonamesset, are still actively farmed. Lower Bog and Flax II have been in natural restoration for approximately 6 years, Red Brook has been in restoration for 56 years, with moderate active restoration in recent years, and Zeke's Way, on the Coonamessett, has been restoring for 80 years. An upstream section of the Coonamessett and a section of the Mashpee River that had never been farmed for cranberries were also investigated; the upstream Coonamessett section was more disturbed than the Mashpee location. (Table 1)

A minimum of two field days was spent at each site. Habitat diversity and complexity was measured in the field using a point transect method (Hauer and Lamberti, 2006). Ten transects were completed for each site, and each transect consisted of eleven evenly spaced points. To set up the transects, a token stream width was measured and multiplied by five to determine the length of stream to be studied. This length was then divided by ten to determine how far apart the transects should be spaced. An area of 100 cm^2 was examined around each point along the transect and the water depth, sediment type, dominant cover type, and all cover types present were recorded (Table 2). Each point was then classified as "cover" or "no cover" depending on its ability to support and shelter fish. If the area was 50% covered and had a minimum depth of 15 cm it was considered cover.

The invertebrate community at each site was sampled using a Surber sampler with a 500 µm net and a base area of 929 cm^2 (Hauer and Lamberti, 2006). Three samples were collected at each location. The samples gathered were representative of key dominant habitats within the site (Table 4). Samples were taken by resting the metal base of the Surber sample on the desired riverbed location with the opening to the net facing upstream. Any vegetation or debris within the Surber area was collected in large plastic bags, with extra care given to ensuring that all items did not exit the water during the collection until secured in the bag. The sediment within the Surber area was then disturbed to a depth of 2 cm. Once the water cleared, this disturbance was repeated. All material gathered in the Surber sampler was stored in large plastic bags and put on ice until they could be processed or stored in the lab's cold room (15°C). The samples were processed ½-1 cup at a time. Any macro invertebrates found were removed from the sediment and debris of the sample using tweezers or plastic transfer pipettes. Identification was done by eye and with the assistance of a magnifyinig glass and a top-lit dissecting scope. All invertebrates were identified to family or order whenever possible (Voshell, 2003; Thorp and Covich, 1991). Each invertebrate classification was counted and massed as a group to determine an average wet weight per individual. Wet weights were used to estimate productivity levels. (Productivity reference.) A water quality index (Figure 5) was used to rank the tolerance of collected invertebrate taxa and assign a water quality ranking to each site; sites could be ranked poor, fair, good and excellent. All samples were then frozen for storage.

Representative invertebrate and vegetation samples were selected for each site to be sent for stable isotope (^{13}C and ^{15}N) analysis. These samples were oven-dried for 48 hours and ground with mortar and pestle or Wig'L'Bug apparatus. Wig'L'Bug was manufactured by the Crescent Dental Mfg. Co. located in Lyons, IL, USA (Serial Number 6-0748). Stable isotope analysis was completed by the Stable Isotopes Laboratory at the Marine Biological Laboratory in Woods Hole, MA. Isotope results were used formulate a food web for each site and isotope values from previous SES projects were used to flesh out observations whenever possible.

Nutrient analysis was run on filtered water samples taken from each site. These samples were filtered with 25 mm, 0.45 µm GFF filters in a Swinex apparatus. Nitrate, ammonium and phosphate determinations were done for two samples from every location. Nitrate analysis was completed using the Lachat Flow Injection Analyzer in an adaptation of E. D. Wood et. al. Ammonium determination was adapted from J. D. H. Strickland and T. R. Parsons, and L. Solarzano. Phosphate determination was adapted from J. Murphy and J. P. Riley. Results were considered for signs of nutrient loading. Two additional water samples for each site were filtered at a pressure ≤12 mm Hg through 45 mm, 0.45 µm GFf filters and incubated in culture medium (Millipore m-FC with Rosolic Acid) for fecal coliform bacteria and any resulting colonies were counted at 12, 24 and 48 hour increments. These counts were compared with EPA standards for water quality (Table 4).

RESULTS

The percentage of cover suitable for fish habitat varied from site to site. Lower Bog and Flax II, both in their first decade of restoration, had the least available cover for fish with values of 5.46% and 2.73%, respectively. A significant increase occurred between these two 10-year sites and Red Brook and Zeke's Way, both of which have been in restoration for seven decades. The greatest fish habitat percentage occurred in Middle Bog, at 50.9%, followed by the other active bog site, Reservoir, at 40.1%. (Figure 6)

The diversity of available cover types increased with age of restoration. Reservoir Bog and Middle bog had only two types of dominant cover available (Figure 7, 8). More cover types became available in the first decade restoration sites of Lower Bog and Flax II (Figure 9, 10), and further increases, from 3-4 to 5-6, occurred between these preliminary restoration sites and the 70 year old Red Brook and Zeke's Way (Figure 11, 12). Cover variety was greatest in the unfarmed areas of Mashpee River and the forested, upstream Coonamessett River site. Each of these locations had seven 6 dominant cover types in addition to bare sediment regions (Figure 13, 14).

Invertebrate abundance followed two general trends: 1) Locations that were still being farmed or had been in restoration for shorter periods of time and had not achieve canopy closure over the stream had one dominant organism and trace abundances for all other invertebrates, and 2) locations that were natural and undisturbed from cranberry farming, or locations that had been restored long enough to achieve canopy closure, had less dramatic dominance and a more even distribution of abundance among the invertebrates present. The most common dominant organisms were *Amphipods.* The one anomaly to these trends was Flax II, which had a very distributed abundance and is a location that has only been in restoration for one decade. (Figure 15-22)

Productivity was highest in Middle Bog and Flax II (Figure 23). No distinct trend relating productivity values to restoration stage could be found. With the exception of Reservoir Bog and Flax II, invertebrate richness increased slightly with time spent in restoration (Figure 24). Water quality ranking based on the *Key to Macroinvertebrate Life in the River* also exhibited an increase with restoration on both a point scale (Figure 25) and a tally of the healthy, S taxa organisms present at each site (Figure 26). Flax II and Reservoir Bog remain the exceptions to these trends.

δ^{13}C results for detritus samples from all sites indicate that the detrital pool is primarily driven by terrestrial inputs at all locations (Figure 27). Live plant samples, including several types of submerged aquatic vegetation and one algae sample, meet expectations for δ^{13}C, but had higher than anticipated values for δ^{15}N (Figure 27). These high δ^{15}N values do not create traditional trends within each site when plotted against their respective δ^{13}C values (Figure 28-36). No feeding down the food web is immediately present through comparison of the sites (Figure 28-36); this is illustrated by the small range of δ^{15}N values seen among *Amphipods* for all locations they were sampled in (Figure 36).

Elevated nitrate conditions were found in Reservoir Bog, Middle Bog, Lower Bog and Zeke's Way, all of which fall in succession along the Coonamessett River (Figure 37). These values peaked at 44 µM NO_3^-. Lowest values were found in Flax II where the concentration was approximately 13 µM NO_3^-. Due to complications during storage, Ammonium and Phosphate determinations were spoiled, and the results of these determinations is thus unreliable. Fecal coliform colony counts fell between 0 and 2 for six of the studied locations (Table 5). After a 24 hour incubation, one Mashpee River sample had 3 colonies present, and Flax II supported 8 colonies on one sample and 11 on the site's second.

DISCUSSION

Habitat complexity increased with restoration time. This increase is clear in the amount of suitable fish habitat available in the younger restored bogs, Lower Bog and Flax II, and the bogs that have been restoring for seven decades, Red Brook and Zeke's Way (Figure 6). While the active bogs, Reservoir and Middle, have a large percentage of available cover for fish, this cover is less complex than what was found in well restored locations such as Zeke's Way and natural locations such as Mashpee River (Figure 6, 7, 8, 12, 14). Zeke's Way, Mashpee River and the upstream Coonamessett location all had mature trees alongside the rivers, adding complexity to the stream in the form of submerged roots, fallen branches, fallen trunks, overhanging branches, and allochthonous input such as leaf pack in the stream bed. This environment is much more complex than the beds of emergent marsh plants and submerged aquatic vegetation found in Reservoir Bog and Middle Bog and is more likely to support fish species as it not only provides in-stream protection, but protection and shading from predators outside of the stream as well.

While Mashpee River didn't have the highest available fish cover, it displayed a healthy distribution of invertebrate abundance (Figure 22). The high amount of bare sediment in Mashpee (Figure 14) may help to support this. The gravel-based sediment in Mashpee River is conducive to algae growth and is the preferred habitat of stonefly larvae and mayfly larvae, two invertebrates that are known to prefer high water quality. Mashpee River scored highest in the macroinvertebrate key to water quality in both the numerical score and its abundance of high quality species (Figure 25, 26). This river is the least disturbed of the study locations and is considered to be the most pristine river environment on Cape Cod; it is likely that prior to being cleared for agriculture the active and restoring bog sites resembled Mashpee. When using this as location as the benchmark for restoration, none of the restored sites match it completely in terms of the water quality index, invertebrate distribution, and habitat complexity.

The distributions of invertebrate abundance for Reservoir Bog, Middle Bog, Lower Bog and Red Brook are all dominated by one type of organism (Figure 15, 16, 17, 19). For each of these cases, the dominant organisms are *Amphipods*, commonly known as scuds. Scuds are an invertebrate that's linked to average water quality (Figure 5). This pattern of dominance by one organism was anticipated in areas that haven't been in restoration long enough for the nearby terrestrial riparian zone to mature completely. These locations don't have tree closure over them, leading to very low shading in the stream and a lack of the terrestrial based habitat diversity seen in locations such as Zeke's Way, where tree roots create overhanging banks and fallen branches provide complex cover. Invertebrate abundances in the forested, upstream section of the

Coonamessett and Zeke’s Way more closely match that of the Mashpee River, leaning away from dominance by one organism and showing more even distribution among the most prevalent invertebrates (Figure 20, 21).

Flax II proved to be an interesting study site. The invertebrate abundance present at Flax II was more evenly distributed than Mashpee (Figure 18), and it had the highest productivity of any site (Figure 23). It also had high species richness, particularly when compared with Lower Bog, its fellow first decade restoration site (Figure 24), and Flax II scored excellently in the macroinvertebrate quality test (Figure 25, 26). However, Flax II had very low cover complexity and the least available habitat for fish (Figure 6, 10). The stream studied at Flax II is positioned between two ponds. At the head of the stream is Flax Pond, the reservoir that feeds into the stream, and at the base of the studied section was a developing pond in a sink holed that had formed in the middle of the bog. While the stream still flows, albeit slowly, through this developing pond and ends as a tributary of the Coonamessett River, it is heavily influenced by the pond systems present in Flax II. The rich, invertebrate community of Flax II could indicate a mixing of the stream and pond environments, and the slow moving water of the Flax II stream could be allowing species that normally prefer still-water to develop. Flax II was also the only system to show consistently high levels of fecal coliforms (Table 4). This could be the result of the pond environments surrounding Flax II, as the still-water in these locations would more readily allow fecal coliform bacteria to grow. Additionally, development around Flax Pond could have contributed septic leakage.

Taking into account the anomaly of Flax II, the invertebrate richness increases distinctly with restoration age (Figure 24). Water quality, as indicated by the macroinvertebrate key, also increases with restoration age (Figure 25, 26). Reservoir Bog functions as an exception, as its high invertebrate counts stem from an abundance of very tolerant organisms that are traditionally indicative of low water quality. The trend in increasing water quality is best seen in the S taxa counts (Figure 26). S taxa are invertebrates, such as caddisflies, that are associated with high water quality. These patterns imply that with longer periods of restoration, streams are capable of hosting a healthier invertebrate population, suggesting that the stream quality of restored bogs is better than that of active bogs.

The vegetation samples sent for stable isotope analysis returned high δ^{15}N values (Figure 27). High δ^{15}N values such as these normally indicate that an organism is located higher in the food web— something that is unlikely for plants, as they typically form the base of the food web. This trend is partially explained by the nitrate concentrations for the test sites. Nitrate is an excellent indicator of nutrient loading as it is capable of filtering through sediments with low attenuation. Nitrate concentrations were particularly high in the Coonamessett locations (Figure 37). It’s possible that the plants growing within these environments have their high δ^{15}N values because of this nitrogen loading. The presence of organic farming along the Coonamessett, within Reservoir Bog and Middle Bog, could also be adding to the δ^{15}N. Organic farming employs fertilizers like fish emulsion. Because fish emulsion traditionally has higher δ^{15}N values due to the carnivorous and omnivorous diets of most fish, when these fertilizers run off into the rivers and streams of the bogs the plants get a dose of heavy nitrogen compounds.

δ^{13}C values for detritus samples taken from each location indicate that the detrital pool is primarily driven by terrestrial inputs (Figure 27). The δ^{13}C values for all detrital samples fall very close to that of a maple leaf, indicating that they have terrestrial origins. The food webs for most of the study sites show that these systems are very detritus based (Figure 28-35). While the invertebrates present at these sites are pulled slightly towards the elevated vegetation values, they remain closest to the detrital pool. In Flax II, sampled invertebrates are pulled towards a carbon source that is not represented in the range of tested vegetation (Figure 32). It is likely that this food web is heavily influenced by an algae or vegetation sample that was not tested. This is also evident if the Lower Bog food web (Figure 31). This trend in young restoration sites may indicate that stream ecosystems that have only undergone restoration for short periods of time are not completely supported by detritus or large primary producers like water starwort, and have a developing foodweb that is distinctly different at its base than the active bogs or older restored sites in.

Amphipods, which were samples for isotope composition in all but one location, show no considerable differences in their δ^{15}N values (Figure 36). This could be an indication that these food webs are all fairly consistent in their placement of organisms, and that no dominant feature is feeding outside of its traditional range to account for stressed environmental conditions. However, sampling of higher trophic levels would need to be performed before this conclusion can be confirmed.

CONCLUSION

Based on the trends found in my habitat and invertebrate data, there appears to be a direct, positive connection between the quality of streams if flow-through cranberry bogs and the amount of time they spend in natural restoration. This result is encouraging for the State of Massachusetts's current efforts in restoring discontinued bogs, and helps show that the efforts to conserve several of the bog-sites along the Coonamessett River, as well as Red Brook in the Lyman Reserve, are justified and promising. These lands are already used actively by the local community as recreational areas, particularly to walk their dogs, and continuing their restoration will only yield more beautiful, natural landscapes for the local Cape Cod population to enjoy.

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TABLES

Table 1: Location and restoration status of all sites

Site ID	**Street Address**	**GPS Coordinates**	**Restoration Status**
Reservoir Bog	John Parker Road East Falmouth, MA		Active Agriculture
Middle Bog	John Parker Road East Falmouth, MA		Active Agriculture
Lower Bog	John Parker Road, East Falmouth, MA		6 Years Restoration
Flax II	Parker Road East Falmouth, MA		6 Years Restoration
Red Brook	Head of the Bay Road East Wareham, MA		56 Years Restoration
Zeke's Way	John Parker Road East Falmouth, MA		80 Years Restoration
Upstream Coonamessettt	Sandwich Road East Falmouth, MA		Never Cranberried
Mashpee River	Great Neck Road Mashpee, MA		Never Cranberried

Table 2: Cover types considered

Vegetation Cover	**Litter Cover**	**External Cover**
Submerged Aquatic Vegetation (SAV)	Leaf Pack (LP)	Overhanging Branches <1 m Above Surface (OB)
Emergent Marsh Plants (EMP)	River Litter (RL)	Overhanging Banks (Bank)
Benthic Algae	Roots	Leaning/Fallen Trees (Tree)
	Submerged Branches (SB)	

Table 3: Surber sample locations within each site

Site	Surber Habitat			
	Pebbled Sediment	**Sandy Sediment**	**Leaf Pack**	**Submerged Aquatic Vegetation**
Reservoir Bog		1		2
Middle Bog		1		2
Lower Bog		2		1
Flax II				3
Red Brook	2	1	1	2
Zeke’s Way	1	1		1
Upstream Coonamessettt		2		2
Mashpee River	1	1	1	

Table 4: Environmental Protection Association water quality standards for fecal coliform contamination

Fecal Coliform Colony Count after 24 Hour Incubation	**Water Quality**
0	Suitable for drinking water
≤14	Suitable for shellfishing
≤200	Suitable for swimming

Table 5: Fecal coliform colony counts for all locations

Check Point		t_0	t_1	t_2	t_3
Time (hrs)		0	15.7	23.9	48.2
Reservoir Bog	#1	0	1	1	1
	#2	0	0	0	0
Middle Bog	#1	0	0	0	0
	#2	0	0	1	1
Lower Bog	#1	0	0	1	1
	#2	0	0	0	0
Flax II	#1	0	1	8	8
	#2	0	0	11	13
Red Brook	#1	0	0	0	0
	#2	0	0	0	0
Zeke's Way	#1	0	0	0	0
	#2	0	0	2	2
Upstream Coonamessett	#1	0	0	1	1
	#2	0	0	0	1
Mashpee River	#1	0	1	3	4
	#2	0	0	0	0

FIGURES

Figure 1: Map of the Coonamessettt River

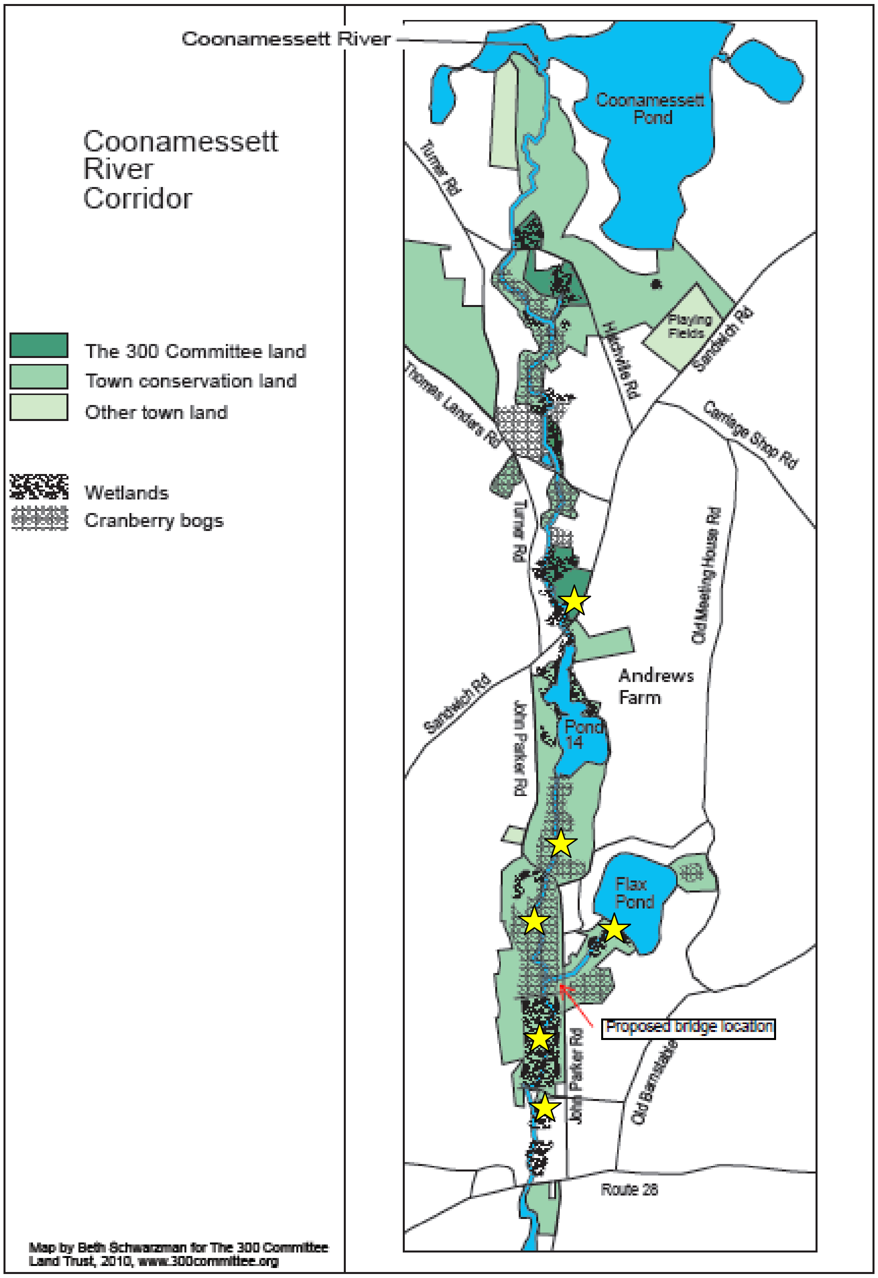

Figure 2: Detailed map of the Coonamessettt River bogs

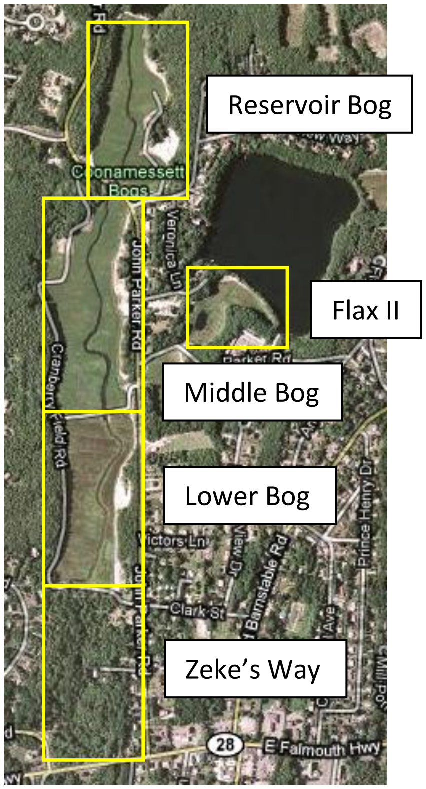

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Figure 3: Map of the Mashpee River

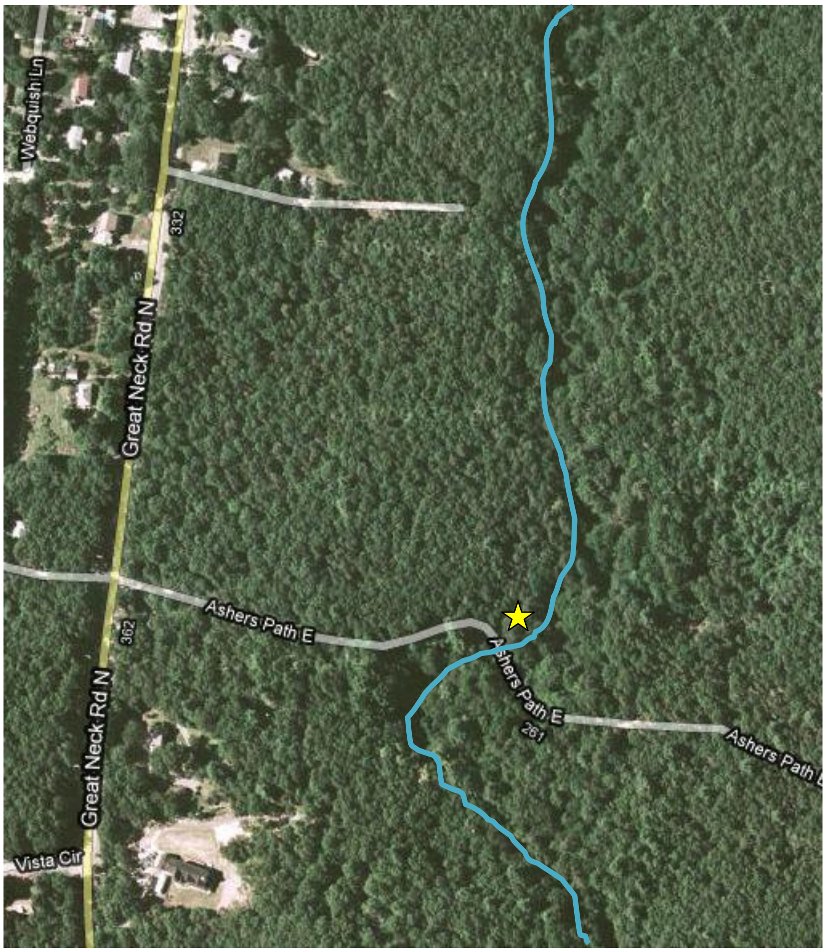
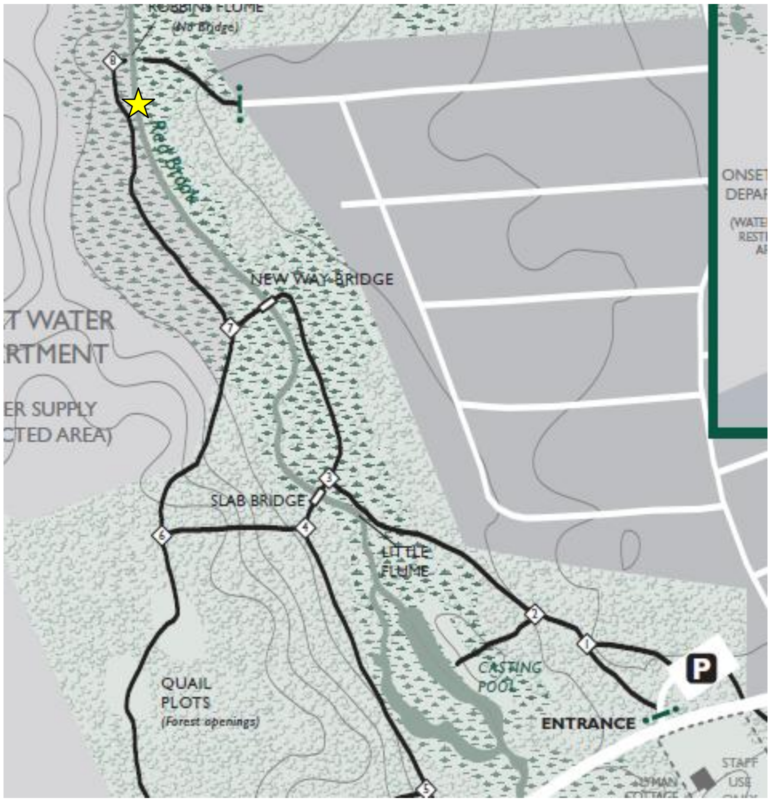


Figure 4: Map of Red Brook



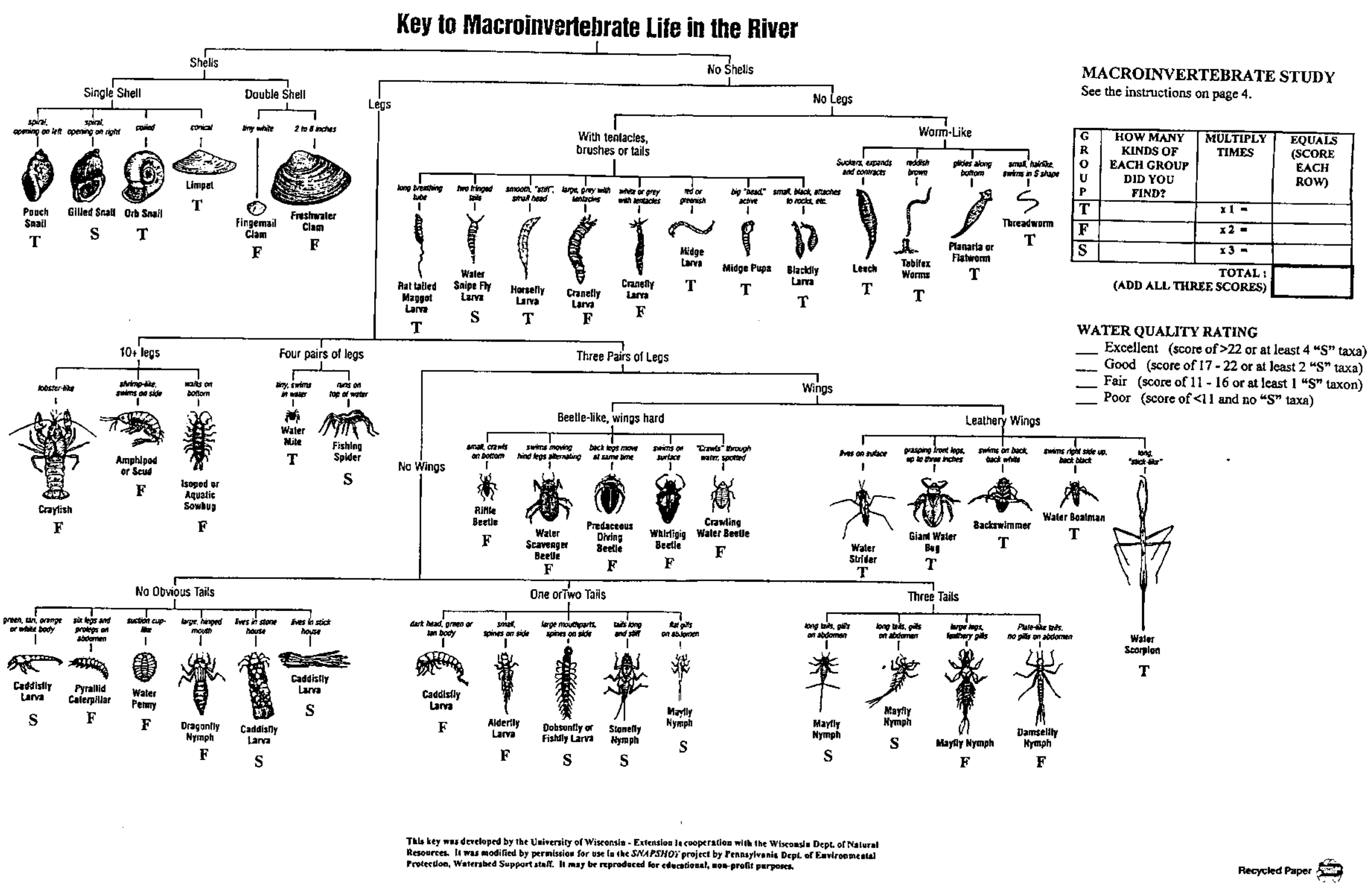


Figure 5: *Key to Macroinvertebrate Life in the River* from University of Wisconsin

MACROINVERTEBRATE STUDY

See the instructions on page 4.

GROUP	HOW MANY KINDS OF EACH GROUP DID YOU FIND?	MULTIPLY TIMES	EQUALS (SCORE EACH ROW)
T		x 1 =	
F		x 2 =	
S		x 3 =	
		TOTAL : (ADD ALL THREE SCORES)	

WATER QUALITY RATING

___ Excellent (score of >22 or at least 4 "S" taxa)
___ Good (score of 17 - 22 or at least 2 "S" taxa)
___ Fair (score of 11 - 16 or at least 1 "S" taxon)
___ Poor (score of <11 and no "S" taxa)

This key was developed by the University of Wisconsin - Extension in cooperation with the Wisconsin Dept. of Natural Resources. It was modified by permission for use in the *SNAPSHOT* project by Pennsylvania Dept. of Environmental Protection, Watershed Support staff. It may be reproduced for educational, non-profit purposes.

Figure 6: Percent of cover suitable for fish habitat per site

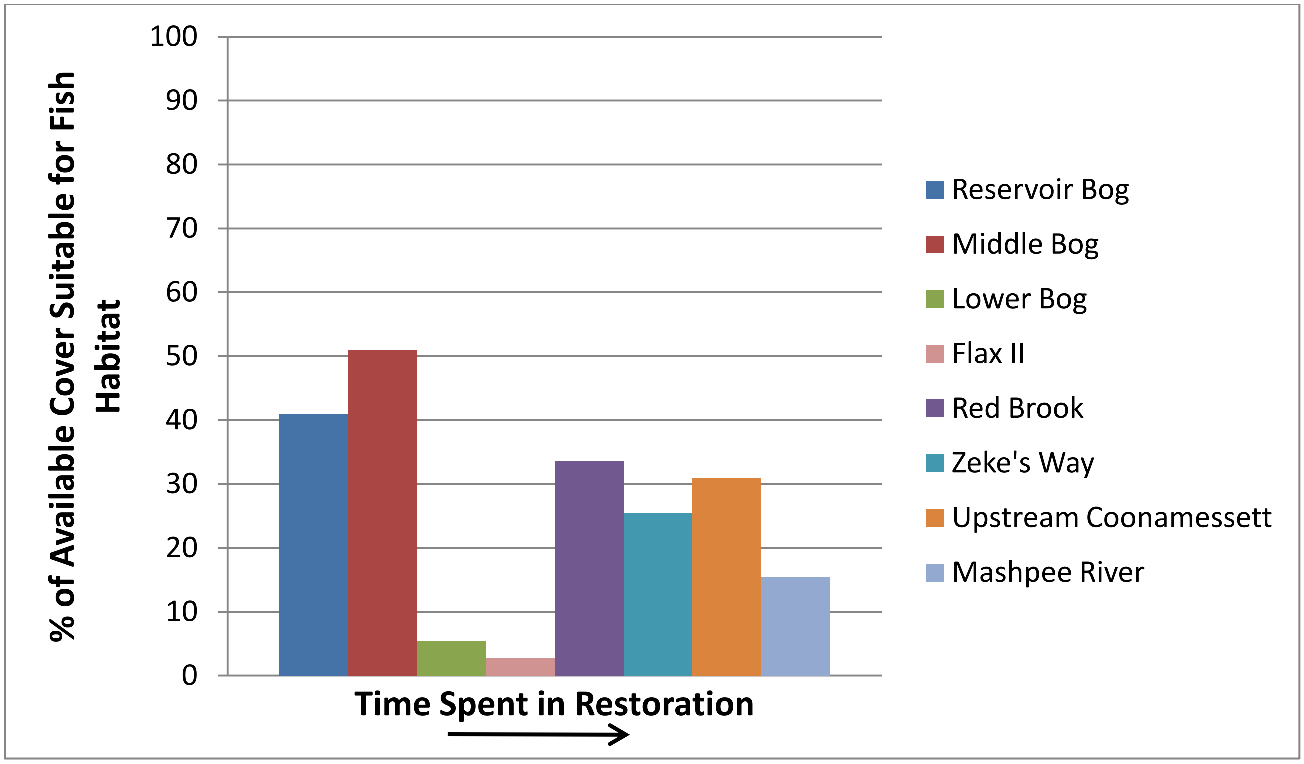


Figure 7: Dominant cover in Reservoir Bog

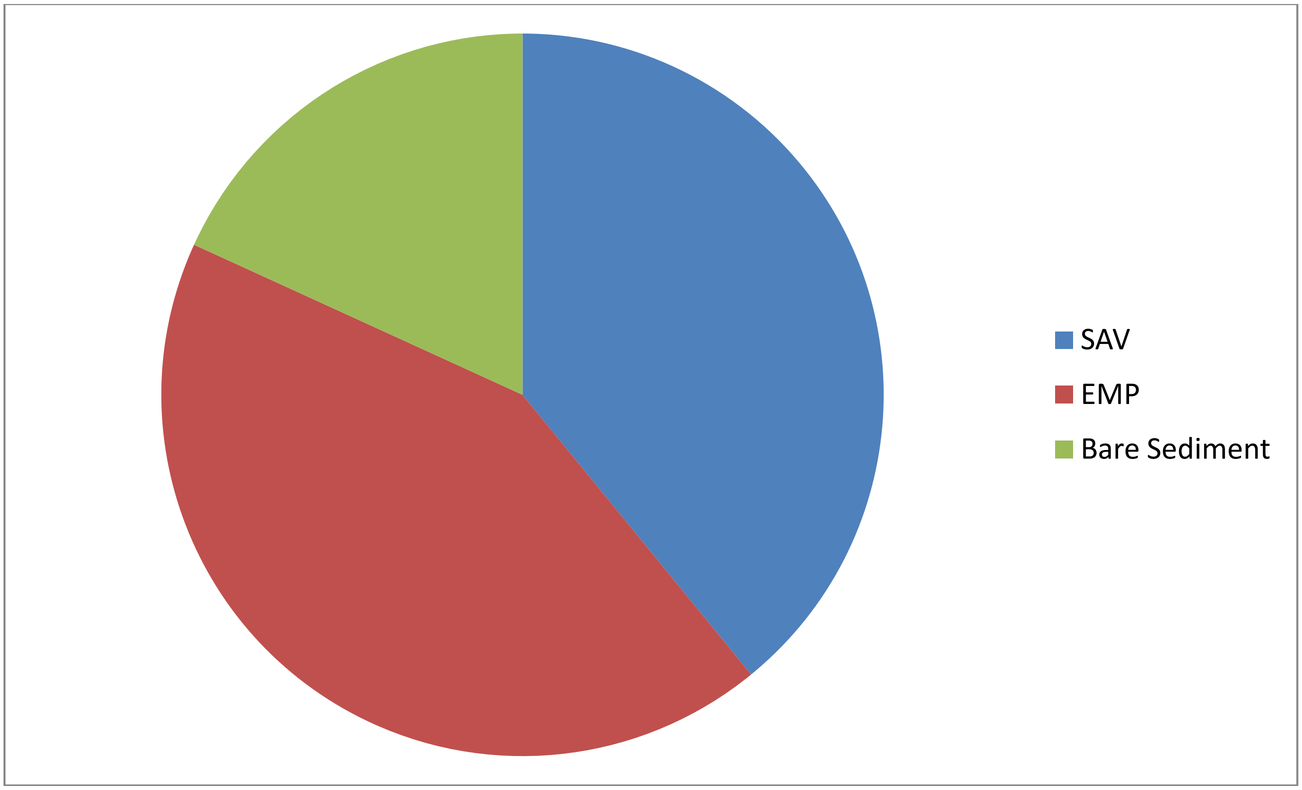


Figure 8: Dominant cover in Middle Bog

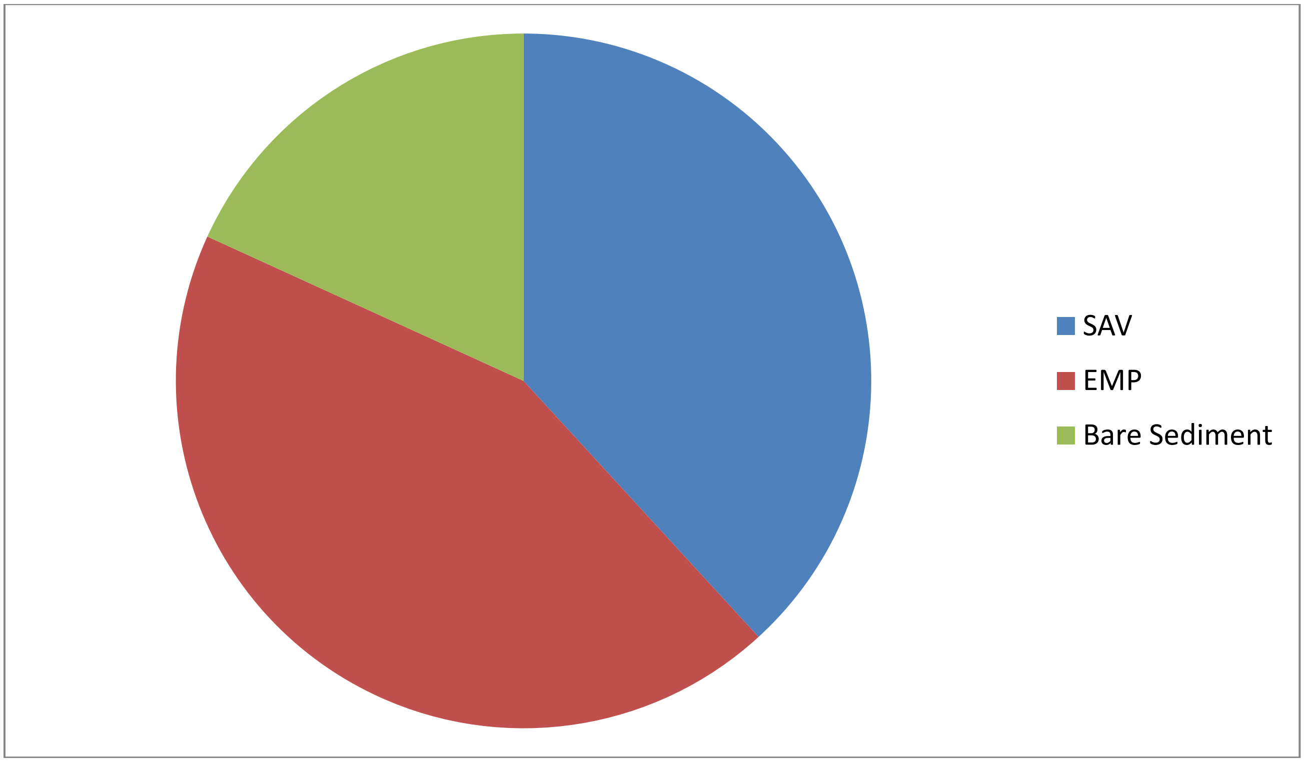


Figure 9: Dominant cover in Lower Bog

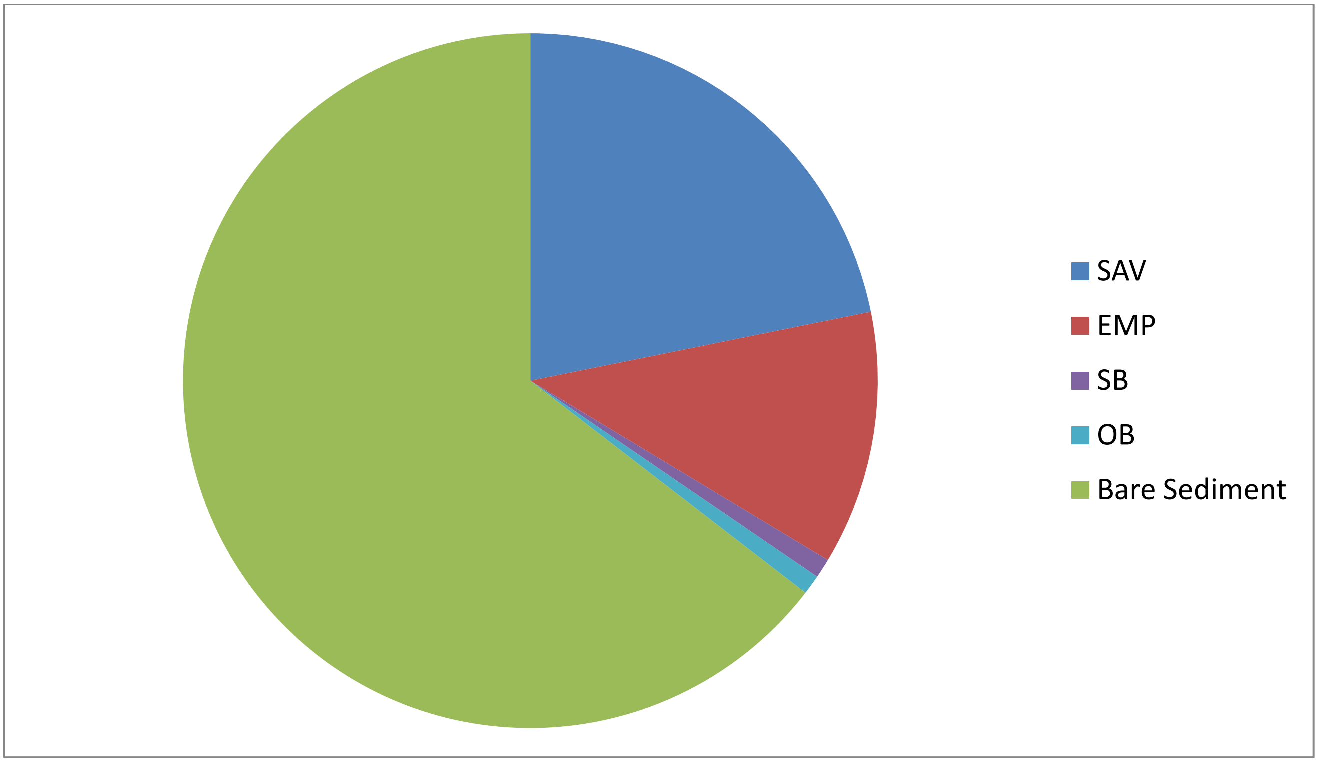


Figure 10: Dominant cover in Flax II

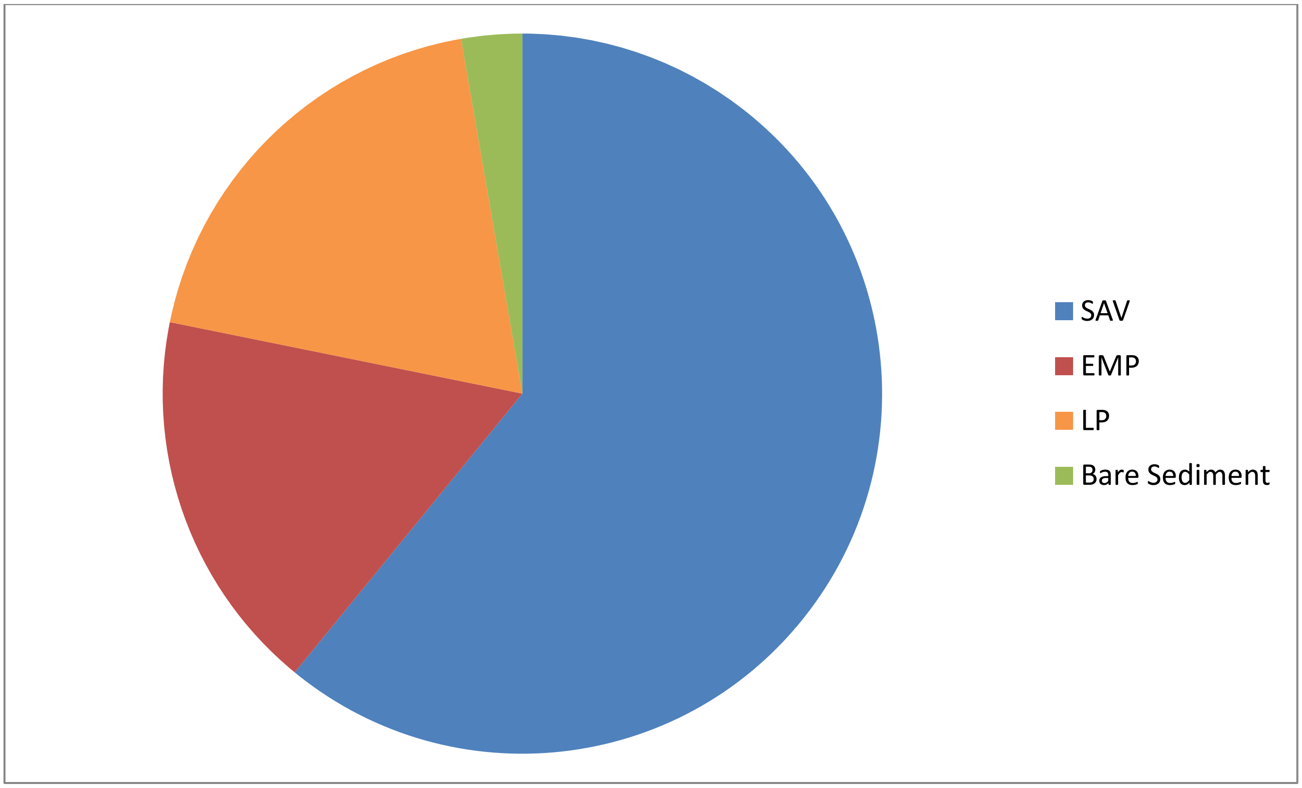


Figure 11: Dominant cover in Red Brook

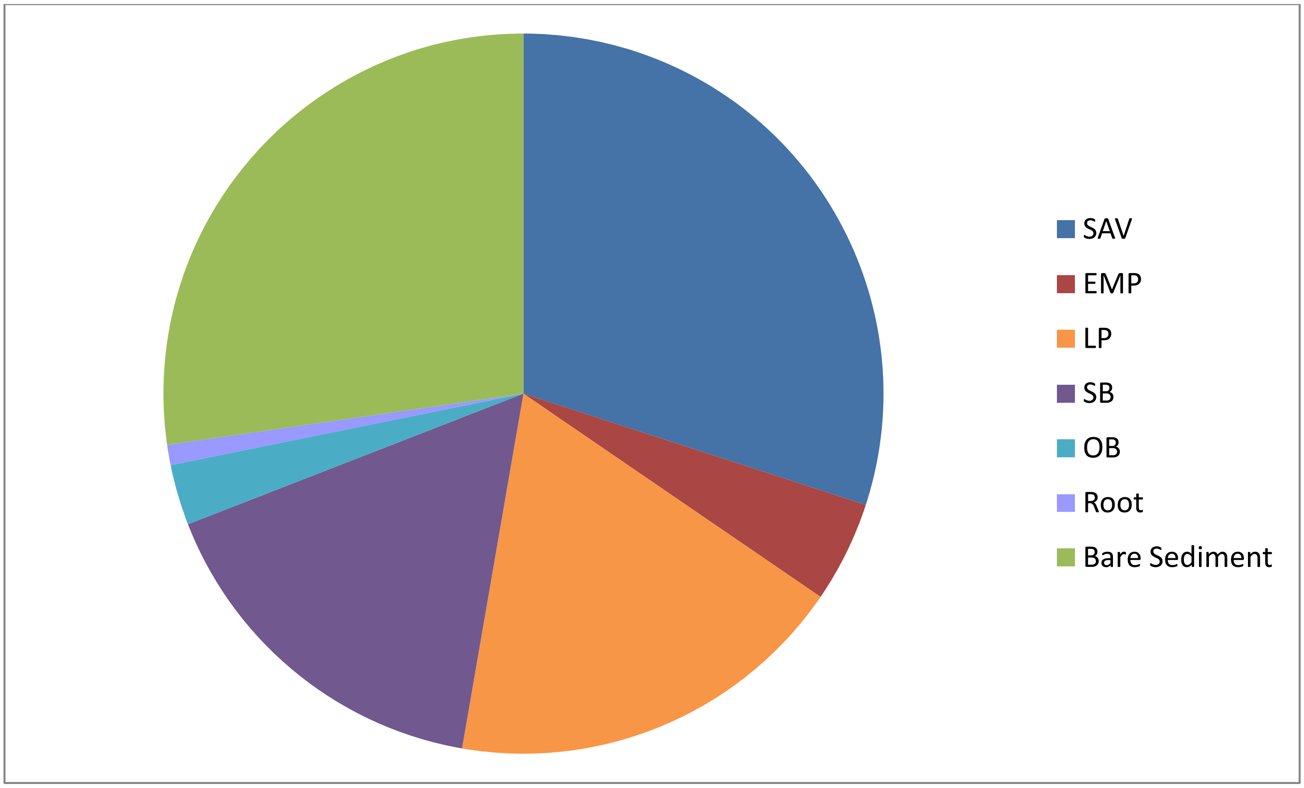


Figure 12: Dominant cover in Zeke's Way

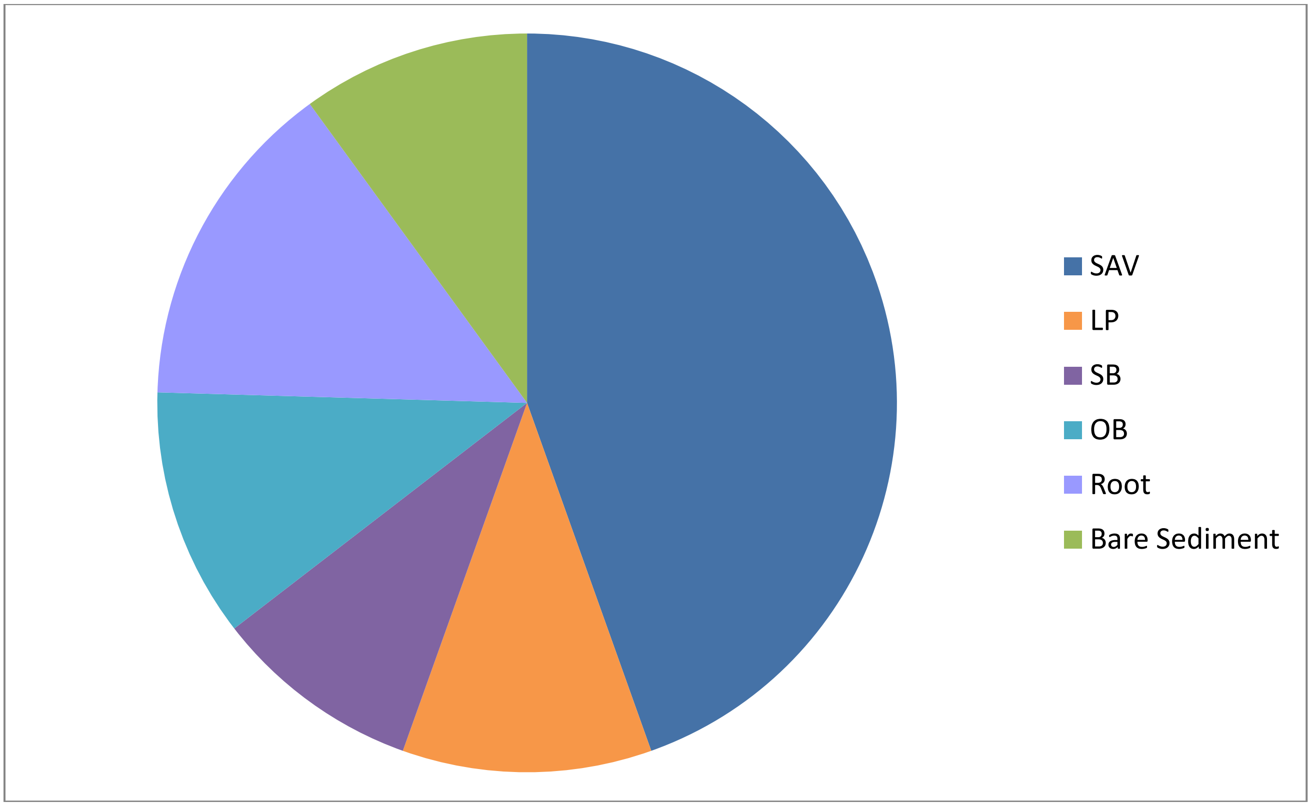


Figure 13: Dominant cover in the upstream Coonamessett site

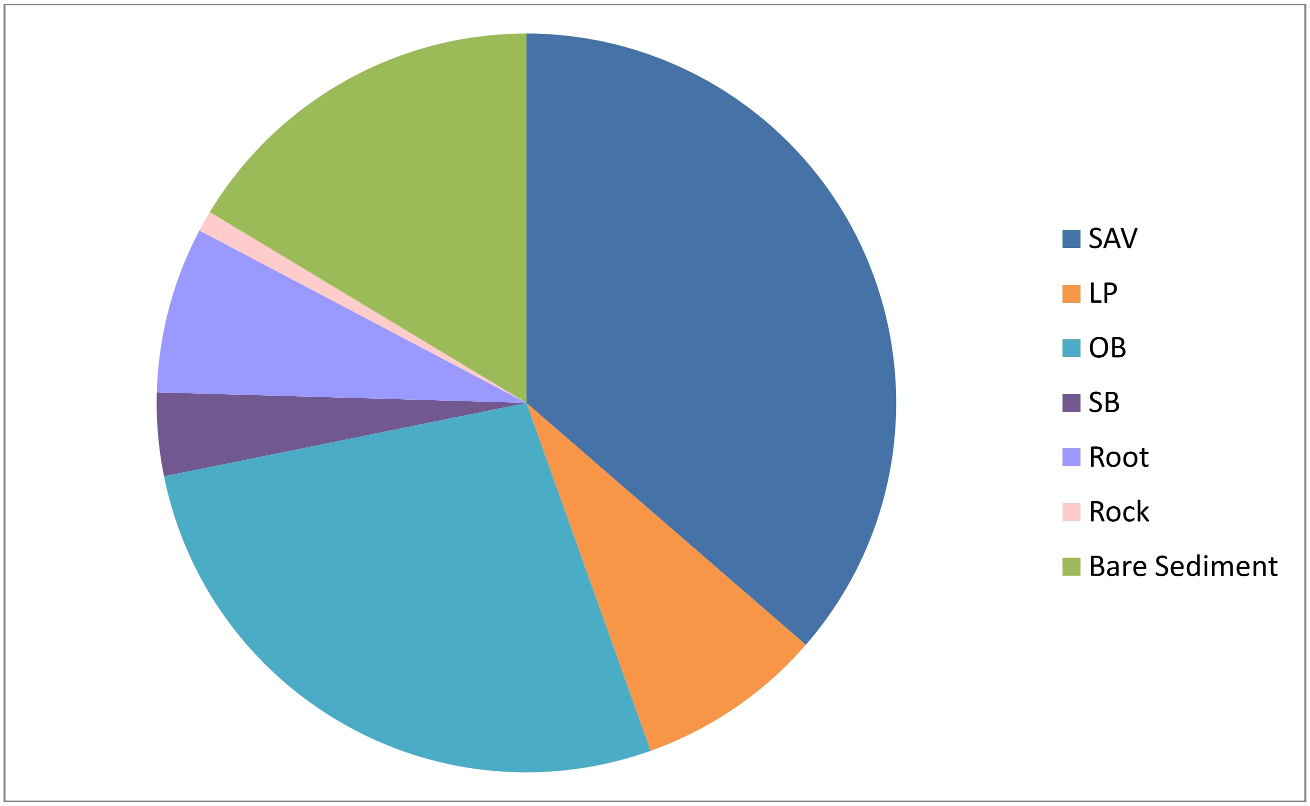


Figure 14: Dominant cover in Mashpee River

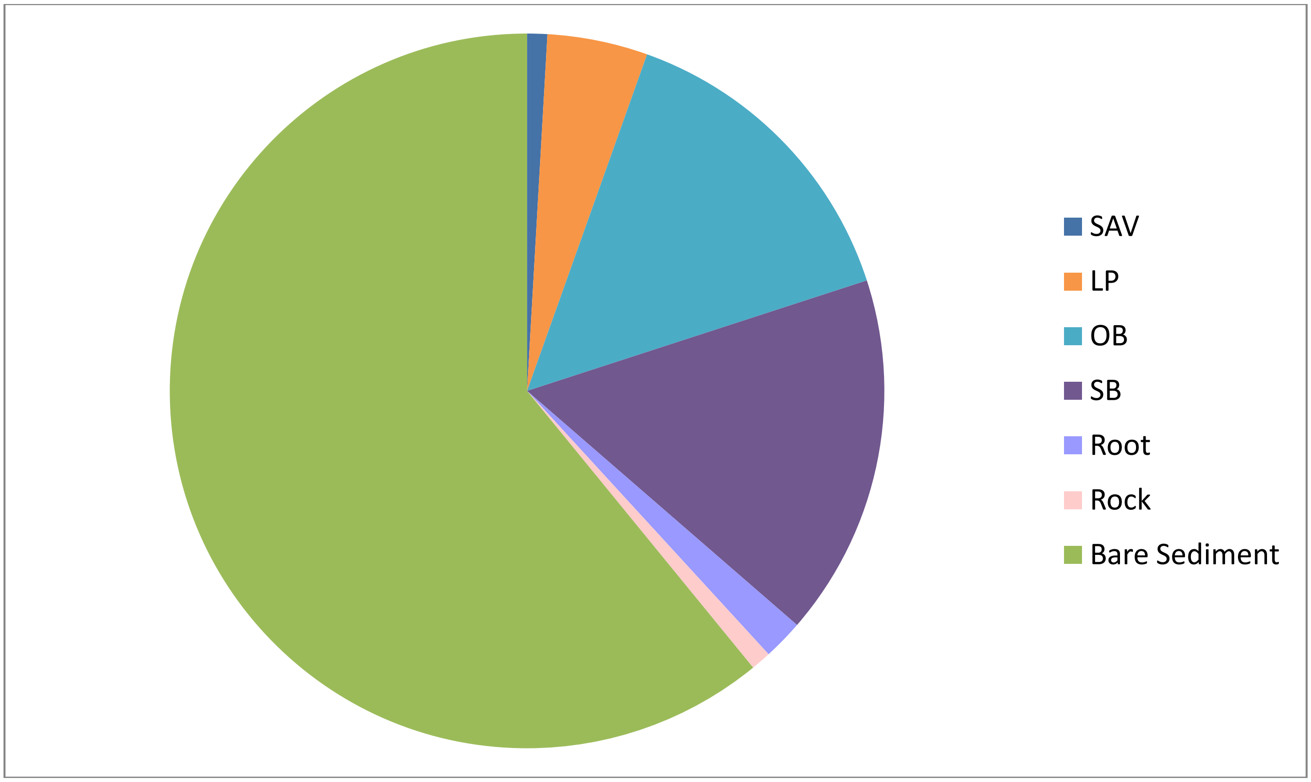


Figure 15: Reservoir Bog invertebrate abundance

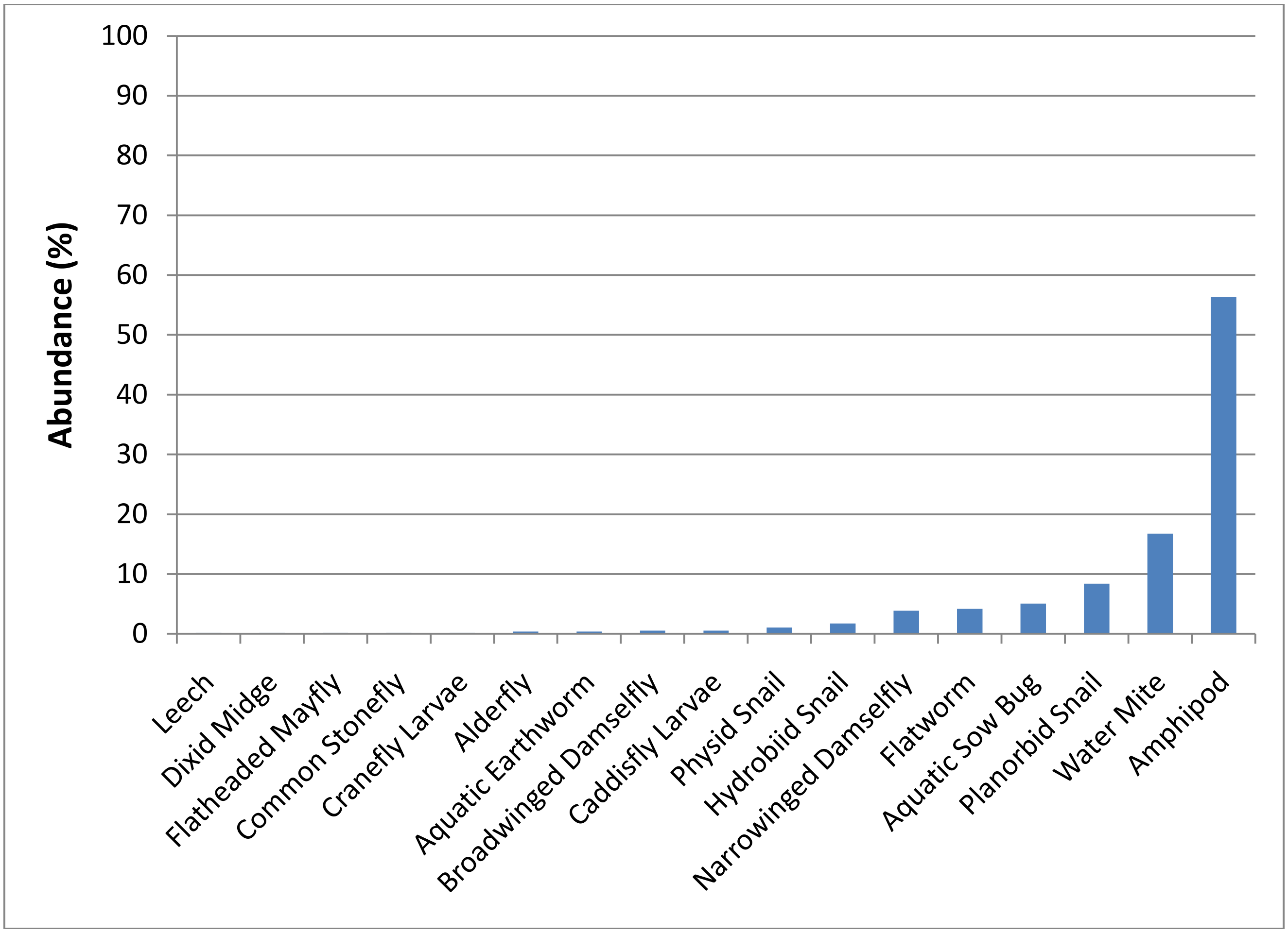


Figure 16: Middle Bog invertebrate abundance

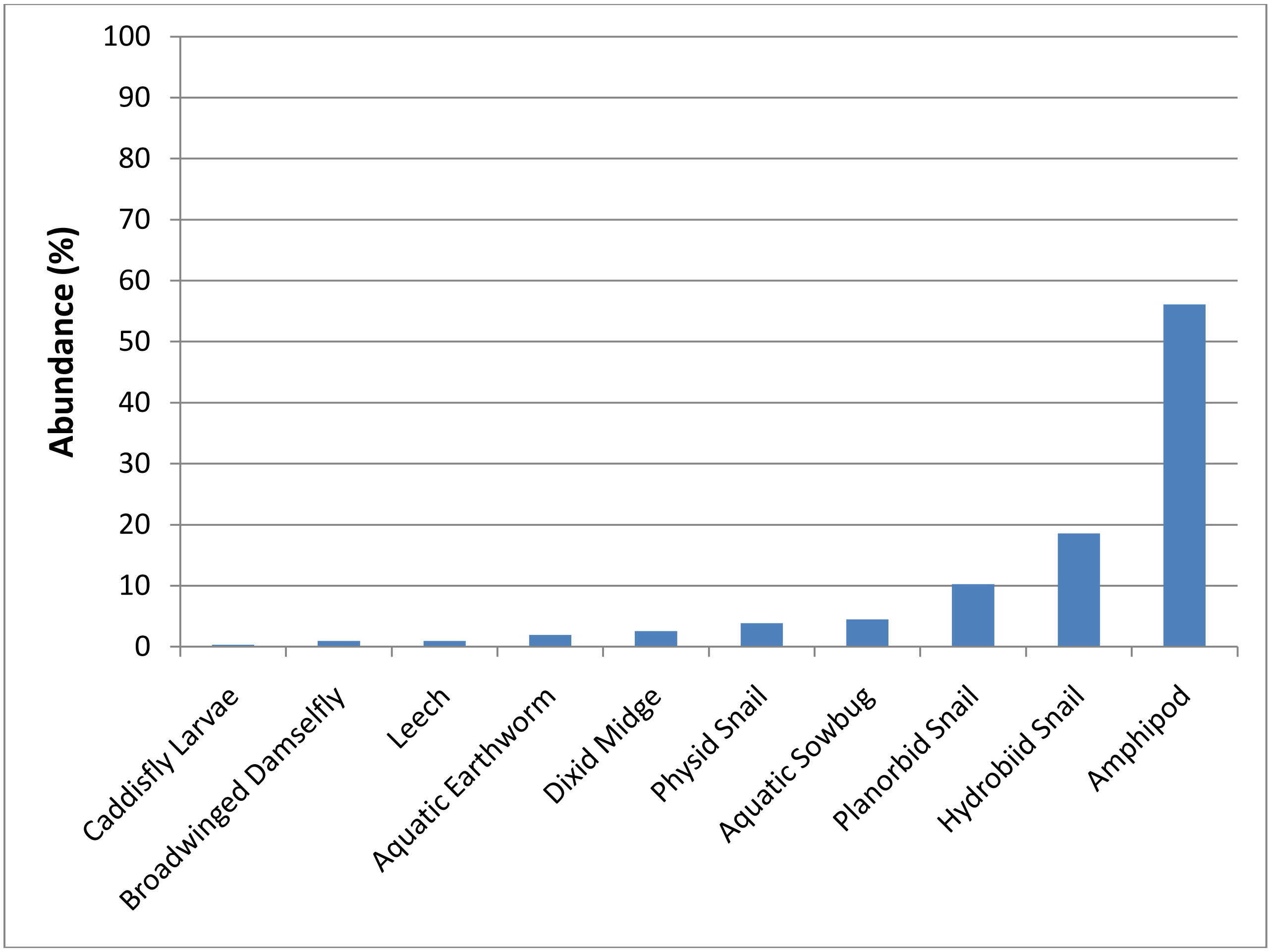


Figure 17: Lower Bog invertebrate abundance

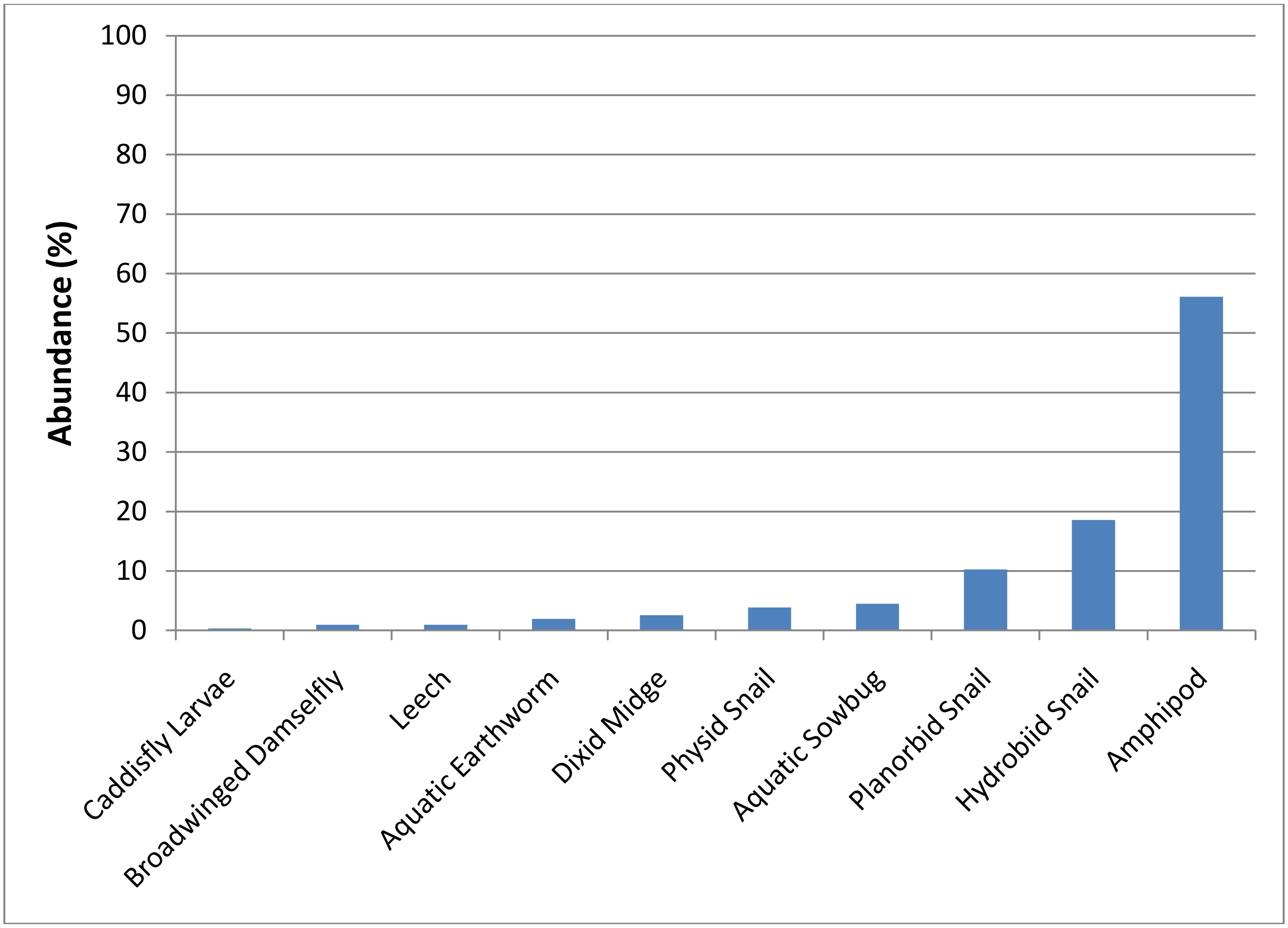


Figure 18: Flax II invertebrate abundance

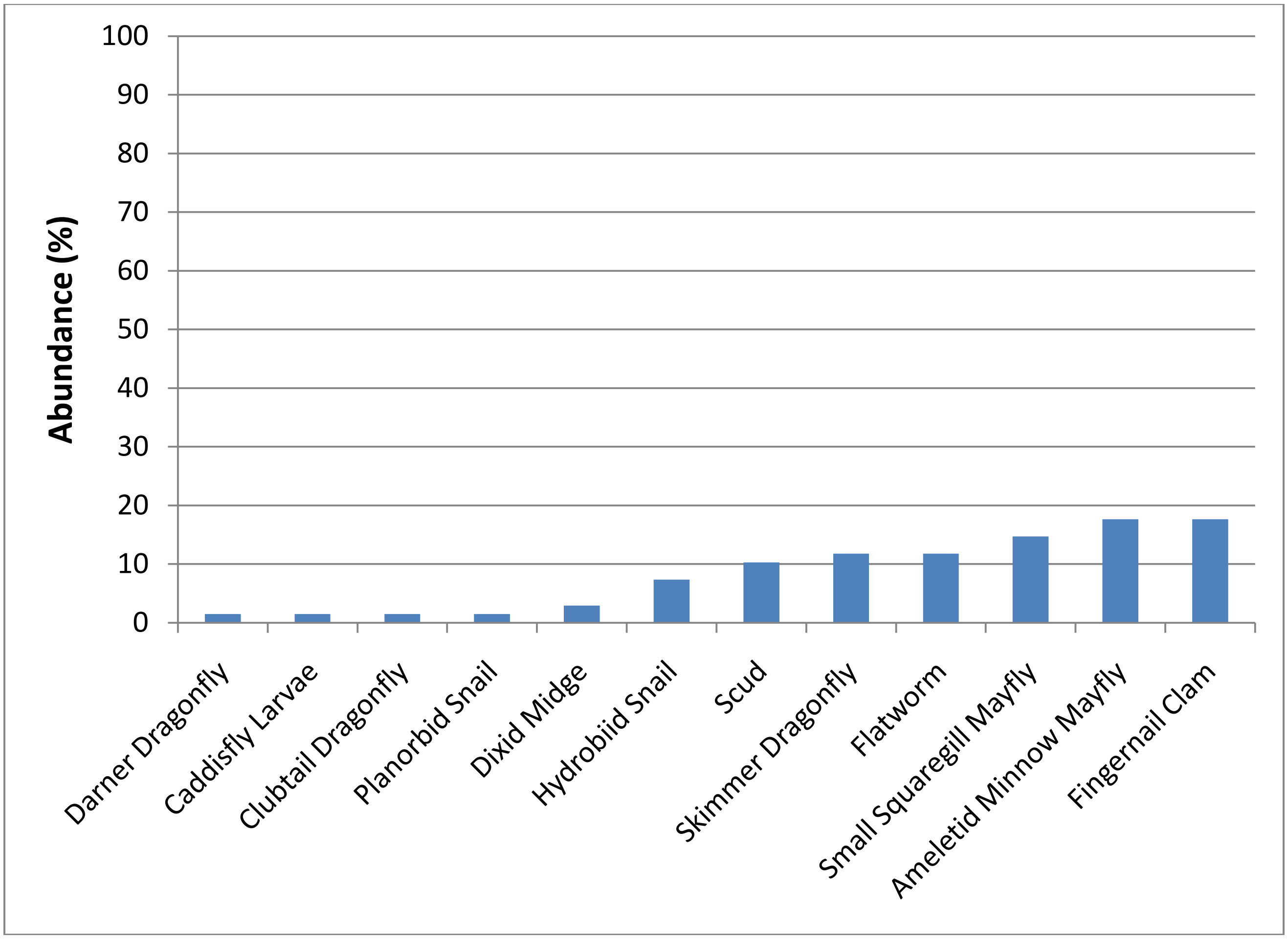


Figure 19: Red Brook invertebrate abundance

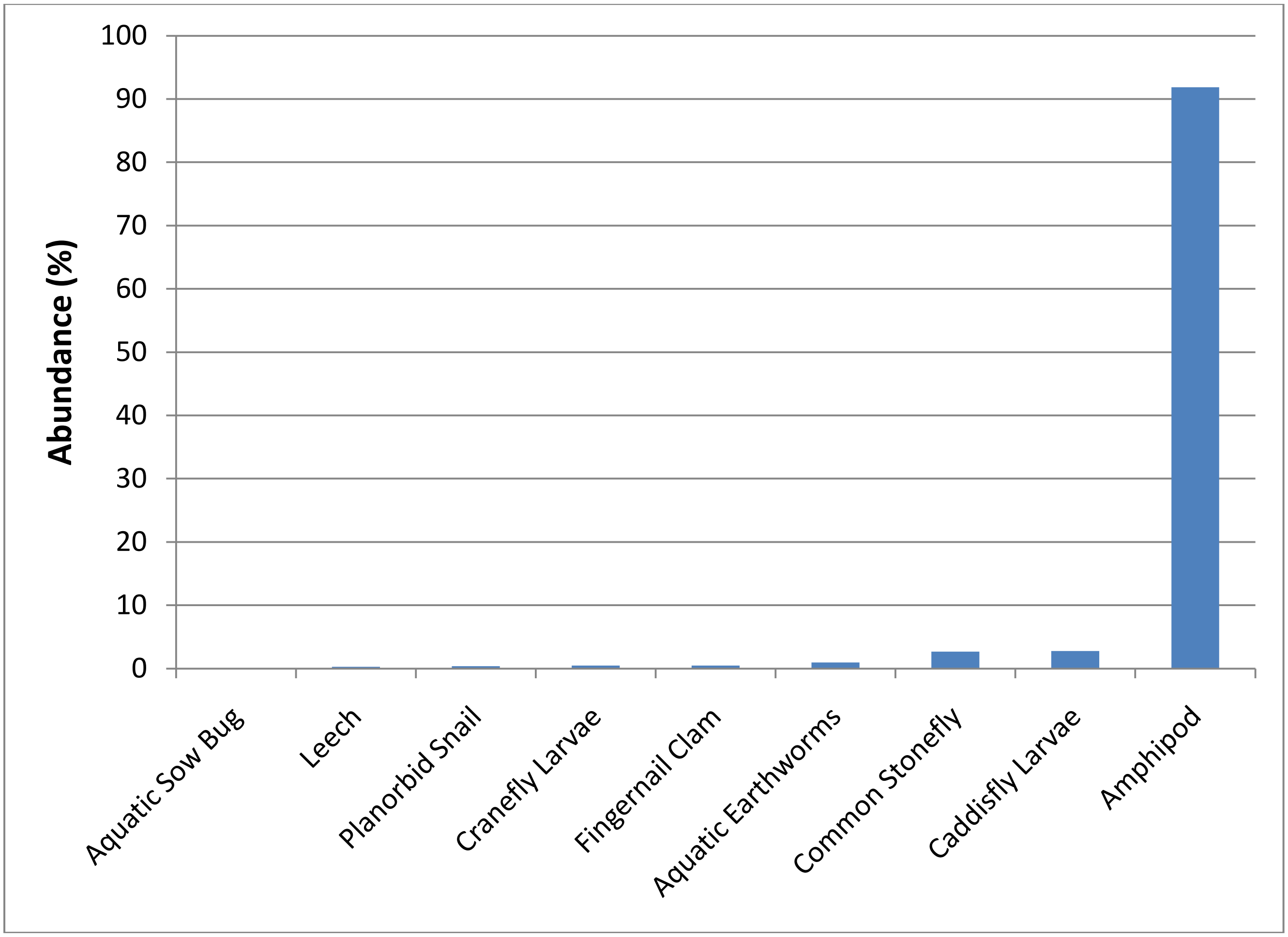


Figure 20: Zeke's Way invertebrate abundance

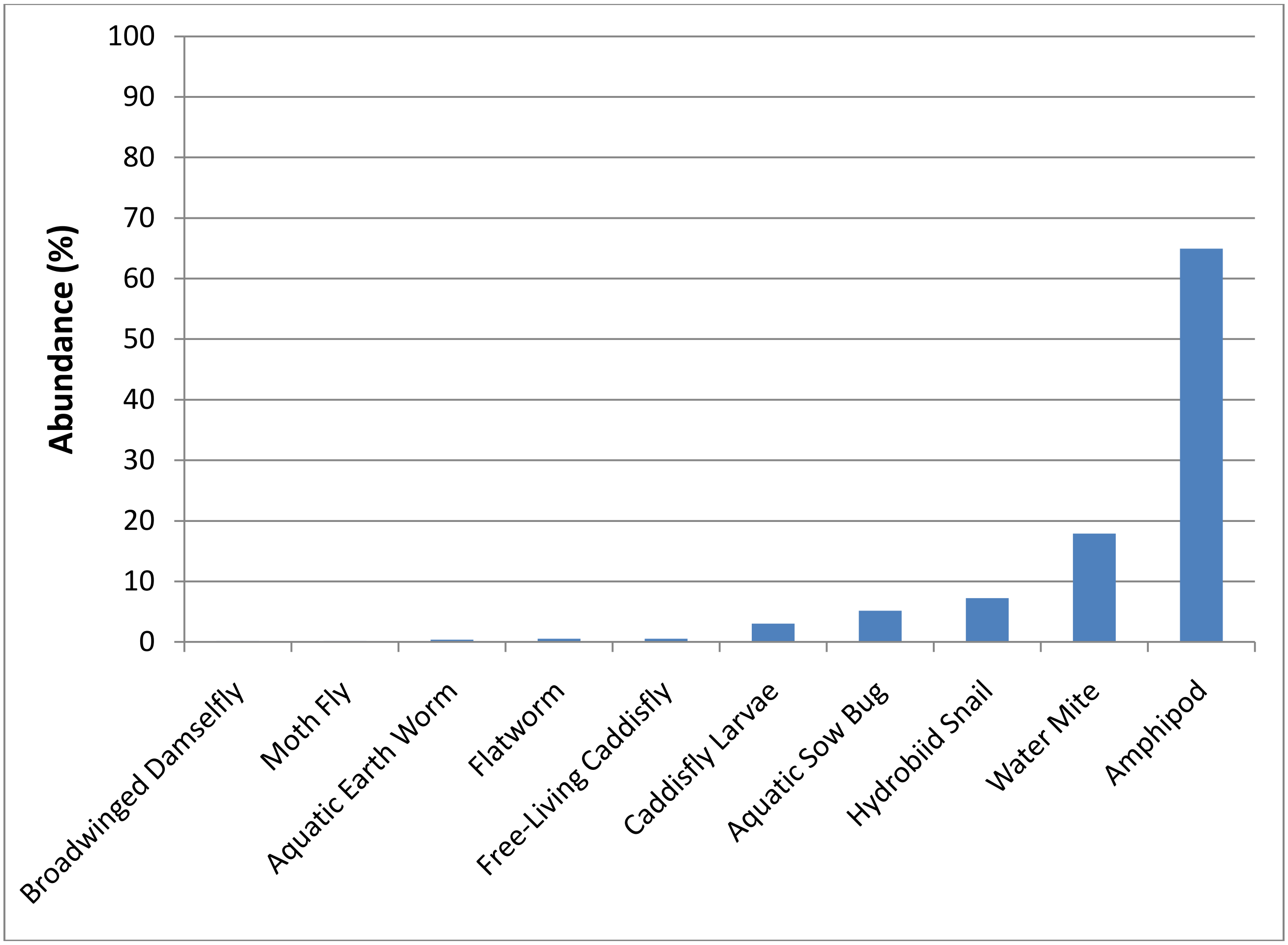


Figure 21: Upstream Coonamessett invertebrate abundance

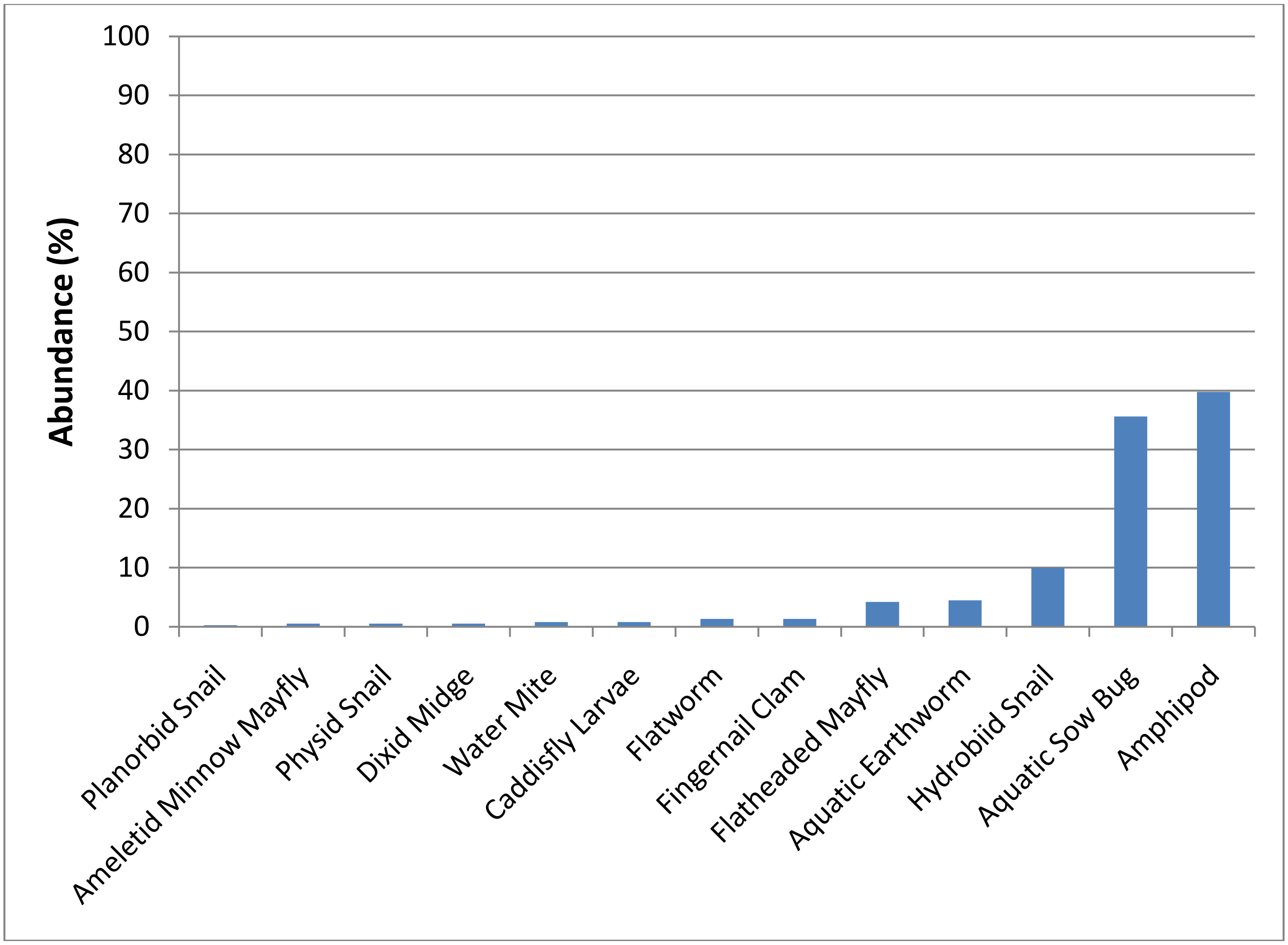


Figure 22: Mashpee River invertebrate abundance

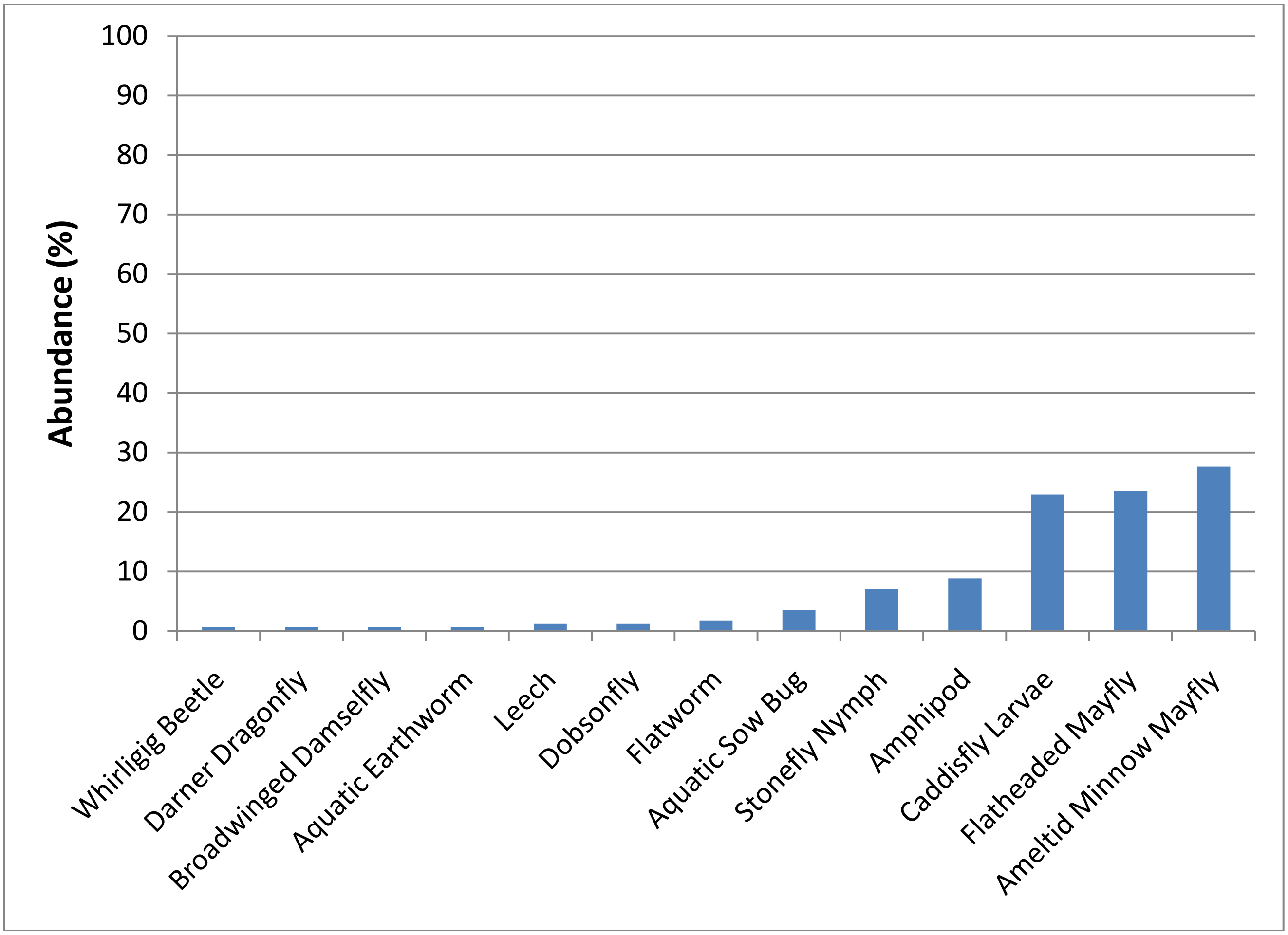


Figure 23: Invertebrate productivity per site

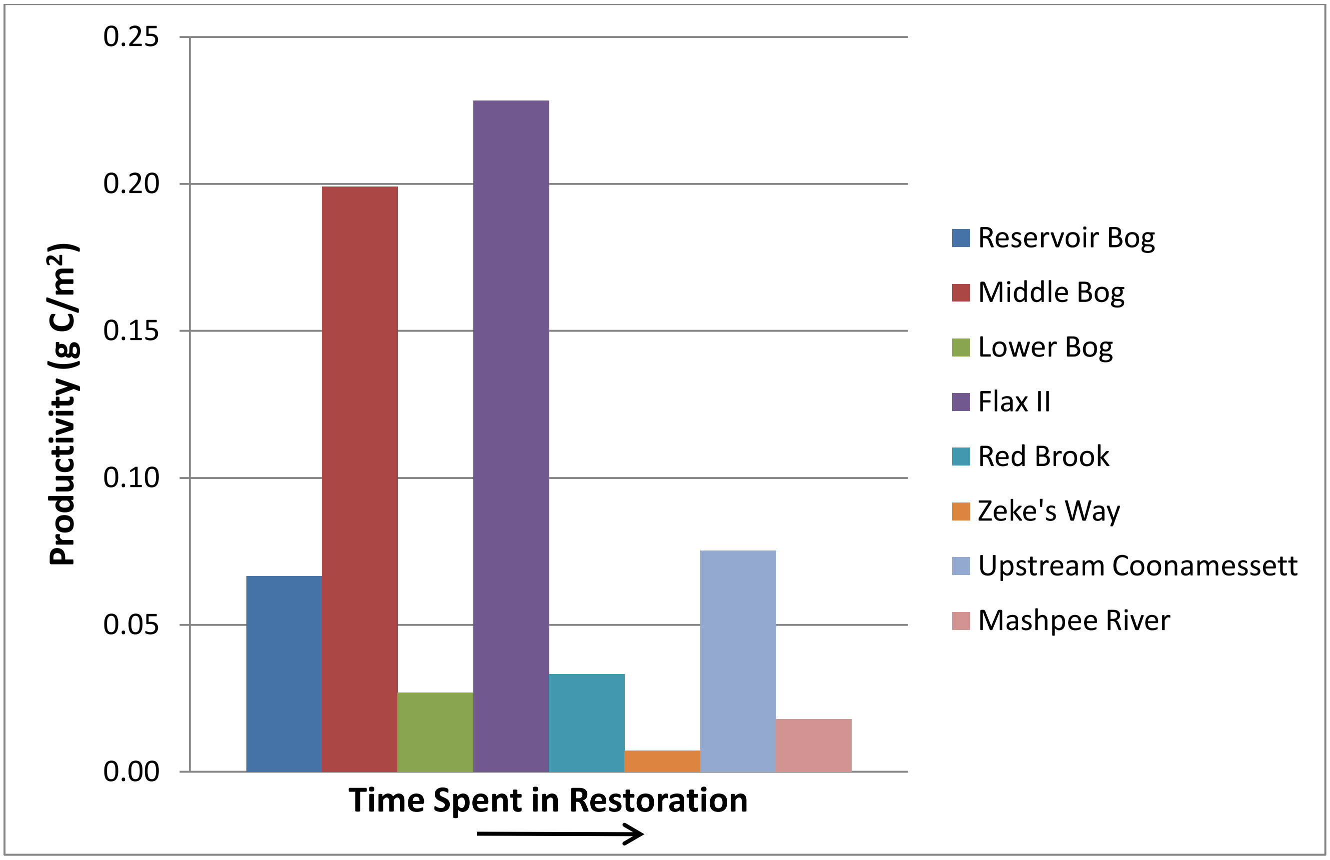


Figure 24: Invertebrate community richness per site

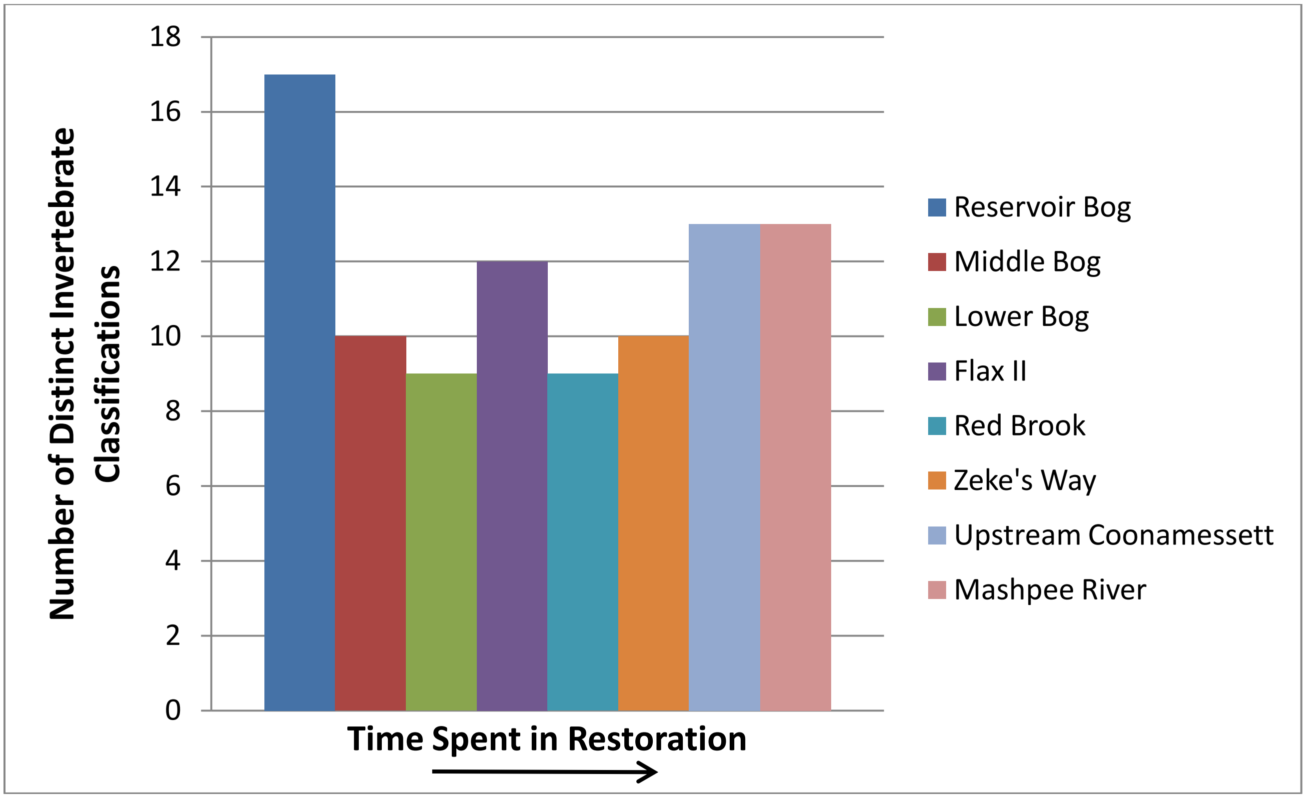


Figure 25: Macroinvertebrate key water quality scores

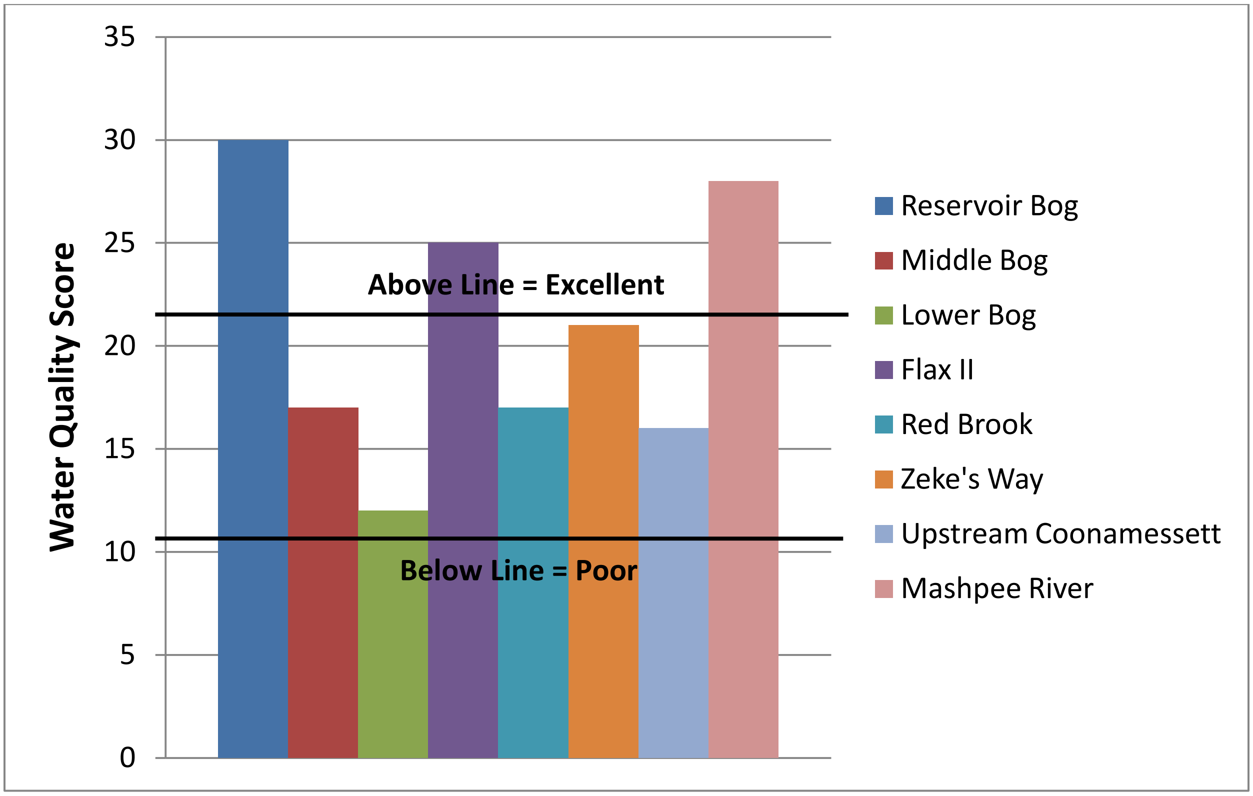


Figure 26: Total S taxa per site

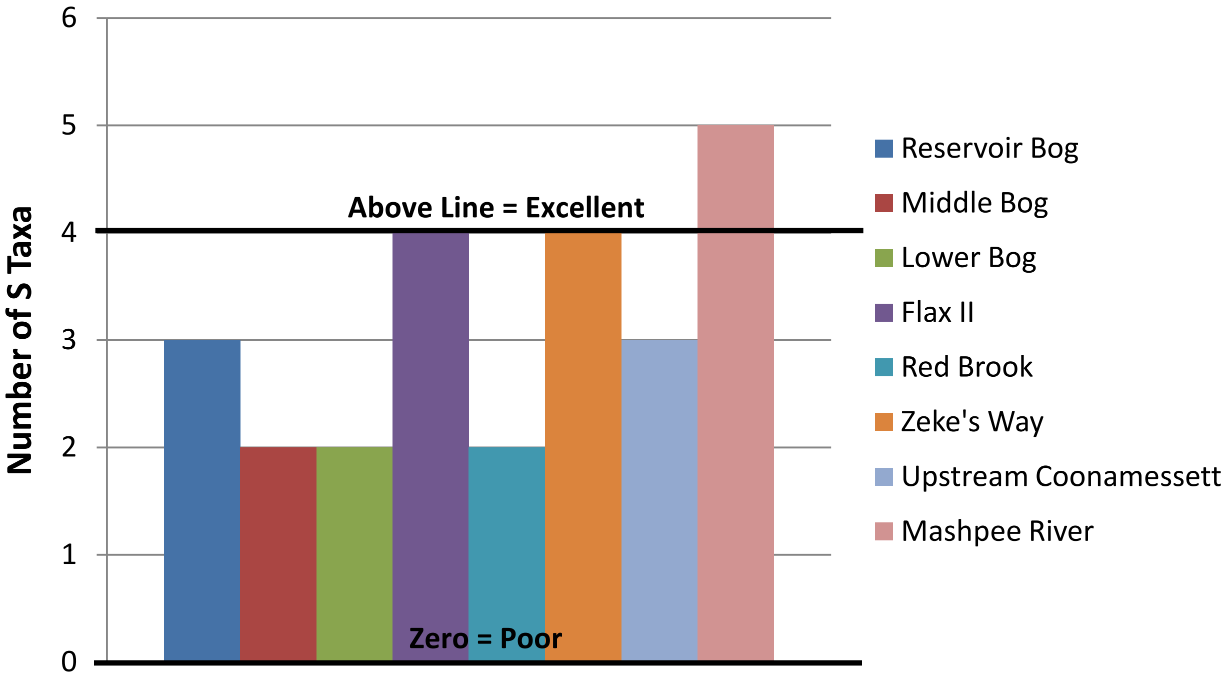


Figure 27: Vegetation stable isotope results for ^{13}C and ^{15}N

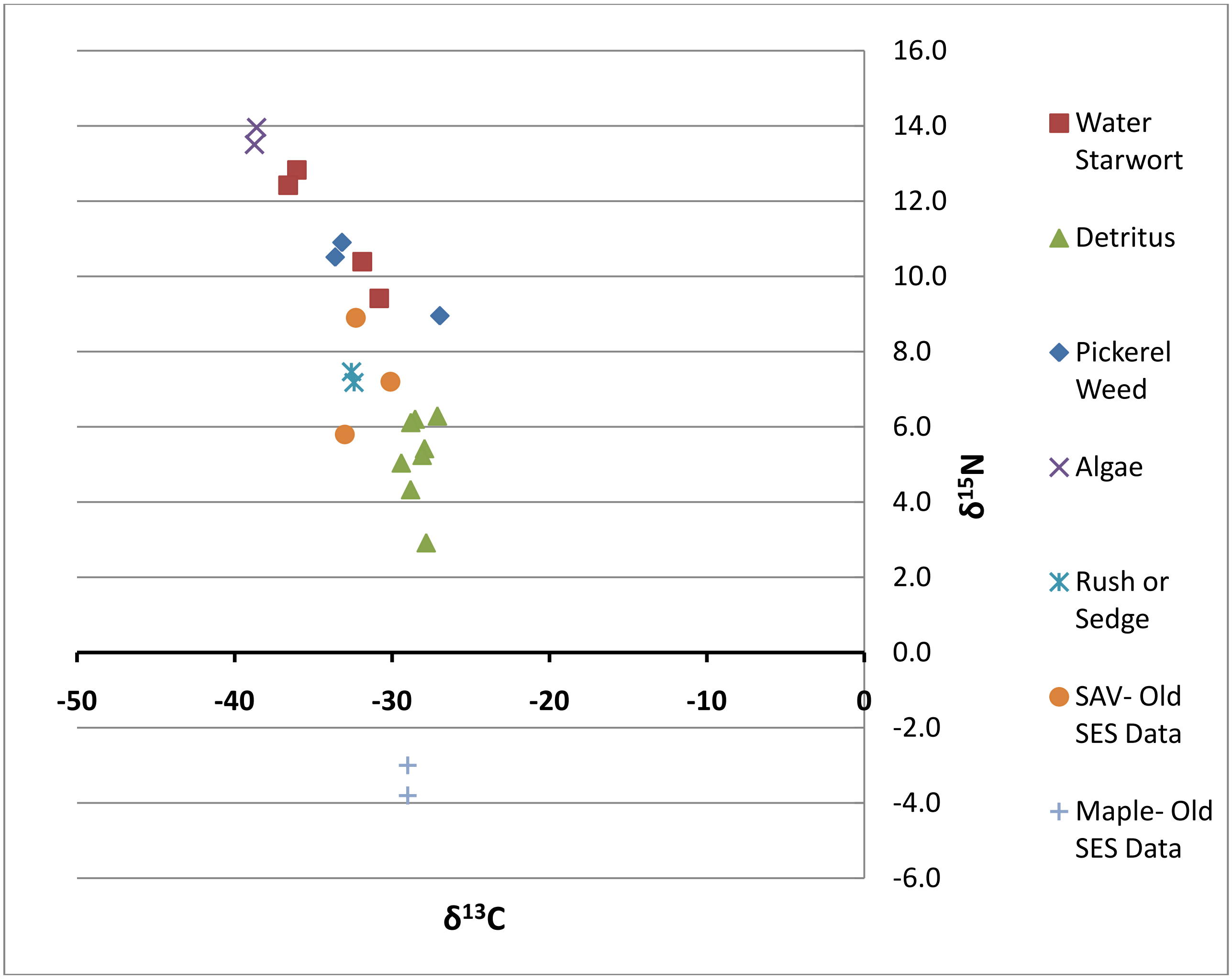


Figure 28: Reservoir Bog ^{13}C and ^{15}N stable isotopes

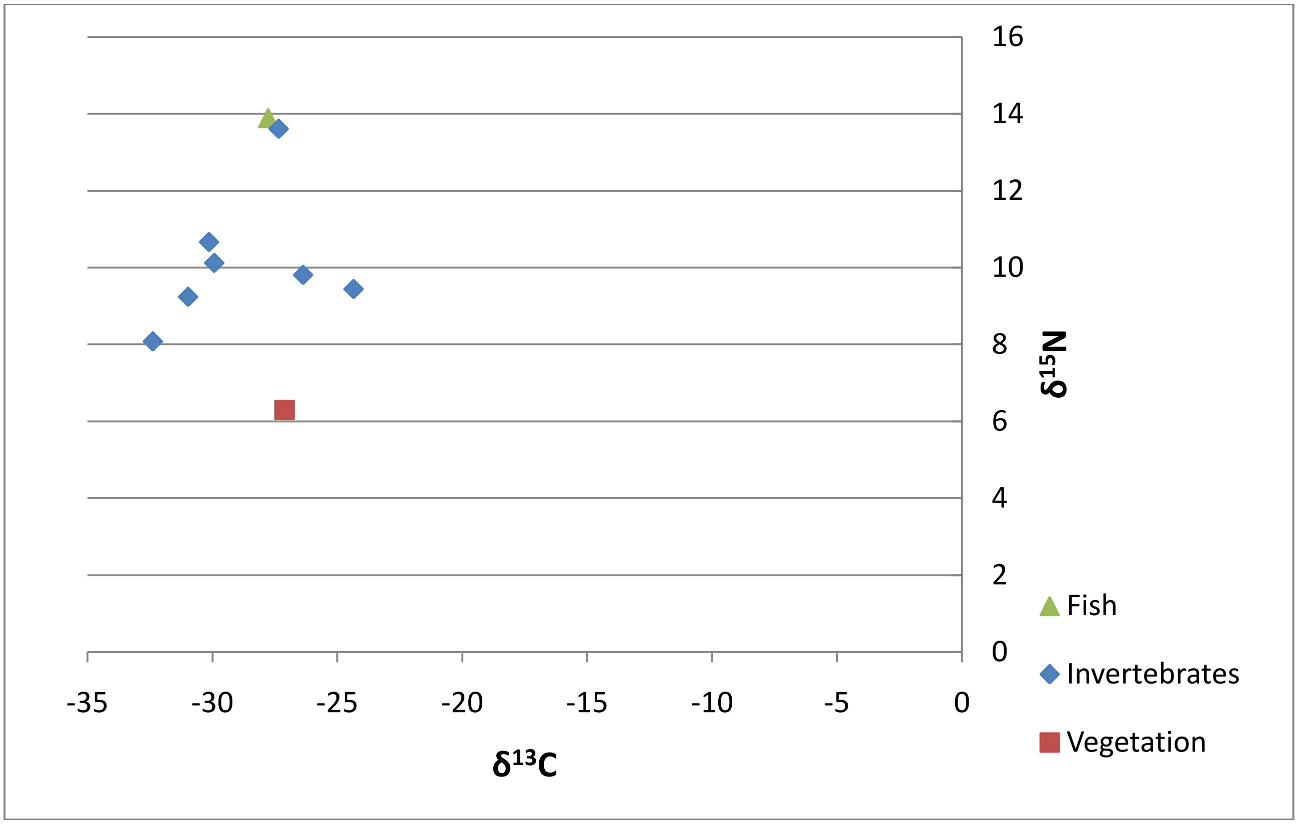


Figure 29: Middle Bog ^{13}C and ^{15}N stable isotopes

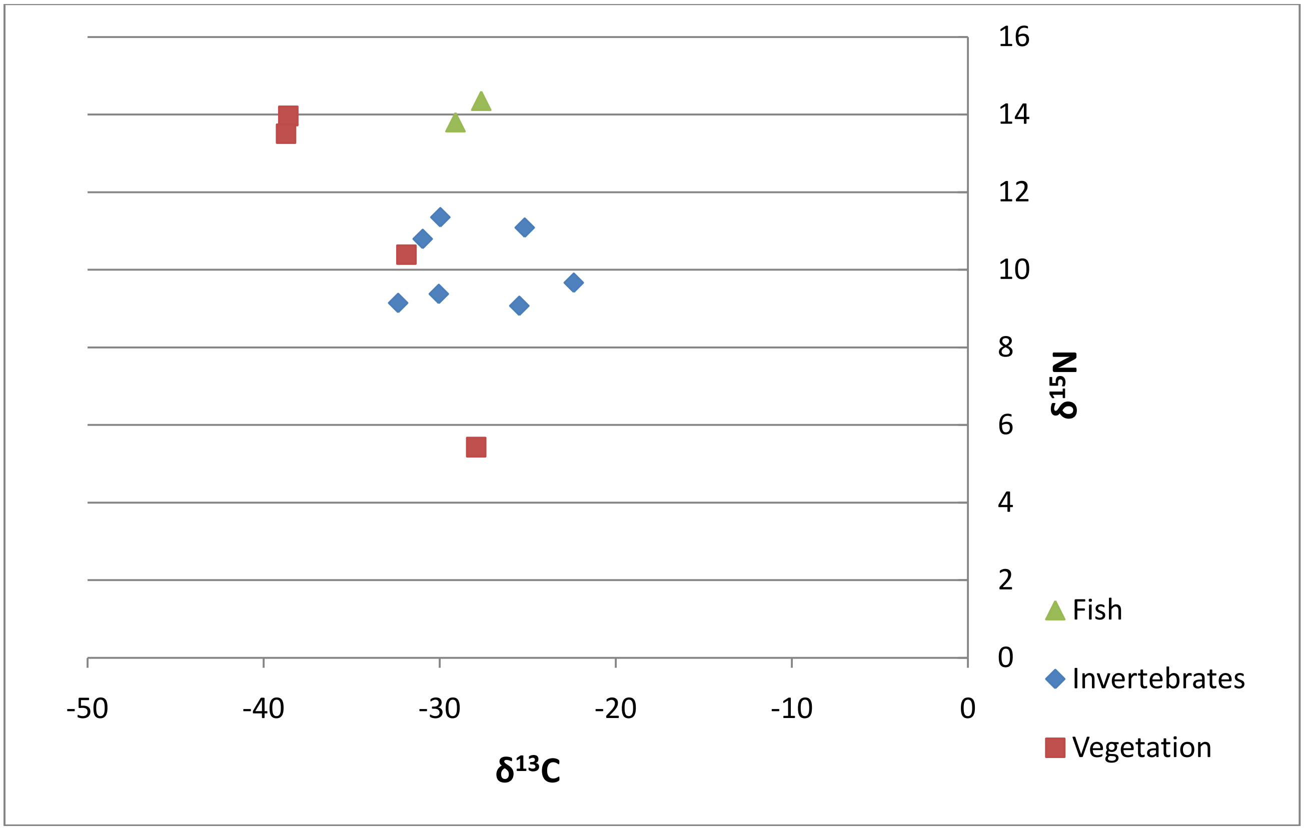


Figure 30: Lower Bog ^{13}C and ^{15}N stable isotopes

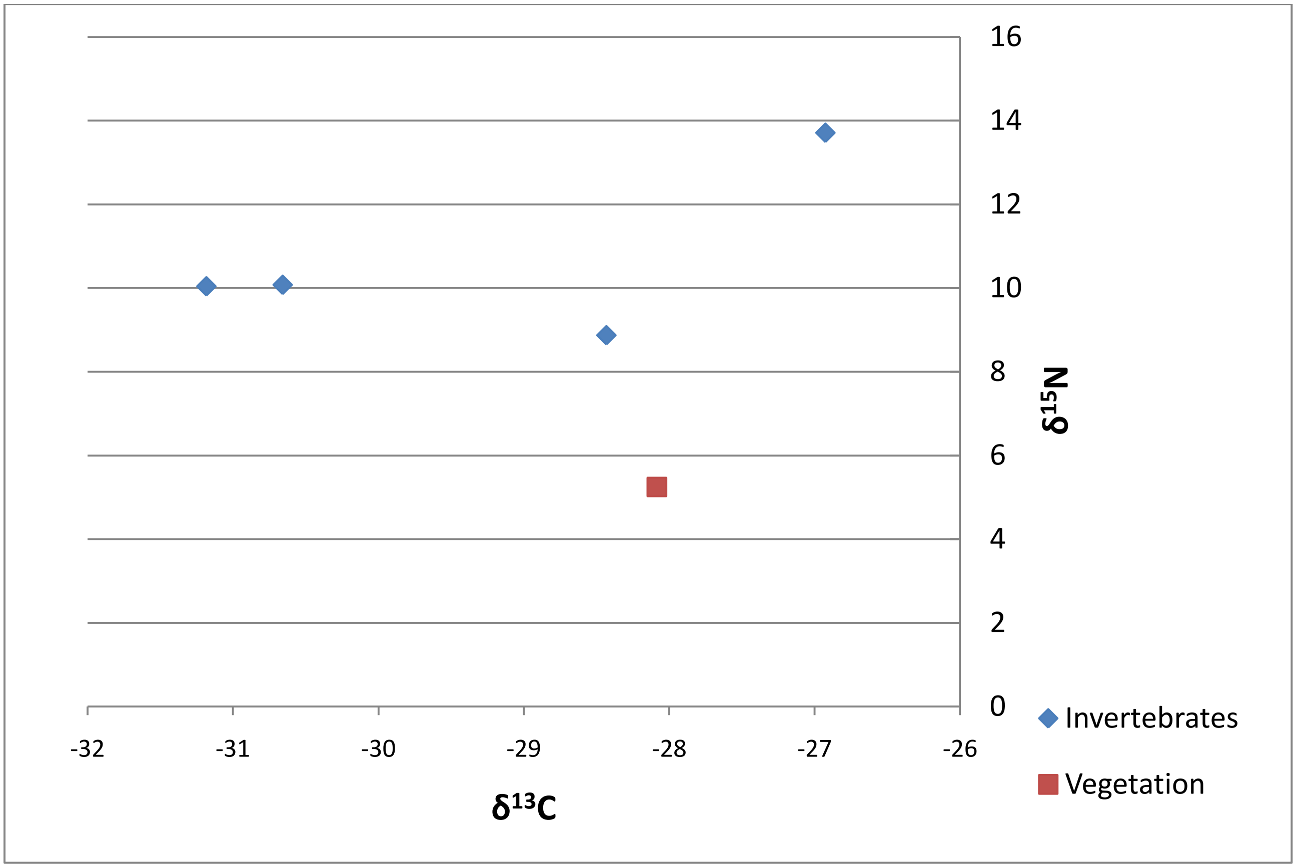


Figure 31: Flax II ^{13}C and ^{15}N stable isotopes

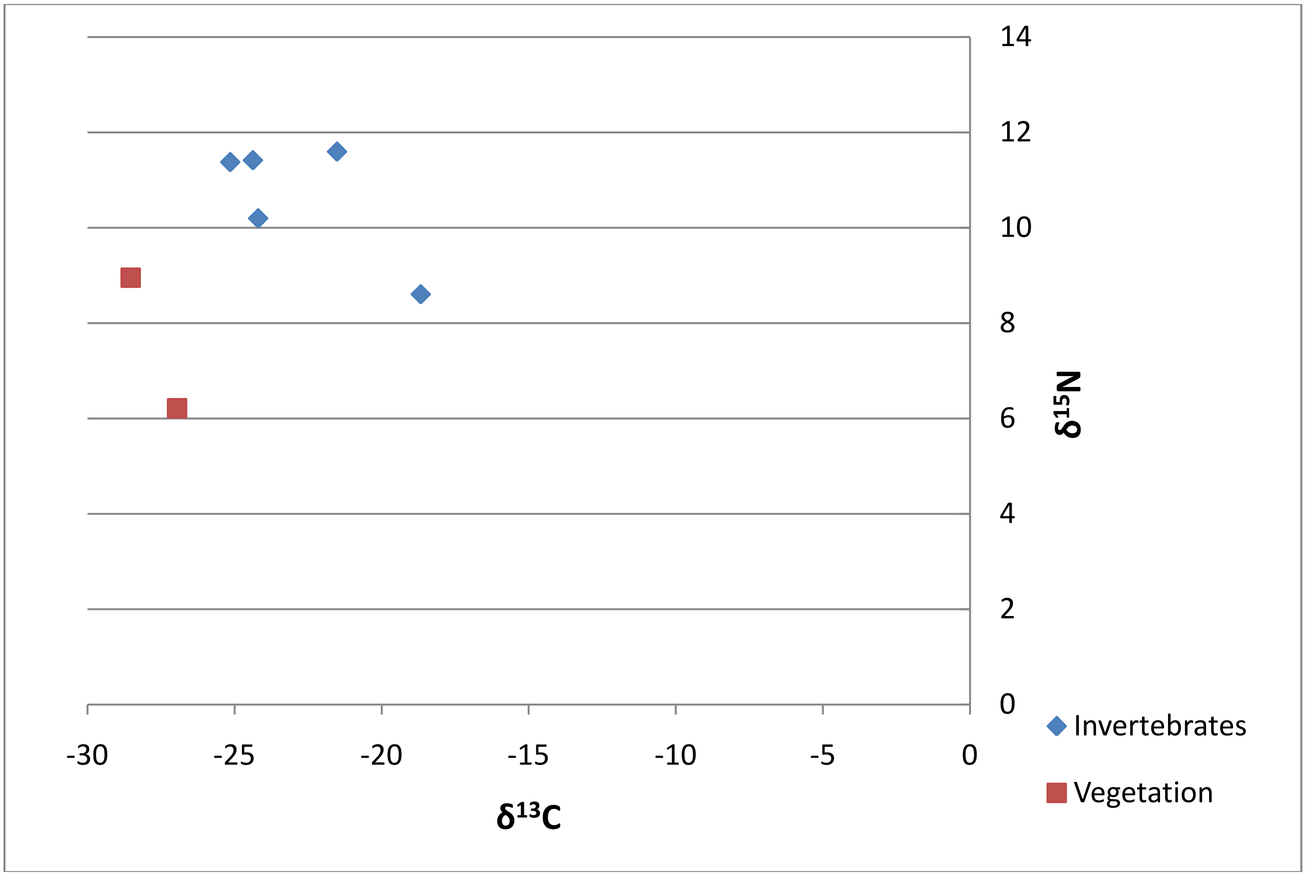


Figure 32: Red Brook ^{13}C and ^{15}N stable isotopes

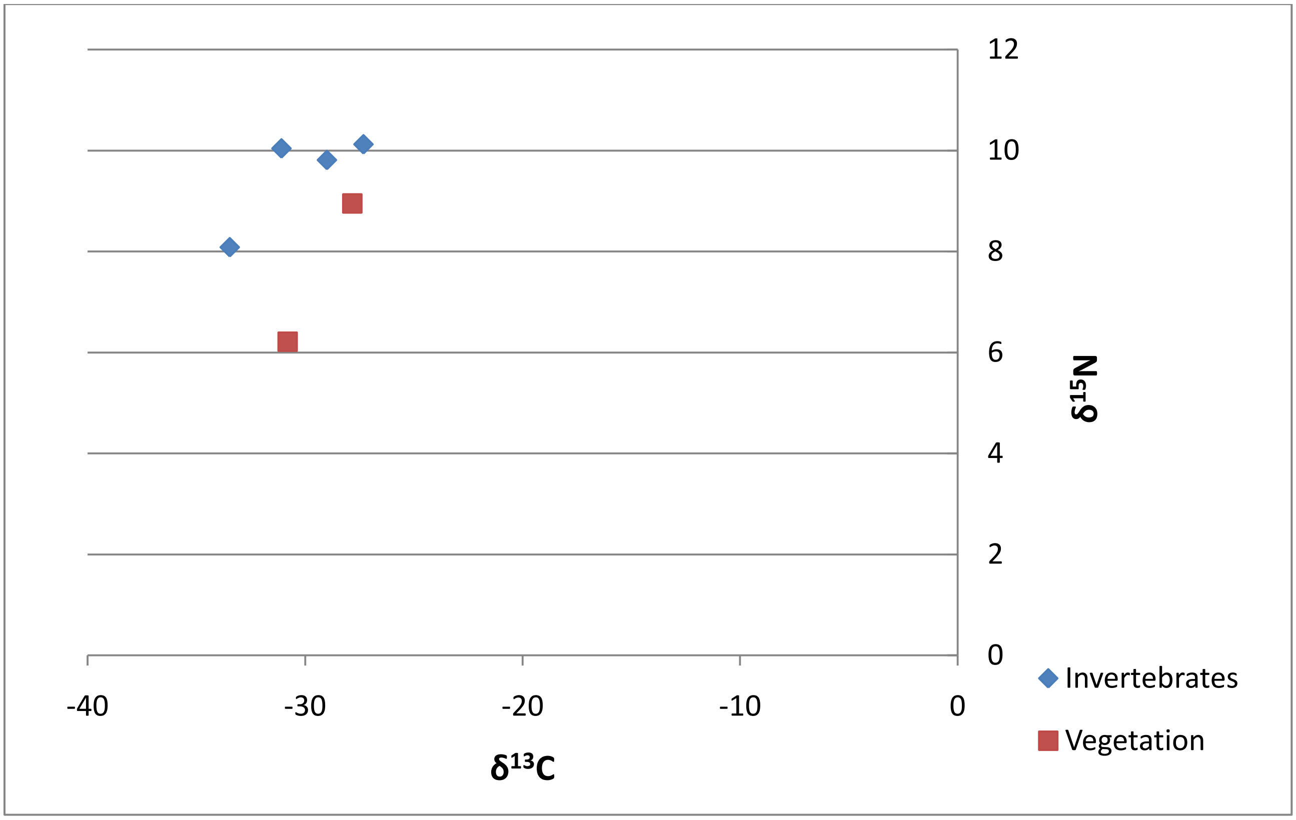


Figure 33: Zeke's Way ^{13}C and ^{15}N stable isotopes

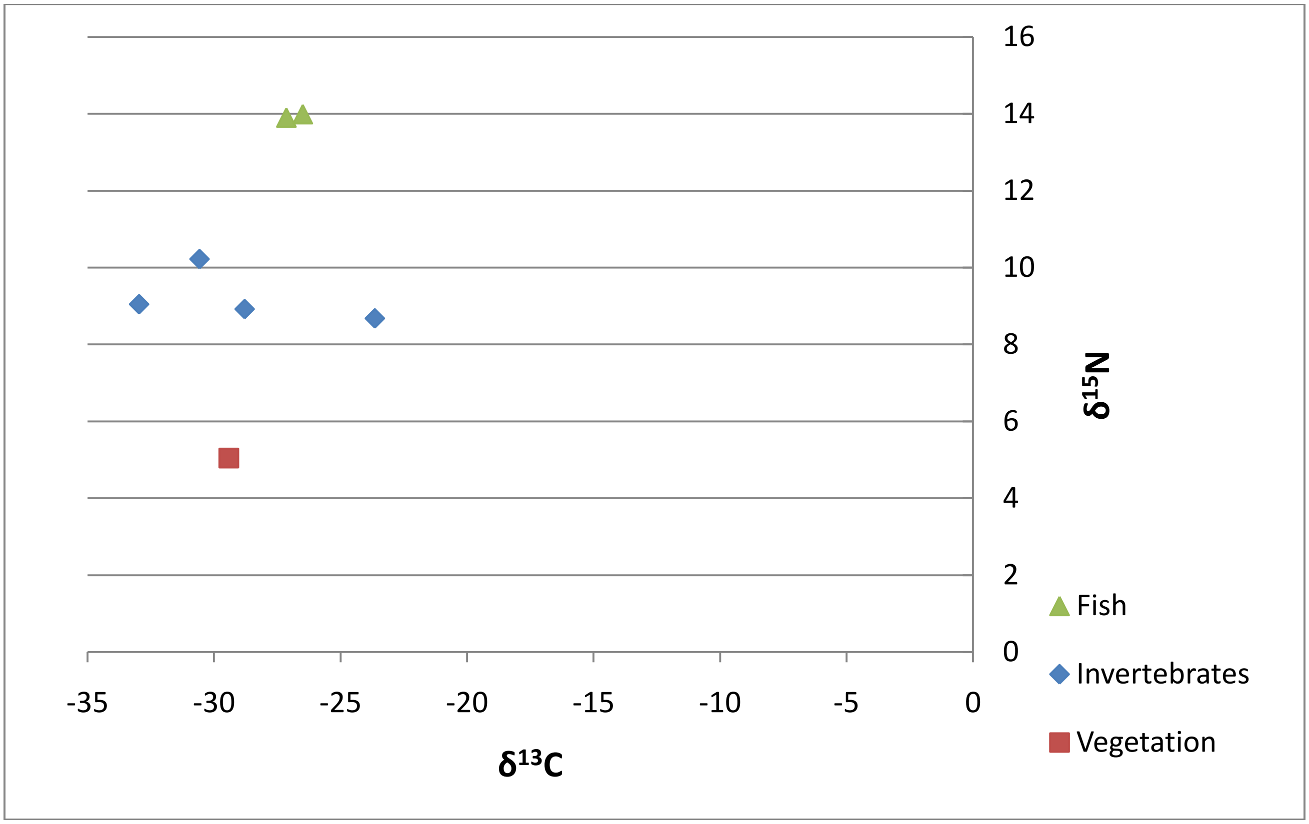


Figure 34: Upstream Coonamessett ^{13}C and ^{15}N stable isotopes

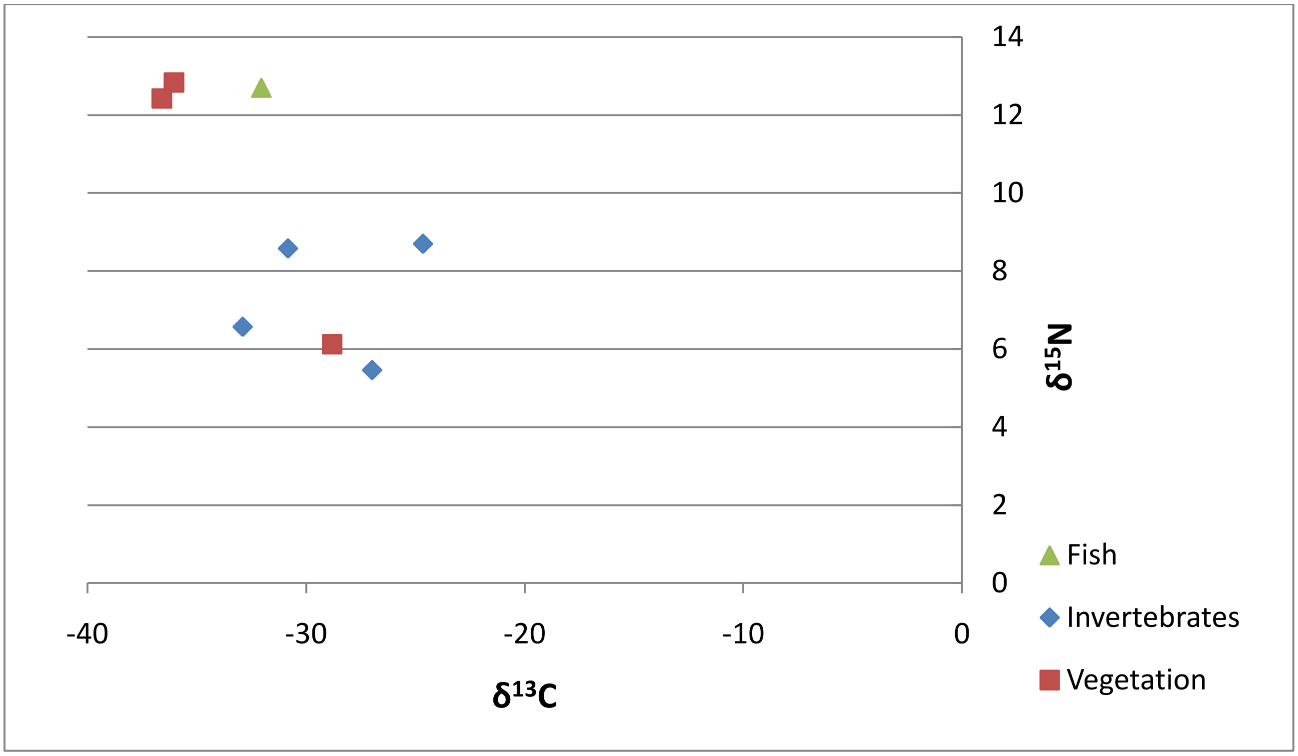


Figure 35: Mashpee River ^{13}C and ^{15}N stable isotopes

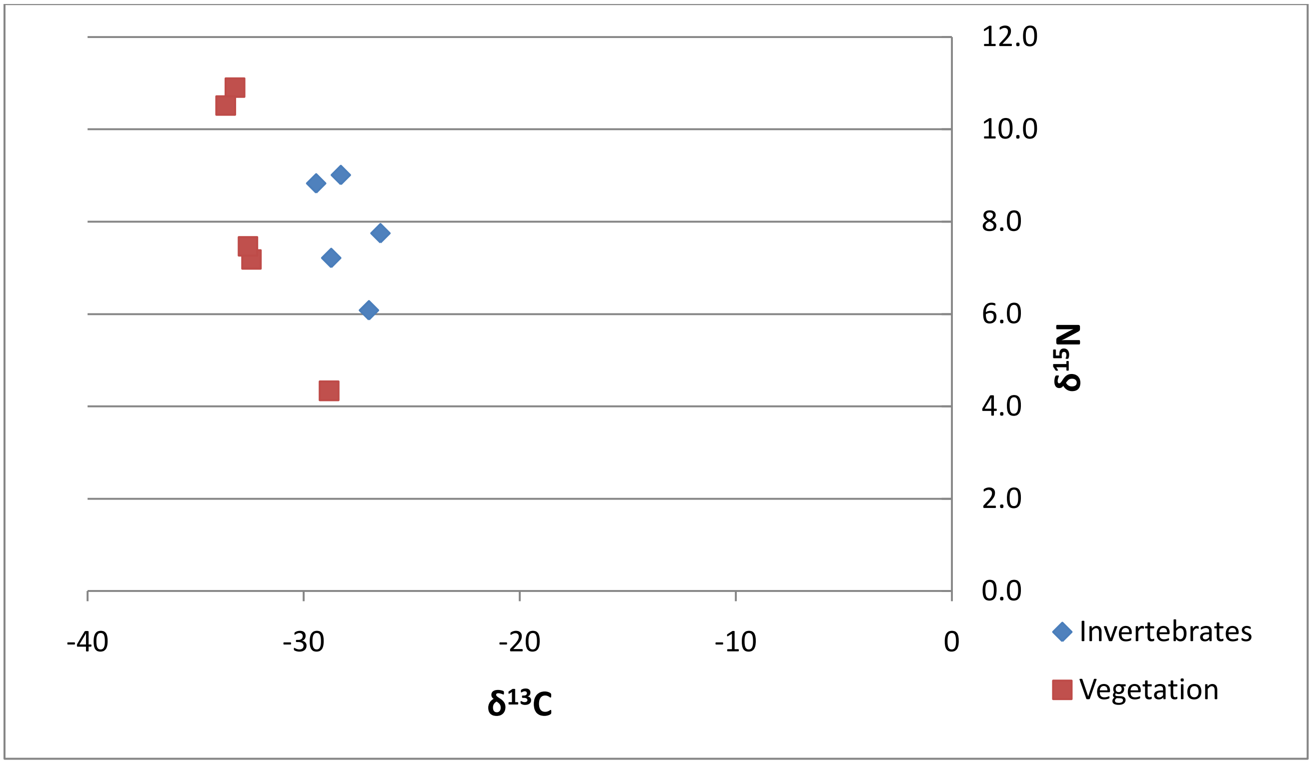


Figure 36: ^{13}C and ^{15}N stable isotopes for Amphipods at all sites

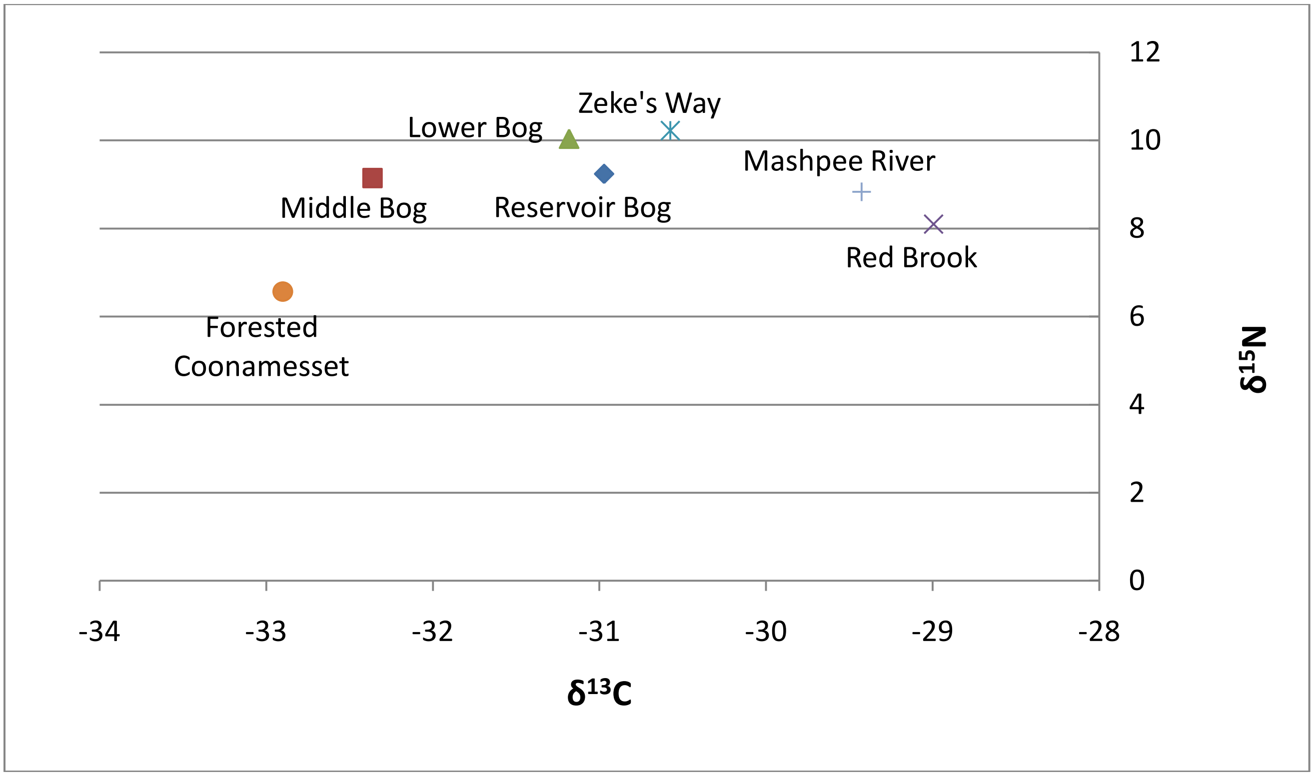


Figure 37: Nitrate concentrations at all sites