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Response and environmental assessment of two Chinese conventional carps to water quality regulation in recirculating aquaculture

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ABSTRACT

In this study, a ditch-type of a four-stage hybrid constructed wetlands (CWs) was integrated into a group of series-connected ponds that form a recirculating aquaculture system, which was used to rear silver crucian carp (*Carassius auratus gibelio*) and grass carp (*Ctenopharyngodon idellus*). The results indicated that the hybrid system operated at a mean hydraulic loading rate (HLR) of 0.727 $m^3/(m^2\,d)$ and had a notable purifying capacity, which resulted in a significantly lowered trophic status of the recirculating ponds compared to the control. Both the grass carp and crucian carp yield were negatively correlated to water quality parameters, implying that both species might prefer to live in a less eutrophic system. Although the value of the increased product yield had nearly been offset by construction and system operation costs, this integrated culture system used no fish pharmaceuticals and fewer freshwater resources. Hence, the integrated culture system was a more environmental friendly production method compared to the traditional methods.

1. Introduction

China is the largest producer of aquaculture products in the world, with pond cultures being the main method of production. Although pond culture has expanded quickly in the recent decades, the resultant environmental problems are becoming increasingly prominent. It is imperative that more efficient systems for water recycling or reuse are developed. Constructed wetlands (CWs), due to their low costs, high performance and easy management, have been employed to treat various aquaculture wastewaters (Gregory et al., 2012; Konnerup et al., 2011; Liu et al., 2014; Shpigel et al., 2013).

Previous research suggests that many types of CWs function well to purify water when employed within integrated culture systems (Konnerup et al., 2011; Liu et al., 2014; Shi et al., 2011; Zachritz et al., 2008). Nevertheless, environmental assessment as related to investment/profit is still lacking. Meanwhile, the selection of appropriate rearing species is also of vital importance for actual production because the integrated culture systems are more suitable for species that prefer less eutrophic systems (Zhang et al., 2011). Crucian carp (*Carassius auratus gibelio*) and grass carp (*Ctenopharyngodon idellus*) are currently two major conventionally produced freshwater fishes in China. In the past, these carps were the main culture species produced in the classic mulberry dike-pond systems (Astudillo et al., 2015). At present, the carps are also produced through intensive pisciculture. In the context of intensive pisciculture, what type of systems do the two carps prefer: oligotrophic or eutrophic?

In this study, we tackle two issues that have been scarcely addressed in previous analyses regarding integrated culture systems: response of the above-mentioned two carps to water quality regulation and their associated environmental assessment. To this end, an integrated culture system based on four-stage, ditch-type hybrid CWs was comprehensively investigated for an entire grow-out season.

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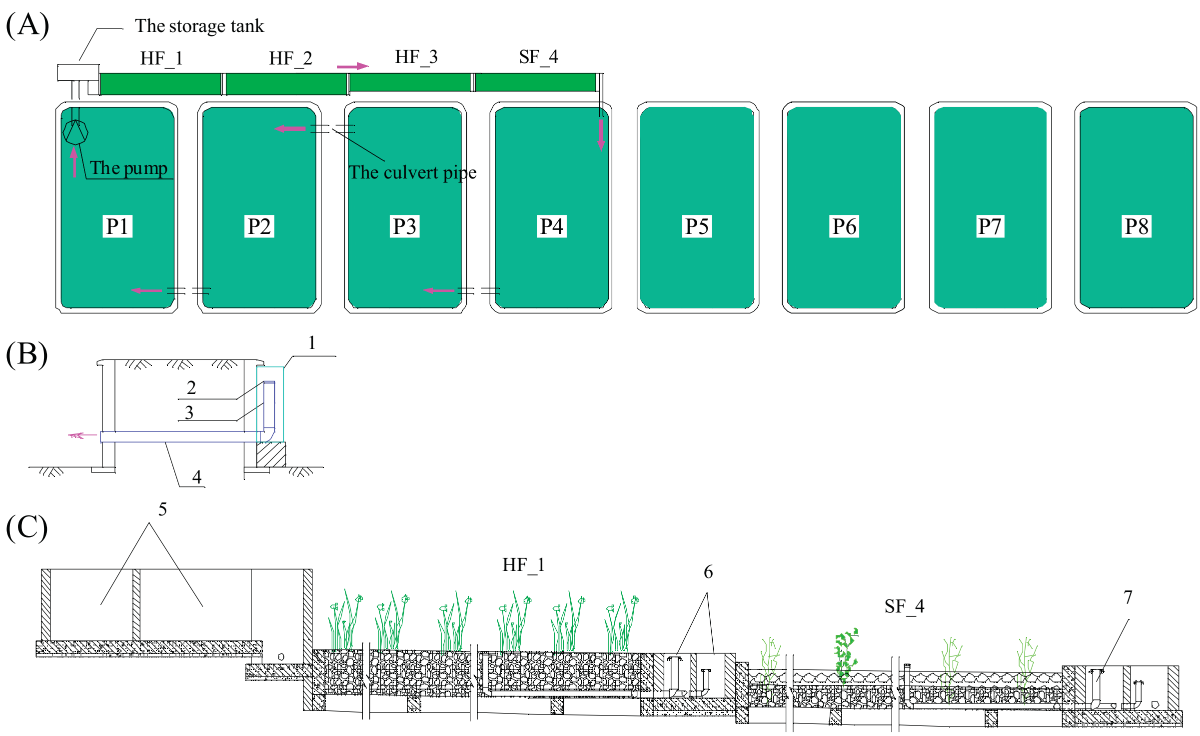

Fig. 1. (A) Plan of the whole recirculating aquaculture system; (B) Connection facilities among the recirculating ponds; (C) The section drawing of the storage tank, the inlet, HF_1, SF_4 and their outlets. Because HF_2 and HF_3 had the same configuration as HF_1 (only difference in width), only HF_1 and SF_4 were presented in the section drawing. Note: P1-P4 represent the four recirculating ponds and P5-P8 denote the control ponds; arrows show the direction of water flow; 1-fish exclusion net, 2-perforated sleeve, 3-standing pipe, 4-culvert pipe, 5-storage tank, 6-storing cistern, 7-PVC pipe.

Table 1
Summary of fry stocking in each fish pond for the two different culture modes.

Species	Mode mainly stocked with crucian carp in P1, P3, P5 and P6			Mode mainly stocked with grass carp in P2, P4, P7 and P8		
	Density (ind./ha)	Initial mean weight (g/ind.)	Biomass (kg)	Density (ind./ha)	Initial mean weight (g/ind.)	Biomass (kg)
Crucian carp	24242 ± 97	18.8 ± 1.2	30.0 ± 1.9	1515 ± 16	18.8 ± 1.2	1.9 ± 0.1
Grass carp	1515 ± 16	19.3 ± 1.4	1.9 ± 0.1	24242 ± 97	19.3 ± 1.4	30.9 ± 2.0
Silver carp	2046 ± 19	47.2 ± 4.6	6.4 ± 0.6	2046 ± 19	47.2 ± 4.6	6.4 ± 0.6
Bighead carp	330 ± 8	371.3 ± 41.7	8.1 ± 0.9	330 ± 8	371.3 ± 41.7	8.1 ± 0.9
Total	28133 ± 112		46.4 ± 2.6	28133 ± 112		47.3 ± 2.7

2. Materials and methods

2.1. System construction

The study site was located at an experimental base in the Hubei province in central China (30°16′N, 112°18′ E) with a typical subtropical climate. A ditch-type of four-stage hybrid CWs (*i.e.*, three horizontal subsurface flows [HF_1 to HF_3] followed by one surface flow [SF_4]) was integrated into four (P1-P4, set as the recirculating ponds) identical series-connected fish ponds for water quality regulation. An additional four non-connected identical ponds (P5-P8) were set as the control representative of traditional static fish ponds (Fig. 1A).

The four recirculating ponds (P1-P4) were joined together by culvert pipes across the pond banks. More specifically, a standing pipe was connected to the culvert pipe at the inlet with short sleeve on the top to regulate water level (Fig. 1B). To prevent fish escape, fish exclusion nets were fixed on the standing pipe. When operating the system, the inner short sleeve was removed, allowing the upper stratum water rich in dissolved oxygen (DO) during the daytime to flow passively into the bottom of the next pond under hydraulic pressure. This passive aeration *via* mixing could therefore elevate the total stock of DO in the next pond.

The design parameters of the four-stage, ditch-type hybrid CWs were as follows: 30 m in length, 3.1 m in width and 1 m in depth for HF_1 and HF_2, and 30 m in length, 2.4 m in width and 1 m in depth for HF_3 and SF_4 (Fig. 1A). Wastewater from the last recirculating pond (P1, Fig. 1A) was first pumped into a storage tank, flowed passively through the four-stage hybrid CWs in turn, and finally flowed back into the first recirculating pond (P4, Fig. 1A).

In the bottom of each wetland near the outlet, a system of perforated Φ 200 mm PVC pipes was fixed to enable efficient drainage. The frame of all the CWs was built using bricks and mortar, while the bottom received geotextile as an impermeable liner fixed to a slope of 0.33% for HF_1 and 0.17% for HF_2, HF_3 and SF_4. The first three units (HF_1 to HF_3) were filled with ceramisite (nominal diameter: 80–150 mm) to a depth of 80 cm. In SF_4, an Φ 160 mm PVC pipe (connected to the drainage pipe) was erected at the outlet with the tail end 40 cm higher than the surface level of the media to store water. After impounding, *Myriophyllum spicatum* L. and a minor quantity of *Nymphaea alba* L. were planted in SF_4 with a plant distance of 80–100 cm for *M. spicatum* and 5–7 m for *N. alba*.