The effect of cranberry cultivation and restoration on nutrient uptake, cycling, and decomposition in three streams on Cape Cod

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December 17, 2006

Abstract

The world's wetlands are drastically diminishing due to their alteration and degradation by agricultural practices. Wetlands are key components in almost every ecosystem, and so their loss is potentially fatal to our environment. In order to ameliorate the negative impacts of agriculture and return the wetlands to their original state, a number of restoration efforts have been implemented. In this study, three first-order streams at different stages of cultivation and restoration were analyzed to determine the effect of cranberry cultivation on stream health, and the ability of restoration to return a stream to its natural state. Nutrient uptake was measured in each stream using a solute addition experiment. Internal nutrient cycling and decomposition were measured in each stream using sediment cores, incubated over 24 hours and analyzed at different time points for oxygen consumption and change in nutrient concentration. The results demonstrated that streams in their original state have much faster rates of uptake and decomposition than streams that have been cultivated. Further, these rates improve in streams that have been actively restored over time. This indicates that agriculture has a significant impact on a stream's health and functionality, but also that these impacts can potentially be remedied in part by restoration.

Key words: *streams, riparian vegetation, nutrient uptake, nutrient regeneration, decomposition, agricultural impact, cranberry cultivation, restoration*

Introduction

Humans manipulate and alter whole ecosystems in order to meet their needs. We clear forests, pollute air and water supplies, and restructure the landscape for our own purposes. However, in recent years we have come to recognize the negative impacts of our actions on the environment. A classic example here in Cape Cod is the impact of agriculture, specifically cranberry bog cultivation, on the health of local streams.

Streams are the plumbing of the planet, and are necessary to maintaining a healthy environment. They link aquatic and terrestrial ecosystems, and filter anthropogenic nutrient loading from ground water inputs, preventing harmful plumes and potential eutrophication (Nijober et al, 2003). They transport water and sediments across continents, are more productive than almost any other system, and provide a home for spawning fish, benthic invertebrates, and hundreds of other species (Moore, 2004).

However, despite the importance of streams, farmers completely alter streams' structure and composition in order to harvest berries. They clear the riparian vegetation, reroute the water, flood the streams seasonally, and input sand along the entire bottom of the system. All of these changes convert the streams from healthy ecosystems to barren backwaters.

A number of studies have measured the specific environmental problems that arise from cranberry cultivation. Howes and Teal (1995) found that bogs contributed a net outflow of 25 kmol of nitrogen, which was more than the neighboring residential area released. This loading of nutrients can cause such problems as downstream eutrophication, which creates an anoxic environment and destroys plant life and animal habitat (Garrison and Fitzgerald, 2004). Yaindl (2004) found that streams affected by cranberry cultivation lack important transient storage for nutrient uptake, which could explain the nutrient loading observed by Howes and Teal.

In order to address some of these problems, environmentalists and scientists have come together to develop restoration efforts, with the intention of returning streams and other impacted areas to their original state. These efforts could potentially solve some of the major issues facing wetlands today, but it is also possible that they do not address all of the intricate balances disturbed by agriculture. It is even possible that the efforts cause more harm than good.

The purpose of this project is to assess the impacts of cranberry cultivation on stream health, and to determine whether restoration can effectively ameliorate these impacts. I studied three streams in similar locations. The first one is the Mashpee River, a cold, ground-water fed stream that enters into Waquoit Bay, has never been touched by agriculture. I used this stream as an example of a stream in its original state. The second is the Quashnet - a cold ground-water fed stream that connects to Childs River – that was actively cultivated for cranberry bogs until 1954, when a salt water infiltration destroyed the harvest. In the 1970s, an independent group of environmentalists began a restoration effort to return the stream to its natural state. I used this stream as an example of an actively restored stream. The final stream is the Coonamessett River, which has been actively cultivated for cranberries since the 1850s. Two years ago, the town decided to cease cultivation on a number of sites, including the stream's Lower Bog. I used this stream as an example of a passively restored stream, and compared it to the Lower Bog's condition in 2004 while it was still being actively cultivated.

In this study, I examine the nutrient uptake capabilities of these three streams, as well as the rate of decomposition and nutrient regeneration in the sediment. These factors are good indicators of a stream's health because they encompass many functions. Nutrient uptake is the ability to sequester nutrients from the water. A fast rate of nutrient uptake indicates a stream with a healthy population of primary producers. It also indicates that the stream has good structure and a diverse set of habitats, which is important to the organisms living there. Fast rates of decomposition and internal nutrient cycling indicate rich sediment and substantial sources of organic matter. These processes provide nutrients to all of the other organisms in the sediment and in the stream, and are good indicators of an overall healthy environment.

By comparing these functions across the three streams, I can observe the differences between a cultivated stream and a stream in its natural state. I can also gain insight into the effects of restoration, and hypothesize about the effectiveness of the approach. I can also combine my results with those of my colleagues, Kim Morrell and Yusuke Kumai, who are studying different factors in the same three streams, to strengthen my conclusions and paint a better picture of stream ecology, cultivation, and restoration.

Methods:

Site selection

I chose to study the Mashpee River, Quashnet River, and Coonamessett River in order to have a gradient of comparison, both among the three sites, and between this study and the study performed in 2004. All three rivers are relatively close in location and size, and all three begin in ponds and end up in estuaries (figure 1). Within the Coonamessett, I looked at the Lower Bog, which is the area that has been passively restored over the past two years.

After choosing the three sites, I set a reach (the length of the river to be analyzed) in each of the streams. Each reach was a different length, determined by the average width of the stream and its overall shape and structure (Methods in Stream Ecology, 1996). The reach was 320 meters in the Mashpee, 340 meters in the Quashnet, and 400 meters in the Coonamessett. I also measured discharge at the head and the base of each river, and set level loggers to track the change in water height during the time that I was performing the experiments (figure 2).

Nutrient addition

In order to determine the uptake capacity of the three rivers, I performed a nutrient addition. I dripped a certain amount of nitrate (in the form of $NaNO_3$ fertilizer) and phosphate (in the form of NaH_2PO_4 fertilizer) into the water to raise the ambient concentration enough to detect a change along the reach. I calculated the amount of each nutrient to add to the stream using ambient concentrations calculated by Gocke (2003) and the discharge I measured earlier using a Marsh-McBirney Flow Meter (table 1). I also added NaCl as a tracer to determine any solute loss due to dilution, as well as to determine when the stream had reached a point of equilibrium during the addition.

On the day of the addition, I placed a Hydro lab at the bottom of the reach to measure when the nutrient mixture had arrived at the last sampling point, and when the conductivity in the water was constant (indicating equilibrium). I took initial water samples at each of my sampling sites along the reach (0, 40, 100, 150, 250, and 320 for the Mashpee, 0, 50, 100, 150, 200, 220, and 340 for the Quashnet, and 0, 50, 100, 200, 300, and 400 meters for the Coonamessett,), and filtered them using 25 mm GF/F filters, syringes, and swinexes. I also measured conductivity at these six points using a Hydro lab. I mixed the pre-weighed nitrate, phosphate, and sodium chloride into a 120 liter drum along with about 90 liters of river water. I pumped this mixture into the stream using a Geopump set to 10 mL/second and attached to a PVC pipe with several holes of different sizes to adequately space the addition of the mixture across the width. Once the Hydro lab indicated equilibrium, I sampled and filtered water at the same six points, and measured final conductivity. I also collected water samples along the width of the second sampling station and measured conductivity in order to determine the level of mixing.

In the lab, I analyzed the initial and final water samples for nitrate concentration using the Lachat analyzer, and for phosphate using the spectrophotometer. To determine nutrient uptake, I calculated the difference between initial and final nitrate and phosphate concentrations at each sampling site, and graphed them against distance. I fit an exponential curve to the points, and used the slope to calculate rate of uptake per linear meter of river.

Sediment Cores

To measure internal nutrient cycling and decomposition, I took ten sediment cores from the three rivers. I took four cores from the organic matter section of the Mashpee, and two cores each from the organic matter section of the Coonamessett and the Quashnet. I also took two cores from the sand section of the Coonamessett to represent the nutrient cycling in the river before passive restoration began. I only analyzed data from two of the four Mashpee cores that I collected.

After I took each core, I removed the overlying water and replaced it with filtered river water. I put the cores in a tub filled with tap water at room temperature and took initial oxygen readings and water samples, sampling again after two hours, five hours, eight hours, fifteen hours, nineteen hours, and twenty-four hours. I analyzed the water samples for nitrate, phosphate, and ammonium using a Lachat analyzer and spectrophotometer, respectively.

After the cores were finished incubating, I removed all of the sediment to analyze the organic matter content. I pushed it through a 2 mm sieve to separate the coarse particulate organic matter (CPOM) from the fine particulate organic matter (FPOM). I weighed the CPOM to determine the percent in each core. I separated a representative sample from the FPOM, dried it at 60 degrees Celsius in a drying oven, and took a dry weight. I combusted it in a Muffle oven for 4 hours at 450 degrees Celsius and weighed it again to determine the percent carbon. In the Coonamessett cores, I also divided the FPOM into silt and sand, and combusted both types to determine percent organic matter in each. I also analyzed a representative sample of the organic matter at each of the three rivers for carbon and nitrogen. I dried each sample for twenty-four hours in a drying oven at 60 degrees Celsius, and ground them using a mortar and pestle. I packed duplicates of each sample using the CHN method, and ran them through a CHN analyzer to measure the C:N ratio

Results:

Nutrient uptake

The water height in the three rivers varied due to rain, but remained relatively constant during the sampling period (figure 2). The water was at a normal level on the days I sampled in the Mashpee and the Quashnet, but was slightly higher on the day that I sampled in the Coonamessett (figure 2). This variability coincided with the removal of a dam at the head of the Lower Bog two days before I sampled.

Conductivity varied slightly at the different sampling points after the NaCl tracer was added, but the difference between sites did not exceed 1 µS/cm in any of the sites (table 4). Conductivity was more substantially different across the mixing zones at each river, with the greatest difference in the Coonamessett (a difference of 15.9 µS/cm). The difference in final conductivity between the mixing zone samples and the reach samples is due to the use of a different Hydro lab; however the relative difference remains the same.

There was discernable uptake of both nitrate and phosphate in each of the three rivers (figures 3 and 4). The Mashpee had the highest rate of both nitrate and phosphate uptake, with a rate of 0.0016 µM m^{-1} and 0.0015 µS/cm (table 3). The Quashnet had a much slower rate of nitrate and phosphate uptake, (0.0004 and 0.0006 µM m^{-1}, respectively), and the Coonamessett had the least (0.0002 and 0.0003 µM m^{-1}). The results for phosphate uptake in the Coonamessett are not very significant, however, because of the high standard error and poor r^2 value (figure 4).

The rate of uptake in the Coonamessett in 2006 was infinitely higher than the rate calculated by Yaindl before the stream had begun passive restoration (table 4). In 2004, Yaindl did not find any discernable uptake of either phosphate or nitrate, but I found a minimal positive uptake of both nutrients.

Sediment cores

The sediment cores taken in the Mashpee and Quashnet were roughly 90% fine particulate organic matter (FPOM <2 mm) and 10% coarse particulate organic matter (CPOM >2 mm) (figure 12). The organic matter sediment cores in the Coonamessett were roughly 2% CPOM, and the sand cores were entirely FPOM. The FPOM in the Coonamessett was roughly 40% silt/sand and 60% sand (figure 5).

The organic matter composition was very different in all three of the sites. The Mashpee cores had the highest total percent of organic matter (measured in percent carbon), and had a high C:N ratio of about 27.3 (figure 5). The Coonamessett organic matter cores had a lower percentage of organic matter, and C:N ratio of 16, while the Quashnet organic matter cores had a higher C:N ratio (22.3), but a slightly lower percentage of organic matter. The Coonamessett sand core had the lowest percentage of carbon, and had no organic matter (figure 5).

The average rate of respiration was highest in the Mashpee cores, and lowest in the Quashnet cores (figure 6). The average rate of respiration was slightly lower in the Coonamessett sand core than in the Coonamessett organic matter core.

There was a negative flux of ammonium and nitrate into the cores, although the rates were more significant. Rates of ammonium uptake were relatively similar in each core (figure 7), but rates of nitrate were highest in the Coonamessett cores and lowest in the Mashpee cores (figure 8). There was a very small negative flux of phosphate into the sediment in all of the cores (figure 9).

Discussion

Nutrient uptake

The rate of nitrate and phosphate uptake was significantly higher in the Mashpee River than in either the Quashnet or the Coonamessett. One of the most obvious reasons for this difference in uptake is the difference in physical structure between the Mashpee and the Coonamessett and to a lesser extent to the Quashnet. The Mashpee is characterized by the physical structures along its length, from logs and sticks to deep pools, inlets, and coves. These structures are still intact because the riparian forest has never been cleared, and the path of the stream has never been altered. Nijober et al (2003) found that physical structures such as these are necessary for the retention of organic material and nutrients because they slow down flow and allow time for nutrients to dissolve and become accessible to the biota. Physical structures like branches and natural dams also provide transient storage, which is necessary for uptake because it provides space for the nutrients to mix (Yaindl, 2004).

The Coonamessett is almost entirely empty of these physical structures, mostly due to the lack of terrestrial inputs from the riparian vegetation that was cleared for cranberry cultivation. This lack of physical structure and subsequent lack of transient storage (Yaindl, 2004) could explain why I measured almost no uptake of either nitrate or phosphate in the Coonamessett. However, my calculated rates were both positive, which indicates that there has been a change in uptake in the past two years despite the fact that none of the physical structure has returned. One reason for the improvement could be due to the change in the benthic habitat distribution in the Lower Bog since the cultivation has stopped. Morrell (2006) found that 16% of the habitat in the stream was submerged aquatic vegetation, and 9.7% was emergent aquatic vegetation. This vegetation could potentially be responsible for the minimal uptake that I observed in the Coonamessett, particularly because in 2004, when Yaindl analyzed the benthic habitat distribution of the Lower Bog, he found that it was 100% sand.

The comparison is not completely equivalent, however, because I raised the ambient level of phosphate to a much higher concentration than Yaindl did (10 µM versus 5 µM). Since freshwater systems are usually phosphorus limited (Valiela, 1995), any increase in concentration will speed up the metabolism and uptake of the stream. Thus, by adding even more phosphate, it is possible that my measured rate of uptake is not typical, and is simply a result of extreme nutrient concentrations. However, it is clear that some changes have been made in the Coonamessett since Yaindl's study, and the uptake capabilities are improving, however minimally.

The rates of uptake of both phosphate and nitrate in the Quashnet River were double the rates in the Coonamessett River. Since the restoration effort in the Quashnet specifically focused on rebuilding the riparian forest and reconstructing the physical structures that cultivation removed, it seems logical that the stream would have much better uptake than a stream like the Coonamessett. Further, the Quashnet has a very high percentage of submerged aquatic vegetation—52% versus 16% in the Coonamessett (Morrell, 2006)—so there is more below-stream biota to take up the nutrients in the water. However, the uptake rates were still much lower than those I measured in the Mashpee. Although the Quashnet has had a riparian forest for over thirty years, and artificial structures specifically built to resemble the physical structures found in the Mashpee and other natural streams, the rate of uptake is still relatively low.

One reason for the difference in uptake rates between the Quashnet and the Mashpee is that the Quashnet has a much faster flow rate than the Mashpee (0.46 versus 0.375 m^3/second). Water that flows faster has less time to allow the nutrients to mix and dissolve, thus creating a better environment for uptake (Nijober, 2004). Because I measured nutrient uptake as a function of distance rather than time, my rates do not take into account the difference in flow rate. It is possible that had I measured uptake rate in terms of time, I would have found a closer rate between the Quashnet and the Mashpee.

Another possible reason for the difference between uptake rates is that no two streams are alike. Despite the fact that the Mashpee and the Quashnet are in similar locations, and are both cold, ground-water fed streams, they are different in their structure. The Mashpee has more visible transient storage, and is shallower and wider, which allows for more mixing. The Quashnet is a much deeper stream than the Mashpee (Morrell, 2006), which means that the same concentration of nutrients must mix even more to reach the benthos and be taken up by the aquatic vegetation. It is possible that even if the Quashnet had not been cultivated, its baseline uptake rate would be lower than the Mashpee.

Overall, it seems that the rate of uptake follows a clear trend among the three streams. The stream that had never been touched by agriculture had a very high rate of uptake relative to the stream that was cultivated until two years ago, and the stream that was restored over the course of thirty years falls somewhere in between. Although the streams are very different from each other, and it is hard to classify any ecosystem as "natural" or "typical," it seems that the process of cultivation has a negative impact on uptake, and that restoration ameliorates this impact to a certain degree.

Sediment respiration and decomposition in the cores:

Assuming a 1:1 ratio between oxygen consumption and carbon dioxide production in aquatic ecosystems, the higher rate of oxygen depletion in the Mashpee cores can be directly correlated to a higher rate of benthic respiration. This rate of respiration can be attributed to the activity of organisms living in the sediment, including benthic invertebrates and bacteria. These two types of organisms are largely responsible for the decomposition of organic matter in streams and the subsequent release of nutrients in available form (Balgey et al, 1997). One reason that the Mashpee sediment cores had such high rates of respiration is the fact that the cores had the highest percentage of organic matter (figure 12). The Mashpee has the most organic matter in general due to the high percentage of CPOM. The sediment receives the most amount of allocthonous carbon because of all the mature riparian vegetation along the edges. Also, the FPOM had the highest carbon content, indicating that there is constant activity in the sediment, and that most of the FPOM is formed from the breakdown of the organic material.

The high rates of respiration directly correlate to the amount of benthic invertebrates living in the sediment. Morrell (2006) found that the Mashpee had the highest number of shredders (such as crane flies, sow bugs, and scuds) out of all three streams. Shredders are the predominant benthic invertebrates involved in breaking down organic matter, and they can't live in places without a lot of leaf pack (Nijboer, 2003). Morrell (2006) found that the isotopic signal of sow bugs indicated a diet of terrestrial leaves like red maple and submerged aquatic vegetation, which supports the theory that the shredders are consuming and decomposing the terrestrial organic matter. This explains why the rate of respiration and decomposition were the highest in the Mashpee River, which has the most amount of organic matter.

The Coonamessett had low rates of respiration because of the lack of the organic material in the form of leaf pack. While the bottom habitat in the Mashpee is 18.3% leaf pack, there is absolutely none in the Coonamessett due to the lack of a riparian forest (Morrell, 2006). Also, the organic matter sediment cores from the Coonamessett are only 2% CPOM, and the FPOM was only about 1.8-2% carbon, so the invertebrates living in the sediment have less available to break down. The sand sediment cores had a lower rate of respiration than the organic matter cores, which is logical considering that they was no CPOM in the sand cores, and considering the low percentage of carbon in the FPOM. These cores are representative of what the Lower Bog looked like before passive restoration began, and the entire benthos was sand. Now that the bogs are not being cultivated, some of the aquatic vegetation has returned, and there is more organic matter available for decomposition.

Based on the above results, it would seem logical that the Quashnet would have a lower rate of respiration than the Mashpee, but a higher rate than the Coonamessett. The Quashnet is 6.5% leaf pack, which falls right between the Coonamessett and the Mashpee, and has a lot of shredders and other invertebrates living in the sediment (Morrell, 2006). However, I found that the Quashnet sediment cores had the lowest rate of respiration, lower than even the Coonamessett sand cores. There are a number of reasons why this could be.

First of all, I took the two Quashnet cores inside one of the artificial structures built for fish spawning and protection. These structures have a lot of organic matter which collect on top (the core was 9.8% CPOM, almost as much as the Mashpee), but their deeper composition is actually quite different from the rest of the sediment. The bottom is constructed from large rocks and logs, and then loam from an outside location is added to the top. This loam, which I measured as FPOM, had a much lower percent of carbon than even the FPOM in the Coonamessett.

Morrell (2006) found that there were no benthic invertebrates living in any of the artificial structures that she sampled. This would explain why the rates of respiration were so low. Even if the sediment were full of microorganisms decomposing the organic matter on the top of the core, the cumulative rate of respiration that I measured would still be much lower because it would be lacking in the larger rate produced by benthic invertebrates.

Another reason why the Coonamessett sediment cores might have a faster rate of respiration than the Quashnet is that breakdown of organic matter is faster in nutrient rich environments (Xie et al, 2004). The ambient nitrate concentration of the Coonamessett is much higher than the ambient concentration in the Quashnet (33 µM vs. 23 µM), which means that the organisms living in the benthos in the Coonamessett have access to more nitrogen than the organisms living in the Quashnet, and so they can break down more of the organic matter in the sediment. Also, the C:N ratio of the organic matter in the Coonamessett is much lower than the ratio in the Quashnet (16 versus 22.3). Therefore, the organisms consuming the organic matter in the Quashnet require even more nitrogen to break down the same amount of carbon. So, it is possible that the low rate of respiration reflects the poorer quality organic matter inhibiting the same amount of decomposition that can occur in the Coonamessett or the Mashpee.

Internal nutrient cycling in the sediment cores

None of the cores produced any net nutrient flux into the overlying water, which means that the sediment is not a source of nutrient regeneration in any of the streams. One reason for the negative flux in ammonium observed in the Mashpee could be the fact that the organic matter in that stream is mostly composed of terrestrial litter fall, and it has a very high C:N ratio. The ratio is probably higher than usual during this time of the year, because before senescing their leaves, trees sequester a lot of the nitrogen into their core biomass (Methods in Stream Ecology, 1996). Because organisms require a certain amount of nitrogen to break down any carbon source, the benthic organisms living in the Mashpee probably must seek a second source of nitrogen to decompose all of the available organic matter. This explains the net uptake of ammonium observed. Similarly, the organic matter in the Quashnet has a relatively high C:N ratio and so some nitrogen uptake is required to provide enough to decompose the available organic matter. However, the rate of uptake is much lower, most likely because the overall benthic activity was much lower than the Mashpee.

The Coonamessett has a relatively low C:N ratio, so the sediment requires less ammonium to break down the organic matter. However, the rate of ammonium uptake is roughly the same as in the Mashpee. It does not seem logical for the rate of uptake to be so high in the Coonamessett however, the standard error and r^2 values for my ammonium uptake rates were all statistically poor, and it is possible that the rates I measured are not significant at all.

There was a difference in nitrate uptake between the three sites, and from the data it seems that the Coonamessett has the most uptake. This does not seem to fit with my data, particularly the overall uptake of nitrate that I saw in my nutrient additions. I expected that the Mashpee, which had the most organic matter, the most nitrate uptake, and the most respiration and benthic activity, would also indicate the most nitrate flux in the sediment. However, there are a couple of potential reasons for my results. One reason is that the ambient nitrate concentration in the Coonamessett is higher than the ambient nitrate concentration in the Mashpee. When I added nitrate and phosphate during my nutrient addition, I increased the nutrient concentration in the water, thus changing the environment and allowing the relative rate of nitrate uptake to be measured. This rate might be different when the river is just at ambient levels.

The negative flux in phosphate is typical of freshwater systems. The phosphorus binds with iron minerals in the oxic layer of the sediment and thus can’t diffuse out into the water. As the phosphate compound goes deeper into the anoxic region of the sediment, the phosphorus diffuses back up, but becomes trapped again at the interface (Schlesinger, 1997). This is one of the major reasons that freshwater rivers like the Mashpee or the Coonamessett are phosphate limited, and explains why the overall uptake rates are just as high or higher for phosphate uptake, even though phosphorus is usually taken up in a smaller ratio to nitrogen, according to the Redfield ratio.

The Mashpee has poorer quality organic matter, so it requires more nitrogen from the water, but since it is so good at uptake, the nitrogen is available. The Coonamessett doesn’t need quite as much from the water, but since there is little to no uptake, it is most likely that not enough nutrients are available to support a healthy benthic population, explaining the lower numbers found by Kim. Also, there has been some return of submerged aquatic vegetation now that it is not being flooded on a regular basis, which has probably improved internal cycling and a little of the uptake. However, to completely restore the stream’s uptake ability, the whole structure would need to be changed. And it is clear that the riparian vegetation supports the important benthic invertebrates necessary to increase decomposition and cycling. If the Coonamessett were restored, it would be an even bigger improvement than in the Quashnet, because the organic matter is already of better quality, and less nitrogen is even needed from the water.

Conclusion: Implications and recommendations for restoration

It is clear from this data, as well as the data collected by Morrell and Kumai (2006), that streams that have not been touched by agriculture are extremely different than those which have been actively used for cultivation. The cultivation process reduces or completely eliminates nutrient uptake and decomposition, alters the stream bottom habitat and decreases the benthic invertebrate population, and removes important habitat and conditions for fish and other higher trophic level organisms. It is also clear that the restoration effort in the Quashnet has addressed some of these issues by rebuilding a riparian forest and simulating physical structures like inlets and gravel beds for spawning fish.

However, restoration is not a simple process, and the effectiveness of any restoration effort depends on a number of factors. The Quashnet was restored specifically for the purposes of bringing back the brook trout population. They grew a riparian forest and built artificial structures in order to create an environment favorable to this specific species. The fact that riparian vegetation also provides an allocthonous carbon source for decomposition and natural structure for nutrient uptake is simply a bonus; the only intended result was to return shade to the stream so that the temperature would be favorable for trout. Thus, no thought was given to the other aspects of the stream ecology, which could explain why the artificial structures, while useful for fish spawning, are actually less productive than the sand in the Coonamessett, and home to fewer benthic invertebrates.

When addressing the current debate about restoring the Coonamessett, it is important to take all of these factors into consideration. It is clear that a riparian forest is crucial to improving the health of any stream. However, it is possible that constructing artificial structures is not the best way to approach changing the stream's overall shape. Some gravel and submerged aquatic vegetation has already returned to the Coonamessett over the past two years of passive restoration. It is possible, therefore, that simply with the addition of a riparian forest, the rest of the necessary changes to the stream bed and habitat would occur naturally. It is clear that the Coonamessett is a very different stream than the Mashpee, and that it is not able to carry out all its former functions. Some sort of restoration effort is necessary to return it to a healthier state. However, it is important to take into consideration all aspects of the restoration process, and to understand all of the different conditions that affect the stream's functioning.

Acknowledgements

A great many people worked incredibly hard on this project, and there is no way that I would have been able to complete any of this without them. First and foremost, I want to thank Linda Deegan for all of her insight, kindness, and guidance throughout the project. She had a new present for us every time we met, and stayed up late nights in the lab to make sure we were all prepared. I also want to thank Rich McHorney for his tireless efforts with us in the field, getting out to the streams early every morning, always prepared with just the right tool. I also would not have been able to get anything accomplished without my two wonderful collaborators, Kim Morrell and Yusuke Kumai. They were out with me every day in the field, carrying bags of nutrients and building dams. Their kindness, willingness to help, enthusiasm, and creativity made this project a joy. In particular, I also want to thank Kim for her wonderful driving skills, and her constant energy. I want to thank Beth Bernhardt, Clara Funk, and Laura Wittman for all of their help in the lab, and in particular Clara for working magic with the Lachat. I want to thank Chris Neill for his help with the water loggers and providing me with important information about the Coonamessett, and Anne Giblin for helping me to decode my sediment core data. I also want to thank Fran Smith, Bob Golder, and Linda Davis for providing outside information about restoration and the history of cranberry bogs from various perspectives. I want to thank Mike Netto for getting us out of a pickle. I want to thank Ken Foreman and the Semester in Environmental Science for providing me with this opportunity, and the members of SES 2006 for making this a wonderful semester.

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Figures and Tables

Figure 1. Map of the Mashpee River, the Quashnet River, and the Coonamessett River

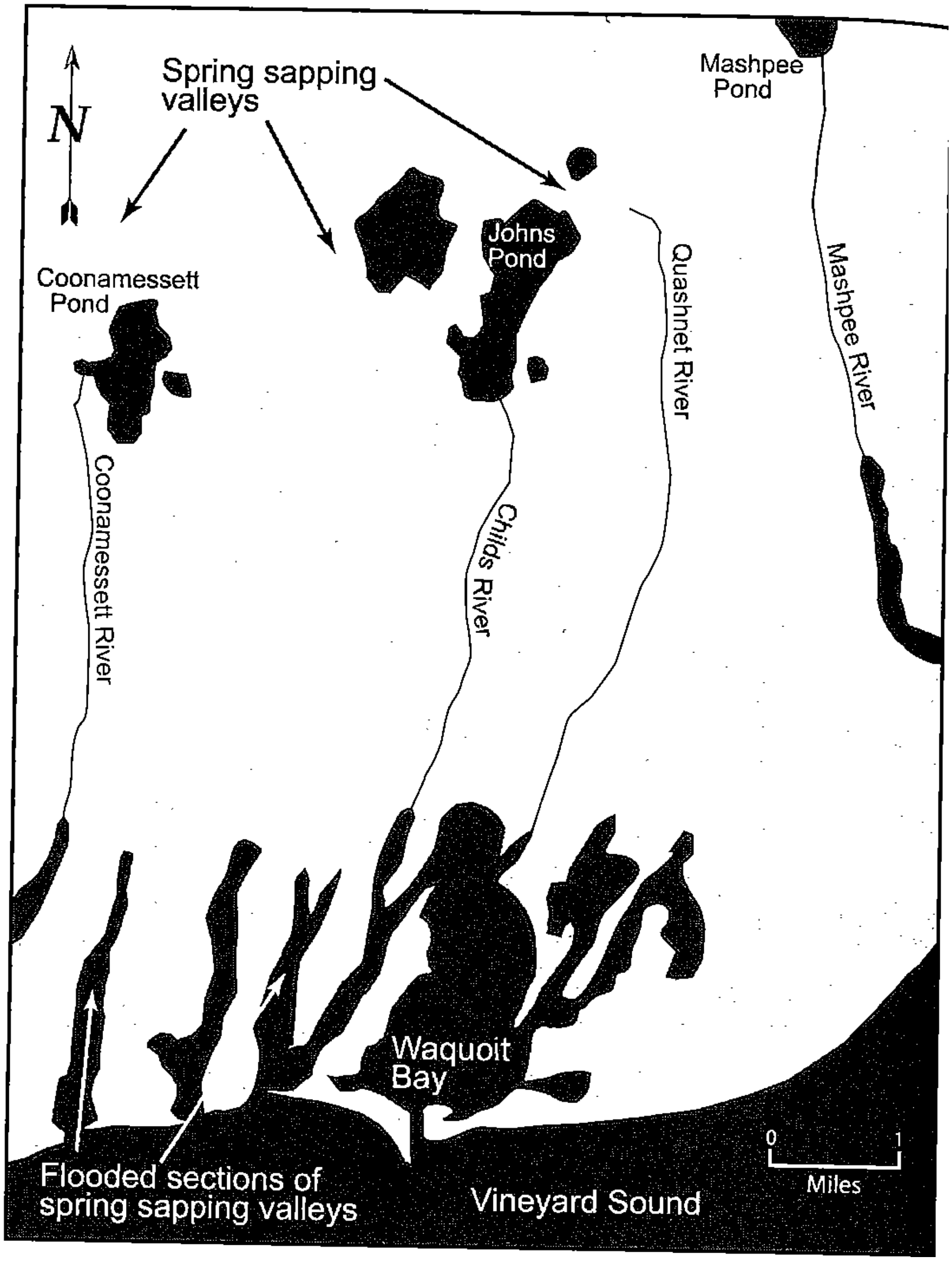
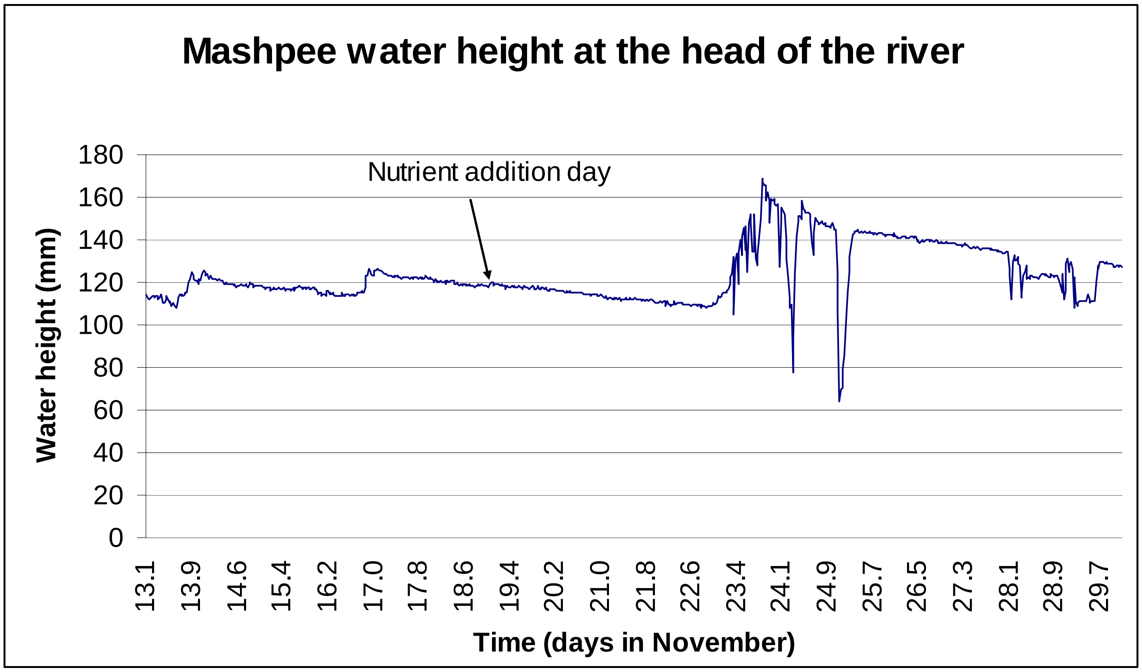
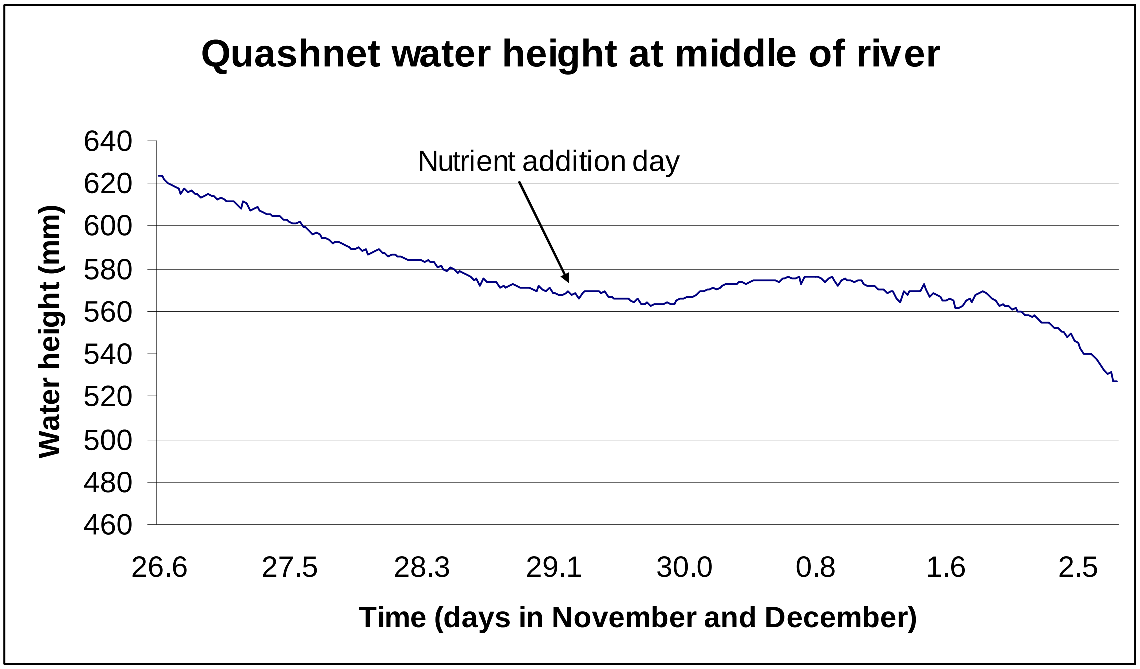


Figure 2. Water height at the Mashpee River, the Quashnet River, and the Coonamessett River in November and December 2006 (day of nutrient addition indicated on each graph)





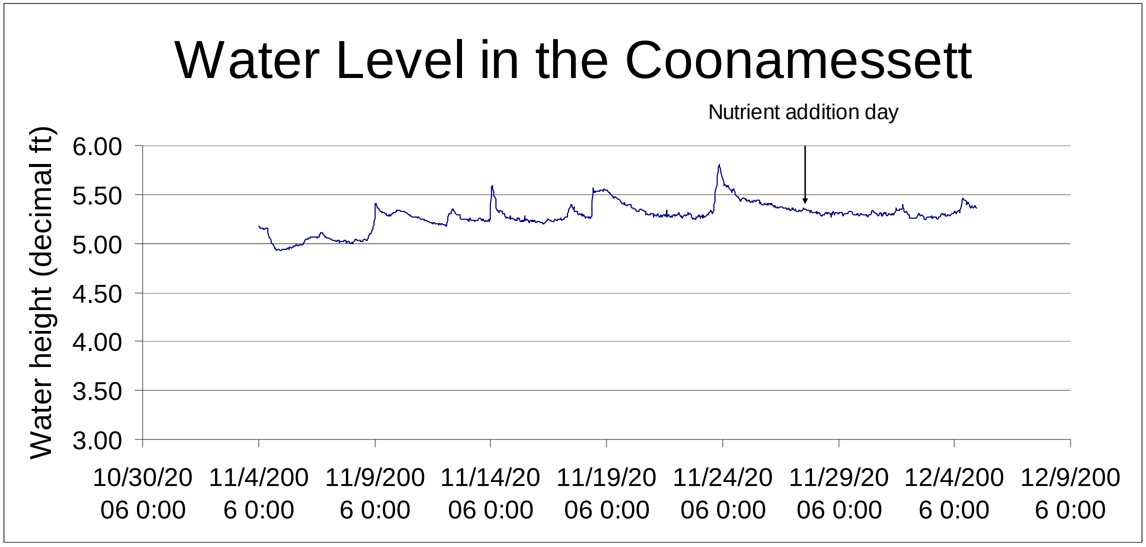
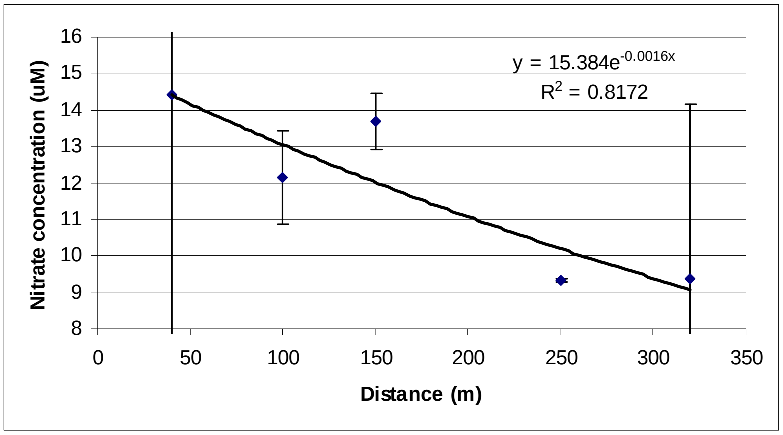
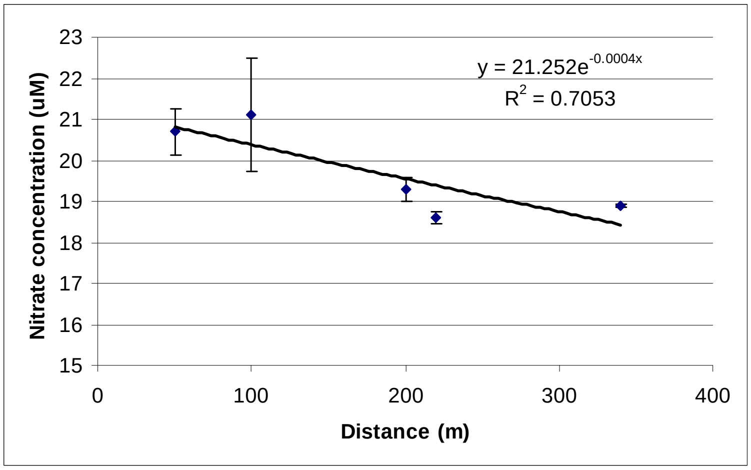
Water Level in the Coonamessett
Nutrient addition day
Water height (decimal ft)
6.00
5.50
5.00
4.50
4.00
3.50
3.00
10/30/2006 0:00
11/4/2006 0:00
11/9/2006 0:00
11/14/2006 0:00
11/19/2006 0:00
11/24/2006 0:00
11/29/2006 0:00
12/4/2006 0:00
12/9/2006 0:00

Figure 3. Difference between ambient nitrate concentration and final nitrate concentration in the Mashpee River, Quashnet River, and Coonamessett River, with standard error bars

Mashpee River



Quashnet River



Coonamessett River

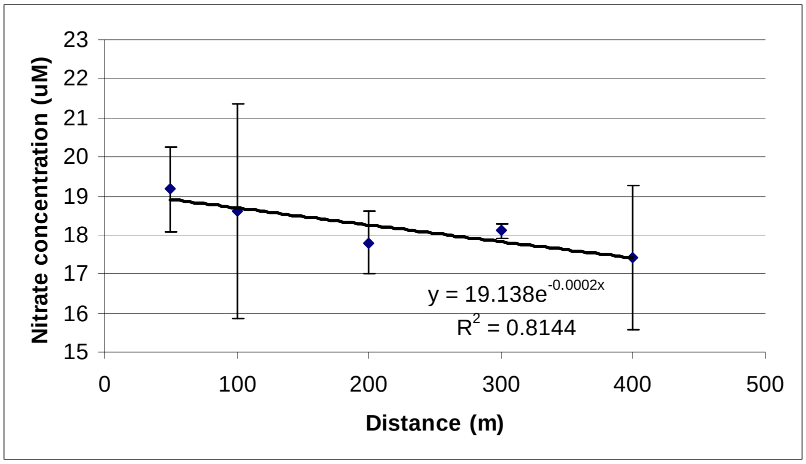
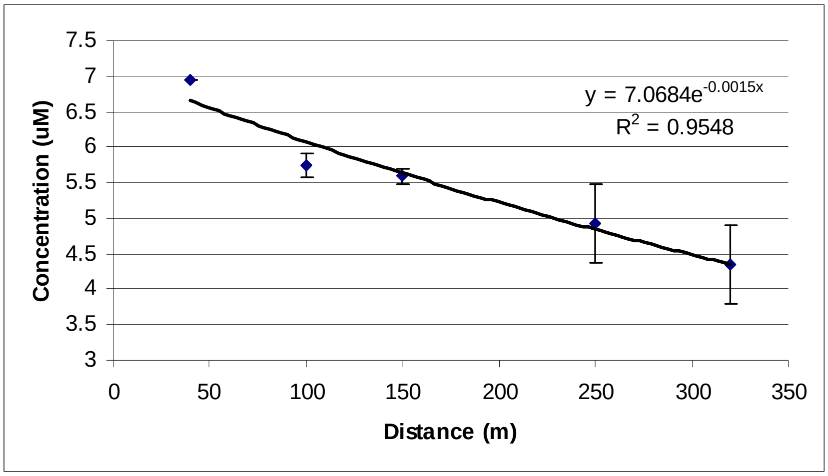
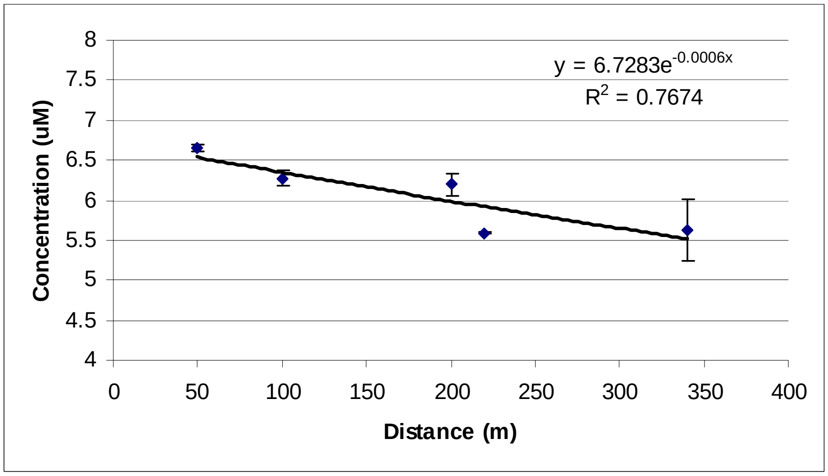


Figure 4. Difference between initial and final phosphate concentration in the Mashpee River, Quashnet River, and Coonamessett River with standard error bars

Mashpee River



Quashnet River



Coonamessett River

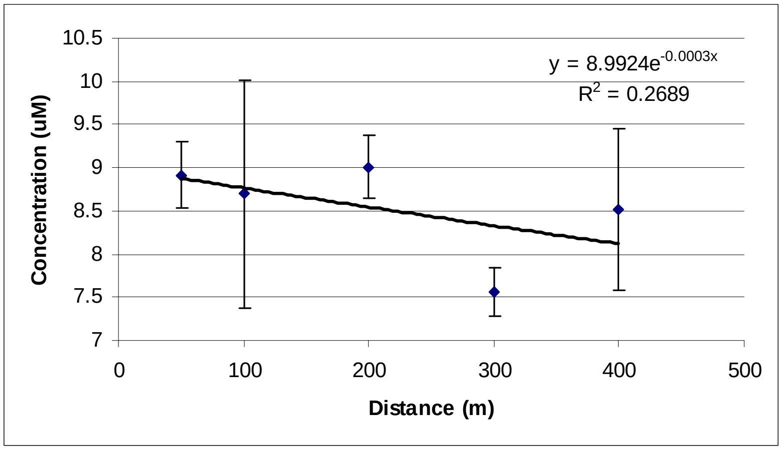


Figure 5. Organic matter composition in each of the eight analyzed sediment cores. FPOM is fine particulate organic matter with a grain size smaller than 2 mm. CPOM is coarse particulate organic matter with a grain size equal to or larger than 2 mm.

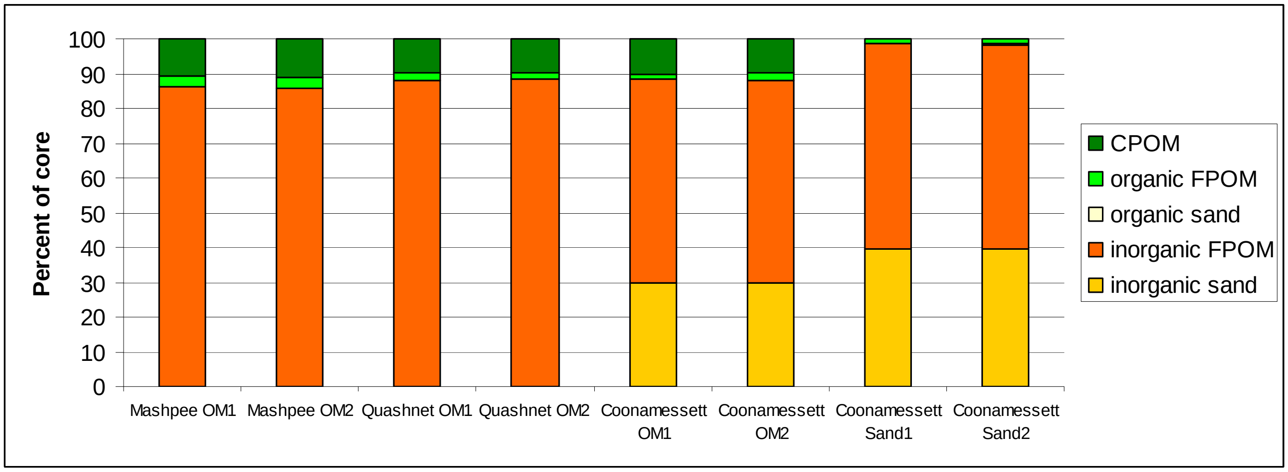


Figure 6. Average rate of respiration in the sediment core in each river, accounting for total sediment volume

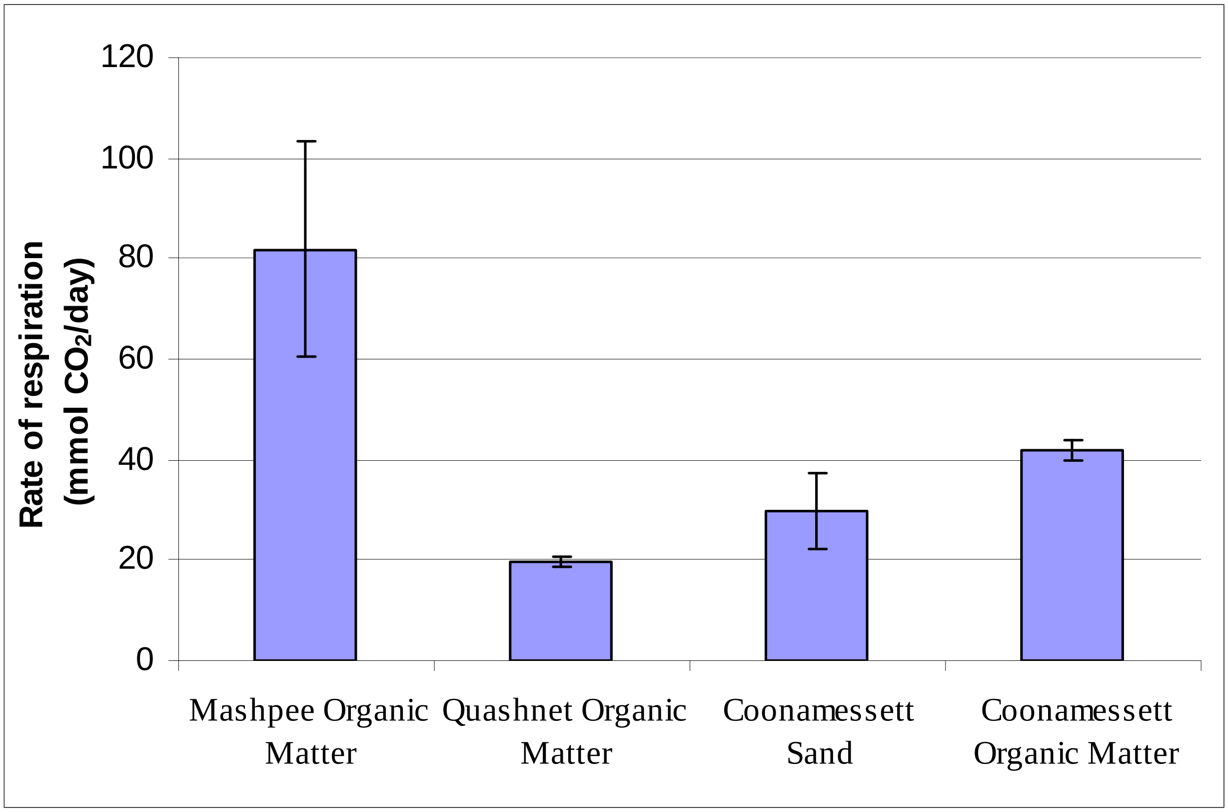


Figure 7. Average ammonium flux in the headwater of each sediment core in the three streams

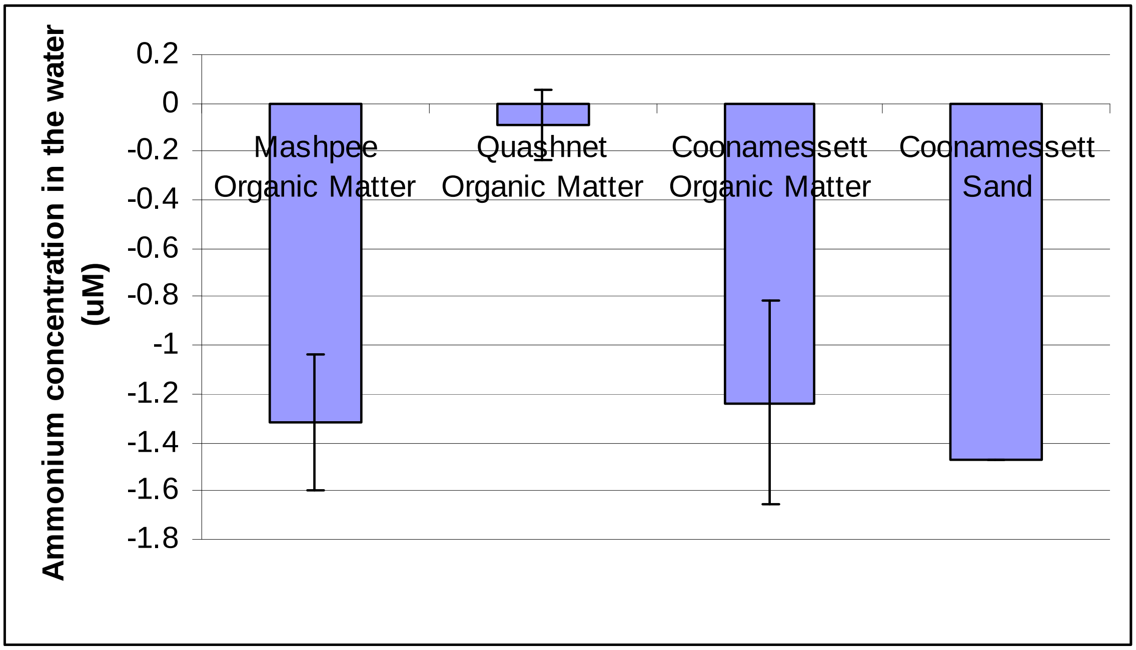


Figure 8. Average nitrate flux in the headwater of each sediment core in the three streams

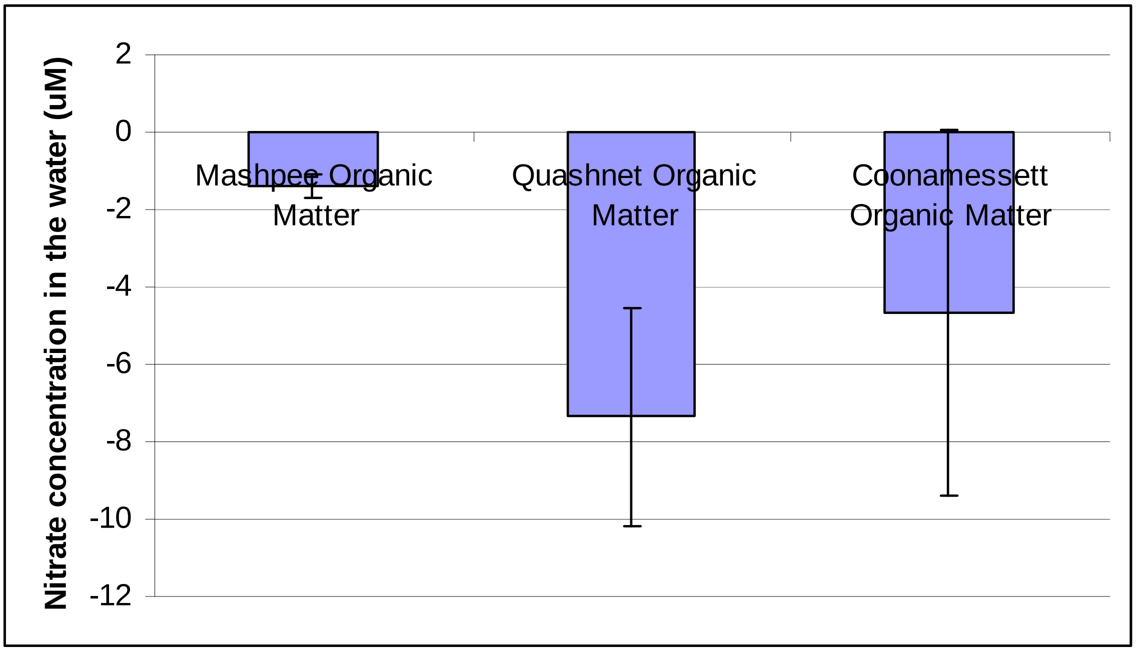


Figure 9. Average phosphate flux in the headwater of each sediment core in the three rivers

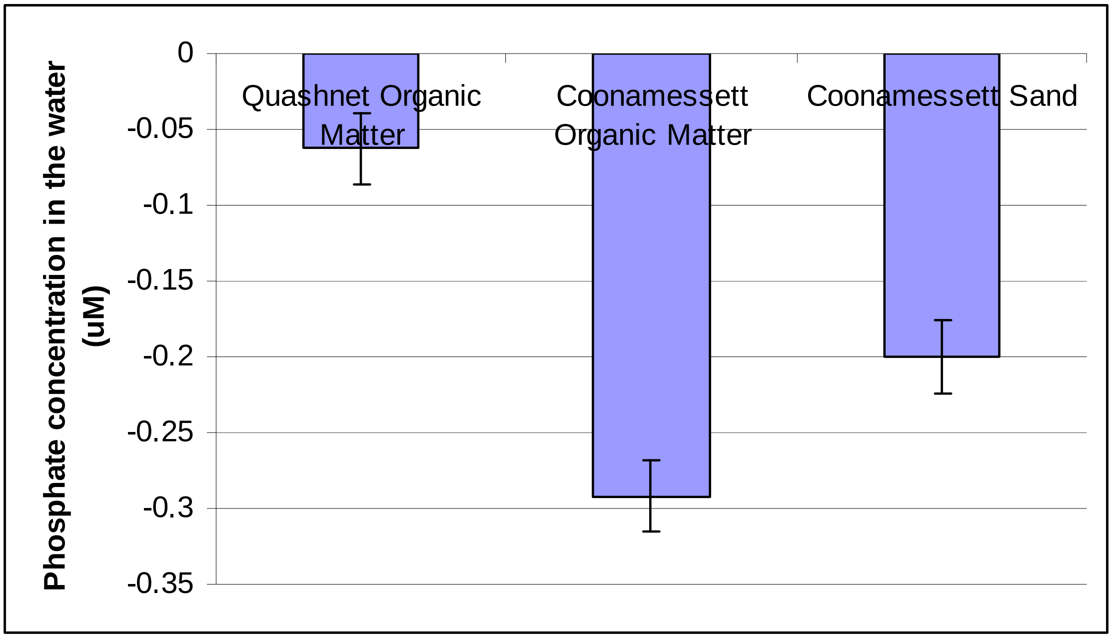


Table 1. Flow at the top and bottom of each river on the day of the addition

	Flow at Top (m^3/s)	Flow at Bottom (m^3/s)
Mashpee	0.47	0.45
Quashnet	0.392	0.358
Coonamessett	0.4	0.28

Table 2. Calculation summary for nitrate and phosphate addition in the Mashpee, Quashnet and Coonamessett

	Mashpee	Quashnet	Coonamessett
Calculated flow (m^3/sec)	0.397	0.377	0.349
Flow on addition day (m^3/sec)	0.375	0.46	0.34
Ambient Nitrate (µM)	24	23	14
Target Nitrate (µM)	48	46	42
Nitrate added (kg)	10.2	9	10.55376
Ambient Phosphate (µM)	0.7	0.7	0.7
Target Phosphate (µM)	5	5	5
Phosphate added (kg)	1.8	3.9	1.545372
Rate of addition (mL/sec)	10	10	10

Table 3. Conductivity across the mixing zones at the second sampling station in the three rivers Mashpee conductivity across the mixing zone

Mashpee

Distance (cm)	Conductivity (µS /cm)
0	84.85
2	82.95
3.5	83.3
5	76.5
6.5	80.1

Quashnet

Distance (cm)	Conductivity (µS /cm)
1.2	82.7
2	83.6
3	84.23333333
4	82.6

Coonamessett

Distance (cm)	Conductivity (µS /cm)
3.6	87.9
4.6	78.2
5.8	72.3
6.8	77.7
7.8	72.9

Table 4. Initial and final conductivity across the reach in the three rivers during the nutrient addition

Mashpee

Distance (m)	Initial (µS/cm)	Final (µS /cm)
40	88.7	97.9
100	89.1	97.1
150	89.1	96.4
250	89.0	97.3
320	89.0	96.1

Quashnet

Distance (m)	Initial (µS /cm)	Final (µS /cm)
0	76.1	76.2
50	79.0	83.9
100	77.4	83.9
200	77.4	83.7
220	77.6	83.6
340	77.8	82.4

Coonamessett

Distance (m)	Initial (µS /cm)	Final (µS /cm)
0	82.9	81
50	83.4	90.6
100	82.8	90.7
200	83.2	89.8
300	83.8	90.3
400	83.7	90.5

Table 5. Rate of nitrate and phosphate uptake in the three rivers per linear meter of river

	Nitrate uptake (µM m^{-1})	Phosphate uptake (µM m^{-1})
Mashpee River	0.0016	0.0015
Quashnet River	0.0004	0.0006
Coonamessett River	0.0002	0.0003

Table 6. C:N ratios in the organic matter in each river

Location	C:N Ratio
Mashpee River	27.3
Quashnet River	22.2
Coonamessett River	16.3