Study on the purification of aquaculture wastewater by the compound wetland ecosystem

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Abstract. Traditional freshwater aquaculture can easily cause serious environmental problems and waste of water resources. Thus, ecological bioremediation techniques for freshwater pond environments are more attractive. In this study, a set of compound wetland ecological system with ecological ditch, constructed wetland and multi-functional ecological pond was constructed, and its purification effect was also evaluated. Our results showed that the compound wetland ecosystem has high removal efficiency for aquaculture wastewater. The concentration of total nitrogen, ammonia nitrogen, Nitrite Nitrogen, total phosphorus, and chlorophyll-a in each treatment unit gradually decreased after the system was stabilized. The annual average removal rates of TN, NH$_4^+$-N, NO$_2^-$-N, TP and Chl-a can reach 73.03%, 74.27%, 91.89%, 64.29% and 83.02%. We found ammonia nitrogen concentration was significantly biodegraded (p <0.05) by the ecological ditch, as well as constructed wetland and multi-functional ecological purification pond had obvious removal effect on TN, TP, NH$_4^+$-N, NO$_2^-$-N, and Chl-a (p <0.05). Moreover, the concentrations of pollutants after purification were lower than the standard value of fishery aquaculture water quality in China, and the purified water was recycled to fish ponds for reuse. Therefore, the compound wetland ecosystem can be adopted by the water shortage area to develop water-saving fisheries in the future.

1. Introduction
Pond culture is the main way of freshwater fishery in China [1]. The residue of bait and the accumulation of fish excrement often lead to the deterioration of water quality, which has many adverse effects on the aquaculture environment [2]. Firstly, the decomposition of organic matter leads to ammonia (NH$_3$) and nitrite nitrogen toxicity in water, which has a serious toxic effect on breeding animals [3]. Secondly, the increase of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) will lead to anoxia water events in pond [4]. Moreover, eutrophication will make the harmful algae blooms (Cyanobacteria), which can release toxic Microcystis to the environment [5]. Therefore, the discharge of aquaculture wastewater will cause pollution and water resources waste, and even threaten animals and human health [6].

In northern China, water shortage and water pollution have become one of the important factors hindering the sustainable development of the regional economy [7]. Previous ecological theoretical studies and engineering demonstrations showed that it is very effective to delay the occurrence and
eutrophication of pond water by repairing the damaged water ecosystem [8], [9]. Therefore, to meet the purpose of standard discharge of breeding wastewater and water-saving breeding, it is urgent to carry out in-depth purification in breeding ponds.

In recent years, monitoring results show that the Jinjinji regions of aquaculture water have a different degree of aquaculture water body pollution problems [10]. Therefore, this study explored a new treatment method of aquaculture water wastewater by artificially constructing a compound wetland ecological system mainly consist of ecological ditch, constructed wetland and multi-functional ecological pond, and studied purification effect on aquaculture wastewater, to gradually restore the structure and function of aquaculture water ecosystem and realize water-saving in the fishery.

2. Materials and Methods

2.1. Compound wetland ecological system (CWES) pond

The CWES pond is constructed in Beijing BaoHeWanLi fishery company Ltd. The system consisted of (1) Fish pond (FP), (2) Wastewater pipeline, (3) Sedimentation tank, (4) Ecological ditch (ED-I, ED-II, ED-III), (5) Constructed wetland (CW), (6) Multi-functional ecological pond (MFEP), (7) Intensive pond (in series) (Figure1.).

![Compound wetland ecological system pond](image)

*Figure 1. Compound wetland ecological system pond*

2.2. Experimental method and statistical method

During the operation of the CWES, water samples were collected from four sampling units (EP, ED, CW, and MFEP) in each month from May to October, and the average removal efficiency of various pollutants in each unit is calculated. The water quality parameters include temperature (T), pH and dissolved oxygen (DO) were tested in the field with a water quality analysis machine (AP-7000, USA). The other water indicators (TN, TP, NH$_4^+$-N, NO$_2^-$-N, and Chl-a) were tested according to the national standard methods in the lab. Average removal efficiency and significance test data were processed using Microsoft Excel 2019 and SPSS 20.0.
3. Results

3.1. Purification effect on total nitrogen (TN)
The average removal rates of TN in each purification unit were 23.24% (ED), 29.19% (CW), and 50.38% (MFEP), respectively. The TN removal rate of the whole water purification system was 73.03%. Our results showed that the TN content in aquaculture wastewater can be significantly purified by the CW and the MFEP ($p < 0.01$) (Figure 2.).

![Figure 2. TN removal efficiency of the ecological purification pond](image)

3.2. Purification effect on ammonia nitrogen ($\text{NH}_4^+\text{-N}$)
The average removal rates of $\text{NH}_4^+\text{-N}$ in each purification unit were 29.67 % (ED), 28.61% (CW), and 48.76% (MFEP), respectively. The $\text{NH}_4^+\text{-N}$ removal rate of the whole water purification system was 74.27%. The results showed that the $\text{NH}_4^+\text{-N}$ content in aquaculture wastewater can be significantly purified in all the purification units ($p < 0.01$)(Figure 3.)

![Figure 3. $\text{NH}_4^+\text{-N}$ removal efficiency of the ecological purification pond](image)

3.3. Purification effect on Nitrite Nitrogen ($\text{NO}_2^-\text{-N}$)
The average removal rates of $\text{NO}_2^-\text{-N}$ in each purification unit were 62.16 % (ED), 48.81% (CW), and 58.14% (MFEP), respectively. The $\text{NO}_2^-\text{-N}$ removal rate of the whole water purification system was 91.89%. The results showed that the $\text{NO}_2^-\text{-N}$ content in aquaculture wastewater can be significantly purified by the CW ($p < 0.05$) (Figure 4.).

![Figure 4. $\text{NO}_2^-\text{-N}$ removal efficiency of the ecological purification pond](image)
3.4. Purification effect on total phosphorus (TP)
The average removal rates of TP in each purification unit were 21.43% (ED), 23.64% (CW), and 40.48% (MFEP), respectively. The TP removal rate of the whole water purification system was 64.29%. The results showed that the TP content in aquaculture wastewater can be significantly purified by the MFEP ($p <0.01$) (Figure 5.).

3.5. Purification effect on chlorophyll-a (Chl-a)
The average removal rates of Chl-a in each purification unit were 27.88% (ED), 40.37% (CW), and 56.69% (MFEP), respectively. The Chl-a removal rate of the whole water purification system was 83.02%. The results showed that the Chl-a content in aquaculture wastewater can be significantly purified by the CW and MFEP ($p <0.05$) (Figure 6.).
4. Discussion

Ecological ditch, constructed wetland and ecological pond technologies are applied to the deep-in treatment of rural domestic sewage in recent years [11]. As a new method of aquaculture and environmental protection, the compound wetland ecological system can purify and recycle high-density aquiculture water efficiently for protecting the water ecological environment and improving the efficiency of aquaculture [12].

The ecological ditch mainly serves the purpose of water purification [13]. In this study, wastewater first flowed into the ecological ditches (ED-I and ED-II), where aquatic plants such as gordon euryale, zizania aquatica and lotus were planted. These two ecological ditches parts mainly used aquaculture wastewater to cultivate high-profit ornamental plants for increasing farmers' income. Then it flowed into ED-III part, where planted submerged plants and aquatic plants like indian shots, mainly for removing pollutants. In this study, we found ammonia nitrogen concentration was significantly biodegraded \((p < 0.05)\) by the ecological ditch.

Constructed wetland is widely used in the treatment of domestic sewage, agricultural point source and non-point source pollution, industrial wastewater and other sewage treatment[14]. It has a good removal effect on chemical demand, suspended solids, heavy metals, and other pollutants. In this study, the removal of NO\(_2\)-N in subsurface flow wetlands was obvious, with the average removal rate of 48.81\%, indicating that the denitrification in constructed wetlands can reduce the concentration of NO\(_2\)-N. Compared with the removal rate of NO\(_2\)-N, the total nitrogen removal rate in the currently constructed wetland was not ideal, with an average removal rate of 32.72\%. Low total nitrogen removal inefficiency is mainly due to the denitrification reaction restrained [15]. As denitrifying bacteria are heterotrophic anaerobes, denitrification with nitrate nitrogen as the substrate is inhibited to some extent under the condition of better oxygen supply in the constructed wetland, which may affect the conversion of nitrate nitrogen into gaseous nitrogen[16], [17], [18].

To make the wastewater can be fully and efficiently purified, this study designed a set of multi-functional ecological purification pond, including the emergent aquatic plant area, ecological floating bed area, floating plant area, and the submerged plant area. Our results showed that the multi-functional ecological purification pond had obvious removal effect on TN, TP, NH\(_4\)+-N, NO\(_3\)-N, and Chl-a. The results indicated the microecological purification system of plant - microorganism - base material was formed, which can absorb pollutants, increase the dissolved oxygen in the water, purify water quality and balance the water ecological environment. It was confirmed that the biofilm formed by the rhizosphere microorganisms of aquatic plants and the ecological floating bed plays a key role in the purification of water quality.
5. Discussion
In this study, a set of compound wetland ecological systems with ecological ditch, constructed wetland and multi-functional ecological purification pond was constructed. The results showed that the pollutants could be effectively removed by this system. In the whole purification system, the annual average removal rates of total nitrogen and ammonia nitrogen were more than 70%. Total phosphorus removal rates were more than 60%, and nitrite nitrogen and Chlorophyll (algae) removal rates were more than 80%. In the process of system operation, the whole pond culture did not discharge sewage, which realized the recycling and efficient utilization of water resources. This study provides practice and technical basis for the research, popularization, and application of new low-cost aquaculture wastewater ecological treatment technology in some aquaculture areas of China.

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