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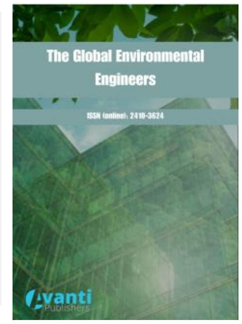

Crab-Aquatic Plant System: A Model for Taking Ecological and Economical Care of the Lakes in Yellow River Delta, China

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ABSTRACT

The lakes, including reservoirs and ponds in the Yellow River Delta, are characterized by many fragile ecosystems and low economic values. How to take into account both ecology restoration and the economic benefits of the lakes in this region is a complex problem. The Chinese mitten crab (Eriocheir sinensis)-aquatic plant system may have this potential. In this study, we planted aquatic plants, e.g., *Elodea nuttallii*, *Hydrilla verticillate*, and *Vallisneria natans*, with the crabs and investigated geochemical parameters in the ponds. The concentration of NH_4^+-N was lower than 0.5 mg/L, the pH of the breeding peiponds was 8.274-9.365, and the dissolved oxygen was 3.554-6.048mg/L, which was better than the class II environmental quality standards for surface water. The more extensive specifications (> 150g/pcs) of the crab growth with the aquatic plants account for >35% of the total production. This model is significant to the ecological utilization of reservoirs in the Yellow River Delta but has low promotion. Therefore, some compulsory breeding policies and breeding standards must be proposed. It is the current ecological needs of the ecological protection Yellow River Delta.

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1. Introduction

The Yellow River Delta are rich in reservoirs and lake resources because of the input of the Yellow River, and it is also a famous aquaculture production area in China [1, 2]. However, flood regulation and water purification were the dominant values of the reservoirs and lakes in the Yellow River Delta [3]. The economy's efficient utilization of reservoirs and lakes in aquaculture is low in this region [4, 5]. High sediment salinization, unreasonable development, and pollution caused by human activities make these water bodies face some serious environmental problems, such as eutrophication and salinization [6]. From 1984 to 2022, the salinization intensity showed an increasing trend in the Yellow River Delta, and human activities were the dominant factor [7]. It was found that the average trophic state index in some lakes or reservoirs was above 3 which was in eutrophication station [8]. It has seriously affected the ecological security and economic development of the Yellow River Delta. In protecting the Yellow River Basin and developing the ecological economy, seeking a development model that considers protecting the reservoir environment while improving economic benefits is significant. However, the reservoir investment often cannot make ends meet in freshwater fish farming in the Yellow River Delta. Hence, choosing a species with high economic value and relatively low investment is crucial. The agriculture of Chinese mitten crab (*Eriocheir sinensis*) seems valuable to solve this problem. It is a traditional aquaculture species with high economic value in China and rich in resources in the Yellow River Delta. The crabs produced in this region also have a higher content of amino acids in their muscles and are the earliest on the market than those produced in the Yangtze River and Liaohe River systems [9]. In addition, Chinese mitten crabs need certain salinity water to stimulate the development of gonads and reproduce their offspring, and then grow in freshwater [10]. Therefore, it will be very suitable for the wide-salt characteristics of reservoirs, lakes, and ponds in the Yellow River Delta.

As of 2019, the scale of crab farming has been expanded to a million-mu level in the Yellow River Delta, and this region has always been an important breeding area for this species in China. However, this aquaculture is facing tremendous environmental and upgrading pressure. Vigorous development has brought a vast scale but not brought optimal economic efficiency. The scale-to-input ratio of the hairy crab breeding industry in this area is not high. Although the breeding area of crabs has exceeded one million acres, the refined breeding area still accounts for less than 10%. Moreover, this 10% breeding area produces more than 70% of hairy crabs. The economic efficiency of lakes, reservoirs, and pond systems is very low. The output of crabs in lakes and reservoirs was only 15 kg/ha or less than 60 kg/ha in the early period. This may have a great relationship with the degradation of aquatic plants in the lake and reservoir system of the Yellow River Delta. The Chinese mitten crabs are omnivorous animals and have a considerable food intake. Aquatic plants, fish, and shrimp are all within its scope. Therefore, the bottom of the food chain in the lake may be easily destroyed by the increase in the stocking more crab larvae [11]. Moreover, the population and quality of crabs in the upper layer of the food chain will also decrease. In addition, the regulation of Yellow River water resources limits the scale of breeding of crabs in the ponds. According to the work program of Dongying City to implement the " four water-based principles", the Yellow River Delta crab farming area needs to be reduced to about 60% of the original farming area. Therefore, exploring the efficient use of lakes and reservoir resources to expand hairy crab farming is meaningful.

However, the nearly 1×10^9 m^3 of water for intensive farming of Chinese mitten crabs often brings tremendous environmental pressure to the wetland environment of the Yellow River Delta. Farmers will put a large amount of fermented soybean meal, fish meal, and live fish into the intensive pond to increase the fat of crabs from August to September every year [12]. However, the feed utilization rate in the pond does not exceed 70%, and the remaining 30% of the bait will be left in the water body to degenerate and deteriorate, and finally converted into N, P, organic matter, and other pollutants [13]. This tailwater of the crab pond will begin to be discharged gradually with the start of fishing at the end of September [14, 15]. Moreover, the ability of the lake ecosystem to digest pollutants is weak because the phytoplankton is dying in September and October. Therefore, a large number of lake ecosystems in the Yellow River Delta are in a sub-healthy state [16]. Consequently, it is crucial to explore hairy crab culture models that reduce the number of pollutants and increase the farming benefits.

In this study, we investigated the output-input and culture model of the Chinese mitten crab in the Yellow River Delta. and analyzed the influence of aquatic plants on the control of inorganic nitrogen and the output specifications of hairy crabs. Moreover, the relationship between the utilization of reservoirs and the planting of aquatic plants, and the policies and methods to improve the ecological and economic benefits of lakes in the Yellow River Delta was also discussed.

2. Materials and Methods

2.1. The Bassline Information of the Breeding Experiment

2.1.1. Aquatic Plant Species

Crabs generally live in natural lakes or rivers rich in aquatic plants [17]. To obtain high-quality hairy crabs, the exploration of simulating the wild growth and breeding model of crabs has been constantly trying [18-20]. The most widely used aquatic plant species were *Elodea canadensis michaux*, *Hydrilla verticillate*, and *Vallisneria natans (lour.)*. So, in this study, we used those three species of aquatic plants.

2.1.2. Temperature Conditions

The suitable growth water temperature for crabs is 10-30°C, which has poor adaptability to high temperatures. High temperatures often lead to precocious crab species and hold the growth of adult crabs, which affects product specifications significantly [19]. Therefore, the study areas with suitable temperatures are a necessary condition for achieving the purpose of this research. The breeding experiment is located in Dongying City, Shandong Province, People's Republic of China. It is a warm temperate semi-humid area with a continental monsoon climate. The average temperature varies from 3.2°C to 25.9°C in this region during the growth period of crabs (March to November) [20]. This climatic condition allows the crabs to have enough suitable growth time and reach a larger size with sufficient feeding in the Yellow River Delta [21].

2.1.3. The Pond Condition

Hairy crab farming is carried out in wild reservoirs and intensive ponds. The intensive culture pond covers an area of 43,290 m^2 and comprises dams, ring ditches, and shallow water areas. Ring ditch occupies 20-30%, and shallow water area occupies 80-70% of the bottom area of the pond. This will facilitate the growth of aquatic plants and the activity, feeding, and distribution of hairy crabs. The ring ditch of the pond is shaped like a "mouth" with a depth of 0.8-1.2 m. The breeding base has a complete drainage system outside the pond, and the depth is 1.5 m. The reservoir is 399,600 m^2, and the surrounding terrain is gentle with cultivated or barren soda land. The water depth is one meter, and the bottom quality is flat. The soil is mainly sandy loam, and the surrounding dam is a roller-compacted homogeneous earth dam. The water-facing slope is protected by block concrete, geotextile, or filter layer, and the slope ratio is greater than or equal to 1:3.

2.1.4. Breeding Water Condition

The water used for hairy crab breeding comes from the Yellow River. It is introduced into the sedimentation tank through the main channel of the Yellow River first and then introduced into the breeding reservoir or intensive pond after sedimentation. Most of the pollutants in the river water will enter the bottom of the sedimentation tank along with the sediment particles after precipitation. The pH of the water is about 8.0~8.3, and the total hardness is 2.16~5.56 [22]. The hairy crab will be stocked in March and spend their lives in ponds and reservoirs until sale on the market. Aquatic plants will reduce ammonia nitrogen, increase dissolved oxygen, and provide direct or indirect food sources for crabs in water bodies. The flow chart of the breeding experiment is shown in Fig. (**1**).

2.2. Experiment

2.2.1. Desalination of Pond Sediments

The breeding area used in the experiment is mainly located in saline-alkali soil, with salt contents above 0.35%, and it is not suitable for the growth of aquatic plants. Therefore, breeding pond soil must be desalinated to reduce the salt content. First, we need to level the ground in the central shallow water area of the pool, and the shallow water depth is about 5cm. Water was introduced into the pond ring ditch and central shallow water area. It is necessary to continuously pour new water into the shallow water area of the pond, and keep the surface water depth of the shallow water area above 10 cm for 10-15 days. In this way, the dissolved salt in the shallow water area of the pond will go into the drainage canal, which then penetrates or discharges into the drainage channel around the pond with water permeability and water pressure. It has been tested that the salt content of the pond sediment has fallen below 0.1%, which could be suitable for aquatic plant growth. For the reservoir, a large amount of water and the continuous input of new water will diffuse the dissolved salt in the sediment to the soil surrounding the pool [23]. Therefore, the sediment salinity in the reservoir is usually less than 0.1%, which can be used for aquatic planting [24].

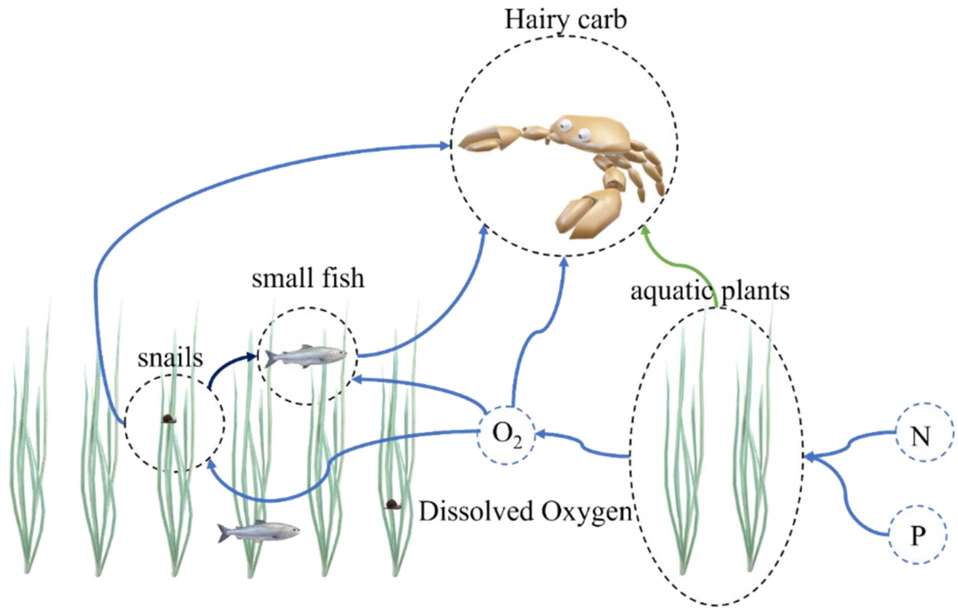

Figure 1: The flow chart of breeding experiment.

2.2.2. Planting Aquatic Plants

Three submerged plants, *Elodea nuttallii*, *Hydrilla verticillate*, and *Vallisneria natans*, were planted in the cultivation ponds from the end of April to the beginning of May. The brief planting process is as follows. In the ponds, the 10 m wide aquatic planting belt and the 5 m wide bait channel are arranged in parallel and alternately. In the reservoirs, we transplanted three submerged plants in shallow water.

Elodea nuttallii and *Hydrilla verticillate* are grown by rooting or cutting adult algae into the bottom of the pond. Buds of two plants could also be sown directly at the bottom of the pond in March. The sowing method is used for planting *Vallisneria natans*. The seeds of *Vallisneria natans* are soaked in water for 3-5 days first, and then about 10 times, the fine sandy loam soil is added and mixed well before sowing. The sowing rate is 6-9 kg/hm of water surface (dry weight of pure seeds). The planting area ratio of each species is: *Hydrilla verticillata* accounted for 40%, *Vallisneria natans* accounted for 30%, and *Elodea nuttallii* for 30%. The depth of the plants submerged was 1.2m-1.5m (Fig. **2**).

2.2.3. Crab Larvae

The hairy crab larva is one year old, and the size is 100-200 pcs/kg. It must meet the following conditions: uniform size, disease-free, good physical fitness, strong vitality, no severed limbs, and asexual precocity. The stocking density of carb larvae is 15000-18000 pcs/ha, and the stocking time is March. In the reservoirs, the stocking time and the size of the crab were similar to pons, but the stocking density was 1450-1650 pcs/ha.

2.3. Monitoring Parameters

Four important indicators, pH, dissolved oxygen, inorganic nitrogen, and the specifications of the crabs at the end of the cultivation, were monitored in this experiment. The pH changes in aquaculture ponds and reservoirs are the primary monitoring indicators. It is related to the salt permeability of pond sediments and affects the growth of submerged plants. The salinity of the water in the saline-alkali pond will gradually increase with evaporation or diffusion. This behavior is conducive to controlling the inorganic nitrogen in the water but holds the growth of the planted aquatic plants [25, 26]. Dissolved oxygen is another indicator that must be monitored. It will directly affect the survival, growth, and disease resistance of hairy crabs and indirectly affect the decomposition and removal of organic or inorganic pollutants in aquaculture water [27, 28]. The inorganic nitrogen is a critical pollutant that must be monitored in the Yellow River Delta. Its concentration change in the pond water body will reflect the health of the aquaculture pond ecosystem and the possible risks to the environment [29]. The final product specifications of crabs are used to evaluate the input-output ratio of ponds and reservoirs.

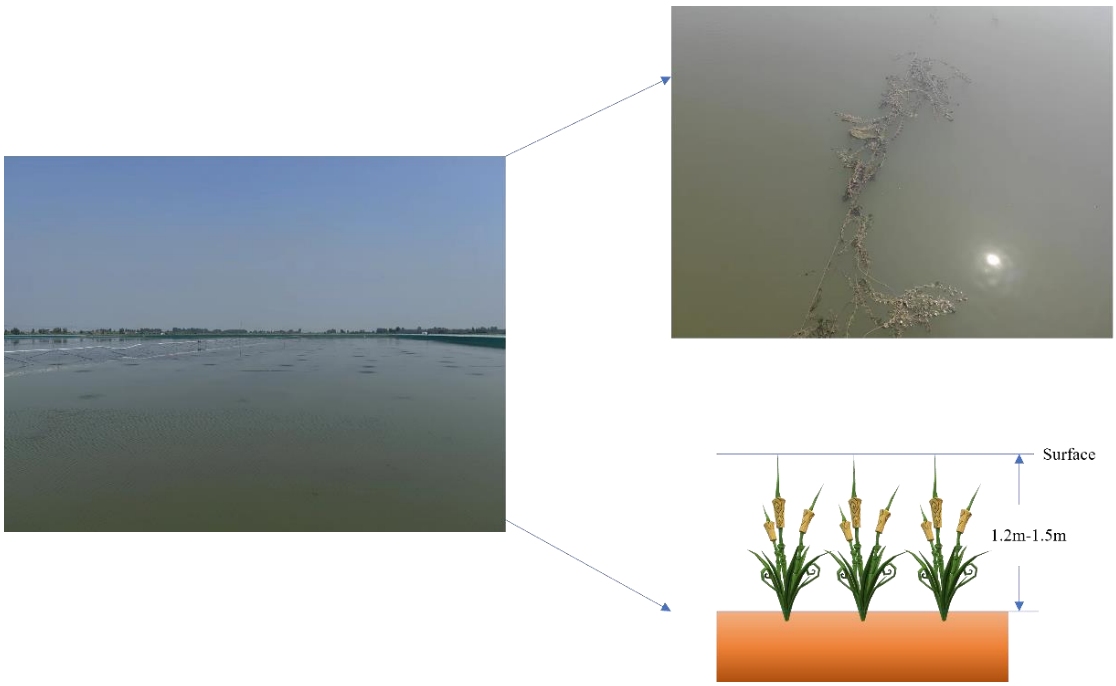

Figure 2: The current situation of the carb pond and the depth of the plants submerged.

2.4. Data Analysis

2.4.1. Ecological Risk Calculation

In this study, we used the damage quotient (DQ) produced by inorganic nitrogen in the tailwater of intensive hairy crab ponds to measure the possible ecological risks of hairy crab farming [30]. The formula defines the following:

$$DQ = \frac{C_{N-P}}{C_{N-S}} \quad (1)$$

DQ: The potential environmental risks of inorganic nitrogen in hairy crab pond tail water; C_{N-P}: Inorganic nitrogen content in hairy crab pond culture tail water; C_{N-S}: Inorganic nitrogen content in the national standard for the discharge of culture tailwater. When the DQ value is less than or equal to 1, it indicates that the environmental risk caused by the aquaculture tail water is relatively small; when the DQ value is greater than 1, it indicates that the aquaculture tail water can pose a risk to the environment, and the greater the DQ, the greater the risk.

2.4.2. Growth of Aquatic Plants

We use the ratio of the growth area to the sampling interval to measure the growth of aquatic plants. The formula defines the following:

$$V_t = \frac{S_o - S_i}{t_o - t_i} \quad (2)$$

V_t: plant growth rate; S_o: water plant area at the time of sampling; S_i: water plant area at the previous sampling time; t_o sampling time; t_i: previous sampling

3. Results

3.1. Plant Growth and pH

The duration of the breeding season is from March to October 2020, approximately 8 months. In three experimental ponds, the area of aquatic plants and the growth rate gradually increased with a temperature rise (Fig. **3**). In summer, the site of the elodea appears to shrink, and the growth rate of the three aquatic plants also slows down, but the population density is the largest [31-33]. In September and October, the area of aquatic plants gradually decreased, and the growth rate slowed. It was found a very obvious phenomenon that the growth rate of water plants in ponds was higher than in reservoirs. This is a reflection of the fact that the inorganic nutrients in the ponds are higher than in the reservoirs [34]. A similar trend was observed in pH changes (Fig. **4**). Before July, the pH in the pond had been increasing, and the pH gradually decreased after July. The pH increased again in October, but the increase rate was significantly lower than that from March to June.

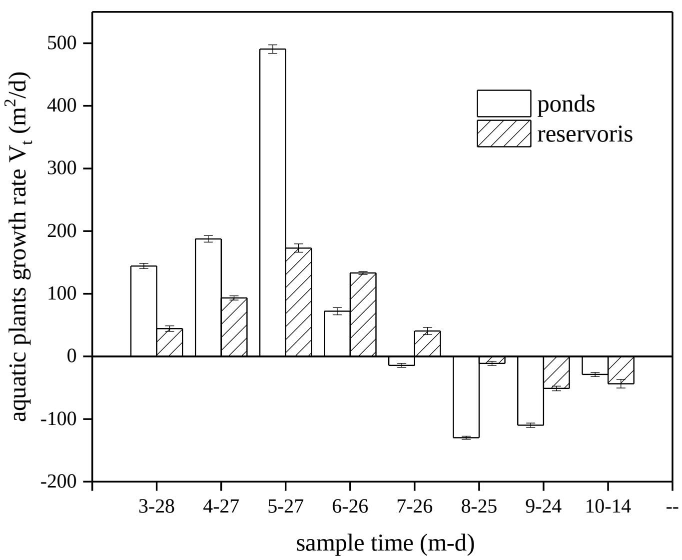

Figure 3: The growth rate of three aquatic plants in ponds and reservoirs.

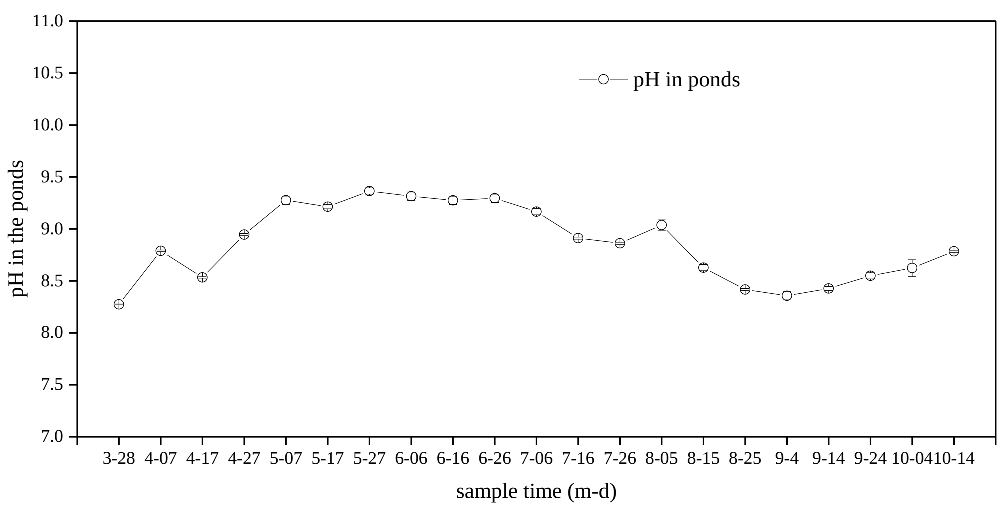

Figure 4: The change trend of pH in ponds during the breeding period.

3.2. Inorganic Nitrogen

In this study, we only consider the effect of plants on the denitrification of microorganisms in organic matter decomposition [35]. Only the change trend results of NH_4^+-N and NO_2^--N in pond water were detected. From the trend in Fig. (**5**), it can be found that the highest concentration of NH_4^+-N is about 0.47±0.02mg/L, and the NH_4^+-N in the pond water body shows an upward trend from March to May. The NH_4^+-N level decreased between June and August with the high temperature, but this change is relatively smaller. From September to October, NH_4^+-N increased first and then reduced, and the peak concentrations of NH_4^+-N in May and September 2020 were close.

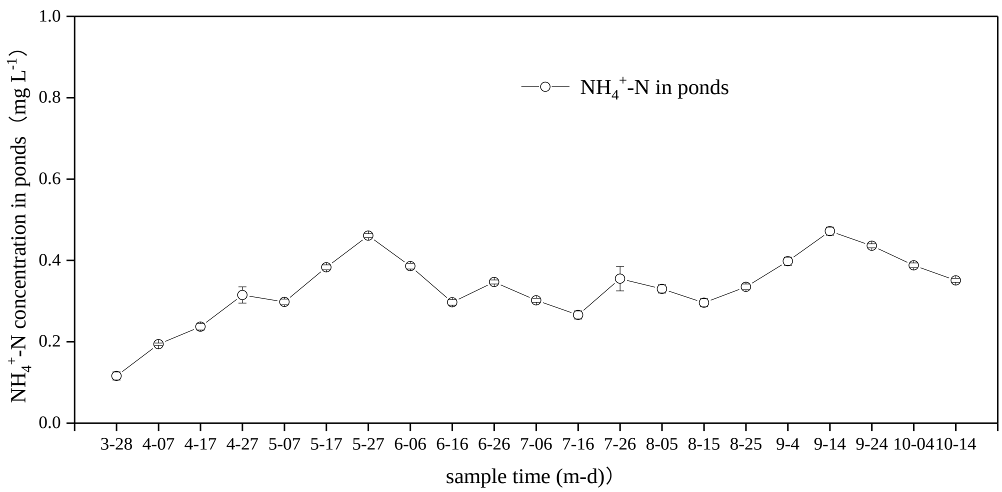

Figure 5: The change trend of NH_4^+-N in ponds during the breeding period.

The changing trend of NO_2^--N is similar to that of NH_4^+-N (Fig. **6**), but the change range is more prominent. The peak of NO_2^--N was nearly 20 days earlier than that of NH_4^+-N from March to May 2020, and the peak of NO_2^--N in September was significantly higher than in May. The highest concentration of NO_2^--N appeared in September at about 0.18±0.05 mg/L, and the lowest concentration was only 0.08±0.002 mg/L.

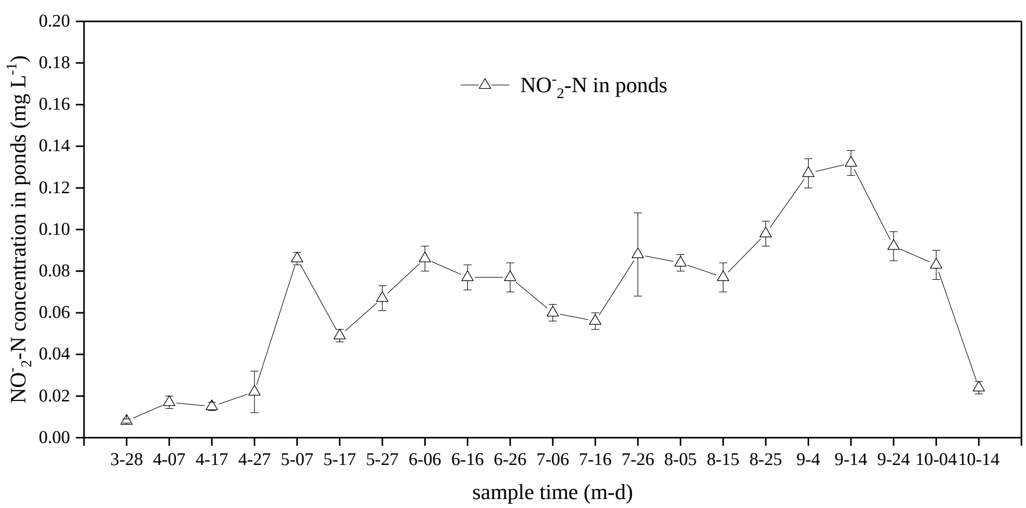

Figure 6: The change trend of NO_2^--N in ponds during the breeding period.

3.3. Ecological Risk

Since only the NH_4^+-N standard is included in the aquaculture water standard, the ecological risk of the pond only considers the environmental damage quotient (DQ) of NH_4^+-N. The changing trend of environmental damage quotient of hairy crab culture water is shown in Fig. (**7**). It could be found that the DQ values of NH_4^+-N are all lower than 1, and the quotient is the largest in May and September. However, regarding the habitat of hairy crab ponds, the risk of aquaculture water in September is higher than in May. The growth of aquatic plants in the pond stopped and began to die out in September, but a vigorous stage of growth of aquatic plants in May [36]. The growth of aquatic plants will consume inorganic nitrogen in the water, and the NH_4^+-N in September will follow the tailwater into the environment of the Yellow River Delta.

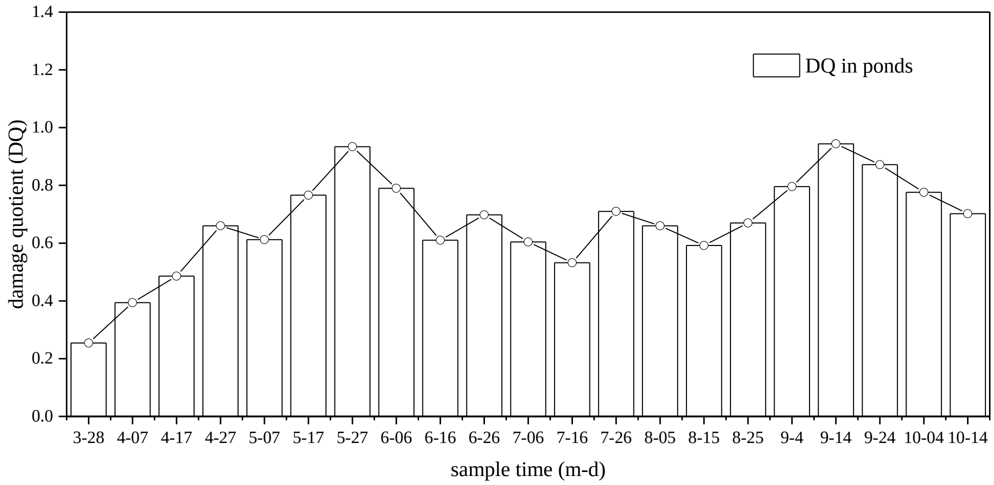

Figure 7: The change trend of damage quotient (DQ) in ponds during the breeding period.

3.4. Crab Specifications

The crabs in ponds and reservoirs produced good results after nearly 8 months of breeding. Fig. (**5**) shows the proportion of ponds and reservoirs with different specifications and the output analysis. The crabs are about 16.74 t in the pond and the average yield is about 1395 kg/ha. The average size is 144 g/pcs, and large-size crabs (greater than 150 g/pcs) account for more than 60%. The total output value is 15,412,000 yuan, and the input-output ratio is 1:1.75. The crabs in the reservoir are 40 ha, with a yield of 3.0-3.6 t. The average yield of the reservoir was about 75-90 kg/hm and the average size of 123 g/pcs. Large-size crabs (above 150 g/pcs) account for 34%, the input-output ratio is close to 1:3.

4. Discussion

In the aquatic plant-crab polyculture system, the average production of crabs larger than 144 g/pcs in ponds and 123 g/pcs in reservoirs and the large-size (>150 g/pcs) carb accounted for more than 60% and 34% of the total production. However, the average size of crabs cultured in ordinary ponds or conventional reservoirs was about 100 g during the same period, and the yield of large-size crabs was about 10-15%. It indicated the polyculture aquatic plant system has a larger input-output ratio of crabs than those of general centralized culture ponds. This phenomenon may have an essential relationship with the niche of aquatic plants in the pond system. The aquatic plant system is an important species that maintains the ecological safety of reservoirs and ponds [37, 38]. It could increase the dissolved oxygen and the number of plankton in the ponds [39], and reduce the level of inorganic nitrogen and the possibility of eutrophication of the water body [40]. Most importantly, aquatic plants can also provide a stable and high-quality food source for hairy crabs, trash fish, and other herbivorous or omnivorous animals in the food chain in the pond system [41]. As a primary producer of the ecosystem, aquatic plants provide sufficient food for a variety of animals in low food chain levels [42], which makes the food chain in the water ecosystem more stable. This makes the hairy crabs, at the highest level of the pond food chain, obtain a more high-quality and stable food source besides artificial feed, and the food contention was avoided. In addition, aquatic plants can also provide more three-dimensional living space to reduce the survival pressure of the carb population [43]. Therefore, aquatic plants carried in ponds or reservoirs could maintain pond ecosystem stability and increase the input-output ratio.

The environmental risks of carb cultivation cannot be ignored. They mainly discuss the risk of NH_4^+-N in aquaculture waters because this pollution is the key and monitored pollutant in the water quality standards. In this study, NH_4^+-N in the water body did not exceed 0.5 mg/L, which fit the Class II environmental quality standards for surface water. This shows the water ecosystem is relatively healthy in a high-density or low-density breeding environment. Aquatic plants may be the main factor in maintaining this health. They are essential in neutralizing and buffering nitrification and denitrification [44]. There are various forms of N-containing compounds in hairy crab breeding ponds. Among them, inorganic nitrogen mainly comes from biological nitrification, denitrification, and hairy crab excretion, and organic nitrogen mainly comes from organic waste, food residues, and fish and shrimp residues [45, 46]. In addition to inorganic nitrogen that aquatic plants can use directly or indirectly, the decomposition of organic nitrogen requires a lot of oxygen. Aquatic plants, as primary productivity, could significantly increase dissolved oxygen in water by photosynthesis. During the breeding process, most of the dissolved oxygen in the experimental pond was between 4-6 mg/L (Fig. **8**). The dissolved oxygen level was high and fit between II and III environmental quality standards for surface water. The low level of dissolved oxygen appeared in September, which may be related to the fattening behavior of crabs in September. At this stage, a large amount of protein will be transported to the pond, and the food conversion rate at this stage is only 60%, and about 40% of the organic matter remains in the pond. Therefore, to decompose these residual substances, a large amount of dissolved oxygen is consumed [47, 48]. The root system of aquatic plants can also accumulate or produce a large number of nitrifying microorganisms to enhance the ability of water to degrade pollutants [49]. It was found that the amount and species of nitrifying bacteria in the pond environment with large plants were significantly higher than that out of plants [50]. In general, the content of nitrous nitrogen in crab breeding is less than 0.05 mg/L, indicating that aquatic plants inhibit the production of unstable N elements. Therefore, the element cycle of N is in a relatively stable state.

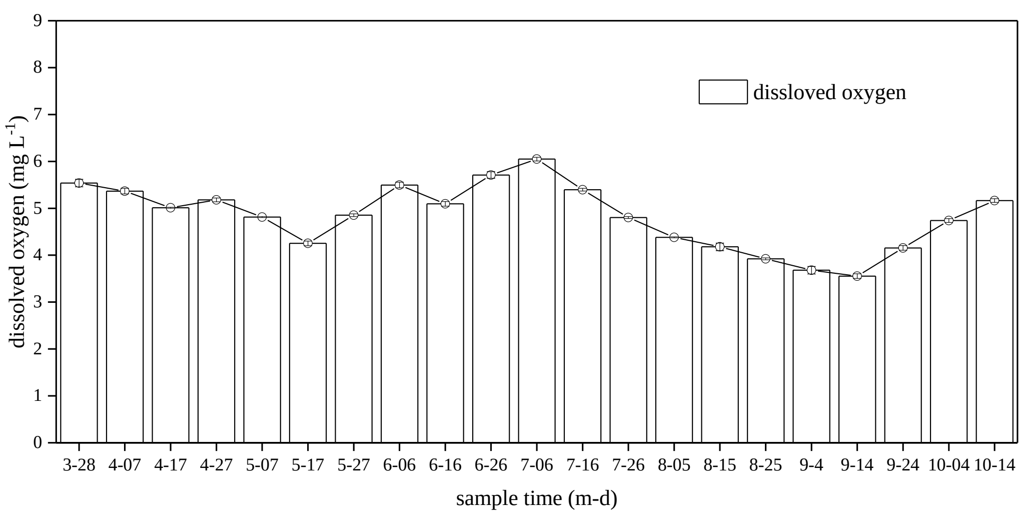

Figure 8: The change trend of dissolved oxygen (DO) in ponds during the breeding period.

This study uses the law of salt diffusion with water and pond engineering measures to break the bottleneck of salinity, inhibiting the growth of aquatic plants. Through the continuous input of fresh water, the dissolved salt in the soil in the shallow water area of the pond will seep into the pond gutter and then into the drains around the pond. This method reduces the salinity of the soil in the shallow water area of the pond and the ring ditch effectively. The saltiness of the soil could decline to less than 0.1% after more than a week of alkali discharge. It is suitable for the requirements for the soil salinity of aquatic plant growth. In this study, the transplant of *Elodea nuttallii*, *Hydrilla verticillate*, and *Vallisneria natans* was successful. *Elodea nuttallii* can grow through the winter naturally in local ponds. *Hydrilla verticillate* and *Vallisneria natans* can be transplanted and planted in local ponds during the warm season. Those plants, like the Potamogeton, Myriophyllum, Ceratocarpa, and reeds in local ponds, could grow naturally. The coverage rate of aquatic plants on the water surface reaches about 60%, which can fully meet the growth and life needs of the crabs in ponds [45].

The Yellow River Delta mainly consists of chloride saline soil, and salinity is generally above 0.6% [51]. This high salinity of the sediment restricts the emergence and sinking of plants in a large number of wild ponds. Water plants must generally grow in sediment with less than 0.1% salinity. Therefore, many natural reservoirs in the

Yellow River Delta lack aquatic plant species to maintain the stability of the ecosystem in water bodies [52]. Those water bodies face huge environmental risks, such as inorganic nitrogen, heavy metal pollutants, and the destruction of aquatic biodiversity [53-55]. In addition, the utilization rate and the economic value of reservoirs in the Yellow River Delta are low [56]. Applying the ecological breeding model of crabs will increase the utilization rate and provide a path for restoring the ecosystem of the reservoirs in the Yellow River Delta. The alkali drainage ditches could reduce the salinity of the sediments in the reservoir or ponds. This retrofit will increase the survival chance of large aquatic plants and make it possible to restore aquatic plants in the reservoir. These aquatic plants can provide food for crabs and eventually form a stable food chain [45]. At the same time, the growth of aquatic plants can also take away excess nutrients in the water body, increase the nitrification and denitrification of organic waste by microorganisms, and stabilize the reservoir ecosystem [57, 58]. In addition, aquatic plants can also increase the three-dimensional living space protection of the creatures and improve the biodiversity of the reservoir [58].

5. Conclusion and Prospect

The Yellow River Delta hairy crab-waterweed polyculture model can increase the production of hairy crabs and maintain the ecological safety of pond water. It is a breeding model that takes into account both ecology and economy. In protecting the Yellow River Basin, the ecological operation of the Yellow River Delta reservoirs, breeding ponds, and lakes is imminent. How to protect the ecology and find economic growth points is a contradictory topic. The polyculture model of crabs and aquatic plants may be an essential way to solve this contradiction. Transplanting aquatic plants can repair the environment of reservoirs and lakes, and raising crabs can improve the economic benefits of reservoirs and lakes. However, there are still many difficulties in the promotion of this model. This mode is still recommended, and the benefit of a large number of crab ponds is still not high. In addition, applying it in reservoirs and lakes still faces many technical problems, such as how to build the alkali drainage ditches, the planting area and range of aquatic plants, etc., that need to be discussed in depth. In general, the crabs-aquatic plant's system may be one of the optimal solutions for the ecological and economic benefits of delta reservoirs and lakes.

Conflict of Interest

Authors declare no conflict of interest.

Funding

None.

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