Wetland Vegetation Effectiveness in Stormwater Treatment

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Abstract The use of natural or constructed wetlands for controlling stormwater contaminants is a relatively new and increasingly popular method for stormwater treatment. Because of this, there have been increased demands for improvements of the design parameters in constructed wetlands. One such design parameter for a constructed wetland treatment system deals with the species of wetland plants. The information presented in this research report measures the relative removal rates of stormwater pollutants by specific wetland plant species. Stands of *Typha* spp., *Phragmites* spp., and *Scirpus* spp. were tested against a control treatment (no vegetation). Each treatment was continually fed with synthetic stormwater containing total phosphorus (TP), copper (Cu), chemical oxygen demand (COD), and total organic carbon (TOC) for two detention times (7 and 14 days) under low and high pollutant concentrations. Unexpectedly, analysis of the water quality indicated export, or elevated levels, of TP in most of the vegetated treatments. The unvegetated treatment indicated consistent removal averaging 53% for all detention times. Eventually, the export of TP gradually decreased with time for the vegetated treatments. Towards the end of the observed interval, most treatments showed a positive removal of TP. Furthermore, among the vegetated treatments, *Typha* spp. demonstrated the highest removal rates in copper while *Phragmites* spp. demonstrated the highest removal rates for chemical oxygen demand and total organic carbon. *Scirpus* spp. showed the greatest variability and least effect on pollutant reduction for all pollutants compared to other species tested. Overall the unvegetated control treatment yielded the highest removal for all contaminants.

Introduction

Wetlands are among our most valued but least understood ecosystems. Current law places very high value on their preservation, restoration, and creation (Mitsch & Gosselink 2000). Wetland vegetation has long been regarded as a potential sink for many pollutants, and today constructed wetlands are becoming accepted for the treatment of stormwater (Mitsch & Gosselink 2000). Constructed wetland systems have been used to treat municipal and industrial wastewater and have been found to be more cost-effective than advanced wastewater treatment systems (Kulzer 1998). However, the design parameters needed to construct a reliable system are not well established (Kulzer 1998). Using natural or constructed wetlands for controlling stormwater pollution is a relatively new method for stormwater treatment. Plant response to constant hydrologic and pollutant loadings are well documented in the literature (Kulzer 1998), whereas little information is available regarding the pollutant removal performance of specific California wetland plant species.

Managers, engineers, policy makers, and biologists are often required to consider wetlands during construction or development and may have insufficient knowledge on wetlands to make good decisions concerning the balance between development and a sustainable wetland (Kulzer 1998). Presently, regulators demand that wetlands be both safe and deliver effluent with a known concentration of toxicants or biostimulants such as total phosphorus or the chemical oxygen demand of the water (Mitsch & Gosselink 2000). Therefore, improvement in wetland design is needed, as well as a better understanding of which vegetation type has maximum efficiency in stormwater treatment. Such information would be a valuable resource for the design of stormwater treatment wetlands.

Some past studies have examined similar types of topics. One such study measured the effectiveness of a vertical flowing constructed wetland in the removal of heavy metals such as copper, zinc, and lead (Cheng 2002). The chambers of the constructed wetland were filled with vegetation such as *Cyperus alternifolius* and *Villarsia exaltata* (Cheng 2002). The end result of the study found that no heavy metals could be detected in the effluent. The study concluded that the vegetated chambers were predominantly responsible for the decontamination of the water, and that a vertical constructed wetland is an effective tool in phytoremediation for treatment of water polluted with heavy metals (Cheng 2002).

Another study discussed nine pilot wetlands that have been constructed for the treatment of municipal wastewater. The wetlands had several geographical locations and contained a variety of macrophyte types and species found in Australia (Greenway 1999). The paper examined the performance efficiency of the wetlands and pollutant bioaccumulation in wetland plants (Greenway 1999). The study ultimately found that all the species removed pollutants from the water column. Emergent plants had lower pollutant concentrations than others while aquatic grasses had higher pollutant content. Furthermore, nitrogen concentrations were found to be higher in leaf/stem tissue, while phosphorus was higher in root/rhizome tissue (Greenway 1999).

Finally, a study conducted by J.H. Rodgers presents a research strategy for evaluating the capability of constructed, restored, and natural wetlands to assimilate and process pesticides associated with agricultural runoff from croplands (Rodgers 1992). No actual experimentation was done in this study, so specific numbers regarding pesticide removal by wetlands are not available.

These studies discuss many vegetation types that are important in effective pollution removal of heavy metals and nutrient bioaccumulation, however they do not discuss the relative removal efficiencies of specific California wetland vegetation. My study will be similar to these previous studies, but will focus on the types of vegetation that are predominantly found in California. The information presented in my study will subsequently allow one to determine how to create an efficient wetland with the most effective vegetation for California wetland treatment facilities. What I hope to accomplish with my study is to provide more information about pollutant removal efficiencies so that engineers or biologist will be able to make more informed decisions about how to make a constructed California wetland most efficient.

The main objective of this research project is, therefore, to measure the relative removal efficiencies of characteristic stormwater pollutants by a dense stand of common California wetland vegetation under various loads and hydrologic conditions in a controlled greenhouse setting. Monoculture stands of *Typha* spp., *Scirpus* spp., and *Phragmite*s spp. will be tested in wetland treatment cells against an unvegetated control. Treatments will be continually fed with synthetic stormwater containing total phosphorus (TP), chemical oxygen demand (COD), copper (Cu), and motor oil. These pollutants are commonly found in stormwater, which is why they will be tested. The water quality analysis will test for various trends with respect to pollutant removal and time, and will therefore help to determine what type of vegetation, or combination of vegetation, will be most effective in constructed wetlands. These answers may help to determine which type of design is best suited for the removal of common pollutants.

I hypothesize that the best type of vegetation to use in a stormwater treatment wetland highly depends on what is being removed. In general, though, I predict that cattails (*Typha* spp.) will be the most effective wetland vegetation type for stormwater treatment. These emergent plants grow very quickly, have a high denitrification rate, and are well adapted to the wetland environment (Crawford 1998). Not many plants are able to withstand the wetland environment, but cattails will be successful due to their many adaptations and characteristics. Cattails would be good wetland vegetation because they have a large, dense root system, which provide a place for biofilm to develop (Alphin 2000). Biofilm is the food source for many bacteria, which aid in the removal of certain pollutants and the conversion of pollutants into a less toxic form like nitrates. Biofilm can be found in bulrush (*Scirpus* spp.) and reeds (*Phragmites* spp.), but not in high concentrations like that found in cattails.

Methods

My study was conducted in a temperature and light controlled greenhouse at the Don Edwards San Francisco Bay Wildlife Refuge in Fremont, CA. The materials needed to conduct this study include plastic containers with dimensions of 0.46m (W) x 0.60m (L) x 0.53m (H), and wetland vegetation seeds of cattails (*Typha* spp.), bulrush (*Scirpus* spp.), and reeds (*Phragmites* spp.). These specific wetland plant species are chosen because they are predominantly found in California wetland areas. Gravel was also needed to plant the seeds in and synthetic stormwater. The synthetic stormwater contains pollutants of total phosphorus, chemical oxygen demand, copper, and total organic carbon. Concentrations and the types of pollutants used in the synthetic stormwater are representative of those found in urban runoff, according to the Nationwide Urban Runoff Program (NURP) study (USEPA 1983). Each pollutant concentration is summarized in Table 1. Finally, a fluorescent grow light was also used for the study to aid in the light requirements for the treatment cells.

Pollutant	Source	Low Range Target	High Range Target
TP	Fertilizer	2.5 mg/L	5 mg/L
COD	Potassium salt	60 mg/L	120 mg/L
Cu	Pesticide	0.75 mg/L	1.5 mg/L
TOC	Motor oil	30 mg/L	60 mg/L

Table 1. Synthetic Stormwater Composition

Four groups of wetland treatment cells were constructed. The first three replicates in each group contained each of the vegetation species listed above, and the last replicate in each group was unvegetated, which served as a control for the experiment. The set-up of each group is illustrated in Figure 1. Each replicate was filled with gravel and was planted with either a monoculture of cattails, bulrush, or reeds. The group of unvegetated replicates was run parallel with the three groups of vegetated replicates. After completion of the growth phase (approx. 1 ½ months), every replicate was inundated with a constant influx of synthetic stormwater under low and high concentration levels for two detention times (7 days and 14 days). To initiate pollutant inundation, clean water was pumped out of the treatment replicates and then was replaced by the mixture of synthetic stormwater. Grow lights were suspended approximately 1.3m above the replicates, and aluminum foil lined the sides of the containers to increase light penetration.

After each detention time, water samples were collected at four locations within each treatment replicate as shown in Figure 1. This was to ensure that an even sample of water was taken from each treatment replicate. Flow rate into and out of replicates were collected daily from Monday to Friday. Samples were collected from replicates using plastic hand pumps. All samples were collected in appropriate containers, preserved, and stored according to US EPA approved methods (USEPA 1992). Collected samples were measured using a portable storm drain analysis lab provided by the Environmental Sciences major.

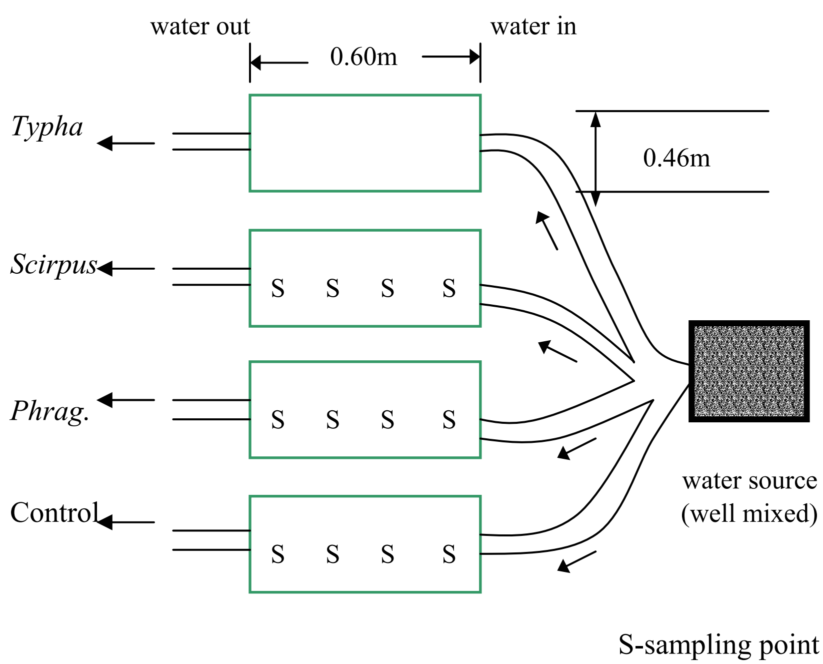

Figure 1. Constructed Vegetative treatment cell site set-up

Nonparametric statistical evaluations were performed using a One-Way ANOVA test. An ANOVA was run for each water variable with a control and plant species as a fixed effect. Cell pollutant removal is considered as the reduction in concentration according to:

$$\frac{(C_{in} - C_{out})}{C_{in}} \times 100\%.$$

Pollutant removal was calculated for each detention time, for an entire treatment from the average of each detention time, and for the overall performance from the average of the four individual treatments.

Results

Plant Type	Test	Total Phosphorus	Copper	Chemical Oxygen Demand	Total Organic Carbon
		Total Removal (mg/L)	Total Removal (mg/L)	Total Removal (mg/L)	Total Removal (mg/L)
Typha	1	-1.26	2.66	2.31	0.98
	2	-3.78	1.40	2.17	2.59
	3	-0.84	-8.05	2.52	4.13
	4	3.92	0.98	6.51	5.95
Scirp.	1	1.54	-8.40	4.83	2.24
	2	-6.09	3.57	2.80	1.61
	3	-1.89	-106.12	6.93	4.06
	4	3.29	-0.98	3.78	5.60
Phrag.	1	-1.40	1.47	5.32	3.71
	2	-4.34	0.07	2.52	1.96
	3	-0.70	-25.13	4.83	3.15
	4	3.35	2.87	6.37	0.63
None	1	3.99	3.43	5.04	4.90
	2	2.31	5.11	4.27	4.55
	3	4.06	3.22	6.23	5.81
	4	3.64	2.59	6.23	2.94

Table 2. Pollutant Reduction of Plant Type, replicates represent consecutive experiments in the set-up shown in Figure 1. Negative figures represent elevated levels of pollutant.

Table 2 shows the total reduction of each pollutant for every vegetation type, including the control. Although there were initially two detention times (7 and 14 days), only data from the first 7 days of the 14 day detention times were considered. The purpose of this is to maintain a consistent factor (7-day detention time) throughout the experiment. Hence, tests 1 and 3 demonstrate pollutant reduction for 7 days under low pollution concentration, and tests 2 and 4 demonstrate pollutant reduction for 7 days under high concentration. By determining which vegetation type has the highest reduction values, I can conclude which vegetation type is able to reduce pollutants most effectively. The concentration values were obtained using the Storm Drain Analysis Kit provided by the Environmental Science major.

The form of statistical analyses that was used to test my hypothesis was the One-Way Analysis of Variance (ANOVA) test. Table 3 below indicates the significance of each treatment in the removal of the specified pollutants.

		DF	Sum of Squares	Mean Squares	F-Value	P-Value
Total Phosphorus	Plant type	3	52.7	17.5	1.8	0.19
	Residual	12	114.4	9.5		
Copper	Plant type	3	2373.4	791.1	1.1	0.39
	Residual	12	8824.2	735.3		
Total Organic Carbon	Plant type	3	9.5	3.1	1.1	0.36
	Residual	12	33.2	2.7		
Chemical Oxygen Demand	Plant type	3	8.8	2.9	1.0	0.39
	Residual	12	33.2	2.7		

Table 3. ANOVA Tables for all contaminants

Figure 2 below illustrates the reduction values obtained from the experiment. Instead of plotting the total reduction of pollutants for each detention time of each vegetation type, the average removal of all detention times is plotted. Error bars are also plotted to express standard errors.

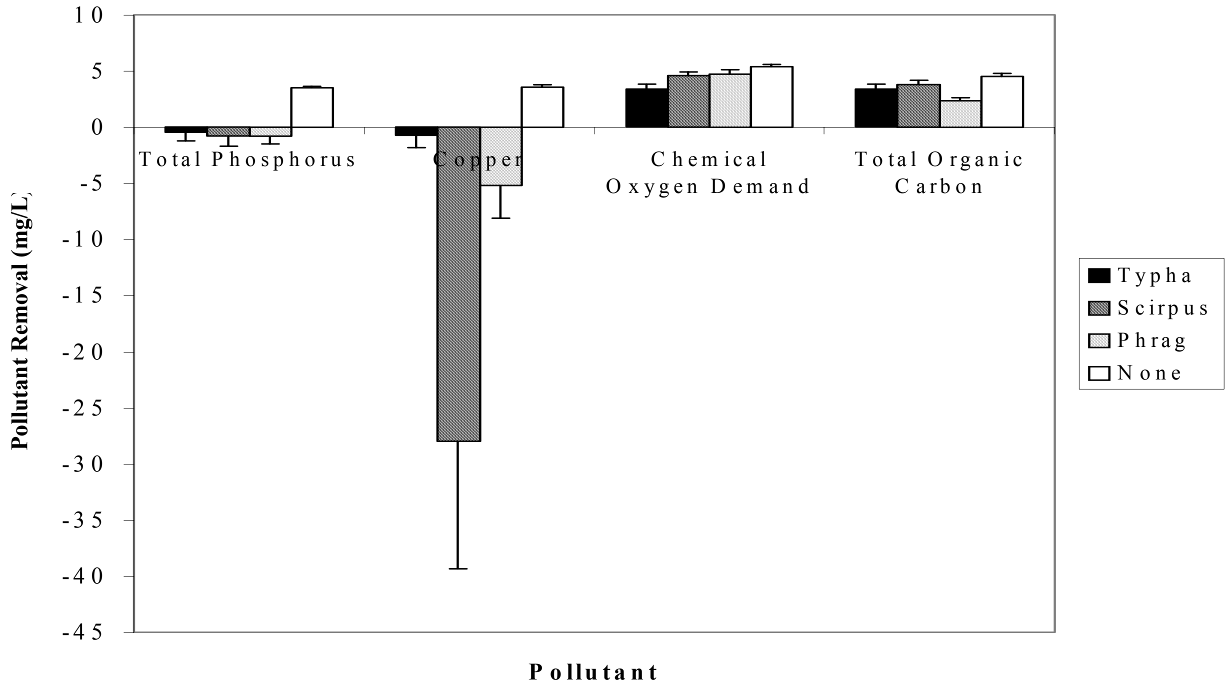

Figure 2. Total Pollutant Removal in Treatments, bars represented are standard error

Discussion

Results indicate the importance of acclimation for constructed wetlands in stormwater treatment. The treatments containing *Typha* spp. demonstrate the effects of plant maturity on total phosphorus (TP) removal. Significant export of TP was seen for most tests, but the rate of export may decrease with time, as suggested by results in Table 2. Export of TP is most likely due to plant death from inundation by pollutants. Similar to *Typha* spp., the treatment containing *Phragmites* spp. also indicates the effect of plant maturity on TP removal as shown in Table 2. Results suggest that as vegetation matures, increased pollution removal should be realized, especially for TP. Combining all treatment results for total phosphorus removal, *Typha* spp. observed a removal ranging –100% to 64.8%, and *Phragmites* spp. observed a removal ranging –140% to 65.1%. The negative sign here indicates a negative reduction or increase in the amount of pollutants.

The wetland vegetation species do not show a significant positive impact on reducing copper concentrations. Copper (Cu) removal was generally low in *Typha* spp., but again there was some evidence of improved performance with time. *Scirpus* spp. showed the greatest variability and the least effect on copper reduction compared to other species tested. Substantial export of Cu was measured in all vegetated treatments during test 3, however average Cu removal for *Scirpus* spp. was significantly reduced by the results of this test. This may have been due to low water column concentrations which may have resulted in leaching of the contaminant from the plants. If results of test 3 are not considered, average removal of copper ranges between 24%, 21%, -28%, and 53% for *Typha* spp., *Phragmites* spp., *Scirpus* spp., and the unvegetated treatments respectively. In general, results do not indicate that the plant species tested had a significant impact on the reduction of copper relative to the control.

A reduction of total organic carbon (TOC) was evident throughout data. Within each treatment, TOC removal was relatively consistent with an average removal level ranging from 24%-69%. Among the vegetated species, *Scirpus* showed the best TOC removal however the unvegetated treatment maintained the highest reduction values.

A positive removal of chemical oxygen demand (COD) was observed for all treatments with average removal ranging 54% to 78%. COD reduction remains consistent with the results from other vegetation as shown in Table 2. Figure 2 demonstrates positive removal of COD with the highest removal for *Phragmites* spp. among the vegetated treatments.

Pollution reduction in the unvegetated treatment demonstrated the most consistent results. Pollution reduction in vegetated treatments showed much greater variation compared to the unvegetated treatment. Although performance varied substantially, tests with a high concentration level of pollutants resulted in the best overall reduction of the stormwater contaminants tested. Results suggest that wetlands may be able to manage heavy loads from stormwater “hot spots”. Overall, results suggest that the presence of plants does not positively impact the results of pollutants as shown in Table 3.

There are many factors that may have contributed to unexpected results of the experiment. One such factor is the maturity level of plants during pollutant inundation. My experiment was conducted while vegetation was still maturing, however, studies conducted in the past tested pollutant removal with fully matured vegetation (Ayaz 2000). The lack of maturation within my vegetation may have resulted in the vegetation not being able to remove as much pollutant as it could have had it been fully matured. In connection to this is that plants may not have had enough time for biofilm to develop on their roots. It takes about 8-10 weeks for fully functioning biofilm to develop however the plants were grown for about 6 weeks before they inundated. Another factor that may have affected my results is the concentration of pollutants during inundation. In the study conducted by S.C. Ayaz, high levels of pollution concentrations (i.e. 670

mg/L of COD) were used to determine pollution removal and the final results determined that wetland plants do indeed reduce pollutants (Ayaz 2000). However, my study suggests the opposite conclusion perhaps because lower levels of pollutants (i.e. 120 mg/L of COD) were used to inundate plants rather than higher levels. Furthermore, the sample size that was chosen for my experiment may have been too small. Past studies included eight or more sample sizes for their experiments (Greenway 1999). Increased sample sizes may have yielded a higher removal of pollutants and a decrease in variance. A final factor that may have altered the results of my experiment is the type of species chosen for my experiment. Past studies experimented with different species of wetland vegetation such as *Cyperus alternifolius* or *Villarsia exaltata* (Cheng 2002). Perhaps the species that I have chosen may not have been ideal for the removal of stormwater pollution.

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