Farming the eddys: In-stream prevention of lake and coastal eutrophication

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Abstract

Eutrophication is a major issue for many bodies of water and coastal areas around the world. Phytoextraction has been used as a tool to mitigate eutrophication in the past, however it has not been done with agricultural crops to produce a harvestable product while removing nutrients from stream systems. In this study we modeled eddy systems and used watercress plants to mitigate nutrient loading in a closed system. We found that the watercress removed phosphate from the system but was ineffective at removing ammonium and nitrate in our modelled system. Future studies are needed to find a reduction in nitrogen levels and implement this method in natural streams that experience nutrient loading.

Keywords: Phytoremediation, phytoextraction, watercress, eutrophication, eddys, nutrient loading, agricultural runoff

Introduction

Many surface waters are significantly impaired by runoff from agricultural and urban land use (Simth et al., 1999). Agricultural runoff, in particular, often has elevated concentrations of nitrogen (N) and/or phosphorus (P), both of which can lead to severe downstream eutrophication problems in lakes (P) and estuaries (N) (Dillaha et al., 1989; Carpenter et al., 1998). Once excess nutrients reach surface waters, remediation is controlled by biological processing such as immobilization and denitrification in channel and floodplain sediments (Boyd, 1970; Schaller et al., 2004). However, nutrient concentrations far in excess of biological demand, wetland loss from development, and increased hydrologic flux often reduce the effectiveness of natural controls on nutrient transport and eutrophication.

Highly impacted landscapes, such as those where small streams and tributaries to larger rivers, are influenced by proximity of intense agricultural or urbanization. Once excess nutrients reach lakes and estuaries, the ecological effects magnify and the effects are much harder to mitigate. Literature does not address the intermediate phase between the point-source pollution and the larger stagnant body of water. In addition, few studies have examined the high levels of toxin buildup in flowing systems such as streams, and only focus on stagnant waters. Therefore, it is necessary to consider the impacts of concentrated nutrient runoff into stream systems before they contaminate larger ecosystems.

One potential means of reducing surface water nutrient concentrations is through phytoremediation. Phytoremediation is the use of plants to absorb pollutants from an ecosystem and can be used to treat eutrophic systems with plants that absorb high concentrations of N and P (Kiraly et al., 2013; Lu, 2010). Elevated N levels produce algae blooms that compete with fish and other aquatic species at high biomass (Chen et al., 2009); in removing excess N from the system, these ecosystems will be more productive. Similar ideas have been implemented to mitigate contaminants in pond and lake systems using inedible tropical plants (Todd, 2016). Phytoremediation has also been implemented on land, where plants and trees are planted to absorb contaminants such as lead or other heavy metals (Salt et al., 1995).

Although phytoremediation in point-source meshes and storm water ponds has been previously examined (Hunt, 2006), flowing surface waters such as small streams and tributaries have received less attention. Eddy flow systems are of particular interest because of longer retention time and slower water velocity, suggesting greater potential for nutrient uptake (Kopecky &

Torrance, 1973; Ensign & Doyle, 2006). Thus, eddys provide conditions for plants to extract excess N and P that cause eutrophication (Zhao et al., 2012; Schnoor et al., 1995).

We proposed an experiment to evaluate stream eddy nutrient uptake by harvestable watercress. We hypothesized that nutrient concentrations will decrease as plant uptake increases, until a nutrient becomes limiting (Mengel & Kirkby, 1978; Tanner, 1996). We also hypothesized that a slow moving eddy system will foster nutrient uptake (Carpenter et al., 1998). We studied uptake rate in modelled eddy systems to examine the effects of plant traits and tissue stoichiometry on phytoremediation efficiency. For example, watercress grows rapidly and is known to uptake more nutrients per unit tissue than species in the *brassica* family (Tanner, 1996). Watercress is also a very marketable agricultural crop that has the potential to increase the feasibility of implementing it in eddy systems. These experiments allow us to evaluate an effective method to reduce excess nutrient loading in surface waters that is cost and resource efficient. Further research could investigate the effective uptake of harmful organic and inorganic waste for selective uptake (McKone & Maddalena, 2007).

Methods

Eddy modeling

To uptake excess nutrients in a stream system, we modeled eddys in Skidmore's greenhouse. Eddys generally have long retention times and lower velocities in streams, which allows plants more time to extract excess nitrogen and phosphorus from the water that causes eutrophication further downstream into lentic ecosystems (Pauer & Auer, 2000). In these lake and pond ecosystems, stratification makes it more difficult to use phytoextraction as a method of mitigating eutrophication.

We modeled eddys using three rectangular-shaped basins with a 5.258 x 10^-5 m3/s pump in each one to keep the water moving with an average velocity of 0.03 m/s circular motion. We also added an airstone from an aerator to each basin to eliminate anoxic conditions and promote aerobic bacteria, important for nutrient uptake in stream systems. The outer bottom half of each basin was wrapped in black plastic to prevent much light from harming the plant roots from the side of the container, as solar radiation would not be natural at this angle in stream.

The plants were placed in a raft made of condensed Styrofoam insulation board with a reflective surface on the outside. Holes were cut into the insulation board to accommodate 5.08 cm net pots, spaced about 7.62 cm apart. Using this method, the plants can expand their roots into the water and absorb nutrients easily. Each of the three Styrofoam rafts holds 24 net pots. We placed the plants in the rafts to grow their root systems and above ground biomass, four weeks before we began the study.

Plant Growth

We started the watercress plants from stem cuttings from a nearby stream. We placed a five cm cutting into each Rockwool cube of a 98 cube perforated tray. We placed these Rockwool trays into a shallow tray containing our compost tea nutrient solution diluted 50 %. To grow out our plants quickly, we installed a six-bulb T8 fluorescent grow light fixture 20 cm above the tops of the Rockwool trays. These lights were set for a 24-hour period to promote rapid growth. Once the watercress was well rooted (12 days), we transferred each plant into 5.08 cm net pots and placed them into a floating raft system with the same nutrient solution and under the same lighting conditions to have the roots extend and cover more surface area in the water column. This allowed the watercress to uptake as much nitrogen and phosphorus as possible. Once the watercress cuttings were well rooted and growing in the floating raft system for two weeks, we moved them into the experimental basins in a separate room in the greenhouse. We installed a four bulb high output T5 fluorescent grow light fixture 60 cm above the tops of the four experimental floating raft systems and continued with the 24-hour photoperiod.

Experimental Set-Up

We chose to use two different solutions to mimic nutrient loading in the eddy systems. The first solution was an organic compost tea while the second one was a hydroponic synthetic fertilizer called Age Old Grow. 11.36 liters of each fertilizer solution were used in each bin. These two solutions mimic runoff containing both manure and synthetic fertilizers coming off agricultural fields and flowing into streams. These floating raft systems needed to be effective at removing nutrients from both fertilizer solutions.

Before placing the floating raft mechanism into the simulated eddy, we let the pumps and aerators run for 15 minutes; this allowed the nutrients to be completely mixed. Once the nutrients were added to the system, the pumps circulated the water for 15 minutes, and then water samples are collected from the system. The floating raft of watercress was added immediately after the initial samples were taken and was not removed for the duration of the experiment.

Nutrient Concentrations and Sources

For nutrients, we made a solution of compost tea that consisted of 4.500 kg of composted cow manure and plant material mixed with 30 liters of water. We left this mixture for 48 hours with a pump to keep it aerated and mixing before we filtered it all through a strainer and coffee filter to get our concentrated nutrient solution. We diluted this compost tea solution to 50 % in tap water to grow the watercress before the study began, and as the organic fertilizer experimental addition.

For our synthetic fertilizer trial, we added Age Old Grow hydroponic fertilizer at a rate of ¾ tablespoon per gallon of water. Age Old Grow contains 12 % total nitrogen (3 % water insoluble and 9 % water soluble organic nitrogen), 6 % available phosphate, 6 % available potash, 0.02 % boron, 0.05 % chelated copper, 0.1 % chelated iron, 0.05 % chelated manganese, and 0.05 % chelated zinc. We added the Age Old Grow to tap water and mixed it well before adding it to the eddy system (Age Old Organics, 2016).

Sampling

We systematically judged six sample areas throughout the basins based on the different microenvironments and flow rate in an eddy system to gain a better representation of the overall system: six samples alternating within the interior of the styrofoam mat, and reaching lower into the plant root mass. After initial analysis (t=0), then we measured at 6, 12, 24, 48, and 72 hours for our organic compost tea approach and at 6, 12, 24, 48, 72, 96, and 120 hours for the synthetic fertilizer trial. Six samples were taken at each time interval and were then filtered into one sample bottle which was stored frozen until analysis. All samples were thawed in warm water and shaken for 15 seconds to mix before analysis.

Nutrient Analysis

These analyses will examine the nutrients in a micro well plate and spectrophotometrically measure the absorbances, to compare them to a known standard curve. We examined phosphate (D'Angelo et al., 2001), nitrate (Doane & Horwath (2003), and ammonium (Rhine et al., 1998) through protocols.

Results

Using the organic fertilizer solution, we observed an increase in phosphate from an initial 1.4 ppm to 1.9 ppm after 12.5 hours, followed by a decrease to 1.7 ppm by 24 hours ($y = -00025x^2 + 0.0752x + 1.3662$; $R^2 = 0.9904$). The average ammonium concentration decreased from 0.9 to 0.3 ppm ($y = -0.0013x^2 + 0.0077x + 0.8426$; $R^2 = 0.8315$). On the other hand, we observed an increase in nitrate from 0.6 to 3.3 ppm after 24 hours ($y = -0.0011x^2 + 0.1338x + 0.6684$; $R^2 = 0.9984$).

When using the inorganic synthetic fertilizer, we observed an overall decrease in phosphate from 18.5 to 14.9 ppm over 4.4 days ($y= -0.0004x^2 + 0.0107x + 18.25$; $R^2 = 0.9179$). The nitrate concentration peaked from at 4.74 ppm after 57 hours, then showed a decreasing trend to 2.21 ppm at the end of the experiment ($y = -0.0011x^2 + 0.1438x – 0.7947$; $R^2 = 0.8164$). Finally, there was a large initial increase from 15.4 to 70.8 ppm after 82 hours, which had a decreasing trend to 61 ppm to 23 hours after ($y = -0.0057x^2 + 1.1028x + 11.7$; $R^2 = 0.9430$).

The data show a decreasing trend in phosphate using both organic and inorganic fertilizers, as well as a high increase in nitrate with the organic fertilizer and high increase in ammonium with the inorganic fertilizer.

Discussion

In both solutions there was a projected decrease in phosphate over time. As phosphorous tends to be the limiting nutrient in lakes and ponds, a decrease in the tributaries would lead to a lower potential of eutrophication in these larger stagnant bodies of water downstream. This shows the plants took up nutrients using this method, however the available nitrogen levels fluctuated differently.

In the organic cow manure compost tea solution, the ammonium decreased which caused an increase in nitrate at the same time due to nitrification (Figure 2). Nitrification transforms ammonia or ammonium to nitrate and nitrite, which is typically the limiting step of nitrification. This is largely an aerobic process performed by autotrophic bacteria (Prosser, 1990). Despite nitrification being a natural process in stream ecosystems, nitrification could be the primary reason for the unexpectedly high increase in nitrate. However, extending this solution to longer than three day is necessary to examine the overall fate and fluctuations in the nutrient concentrations.

In adding the inorganic synthetic fertilizer, there was an unexpected increase in ammonium to high toxic concentrations after only three days (Figure 3). More ammonium could have been released due to mineralization within the basin as the particles may not have been completely dissolved especially near the root mat of the watercress (Westerman & Tucker, 1974). Another reason may be that the growth of cyanobacterial along the edges of the basins and top of the rockwool cubes could have fixed more nitrogen from the atmosphere and into the water (Vitousek et al., 2002). Finally, there was slight evaporation from the bins, as well as potential stress and die-off from plant roots that could have made the later samples more concentrated.

These processes could have created higher concentrations of ammonium, but it is unlikely that this caused a 65 ppm increase in ammonium, which would burn watercress roots; this was not seen (Westerman & Tucker, 1974). We found that the synthetic fertilizer was composed of 12 % nitrogen, 9 % of the nitrogen being stored in organic form. In the study by Rhine et al., results showed organic forms of nitrogen such as amino acids and proteins could interfere with the citric acid in the ammonium protocol, causing higher than expected ammonium measurements. This interference could be reduced somewhat by lowering the temperature or pH of the reaction (Rhine et al..,1998).

As we observed a noticeable decrease in phosphate, additional trials should eliminate interferences and use a different inorganic solution with the floating raft method. After refining the method, field tests in a natural eddy system with watercress would be the next step to determine if the expected trends are seen in the natural environment; taking into account various microbial communities. We can also examine other plants in the *brassica* family to determine difference in uptake and examine other plants that may take up a greater volume of phosphate compared to nitrate depending on the limiting nutrient of the ecosystem (Fraser et al., 2004).

Future studies could also include changing the ratio of plants to the surface area or volume of the eddy to see what effect it may have on the nutrient uptake rate and amount of harvestable watercress that can be grown. Higher densities of watercress may produce a higher harvestable yield while taking up more nutrients.

To examine the model more specifically, we could measure nutrient uptake in the plant tissue instead of the surrounding water (Mattina et al., 2003; Cataldo et al., 1975). We could also trace the isotopes throughout the modelled eddy system to determine the fate of the nutrients and how much is being stored in bacteria as well as the pace of the enzyme activity (Handley & Raven, 1992). A closer analysis of these processes helps us understand how the model can best represent a natural system, and where to channel effective nutrient absorption to prevent eutrophication and produce a harvestable crop.

Through experimentation with using eddys to grow harvestable watercress while mitigating nutrient loading in stream systems, we have found a significant decrease in phosphate concentrations. This means that farming eddys would be feasible as a method of mitigating nutrient loading in phosphorus limited lake systems. Our results did not show a decrease in nitrogen concentrations in the form of ammonium and nitrate, therefore this may not be a feasible way to mitigate excess nutrients in nitrogen limited systems such as rivers and coastal areas. Farming eddys may be a feasible way to mitigate nutrient loading before it makes it downstream to lakes or coastal areas where it causes eutrophication while growing more crops in areas that we have not been able to farm previously.

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