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Comparison of effects of plant and biofilm bacterial community parameters on removal performances of pollutants in floating island systems

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ABSTRACT

This study focused on a comparison of the role that plant and biofilm bacterial community parameters played in mediating removals of pollutants in the floating island microcosms mono-cultured with different macrophytes. The greater removals of BOD_5, COD, total phosphorus and NH_4–N were observed in floating microcosms planted with *Alternanthera philoxeroides* or *Cyperus alternifolius*, respectively. The microcosms planted with *Scirpus validus* exhibited the greatest removals of total nitrogen, and those planted with *Canna generalis* showed a great removal of NO_3–N. The above-ground biomass was positively related to the removal of the NO_3–N, while the translocation factor for nitrogen was positively related to total nitrogen and phosphorus, the translocation factor for phosphorus was positively related to the removals of total phosphorus and NO_3–N, respectively. Nevertheless, bacterial community parameters such as the ribotype number and diversity index were not correlated with the removals of pollutants.

1. Introduction

Constructed floating islands (CFIs), also known as floating beds or sudds, are composed of native or exotic plants growing on a buoyant mat. CFI systems includes small (less than 0.01 ha) free-floating beds, and extensive, stationary, vegetated islands which may cover hundreds of hectares of water (Mallison et al., 2001; Stewart et al., 2008). Because of its low-cost and convenient management, the CFI technology has been widely applied into treatments of variant eutrophic waters around the world (Sun et al., 2009). The effectiveness of this technology in removals of nitrogen, phosphorus and cyanobacterial biomass from wastewater has been confirmed by some recent studies (Nakai et al., 2008; Stewart et al., 2008; Li et al., 2010, 2012).

The removal efficiencies of pollutants in CFI systems are often influenced by many factors such as the CFI scheme structure, aeration level, temperature, pollutant contents in wastewater (Li et al., 2010; Wang et al., 2012). Except for these factors mentioned above, it is well known that plant species and microorganisms are two most important biological components for mediating removal performances of CFI systems (Stewart et al., 2008). Recently, Li et al. (2012) indicated that plant species in CFI systems have different removal capacities of pollutants due to their specific biological properties such as uptake efficiencies for nutrients, growth rate and root types. Stewart et al. (2008) studied the relationships between microorganisms in the municipal wastewater and removal performances of ammonium and nitrate in floating islands without plant species, indicating that the floating islands with microorganisms had higher removals of both ammonium and nitrate than those without microorganisms. Sun et al. (2009) confirmed that the removal efficiency of nitrogen was greatly enhanced by adding the immobilized denitrifiers into water of floating islands.

Generally, macrophytes may release oxygen and exudates upon rhizome and root surfaces, and create additional substrate for development of microbial communities beneath the CFI systems (Masters, 2012). Some microorganisms from wastewater may attach on the root or rhizome surface as influenced by the chemotaxis, and form the so-called biofilm through a repeating proliferation process (Zhang et al., 2014). It is well known that the biofilm attached on root or rhizome surface is important in improving the removal effectiveness of the CFI system. Wu et al.

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(2006) provided the relevant evidence in which root surface with more biofilm created greater removal performance of pollutants, thus showing the importance of the biofilm.

Because of the difference in both root exudates and oxygen release level, aquatic species may be different in microbial composition and activity on biofilm of root or rhizome surfaces (Li et al., 2012). On the other hand, plant species also show a great difference in nutrient assimilation rate due to the dissimilarity in their anatomical and physiological properties such as transpiration power, roots and photosynthetic rate (Zhang et al., 2011). Therefore, CFI systems vegetated with different aquatic species may show a great difference in the removal performance of pollutants. However, one unsettled problem is which of both plant and microbial components attached on the root or rhizome surface is more important in mediating the removal performances of pollutants in CFI systems.

To clarify the above problem, we established fifteen floating microcosm islands vegetated individually with five aquatic species during March of 2013 in Taizhou University of Zhejiang Province, Eastern China. Our experiment was designed to answer two questions: (1) whether the difference in aquatic species impact the removal efficiency of pollutants in CFI microcosms; and (2) which one, plant and bacterial community, of parameters within the biofilms is more important in mediating pollutant removals of CFI systems.

2. Materials and methods

2.1. CFI microcosm design

Fifteen CFI microcosms were established in Taizhou University of Zhejiang Province, in Eastern China (121°21′E, 28°34′N) during March of 2013. Each CFI microcosm was made from polyvinyl chloride polymer, and was 0.6 (height) × 0.5 (length) × 0.5 (width) m in dimension size (Fig. 1). A piece of polyethylene foam (length × width = 0.45 × 0.3 m) was placed in each CFI microcosm to support a plastic basket with many holes, and was covered with double-layered aluminum sheet to enhance its strength. After the plastic basket was placed through the foam board and then was filled with ceramic pellets (diameter = 3–5 mm, Wang et al., 2012) to fix roots and rhizomes of plant species. Five plant species (*Canna generalis*, *Scirpus validus*, *Alternanthera philoxeroides*, *Cyperus alternifolius*, and *Thalia geniculata*) were collected from a full-scale constructed wetland. All species were individually mono-cultured in ceramic pellets of triplicate microcosms. The planting density was 8 stems per microcosm. In the present experiment, Hoagland nutrient solution was used as wastewater, and its water quality parameters were identified as: CODcr = 132.51 mg L^{-1}, BOD_5 = 79.51 mg L^{-1}, total nitrogen = 79.73 mg L^{-1}, total phosphorus = 34.52 mg L^{-1}, NH_4–N = 38.05 mg L^{-1} and NO_3–N = 39.63 mg L^{-1}. 180 L of the solution was irrigated into each CFI microcosm. Once Hoagland solution was irrigated into each microcosm, and was held in each microcosm for 5d, and then drained out each microcosm. After keeping without water in each microcosm for 0.5d, the repeating irrigation was again run in each microcosm. If water level in the microcosm decreased due to the natural evaporation during the experiment, and the tap water was supplied in time to maintain the designed water level. The operation program was repeated from April to August of 2013.

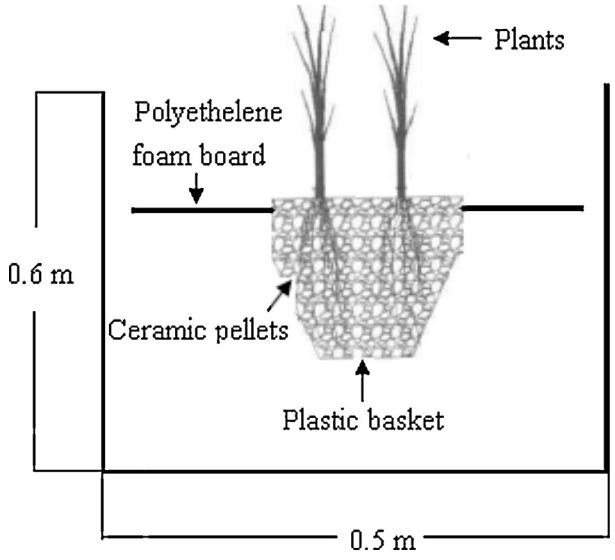

Fig. 1. Dissecting scheme of the constructed floating island microcosm used in the current study.

2.2. Sampling

Firstly, 1.5 L of influent and effluent in microcosms planted with different species were collected into plastic bottles on the end of August of 2013, and stored in a refrigerator of −20 °C for analyzing water quality parameters. Secondly, each plant species was removed from the plastic basket in each microcosm, and the above-ground and below-ground fresh parts of each plant species were separated using a cutting method, i.e. the above-ground part including stem, shoot and leaves was clipped off on the base of each plant body using a clipper, and the below-ground part including roots and rhizomes was simultaneously collected. After some litter was removed, all collected samples were freshly weighed. One small portion of each sample was taken to the laboratory, and was dried at 60 °C in an oven to determine the dry weight percentages of plant samples. Finally, the dried sample was divided into tow sub-portions in the laboratory. One sub-portion was dried to determine the nitrogen and phosphorus contents of both above-ground and below-ground plant tissues, and another sub-portions of below-ground samples were stored in 4 °C of refrigerator for analyzing bacterial community structure on the biofilm of sample surfaces.

2.3. Parameter analysis

2.3.1. Water quality analysis

After the microcosms were established for 120d, we collected the Hoagland solution samples and effluent samples in polyethylene bottles (1 L) to measure biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total nitrogen, total phosphorus, NH_4–N and NO_3–N concentrations following standard methods established by the National Environment Protection Agency of China (2002). COD was determined by the open reflux method and BOD_5 by the 5-d BOD test method. The water samples were digested using an alkal potassium persulfate oxidation method before analyzing both total nitrogen and phosphorus contents. Briefly, 5 ml of water sample was added into a colorimetric tube with a volume of 25 ml, and followed by 2.5 ml of alkal digestion solution (containing 40 g crystallized potassium persulfate and 15 g NaOH in 1 L of water without NH_4^+, respectively) and 2.5 ml of deion water. All the tubes were sealed with grinding glass caps, and placed into an autoclave sterilizer. Both digestion temperature and time were 120 °C and 30 min, respectively. The nitrogen and phosphorus contents in the digested samples were colorimetrically determined using a UV or common spectrophotometer. NH_4–N and NO_3–N contents in influents and effluents were analyzed using a colorimetric technology. Finally, the removal