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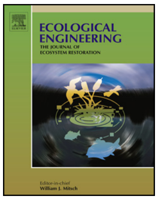

Short communication

Comparative evaluation of influencing factors on aquaculture wastewater treatment by various constructed wetlands

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ABSTRACT

In this work, a long-term observation on fifteen different constructed wetlands covering diverse scales, flow regimes, substrates, plants and operating conditions was obtained and their performance was comparatively assessed by multivariate analyses. The fifteen wetlands were sorted into five categories: i.e. two conventional horizontal flows (CHF), three narrow horizontal flows (NHF), one surface flow (SF), nine submersed vertical flows (SVF) or non-submersed vertical flows (NVF). Results of stepwise regression showed significant linear relationships existed between the various k and measured environment with the latter displaying different impacts on k among all the systems. The significant linear relationships were also evidenced by redundancy analysis (RDA), which demonstrated the existence of multicollinearity among certain influencing factors. Further, variation partitioning revealed that the wetland performance (defined in this study) was mainly affected by structural and operational characteristics, which were also the determinants of redox conditions within subsurface flows. For nitrogen (N) removal, factors which were strongly related to nitrification-denitrification were more closely related to performance compared to other influences for the present systems operated under the specific running conditions.

1. Introduction

Aquaculture usually generates large-volume, low-strength, and heavy-fluctuation wastewaters. The direct discharge of aquaculture wastewater is posing a threat to downstream waters. It is urgent to develop efficient systems for wastewater treatment to obtain sustainability. Constructed wetlands (CWs) are designed as an appropriate eco-system to remove pollutants from various wastewaters. Recently, they have been expanded to aquaculture (Boxman et al., 2015; Liu et al., 2014b).

There are many internal (e.g. plants, substrates, microorganisms, etc.) and external factors (e.g. pH, temperature, dissolved oxygen, etc.) affecting purification capacity of CW (Chen et al., 2015; Liu et al., 2014a; Zhang et al., 2015a). More and more evidences illustrate that wetland performance is not merely determined by structural, operational or running conditions, but also strongly related to the variation of physicochemical parameters on different gradients inside CW (Ding et al., 2014; Meng et al., 2014). However, little literature focuses on describing the contribution of influencing factors to treatment performance. Such detailed information is accordingly necessary for better understanding pollutant removal mechanisms inside CW.

Multivariate analyses have been applied to describe the relationships between treatment efficiency and impact factors (Chang et al., 2013; Hijosa-Valsero et al., 2011). Nevertheless, the contribution of each critical parameter to N loss or retention by various paths remains unclear (Maltais-Landry et al., 2009). The aim of this paper was to evaluate or compare the contribution of each influencing factor to treatment performance in various CWs. To achieve this, an exhaustive dataset collected *in situ* from fifteen different types of CWs treating aquaculture wastewater was statistically treated.

2. Materials and methods

2.1. System construction

Five different categories of CWs including two conventional horizontal flows (CHF $1^{\#}$–$2^{\#}$), three narrow horizontal flows (NHF $1^{\#}$–$3^{\#}$), one surface flow (SF), nine submersed vertical flows (SVF $1^{\#}$–$9^{\#}$) or non-submersed vertical flows (NVF $1^{\#}$–$9^{\#}$) were

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Table 1
Structural and operational characteristics of the fifteen constructed wetlands (CWs).

Flow regime	Scale		Substrate type		Plant species	Duplicates	HLR (m/d)	HRT (h)	Data collection time
	L × W × D (m)	Aspect ratio	Type	Porosity (ε)					
CHF $1^{\#}$–$2^{\#}$	30.0 × 8.5 × 0.6	3.5	Gravel	0.179	*Canna indica, Iris tectorum, Acorus calamus, Cyperus papyrus, Thalia dealbata*	2	0.600	4.3	2010.6.20–2013.10.30
NHF $1^{\#}$–$2^{\#}$	30.0 × 3.1 × 0.8	9.7	Ceramisite	0.400	*Thalia dealbata, Arundo donax f. versicolor*	2	2.581	3.0	2010.6.3–2012.6.18
NHF $3^{\#}$	30.0 × 2.4 × 0.8	12.5	Ceramisite	0.400	*Phragmites australis*	1	3.333	2.3	2010.6.3–2012.6.18
SF	30.0 × 2.4 × 0.4	12.5	/	/	*Myriophyllum spicatum, Nymphaea alba*	1	3.333	2.9	2010.6.3–2012.6.18
VF $1^{\#}$–$3^{\#}$	2.0 × 1.5 × 0.8	1.3	Cinder	0.378–0.410	*Thalia dealbata*	3	0.384–3.456	2.3–19.8	2013.6.13–2013.8.5
VF $4^{\#}$–$6^{\#}$	2.0 × 1.5 × 0.8	1.3	Ceramisite	0.446–0.457	*Thalia dealbata*	3	0.384–3.456	2.5–22.9	2013.6.13–2013.8.5
VF $7^{\#}$–$9^{\#}$	2.0 × 1.5 × 0.8	1.3	Gravel	0.396–0.439	*Thalia dealbata, Canna indica, Phragmites australis*	3	1.152–2.448	3.1–7.3	2013.6.13–2013.7.9

Abbreviations: L for length, W for width and D for filling depth.

constructed at an experimental base (30°16′N, 112°18′E) in Hubei province of China. A detailed description on technical specifications for all the units (Table 1) has been given in our previous reports (Zhang et al., 2015b,c; Zhang et al., 2011).

2.2. Operation, sampling and analysis

For the present survey, the horizontal and surface flow systems were continuously operated under a constant hydraulic loading rate (HLR, Table 1), while the vertical flow systems worked periodically under varying HLRs, which were controlled by adjusting the inflow valves. Meanwhile, the nine vertical flows were alternately operated under two different flooding regimes: i.e. submersed (SVF) or non-submersed states (NVF) (Zhang et al., 2015c).

During the survey, inflow and outflow of all the wetlands were selectively sampled on a frequency from daily to monthly scales from the year of 2010–2013 (Table 1). The sampling methods were specifically depicted in our previous reports (Zhang et al., 2015b; Zhang et al., 2015c; Zhang et al., 2011). On-line parameters including temperature (T), dissolved oxygen (DO), pH, electrical conductivity (EC), total dissolved solids (TDS), and redox potential (ORP) were measured *in situ* with a YSI 6600 V2 multiparametric sonde (Yellow Spring Instruments, USA); laboratory analyses involving chemical oxygen demand (COD), total ammonium N (TAN = $NH_3 + NH_4{}^+$-N), nitrate N ($NO_3{}^-$-N), nitrite N ($NO_2{}^-$-N), total N (TN), and total P (TP) was completed in the lab according to the standard methods (EPAC, 2002).

2.3. Performance assessment

The first-order removal rate constant (k) for each pollutant in subsurface flows was calculated by the following equation: $k = HLR \times (\ln C_i - \ln C_e)/(h_w \times \varepsilon)$, where k was the first-order removal rate constant (d^{-1}); HLR was the hydraulic loading rate (m/d); C_i and C_e were the inflow/outflow concentrations (g/m^3), respectively; h_w was the substrate depth (m), and ε was the porosity.

While for surface flow system, k_a (m/d) was estimated by $HLR \times (\ln C_i - \ln C_e)$ with HLR in m/d and inflow/outflow concentrations in g/m^3 (Kadlec and Wallace, 2009).

2.4. Data analysis

Stepwise regression was performed first to explore the potential linear relationships between removal rate constant (k/k_a) and measured environment. Due to the involved independent variables (namely influencing factors) had different units or dimensions, standardized coefficients were used to assess the contribution of each influencing factor to pollutant removal. These analyses were completed using SPSS 19.0 software package for Windows. Significance was defined with $P < 0.05$.

To further explore the relationships between treatment performance (confined to removal rate constant in this paper) and measured environment, the linear-based redundancy analysis (RDA) was opted for ordination due to the minus k for some circumstances. Furthermore, variation partitioning was performed to distinguish the contribution of each influencing factor to pollutant removal. These analyses were completed in Canoco 4.5 for Windows.

3. Results and discussion

3.1. Comparison and evaluation by stepwise regression

By the results of stepwise regression, there were significant linear relationships found between the various k/k_a and inflow properties with the exception in SF, among which no significant relationships were detected for most indices (Table 2).

According to the factor loadings in the standardized equation, the measured environmental parameters displayed different impacts on pollutant removal among the various CWs. For ammonium N removal, temperature presented a negative effect on k in submersed systems (i.e. in CHF and SVF), while showed a positive effect on k in NVF (Table 2). This could possibly be explained by the fact that, higher temperature would promote the decomposition and/or mineralization of organics (i.e. ammonification process) in either submersed or non-submersed systems. Nevertheless, in submersed systems, the nitrification process was restrained due to the anaerobic conditions (outflow DO: 0.58–0.95 mg/L, unlisted). While in non-submersed systems, the high outflow DO (mean value: 2.98 mg/L, unlisted) promised an aerobic condition for nitrification, which had been in turn enhanced by higher temperature.

For nitrite/nitrate removal, a positive effect of pollutant load on k was observed for nitrite in CHF and NHF, and for nitrate in NHF, NVF and SVF. Similar trends were observed on other indices, such as DIN, TN and COD in CHF, COD in NHF, TN in SVF, etc. (Table 2). This phenomenon was also observed in other cases (Dan et al., 2011; Saeed and Sun, 2011). Meanwhile, a negative impact of nitrite on nitrate k in CHF was partially due to that denitrification was proceeded with nitrite as intermediate, whose accumulation would restrain the reaction rate.

For DIN removal, temperature showed a negative impact on k in submersed systems while a positive impact in non-submersed systems (Table 2). As stated earlier, higher temperature promoted the mineralization of trapped organics releasing an elevated level of