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A comparative study on the budget of nitrogen and phosphorus in polyculture systems of snakehead with bighead carp

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ABSTRACT

The budget of nitrogen and phosphorus in polyculture systems of snakehead (*Channa arguss*) and bighead carp (*Hypothalmichthys nobilis*) was studied with land-based enclosures from August 1 to November 28, 2014. Four treatments were designed, including monoculture of snakehead (C) and polyculture of snakehead with bighead carp (CH1, CH2 and CH3). Snakehead were stocked in all enclosures at 9.00 ind/m^2. Bighead carp was stocked in three different densities, i.e., 0.12 (CH1), 0.15 (CH2) and 0.18 (CH3) ind/m^2. Results showed that all the three polyculture systems showed the higher yield of cultured animals than the monoculture system ($P < 0.05$). The survival rate of snakehead in C system showed the lowest value ($P < 0.05$), while no significant difference was found in the final body weight and yield of snakehead among different systems ($P > 0.05$). The survival rate of bighead carp in CH1, CH2 and CH3 systems were all 100.00%, while the final body weight and yield in the CH3 system showed the lowest value ($P < 0.05$). Feed was the main input of nitrogen (97.89%–98.21%) and phosphorus (99.37%–99.53%) in all systems. The main part of output of nitrogen and phosphorus was sediment accumulation, which accounted for 52.68%–67.31% and 84.33%–86.27% of the total output, respectively. The sediment accumulation of nitrogen in the C system showed the highest value ($P < 0.05$), while no significant difference was found in the sediment accumulation of phosphorus among different systems ($P > 0.05$). The utilization efficiency of nitrogen of CH2 system was significantly higher than that of C system ($P < 0.05$), while no significant difference was found in the utilization efficiency of phosphorus among all the four systems ($P > 0.05$). In conclusion, the optimum stocking density for the polyculture systems in this study was snakehead at 9.00 ind/m^2 and bighead carp 0.15 ind/m^2, which exhibited better ecological efficiency and economic benefit.

1. Introduction

The snakehead *Channa arguss* is an important aquaculture specie in China, with the production reaching 510,340 tons in 2014 (Fisheries Department of Agriculture, Ministry of China, 2015). The products of snakehead aquaculture are beneficial to society. However, the effluents, including residual feed, feces and urine, are released directly into the aquaculture system during the culture period (Zhao et al., 2014). The environmental degradation caused by effluents can be a limiting factor for the sustainability of aquaculture industry development (Yucel-Gier et al., 2007; Domagalski et al., 2007). Polyculture systems could improve both the biological diversity and environmental stability. As a result, these systems may improve the utilization of input material, strengthen the self-purifying ability of aquaculture water, improve economic efficiency, and reduce environmental pollution (Joykrushna et al., 2008; Rahman et al., 2008). The bighead carp *Hypothalmichthys nobilis* is another important aquaculture specie in China and the production reached 3,202,887 tons in 2014 (Fisheries Department of Agriculture, Ministry of China, 2015). The polyculture of snakehead and bighead carp was practiced. However, the farmers usually stock these two animals empirically attributed to the lack of necessary data or guidance. As a result, it inevitably led to highly differential economic benefit and ecological efficiency among different systems.

Both nitrogen and phosphorus, whose concentration can response the environment changing directly, are usually the limitative nutrient in aquaculture ecosystem (Su et al., 2009). Aquaculture activities employ various types of nitrogen and phosphorus (e.g., manure, fertilizers and feed). The accumulation of nitrogen and phosphorus during the aquaculture activities was the greatest contributor to the environment deterioration in areas where culturing takes place (Tian et al., 2001).

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The accumulation of nitrogen and phosphorus may promote harmful algae growth in the aquaculture system (Anderson et al., 2002) and pose a threat to aquatic life. In order to reduce the accumulation of nitrogen and phosphorus in aquaculture systems, it is essential to estimate the nitrogen and phosphorus budget to assess the fate of nitrogen and phosphorus added to the aquaculture systems. Nitrogen and phosphorus budget can not only allow for a quantification of efficiency of materials utilization and the potential impact of pollution, but also serve as a basis for aquaculture management (Green and Boyd, 1995; Teichert-Coddington et al., 2000). Nitrogen and phosphorus budget in aquaculture systems has been widely studied, such as channel catfish (*Ictalurus punctatus*) ponds in America (Boyd, 1985), intensive fishpond of gilthead seabream (*Sparus aurata*) in Israel (Krom and Neori, 1989), shrimp (*Penaeus monodon*) culture ponds (Sahu et al., 2013a) and scampi (*Macrobrachium rosenbergii*) culture ponds (Sahu et al., 2013b) in India. However, the data on nitrogen and phosphorus budget of polyculture system of *C. arguss* with *H. nobilis* is still scarce. Even though this polyculture mode is widely utilized but lack of guidance for suitable stocking rate. The explicit budget of nitrogen and phosphorus in polyculture systems of snakehead with bighead carp can supply necessary data for aquaculture management.

Therefore, this study aimed to assess the nitrogen and phosphorus budget and efficiency of the polyculture system of *C. arguss* with *H. nobilis* and to determine the optimal bighead carp density. The results from the present study will provide a useful reference for the practical multi-species polyculture in snakehead ponds, and eventually, would be beneficial to sustainable development for snakehead aquaculture industry in China.

2. Materials and methods

2.1. Pond and enclosures

The experiments were conducted using enclosure ecosystems in a pond located in Nansha District, Guangzhou City, Guangdong Province, China (22°37′N, 113°36′E). The pond covered approximately 1 ha area, with water depth ranging from 1.6 to 2.0 m. Enclosures made of impervious polyvinyl plastics and supported with timber piles, were constructed in the pond. The area of each enclosure was 64 m^2 (8 m × 8 m). The separation of the pond area by enclosures avoided water exchanging among different experimental systems.

2.2. Cultured animals and experimental design

Snakehead and bighead carp were purchased from Zhongxingou Aquatic Food Co., Ltd. (Guangzhou, Guangdong, China). Four systems were designed in this study. According to the former study of Q.F. Liu et al. (2014) and Q.G. Liu et al. (2014), snakehead was stocked in all enclosures at 9.00 ind/m^2. Bighead carp was stocked in 3 different densities: 0.12 (CH1), 0.15 (CH2) and 0.18 (CH3) ind/m^2. Monoculture of snakehead (C) was used as control. Each system had 3 replicates, resulting in a total of 12 unique enclosures. The stocking information for the different experimental systems and the control is shown in Table 1.

Table 1
Stocking information for different systems (C: monoculture of snakehead; CH1: 9 snakehead, 0.12 bighead carp/m^2; CH2: 9 snakehead, 0.15 bighead carp/m^2; CH3: 9 snakehead, 0.18 bighead carp/m^2).

	Channa arguss		*Hypothalmichthys nobilis*	
	Weight(g/ind)	Density(ind/m^2)	Weight(g/ind)	Density(ind/m^2)
C	1.74 ± 0.53	9.00	–	0
CH1	1.74 ± 0.59	9.00	75.46 ± 16.44	0.12
CH2	1.64 ± 0.58	9.00	72.46 ± 17.15	0.15
CH3	1.65 ± 0.49	9.00	73.46 ± 21.30	0.18

2.3. Duration, feeding and management

The snakehead and bighead carp were stocked on August 1, 2014. All the animals were harvested on November 28. The culture duration was 120 days.

Snakehead were fed with commercial pellet feed manufactured by Guangdong Chia Tai Feed Co., Ltd. (Guangzhou, Guangdong, China), twice daily at 6:00 and 18:00, with a feeding rate determined on the basis of the specification. Feed consumption was closely observed to determine and adjust the feed ration. At the same time, the growth of snakehead and bighead carp was determined by sampling of 3 individuals/enclosure. Animals were returned to their enclosure after measuring. The aerators were operated all the time over the whole course of the experiment.

2.4. Nitrogen and phosphorus budget

Temperature, pH and dissolve oxygen (DO) were measured with the YSI 556 system (YSI Incorporated, USA) weekly in situ. Water samples from the upper (25 cm), middle (50 cm) and lower (150 cm) layers were collected on five occasions in each enclosure every 30 days during the culture period. Rainfall samples were also collected throughout the culture period. Ammonia nitrogen (TAN), nitrate nitrogen (NO_3^--N), nitrite nitrogen (NO_2^--N) and soluble reactive phosphorus (PO_4^{3-}-P) were determined with the method according to Laskov et al. (2007) and Tu et al. (2010). Total nitrogen (TN) and total phosphorus (TP) were determined with the method according to Qian and Fu (1987).

The sediment (0–10 cm) was collected by a cylindrical metal corer (diameter 8 cm) every 30 days. The sediment was dried at 60 °C to constant weight, then ground and sieved through a sample sifter (pore size 0.15 mm). TN of the sediment was determined by a Vario ELIII Elemental Analyzer (Elementar, Dortmund, Germany). TP of the sediment was determined with the method according to Sun et al. (2015).

The stocked animals, feed and the harvested animals were dried at 60 °C to a constant weight, smashed and sieved with sample sifter (pore size 0.15 mm). TN of these samples was determined by a Vario ELIII Elemental Analyzer (Elementar, Dortmund, Germany). TP of the stocked animals, feed and the harvested animals were determined with the method of molybdenum yellow spectrophotometer (National Standardization Management Council of China, 2002).

Nutrient (N / P) input was calculated as follows:

$$\text{Nutrient in feed/animals/water/rain} = \text{nutrient concentration in feed/animals/water/rain} \times \text{total amount of feed/animals/water/rain.}$$

Nutrient (N / P) output was calculated as follows:

$$\text{Nutrient accumulation in sediment/water} = \text{the increase of nutrient concentration in sediment/water} \times \text{total amount of sediment/water.}$$

$$\text{Nutrient in harvested animals} = \text{nutrient concentration in harvested animals} \times \text{total amount of harvested animals.}$$

The volatilization of NH_3-N was measured with the method according to Briggs and Funge-Smith (1994) and Weiler (2011).

The feed conversion ratio (FCR) of snakehead was calculated as total weight of dry feed given divided by the total weight gain.

2.5. Calculation of nitrogen and phosphorus budget

The nitrogen and phosphorus budget was calculated based on inputs from feed, rain, stocked animals and water, and outputs for harvest of