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RIPARIAN CONSTRUCTED WETLADNS FOR IMPROVING WATER QUALITY IN A POLLUTED RIVER IN SOUTHEASTERN MEXICO

HERNÁNDEZ, M.E., RUIZ-ENZÁSTIGA P.

[1] Biotechnological Management of Resources Network. Institute of Ecology. Carretera Antigua a Coatepec # 351, El Haya, C.P. 91070, Xalapa, Veracruz Mexico .elizabeth.hernandez@inecol.edu.mx

CSBE101195 – Presented at ABSTRACT Sordo River is a heavily polluted stream because it receives untreated urban sewage. Riparian Constructed wetlands CW are an adequate alternative to improve water quality in polluted rivers in developing countries. The objective of this study was to compare the efficiency of surface flow water CW (SSFCW) and subsurface flow CW (SFCW) to improve water quality in the Sordo River. The CW cells measured 1.5 m length, 0.25 m wide and 0.6 m depth, four cells were set up for SFCW (upland soils, 0.4 m deep, free water flow column of 10 cm) and four for SSFCW (volcanic gravel 0.04 m diameter, 0.4 m depth, water flow 10 cm below surface). Two cells of each type were planted with *Typha* sp and two cells were left without plants as controls, hydraulic retention time was 5 days. From June to November 2009, concentration of ammonia nitrogen ($N\text{-}NH_4$) in the river water ranged from 2-18 mg L^{-1}, Chemical Oxygen Demand (COD) ranged from 2-450 mg l^{-1}, Phosphates ($P\text{-}PO_4$) ranged from 0.5-5 mg L^{-1} and nitrates ($N\text{-}NO_3$) ranged from 0.5 to 7 mg L^{-1}. Both, SSFCW and SFCW were efficient in $P\text{-}PO_4$ removal (63-93%) but the SSFCW without plants was significantly less efficient (20-83%). COD removal efficiency was similar in SSFCW and SFCW (27-51% and 28-73% respectively) and only the SFCW without plants showed significantly lower efficiencies (21-45%). For $N\text{-}NH_4$, SSFCW showed significantly higher removal efficiencies (48-95%) than SFCW (9-70%). It was concluded that SSFCW are an ecological alternative to improve water quality in this river.

Keywords: water pollution, eutrophication, stream restoration, sewage

INTRODUCTION

In Latin America, only 14 % of the total wastewater receives treatment (Martijn y Redwood, 2005). The Mexican General Law for Environmental Equilibrium was enacted in 1988 and water discharge regulations were published in 1996. However, because of the lack of law enforcement and the economic crisis, several rivers in the country are heavily polluted from both industrial and domestic wastewaters (Alvárez et al, 2006). Currently, river pollution is a country wide environmental problem that still needs to be solved. Within this context, it is necessary to find ecologically and economic alternatives to treat both point source pollution and non point source pollution, in order to improve water quality in Mexican rivers.

Constructed wetlands (CW) are an adequate alternative to improve water quality. Compared with conventional wastewater treatments, CW are more economical, they need less maintenance, they do not consume fossil fuels; they show flexibility for treating several types of wastewater and different pollutants loadings (Kadlec, 1996). In addition, CW provide good aesthetics (Brix, 1997). There are two types of CWs, the surface water flow CW (SFCW) where water flows above the substrate and the subsurface CW, where the water flows below the surface substrate. Both types of CWs have been applied successfully to improve water quality and the criteria for choosing the type of CW, depends of the land availability, pollutant loading and the available funding. The cost of SSFCW might be 1.6 higher than SFCW (Knight, et al., 2003). CWs have been successfully used to treat point source and non point source pollution in developed countries (Greenway and Wooley, 1999, Kovasic et al., 2000, Vymazal, 2001, Belmont and Metcalfe, 2003, Miklas, 2007). More recently, CWs have been investigated to improve water quality in polluted rivers in developing countries in Asia (Jin, et al, 2001, Kim, et al., 2006, Ruan et al., 2006, Juang and Chen, 2007) .In Latin America, despite of the multiple benefits that CWs provide, they have been less applied than in Europe and USA (Vymazal and Kropfelova, 2008). We propose the introduction of riparian constructed wetlands to improve water quality in polluted rivers in Mexico. However, the design of these systems in our region still needs mesocosm studies. In this regards, is important to know what type of CW is adequate to be built in the riparian zones to improve water quality. The aim of this study was to compare the COD and nutrient removal efficiency in SSFCW and SFCW treating water from a polluted river in south-eastern Mexico.

MATERIAL AND METHODS

Study site

This study was conducted in the central part of Veracruz State in Southeastern Mexico. The mesocosms CW were located in a greenhouse of the Botanical Garden Francisco Javier Clavijero in Xalapa (97° 01” W 19° 33.5” N), the capital of Veracruz State. They were fed with water from the Sordo River. This river is a third order stream that originates in the tropical mountain rainforest upstream from the botanical garden, downstream, it joins the Pixquiac River and finally it merges to La Antigua River which flows into the Gulf of Mexico. The area of La Antigua river watershed is 2827 Km^2 (Castro-Fontana, 2004).

Mesocosm CWs

The experimental array of CW cells (1.5 m length, 0.25 m wide and 0.6 m depth) was as follows: four cells were set up for SFCW (substrate upland soils, 0.4 m deep, free water surface flow column of 10 cm) and four for HSSFCW (volcanic gravel 0.04 m diameter, 0.4 m depth, water flow 10 cm below surface). Two cells of each type were planted with *Typha* sp and two were left without plants as controls. CWs were fed with water from the river, which receives untreated urban sewage and industrial wastewaters. Water was pumped to a 500 L homogenization tank and its flow rate was adjusted for each cell to have a Hydraulic Retention Time (HRT) of 5 days.

Sampling and analytical methods

200 ml water samples were taken in the homogenization tank (immediately after water was pumped from the river) and in the outlet of each CW cell. Water sampling was performed twice a week from June to November 2009.

Chemical Oxygen Demand (COD) was measured using the oxidation of $K_2Cr_2O_7$ micro-method (APHA, 1998); ammonia nitrogen was analyzed by the Nessler method (APHA, 1998); phosphates were quantified using the ascorbic acid method according to Sandell and Onsh (1978); nitrates were quantified according to Robarge et al. (1983). All these analyses were performed in unfiltered water samples.

Statistical analyses

Statistical analyses were performed with SPSS version 12 for Windows. Kolmogrov-Smirnov, Lilliefors' and Shapiro-Wilk's tests were used to check normality. The data fit normal distributions. One way analysis of variance (ANOVA) with Tukey HSD multiple comparison tests were used to investigate significant differences of COD and nutrient removal efficiencies among the treatments.

RESULTS AND DISCUSION

Plant growth

The increase in plant height was very similar in both types of CWs (Figure 1). *Typha sp*. height increased from May to July in SFCW and from May to August in SSCW, after this, the size of the plants did not increase.

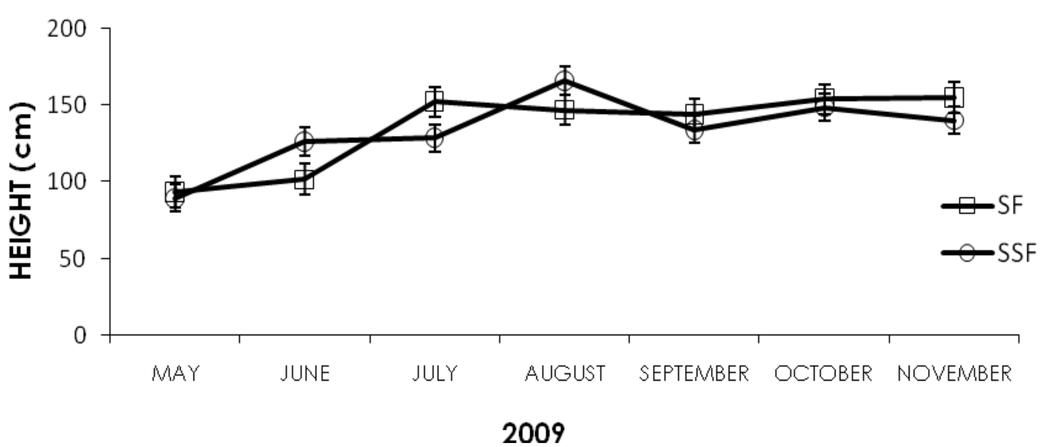

Figure 1. The increase of *Typha* sp height in constructed wetlands treating river water with a different type of water flow. SFCW, Surface flow constructed wetland, SSFCW Subsurface flow constructed wetland; Values are mean (n=60)

Pollutant concentration and removal

COD

COD concentration in the water from the Sordo River ranged from 2 to 430 mg L^{-1} with the higher concentrations observed in August (Figure 2). COD concentrations in the effluents of CWs varied during the study period and sometimes COD concentration was higher in the effluents than in the river. This is explained by changes in the redox potential in the substrate. In upland soils and gravel, iron and manganese occur as oxidized forms (Fe^{+3} and Mn^{+4}) which are insoluble, when soils are flooded, redox potential decreased and these ions were reduced to Fe^{+2} and Mn^{+2} which are soluble and they were washed out from the wetlands (Mitsch and Gosselink 2007). Fe^{+2} and Mn^{+2} are chemically oxidized, therefore they contributed to higher concentration of COD in the CW effluents. Monthly average removal percentage of COD ranged from 6 to 82 % (Table 1), and no significant differences were observed between the CWs, except in September when SFCW-C showed significantly lower removal of COD in comparison with the other treatments.

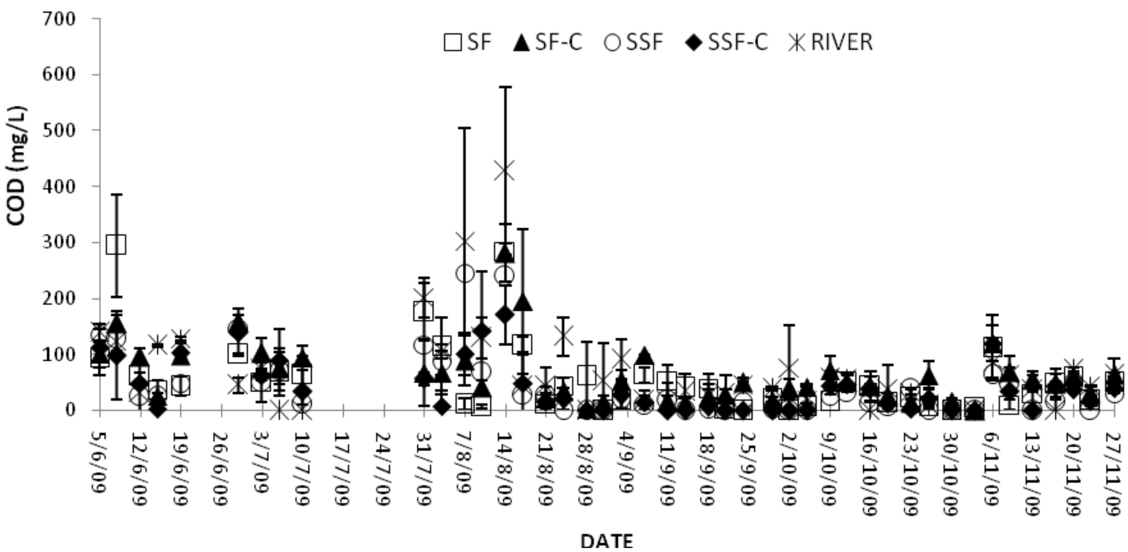

Figure 2. COD concentration in the river water and in the effluents of constructed wetlands from June to November 2009. SFCW, Surface flow constructed wetland; SFCW–C, Non-planted surface flow constructed wetland (control); SSFCW Subsurface flow constructed wetland; SSFCW-C Non-planted subsurface flow constructed wetland (control). Values are average ± SE (n=2).

N-NH_4

Ammonia nitrogen concentration in the river ranged from 2 to 18 mg L^{-1}, with higher concentration in June and August. Concentration of this ion in the effluents from CWs was always lower than in the river and differences among the CWs were observed. SSFCW showed the highest removal efficiency of ammonia nitrogen, followed by SSFCW-C, SFCW and SFCW-C (Table 1). In the SSFCW there were not significant differences between the planted and non planted microcosm, which indicates that the removal of ammonia nitrogen in this type of wetlands involved physical processes.

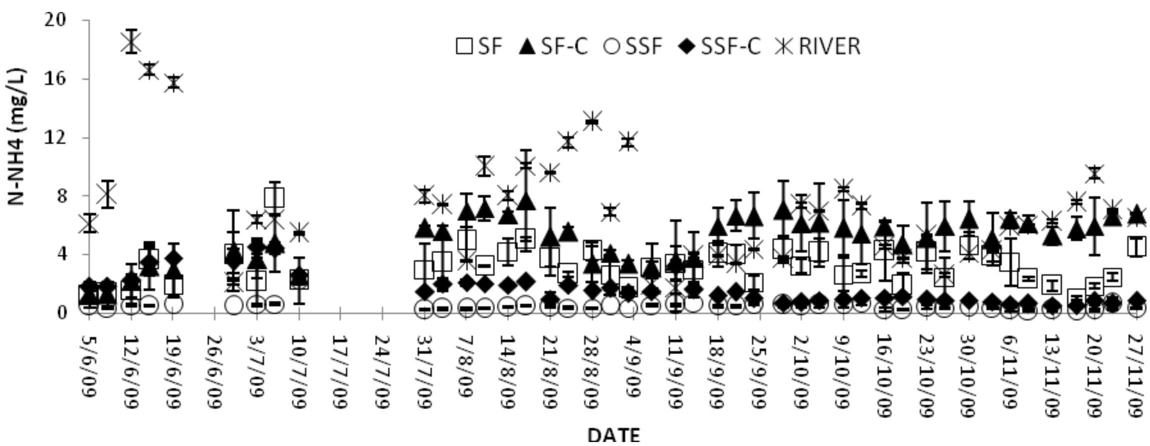

Figure 3. $N\text{-}NH_4$ concentration in the river water and in the effluents of constructed wetlands from June to November 2009. SFCW, Surface flow constructed wetland; SFCW–C, Non-planted surface flow constructed wetland (control); SSFCW Subsurface flow constructed wetland; SSFCW-C Non-planted subsurface flow constructed wetland (control). Values are average ± SE (n=2).

The Taiwanese Environmental Protection Agency, determined that rivers with $N\text{-}NH_4$ concentration higher than 3 mg L^{-1} are considered heavily polluted. The recommended concentration of $N\text{-}NH_4$ in water bodies to protect aquatic life is 0.5 mg L^{-1} (Fritz, 1990). According with this, the Sordo River is heavily polluted and the aquatic life in the sampling station is in danger.

Table 1. Average monthly removal percentage of nutrients and COD in planted and non-planted wetlands with different types of water flow, treating water from the Sordo River.

Month	Type of CW	Removal %			
		COD	N-NH4	N-NO3	P-PO4
June	SFCW	27.7 ± 13.5 [a]	70.2 ± 14.1 [a]	34.5 ± 20.8 [a]	95.2 ± 1.7 [a]
	SFCW-C	21.4 ± 12.3 [a]	68.8 ± 13.8 [a]	61.8 ± 21.1 [a]	97.0 ± 1.5 [a]
	SSFCW	28.3 ± 14.2 [a]	92.4 ± 3.3 [a]	57.8 ± 21.7 [a]	95.1 ± 1.3 [a]
	SSFCW -C	26.3 ± 14.8 [a]	65.1 ± 13.2 [a]	61.3 ± 21.1 [a]	83.3 ± 4.1 [b]
July	SFCW	11.3 ± 7.7 [a]	47.1 ± 15.7 [ac]	63.4 ± 18.6 [a]	66.1 ± 22.3 [a]
	SFCW-C	16.7 ± 16.8 [a]	36.6 ± 6.5 [ab]	73.8 ± 11.4 [a]	63.6 ± 21.7 [a]
	SSFCW	18.7 ± 11. [a]	84 ± 8.5 [c]	60.9 ± 22.9 [a]	63.4 ± 21.2 [a]
	SSFCW -C	22.4 ± 17 [a]	48 ± 12.3 [abc]	58.9 ± 4.9 [a]	20.8 ± 17.3 [b]
August	SFCW	51.5 ± 14.5 [a]	54 ± 7.4 [ac]	59.5 ± 17.4 [a]	95.8 ± 0.9 [a]
	SFCW-C	45.5 ± 10 [a]	33.9 ± 7.3 [a]	46.1 ± 19 [a]	94.3 ± 1.9 [a]
	SSFCW	44.4 ± 11.6 [a]	95.3 ± 0.6 [b]	61.8 ± 15.7 [a]	95.8 ± 1 [a]
	SSFCW -C	51.9 ±13.7 [a]	76 ± 4.8 [ab]	58.1 ± 15.3 [a]	65.1 ± 9 [b]
September	SFCW	40.5 ± 16.3 [ab]	20.1 ± 11.3 [a]	68.6 ± 15.4 [a]	93.4 ± 2.3 [a]
	SFCW-C	21.5 ± 8.8 [b]	9.4 ± 8.8 [a]	72.8 ± 12.6 [a]	94.5 ± 1.4 [a]
	SSFCW	73.2 ± 12.1 [ac]	82.9 ± 3.2 [b]	76.5 ± 13.6 [a]	96.4 ± 1.2 [a]
	SSFCW -C	82.8 ± 10.2 [ac]	56.5 ± 10.9 [b]	60.0 ± 21.1 [a]	57.1 ± 9.5 [b]
October	SFCW	42.3 ± 12.1 [a]	34.3 ± 9 [a]	64.8 ± 10.7 [a]	90.3 ± 3.7 [a]
	SFCW-C	17.1 ± 8.3 [a]	9.8 ± 4 [b]	79.2 ± 3.6 [a]	92.3 ± 1.9 [a]
	SSFCW	53.4 ± 14.9 [a]	91.5 ± 0.7 [c]	77.8 ± 4.5 [a]	93.8 ± 1.7 [a]
	SSFCW -C	44.7 ± 14.9 [a]	80.3 ± 2.8 [c]	56.5 ± 19 [a]	66.5 ± 6.1 [b]
November	SFCW	26.3 ± 10.9 [a]	55.2 ± 9.4 [a]	87.3 ± 4.8 [a]	97.0 ± 1 [a]
	SFCW-C	6.1 ± 4.4 [a]	10.4 ± 5 [b]	88.9 ± 3 [a]	96.4 ± 1 [a]
	SSFCW	43.1 ±13.8 [a]	95.1 ± 0.9 [c]	84.6 ± 3.4 [a]	96.7 ± 1.1 [a]
	SSFCW -C	37.1 ± 12.6 [a]	89.1 ± 1.2 [c]	64.4 ± 14.4 [a]	69.5 ± 8.1 [b]

SFCW, Surface flow constructed wetland; SFCW -C Non-planted surface flow constructed wetland (control); SSFCW Subsurface flow constructed wetland; SSFCW -C Non-planted subsurface flow constructed wetland (control). Values are average ± SE (n=16).Different letters indicate significant differences between the rows ($P < 0.05$).

$\underline{N\text{-}NO_3}$

Nitrate-nitrogen concentration in the river ranged from 0.5 to 7 mg L^{-1}, showing the highest concentration in July (Figure 4). Removal efficiency of this ion was not significantly different among the two types of CWs. The US Environmental Protection Agency (EPA) has since adopted the 10 mg L^{-1} (Reilly et al, 2000) standard as the maximum contaminant level (MCL) for nitrate-nitrogen, thus, N-NO_3 in the Sordo river is not a important contaminant.

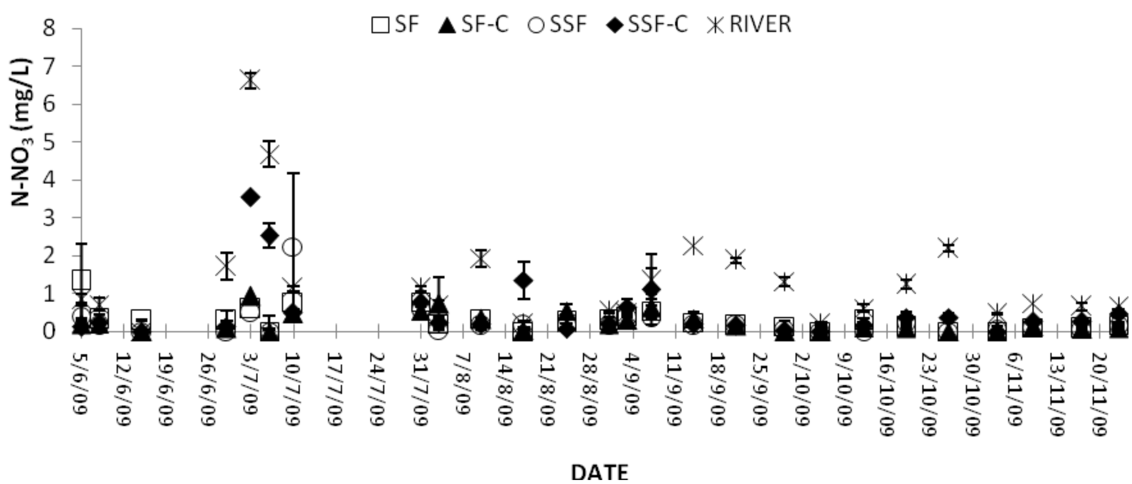

Figure 4. N-NO_3 concentration in the river water and in the effluents of constructed wetlands from June to November 2009. SFCW, Surface flow constructed wetland; SFCW–C, Non-planted surface flow constructed wetland (control); SSFCW Subsurface flow constructed wetland; SSFCW-C Non-planted subsurface flow constructed wetland (control). Values are average ± SE (n=2).

<u>P-PO_4</u>

Phosphate concentration in the river ranged from 0.5 to 5 mg L with the highest concentrations in June and August. Concentrations in the effluents from CWs were always lower than in the river (Figure 5).Removal percentage of this ion ranged from 21 to 97% and was the SSFCW-C systems that showed significantly lower phosphate removal efficiency. This indicated that when the substrate was gravel, plants have an important role in the removal of this ion. However when the substrate was soil, the removal was similar in planted and non planted CWs, which indicated that in SFCW, phosphates were removed by physical methods such as adsorption. A concentration of 0.005 mg L^{-1} is recommended to avoid eutrophication in water bodies (Wetzel, 1981).Phosphate concentration in the Sordo River is a thousand times higher than the recommended value, and CWs were able to decrease the concentration to acceptable levels.

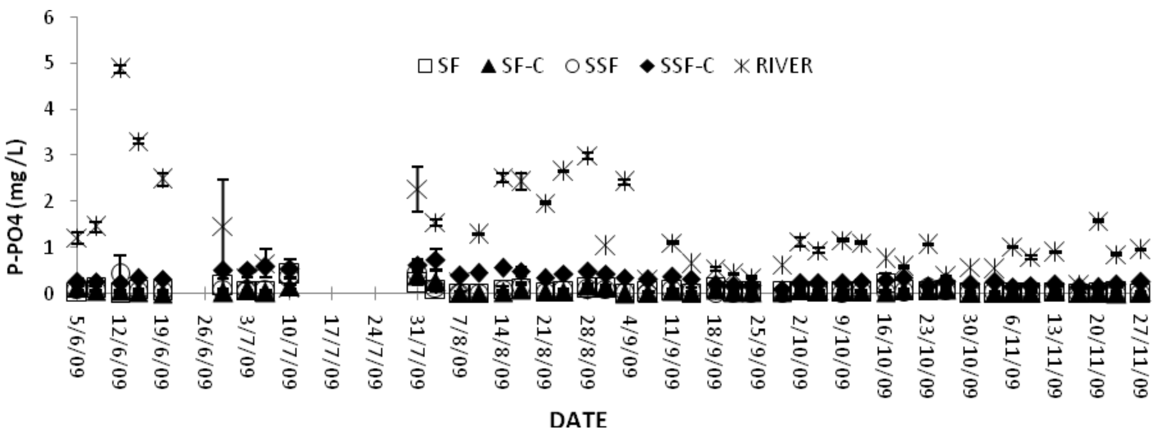

Figure 5. P-PO_4 concentration in the river water and in the effluents of constructed wetlands from June to November 2009. SFCW, Surface flow constructed wetland; SFCW–C, Non-planted surface flow constructed wetland (control); SSFCW Subsurface flow constructed wetland; SSFCW-C Non-planted subsurface flow constructed wetland (control). Values are average ± SE (n=2).

CONCLUSION

The Sordo River is heavily polluted by domestic wastewater according with the concentrations of COD, N-NH_4 and P-PO_4. Constructed wetlands decreased N and P loading in the river water. SSCWs were more efficient in ammonia nitrogen removal than SFCWs.

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