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Aquaculture in an Offshore Ship: An On-Site Test of Large Yellow Croaker (*Larimichthys crocea*)

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Abstract: Ship aquaculture platforms are expected to become a meaningful way to expand offshore farming. The growth performance and nutritional composition of the large yellow croaker reared in an offshore ship aquaculture system and nearshore traditional cage system was evaluated in this study. The results showed that the aquaculture ship could effectively avoid the harsh environment such as typhoons and red tides. The test large yellow croaker adapted to the ship culture system in a short time. No serious stress events occurred during the whole rearing process. During the culture experimental period, the fish fed normally, and disease was controlled. The aquaculture ship has good environment conditions during breeding with a water temperature of 21.5–28.5 °C, salinity 20.7–31.8‰, pH 7.6–8.4, dissolved oxygen 7.2–12.8 mg/L, ammonia nitrogen < 0.08 mg/L, and the number of bacteria and vibrio in water were $1.2 * 10^3$–$1.6 * 10^3$ CFU/mL and $1.2 * 10^2$–$1.8 * 10^2$ CFU/mL, respectively. The survival, weight gain rate, and monthly weight gain of the large yellow croaker in the ship were 99.02%, 41.48%, and 67.52 g, respectively, which were significantly higher than those of cage culture. The crude protein content of the large yellow croaker raised in the ship was significantly higher than that in the cage group, and the crude fat content was significantly lower than that in the cage group. These results indicated that the growth performance and nutritional composition of the large yellow croaker reared in offshore ship were better than those of the fish in the cage. These findings enhanced our understanding of an offshore ship aquaculture model of large yellow croaker.

Keywords: aquaculture ship; traditional cage; large yellow croaker; growth performance; nutrient composition

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1. Introduction

With the increasing demand for high-quality protein, it was estimated that global fish production will increase by 32% by 2030 compared to 2018 [1,2]. However, in recent years, due to adverse factors such as limited space resources, environmental deterioration, excessive aquaculture density, and frequent disease outbreaks, the inland and nearshore aquaculture space has been seriously restricted [3,4]. To reduce the impact of aquaculture on land-based and nearshore areas, it was imperative to expand the aquaculture space. Enclosed aquaculture vessel was a new offshore aquaculture method in recent years. It was expected to be an important way to develop offshore aquaculture [5,6].

The development of offshore areas can be used as an important space for fish farming in the future. Offshore seas have the advantages of a wide area, good water quality, and few pollutions and pathogenic microorganisms [7]. Currently, many practical activities for offshore aquaculture have been carried out in China, Norway, Scotland, Korea, Japan, and other countries [8–11]. Studies have shown that offshore aquaculture can effectively improve the survival and growth of salmon and bluefin tuna and reduce the possibility of fish disease [12–14]. At the same time, offshore areas have relatively harsh environmental conditions, such as large wind waves and currents, which may damage the breeding equipment and fish health [15,16]. Therefore, offshore aquaculture needs to improve the requirements of technology, capital, operation, and other aspects.

As a new model of closed aquaculture, the relevant research data on the aquaculture ship was very scarce. It was reported that only Türkiye (Turkey) transformed a bulk carrier into an enclosed aquaculture vessel and carried out the breeding test of rainbow trout. The initial average body weight was 25.0 $\pm$ 2.7 g and reached 3.7 $\pm$ 0.4 kg after 11 months. The feed conversion ratio (FCR), specific growth rate (SGR), and breeding density were 1.1 $\pm$ 0.1, 1.51 $\pm$ 0.3%/d, and 101 $\pm$ 2.1 kg/m^3, respectively [17]. Large yellow croaker is the main mariculture fish in China, and its production ranks first in mariculture all year-round. Due to its flavor, high flesh quality, and nutritional value, large yellow croaker has a large market space [18]. Large yellow croaker resources almost disappeared from the end of the last century to the current output of more than 250,000 tons, which mainly benefitted from the development of artificial aquaculture technology [19]. However, knowledge about the growth performance and nutritional composition of large yellow croaker that are reared in ships and cages for a short period is limited. Therefore, this experiment takes large yellow croaker as the target animal to explore whether the closed aquaculture system can be used in fish culture, determine the growth performance of large yellow croaker under this culture mode, and analyze the conditions that are suitable for large yellow croaker culture under this mode. In addition, if the platform can be used in offshore areas, the results of this study can establish a set of aquaculture technology standards, such as seed transfer and environmental control, and provide a scientific basis for the establishment of large yellow croaker and other fish.

2. Materials and Methods

2.1. Experimental Animals and Facilities

Traditional aquaculture cages (26°37′35′′ N, 119°51′72′′ E) were set in Sandu Bay, Xiapu County, Ningde City, Fujian Province, China. The closed aquaculture vessel of GuoXin No. 1 was transferred to the sea areas of Ningde in Fujian province, Zhoushan in Zhejiang province, and Qingdao in Shandong province to maintain the best growth conditions.

Large yellow croaker (340 $\pm$ 10 g) were obtained from Guoxin (Taizhou) aquaculture farm in Ningde City, Fujian Province. The test fish were incubated in an indoor hatchery and cultured in open cages in the inshore waters of the inner bay. Before the experiment, according to the initial density of 12.1 kg/m^3, 30,000 healthy large yellow croakers were randomly put into three 280 m^3 breeding tanks with 10,000 fish per tank. In addition, two traditional cages (10.5 m $*$ 7.0 m $*$ 6.0 m) were set up for the comparative test. The density of the traditional cage was subject to the actual production. The initial density of 5.06 kg/m^3 was used to put 6700 large yellow croaker of the same specification per cage. The large yellow croakers spent three weeks acclimatizing to the experimental environment before the experiment officially began. A period of respite, no feeding was performed for the first three days, and the feeding rate gradually increased to the normal level as time passed.

The mid-trial ship "Guoxin 101" was transformed from an offshore bulk carrier, with a total length of 96.8 m, a type of width of 16.6 m, a displacement of 5491 t (Figure 1A,B), a power of 2 $\times$ 662 kW, and a speed of 10.5 kn. It was equipped with three nearly quadrilateral breeding tanks with a volume of about 280 m^3 (Figure 1C,D; 8.8 m $*$ 7.8 m $*$ 5.15 m; the water level was 4.1 m). There was a movable awning on the upper opening. The marine aquaculture system was mainly composed of water circulation, oxygenation, illumination, sewage, and monitoring and alarm systems.

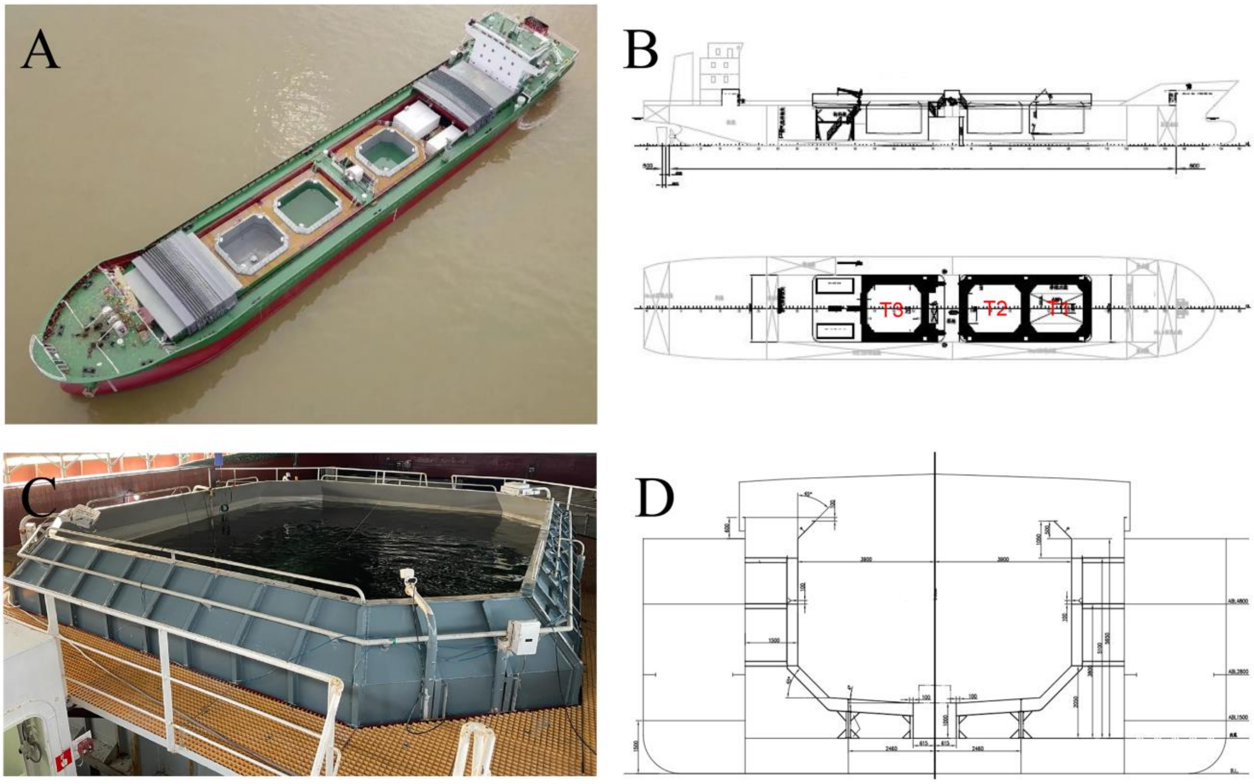

Figure 1. Gouxin No 101 closed aquaculture vessels. (**A**,**B**) represent overall photographs and schematic diagrams of the ship, respectively; T1, T2, and T3 are represented as the three different tanks in the ship; (**C**,**D**) are field pictures and schematic diagrams of the culture tank.

2.2. Experimental Procedures

In this experiment, the ship adopted flow-through systems where the aquaculture water was taken from 4 m underwater. The systems were carried out by water intake from the bottom of the ship and drainage from the starboard side. During the culturing period, the water change rate of the tank was maintained 16 times per day, and water flow was maintained at 0.2–0.4 m/s. The oxygen cone pressure method was adopted to dissolve pure oxygen into the breeding water to keep the dissolved oxygen above 8 mg/L, and no air was added in the breeding chamber. The light intensity was controlled at 300–500 Lux, and the photocycle was set to 12D: 12L from 5:30 am to 5:30 pm. In this study, the commercial special feed (main nutrients: crude protein $\geqq$ 42%, crude fat $\geqq$ 6%, crude fiber $\leq$ 5%, ash $\leq$ 18%, moisture $\leq$ 12%, total phosphorus $\geqq$ 1.2%, lysine $\geqq$ 2.2%) was the feed that was used for large yellow croakers. The fish were feed once in the morning and evening (6:00, 17:00). The daily standard feeding amount was 1.2–1.5% of the body weight of the fish and adjusted at any time according to the changes in water temperature, weather, and water quality, feeding behavior and residual bait situation, to reduce the residual bait amount as far as possible. Every two weeks, the underwater robot was used to clean the bottom of the tanks to ensure the cleanliness of the culturing environment. During ship culture, the noise pressure level of the tanks was recorded between 119–125 dB under mooring conditions and 132–134 dB under sailing conditions by using a hydrophone (C55, Cetacean Research Technology, Seattle, Washington, DC, USA). The planned experimental period was from June to August 2021. The caged group of large yellow croakers were kept according to cage culture rules for normal feeding.

2.3. Determination of Water Quality

During the trophic period, water temperature, salinity, dissolved oxygen, and pH were measured by an automated water quality analyzer (YSI-556, Beverly, MA, USA) once a day. The total ammonia nitrogen was measured once a week using a hash water quality detector (NA8000, Beverly, MA, USA).

The total number of bacteria and vibrio in the water of the tank in ship was measured by the plate counting method [20] and tested once a week. The TSA and TCBS (Sangon Biotech, Co., Ltd., Shanghai, China) was selected as medium. Water samples were collected in the culture tanks, diluted 100 times with sterile seawater, and then coated with 100 μL on the medium and placed at 28 °C for 24 h. Finally, the plate was observed and counted.

2.4. Experimental Sampling

For the period of the test, the number of dead fish and daily food intake of large yellow croaker of two groups per day were recorded to count the survival rate and the feed conversion ratio. A total of thirty fish were randomly collected from each tank in the ship every 15 days, and their body weight and body length were measured. At the same time, their visceral fat was dissected and weighed. After the experiment, large yellow croaker of two groups was starved for 24 h, thirty fish were randomly collected from each tank and cage to measure body weight, body length, and weight of visceral fat. Then, ten fish in each tank and cage were obtained with skinless muscle samples, which were placed at −80 °C for nutrient detection.

2.5. Muscle Chemical Analysis

According to AOAC method [21], the contents of total nitrogen, crude protein, moisture, and ash were analyzed. The moisture of the sample was weighed after desiccating to a constant weight at 105 °C in an oven (DHG-9240A, Keelrein Instrument Co., Ltd., Shanghai, China). The ash content was indicated after samples were incinerated in a muffle furnace (SX2-12-12N, Jinwen Instrument Co., Ltd., Nanjing, China) at 550 °C for 12 h. The crude protein was analyzed by single acid digestion in the Kjeldhal apparatus (Kelplus DISTYL-BS, Pelican Equipment Pvt. Ltd., Chennai, India). After extraction with chloroform-methanol (2:1, *v*/*v*), the crude lipids were measured following previously methods as indicated [22,23].

2.6. Data Calculation and Statistical Analyses

The parameters were determined based on the following calculations:

Survival rate (SR, %) = (final quantity of fish)/(initial quantity of fish) ∗ 100%;
Weight gain rate (WGR, %) = (Wt − Wi)/Wi ∗ 100%;
Feed conversion ratio (FCR, %) = feed intake/(Wt − Wi) ∗ 100%;
Visceral index (VSI, %) = visceral weight/body weight ∗ 100%;
Condition factor (CF, g/cm^3) = body wet weight/body length^3 ∗ 100%;
Stocking density (SD, kg/m^3) = (quantity of fish ∗ body wet weight)/volume of culture;

where Wi and Wt referred to the initial body weight and final body weight of large yellow croaker, respectively.

SPSS version 24.0 (IBM, Armonk, New York, NY, USA) was used for the statistical analyses. Data are expressed as the mean ± SD. Different groups were considered as significant at $p < 0.05$ by *T*-test and a one-way analysis of variance (ANOVA) and Duncan multiple comparative analysis. GraphPad Prism 8 was utilized to create plots of the data.

3. Results

3.1. Culturing Sites and Transfer Routes

The transfer route and anchorage seas of the ship Gouxin 101 and the site of the cage are shown in Figure 2. The ship could obtain the best culturing conditions by moving according to the demand, and the cage was fixed in the Sandu Bay. At the end of May, the temperature of water rose to more than 25 °C in Ningde Sea area in Fujian Province rapidly, and the aquaculture ship shifted from Sandu Bay to the Zhoushan Sea area in Zhejiang Province. Due to the occurrence of the red tide in anchorage seas of Lvhua Island in Zhoushan during the culturing, it was transferred to Peach Blossom Island for a short time. In mid-July, to avoid super typhoon "Yanhua", it moved to the waters off Qingdao, Shandong Province. While in Qingdao, due to short-term gale weather, the ship was temporarily transferred to the inner Bay of Jiaozhou Bay.

Figure 2. Location of experiment area in traditional aquaculture cages (marked with an orange star) and the anchorage location (marked with a red dot) and sailing route (marked with red lines) of the offshore aquaculture ship <http://www.gissky.net/map/ChinaZQYW.html, accessed on 8 November 2022>.

3.2. Parameters of Culture Environment

The daily average dissolved oxygen, temperature, salinity, pH, and weekly average total ammonia nitrogen of water in the ship and cage are recorded in Figure 3. During the experiment, the temperature of the cage increased steadily and kept at a relatively high level on the whole, ranging from 23.3 to 28.5 °C, 26.6 °C on average. The water temperature of the ship remained stable for the first 5 weeks, below the cage temperature. After the ship was moved to the sea area of Qingdao due to the typhoon, the temperature increased significantly and remained until the end of the test, similar to that of the cage group. The temperature of water in ship was maintained between 21.5 and 28.5 °C, with an average of 25.5 °C during culturing (Figure 3A). In the cage group, the salinity did not change significantly during the 8-week experiment, staying at 25–30‰, with an average of 29.4‰. The salinity of the ship increased steadily in the first 6 weeks from 20.7‰ to 29.1‰, which was lower than the cage during this period. It remained stable at around 30‰ for the next 2 weeks until the experiment was completed, when the salinity was similar to that of the cage group. The whole process was maintained between 20.7 and 31.8‰, with an average of 26.9‰ (Figure 3B). In addition, the level of dissolved oxygen on the ship was higher than that in the cage most of the time (Figure 3C). There was a similar pH between the two groups during the trial (Figure 3D). The ammonia nitrogen concentration of the two groups remained at a low level during the experiment, both of which were lower than 0.08 mg/L (Figure 3E). In this trial, environmental conditions in the ship group were harsh, including higher waves and stronger winds (Supplemental Data, Figure S1).

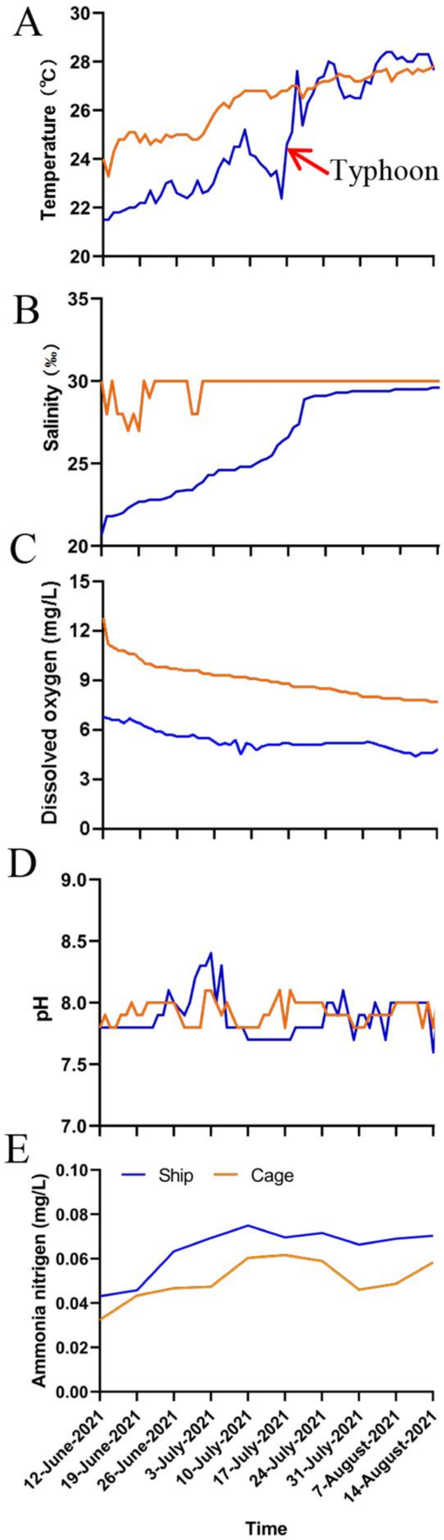

Figure 3. Comparison of water temperature (**A**), salinity (**B**), dissolved oxygen (**C**), pH (**D**), and ammonia nitrogen (**E**) in the ship and cages throughout the experiment period.

3.3. Total Number of Bacteria and Vibrio in Water

The total number of bacteria and vibrio in the tank of the ship were detected by the plate method, which remained stable at a low level and tended to increase slightly with the increase of breeding time. Still, there was no significant difference (Figure 4). The total number of bacteria was maintained at $1.2 * 10^3$–$1.6 * 10^3$ CFU/mL, and the total number of vibrio was maintained at $1.2 * 10^2$–$1.8 * 10^2$ CFU/mL.

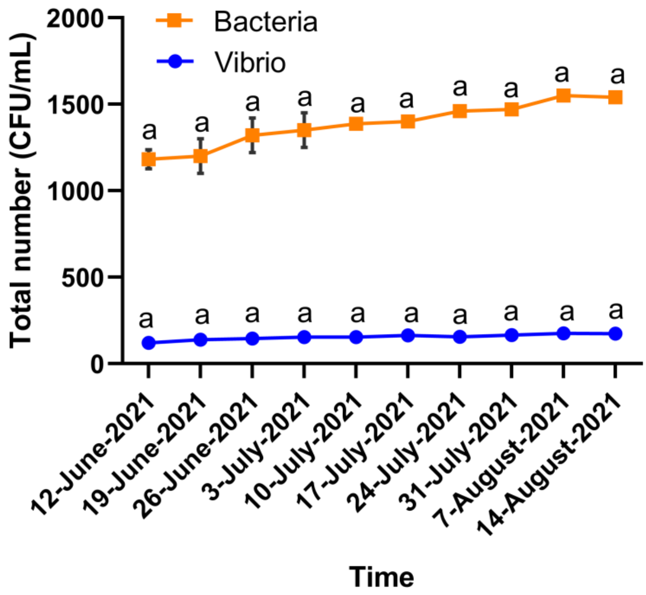

Figure 4. Changes in the total number of bacteria and vibrio in the fish tank of offshore aquaculture ship throughout the experiment period. Bars with different superscripts on the same microorganism are statistically different ($p < 0.05$, n = 3).

3.4. State of Behavior

Through daily observations, the behaviors of the large yellow croaker during swimming and feeding on the ship during the experiment were reported (Figure 5). Large yellow croaker can adapt to the ship environment, actively feed, and exhibit no irregular swimming behavior. Large yellow croaker were usually distributed in the 3–4 m water layer and swam in the reverse current. When feeding, all the large yellow croaker moved upstream to the surface of the water, in a relatively disorderly swimming.

3.5. Survival Rate and Growth Performance

Through almost two months of on-site culturing, the change in the survival of the large yellow croaker was well documented (Figure 6). The result showed that no large-scale death events and serious disease conditions of the fish occurred in the two groups. However, the mortality rate of large yellow croaker in the cage group was relatively high, with the highest single-day mortality rate of 0.23%, which was higher than the highest single-day mortality rate of 0.05% in the ship group.

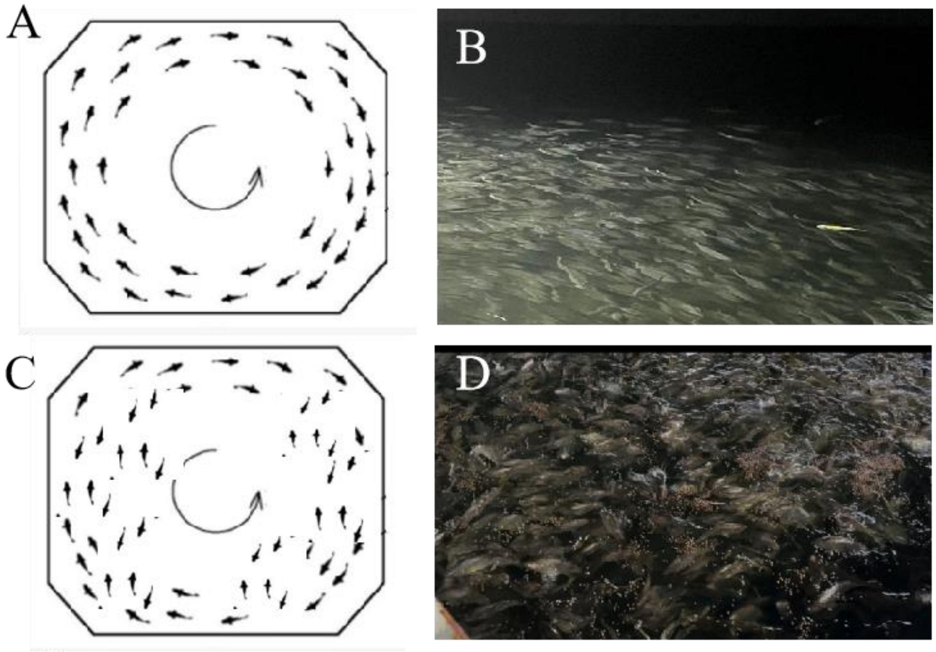

Figure 5. Swimming behavior of the large yellow croaker in the tank of the ship. (**A**,**B**) represent pictures and schematic images of the large yellow croaker colonies swimming against the current. (**C**,**D**) represent pictures and schematic diagrams of large yellow croakers swimming loosely while feeding, respectively.

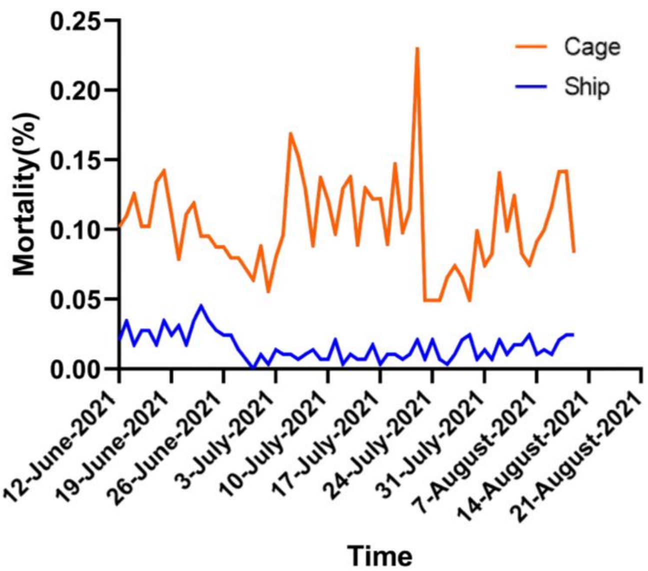

Figure 6. Daily mortality in ranched large yellow croaker in the nearshore cages (denoted in orange) and offshore ship (denoted in blue).

During the culture period, it was found that large yellow croakers in three tanks on the ship grew and developed well through the measured changes in body weight, body length, CF, and VSI (Figure 7). The body weight of large yellow croakers increased from 325.67 g to 460.71 g, with an average monthly weight gain of 67.52 g (Figure 7A). The body length of the large yellow croaker increased rapidly from 25.23 cm to 29.14 cm (Figure 7B). At the beginning of the experiment, the CF and VSI of the large yellow croaker were the highest. With the increase in culturing time, the VSI and CF decreased rapidly in the first 4 weeks and remained stable in the last few weeks (Figure 7C,D).

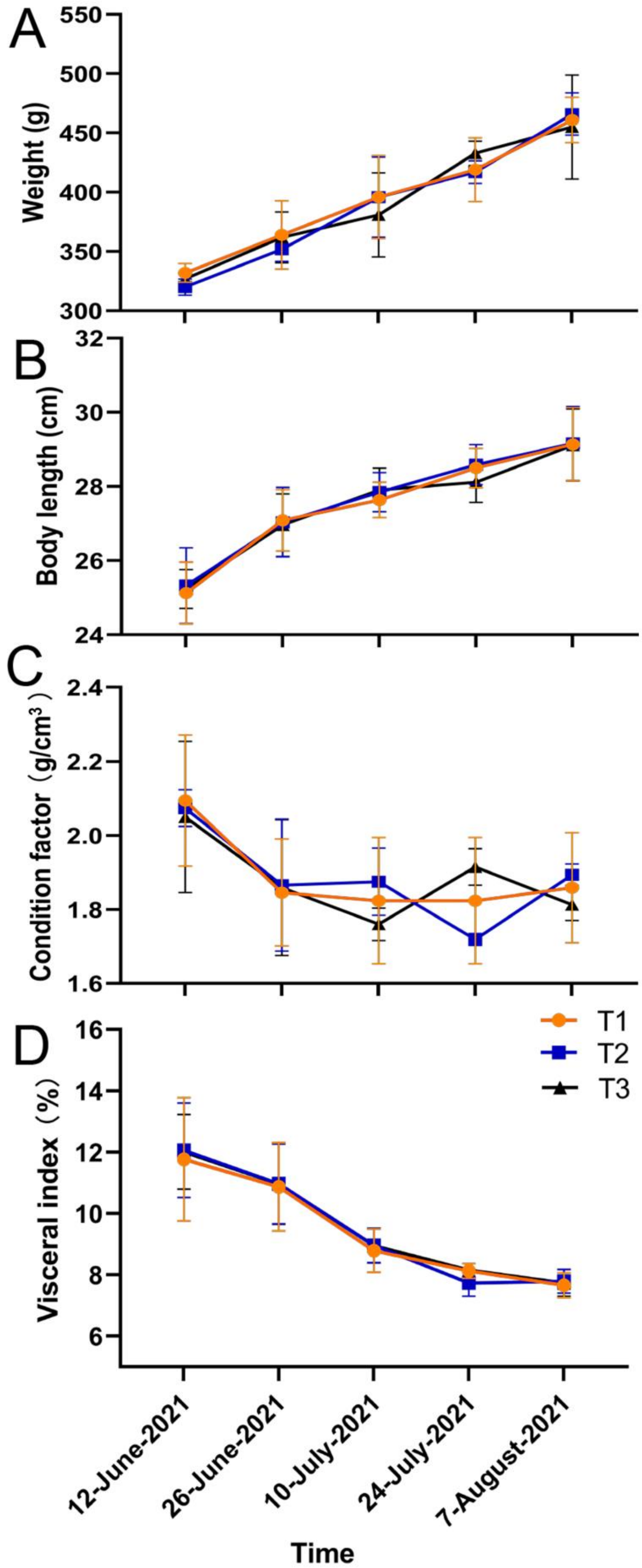

Figure 7. Body weight (**A**), body length (**B**), condition factor (**C**), and visceral index (**D**) in ranched large yellow croaker in the different tanks in an offshore aquaculture ship throughout the experiment period (n = 30); T1, T2, and T3 are represented as the three different tank.

At the end of the experiment, the survival rate (SR), weight gain rate (WGR), feed factor (FCR), condition factor (CF), and visceral index (VSI) of the large yellow croaker were significantly different under different aquaculture modes (Table 1). The SR, WGR, and CF of large yellow croakers in the ship group were significantly higher than in the cage group ($p < 0.05$). The FCR and VSI of the ship group were significantly lower than those of the cage group ($p < 0.05$). During 8 weeks of culturing, the density of the ship group increased rapidly from 12.1 kg/m^3 to 15.74 kg/m^3, while that of the cage group decreased to only 5.02 kg/m^3.

Table 1. Survival rate (SR, %), weight gain rate (WGR, %), feed conversion ratio (FCR, %), condition factor (CF, g/cm^3), visceral index(VSI, %), and stocking density (SD, kg/m^3) of the large yellow croaker that were reared under the different farming environments.

Group	SR (%)	WGR (%)	FCR (%)	CF (g/cm^3)	VSI (%)	SD (kg/m^3)
Cage	93.82 ± 1.96 ^{a}	9.11 ± 4.95 ^{a}	5.43 ± 2.89 ^{a}	1.32 ± 0.19 ^{a}	7.61 ± 0.21 ^{a}	5.02 ± 0.38
Ship	99.02 ± 0.20 ^{b}	41.48 ± 2.48 ^{b}	1.61 ± 1.06 ^{b}	1.85 ± 0.14 ^{b}	6.71 ± 0.15 ^{b}	15.74 ± 0.25

Note: Values represent the mean ± SD. Significant differences ($p < 0.05$, n = 30) among treatments were indicated by different letters.

3.6. Muscle Composition Analysis

The nutrient composition of the muscle of the large yellow croaker was significantly affected by the culture mode (Table 2). The contents of crude protein and ash in the ship group were significantly higher than those in the cage group ($p < 0.05$), and the ether extract and moisture contents were significantly lower than those of the cage group ($p < 0.05$). In conclusion, the muscle nutrient composition of the large yellow croaker in the ship group was better than in the cage group.

Table 2. Nutrient composition in the muscle tissues of the large yellow croaker that were reared under the different experimental groups.

Group	Mass Fraction (%)			
	Tissue Moisture	Ash	Crude Lipid	Crude Protein
Cage	76.76 ± 0.67 ^{a}	1.16 ± 0.03 ^{a}	7.53 ± 0.70 ^{a}	17.13 ± 0.40 ^{a}
Ship	71.14 ± 0.43 ^{b}	1.22 ± 0.03 ^{b}	5.26 ± 0.47 ^{b}	21.53 ± 1.29 ^{b}

Note: Values represent mean ± SD. Significant differences ($p < 0.05$, n = 10) among treatments were indicated by different letters.

4. Discussion

4.1. Comparison of Nearshore and Offshore Aquaculture

In China, mariculture is mainly concentrated nearshore and provides an important economic source for local fishermen [24]. However, with the general deterioration of the nearshore environment, the Chinese government has begun to reduce the area that is used for nearshore aquaculture [19]. On the other hand, there are nearly 70,000 km^2 of almost undeveloped offshore waters in China. The lack of shelter, such as islands in the offshore area, means more severe sea conditions, such as stronger winds, higher waves, and faster currents. This poses a greater challenge to the aquaculture system [25]. This study shows that the ship-platform can resist the more severe offshore sea conditions during the experiment without adverse effects on aquaculture and could ensure offshore aquaculture. In addition, the ship can avoid events such as typhoons, red tides, and other special disaster situations, through the way of autonomous navigation to escape. This also reduces the operational risk for producers. Open cage culture was vulnerable to changes in aquaculture environmental conditions that were caused by climate change, especially water temperature and dissolved oxygen, which have a significant impact on the production of cultured fish [26,27]. For example, due to the influence of high and low temperatures, the optimal growth time of large yellow croaker was only about half a year. In addition, the ship also realized the rapid growth of the large yellow croaker in the summer high-temperature period by transferring the culture in the sea area between Fujian, Zhejiang, and Shandong, which verified the feasibility of shortening the culture cycle. In conclusion, by taking advantage of the stability of the ship platform, the aquaculture ship can expand the space of offshore and move independently to avoid disaster weather and obtain an appropriate water temperature, thus increasing the stability of production.

Traditional nearshore cages use little mechanical equipment, the labor intensity of fishermen was large, and the risk of the marine operation was also high [28]. In contrast, although the cost of large machinery equipment was higher, it can reduce the unit cost of culture through large-scale operation and reduce the number of staff and work intensity. For example, the aquaculture ship uses mechanized feeding and sucking fish instead of manual operation, greatly reducing the use of labor. It was estimated that the production of large yellow croaker could reach 3000 tons per year by the 100,000-ton aquaculture ship, and the culture staff only needs 9–10 people.

4.2. Effects of Aquaculture Mode on Survival and Growth Performance of Large Yellow Croaker

Promoting the healthy growth of aquaculture animals is one of the most important objectives of aquaculture practitioners. Generally, it could be comprehensively evaluated through body weight indexes, body length indexes, key organ indexes, feed efficiency, etc. [29]. In this study, it was found that the large yellow croaker in the ship group gained more weight and died less during the test period. The survival and growth indexes were significantly better than those in the nearshore cage group at the end of the experiment. Similarly, Nicole et al. showed that compared with the traditional nearshore culture areas, the mortality rate of bluefin tuna in offshore culture areas was lower, and the prevalence of parasites was reduced by 30% [9]. Pang et al. showed that large, mechanized platforms offshore were more suitable for medium- and large-size abalone farming, and their growth rate was significantly faster than that of nearshore cages [30].

Previous studies have shown that the difference in water quality parameters that are caused by different farming modes was an important reason affecting the survival and growth of fish [31,32]. In this test, the water quality parameters of the ship and cage were the same except for temperature and dissolved oxygen. When large yellow croaker are exposed to high temperature for a long time, it causes an oxidative stress reaction, adversely affecting digestion, metabolism, and the immune system, and reduce its resistance to pathogens [33]. This study showed that the area of the cage was affected by high-temperature in summer, resulting in rising water temperature, which was higher than the optimal 22–26 °C water temperature for large yellow croaker for a long time [34]. However, the ship can keep the fish at optimum temperatures most of the time by moving. Therefore, in this study, high temperature may be an important reason for the high mortality and slow growth rate of the large yellow croaker in the cage group. In addition, studies have shown that very low dissolved oxygen (<2 mg/L) will cause large area death of large yellow crocks in a short time, and long-term low levels of dissolved oxygen will restrict aerobic metabolism, resulting in the slow growth of fish [35]. In this study, it was found that the water dissolved oxygen level was at a low level for a long time due to the high temperature around the cage. At the same time, the ship culture system could maintain the dissolved oxygen level above 8 mg/L. Therefore, low dissolved oxygen may also affect the survival and growth of cage large yellow croaker.

4.3. Effects of Aquaculture Mode on Nutrient Composition of Large Yellow Croaker

It was generally accepted that muscle quality was a complex set of characteristics, mainly including muscle sensory properties, nutritional value, and freshness [36,37]. Among them, the nutritional value was the most concern. The nutritional value of fish muscle was measured by various components, such as protein and fat, as well as ash and moisture content [38]. This study showed that the nutrient composition of the muscle of the large yellow croaker cultured in ship was better than that of the cage, mainly due to the higher protein and lower fat content. Due to the unique plasticity of skeletal muscle, it was prone to be seriously affected by exogenous factors. In the case of continuous swimming, important biochemical changes occurred in skeletal muscle, leading to changes in muscle nutrient composition [39,40]. There is a lot of research data showing that moderate exercise training can significantly improve the protein content of *Spinibarbus sinensis*, *Barbodes schwanenfeldi*, *Schizothorax prenanti*, and *Mylopharyngodon piceus*, and can also significantly reduce the lipid content of fish muscle [41–44]. It was also found in this study that large yellow croaker could keep swimming under stable flow field conditions (0.2–0.4 m/s), which was consistent with the phenomenon that was observed in the experiment. The cage was also located in the inner Bay Sea area, the water fluidity was poor, and difficult to form a continuous flow field. Therefore, flow velocity may be an important reason for the difference in muscle nutrient composition of the large yellow croaker. In addition, it was found in the experiment that the food intake of the large yellow croaker in the cage was low, and it failed to obtain enough nutrients to synthesize energy substances in the body, which may be another important reason affecting the nutrient composition of the large yellow croaker muscle.

5. Conclusions

In conclusion, we first found that the aquaculture ship was suitable for the breeding of the large yellow croaker, and its growth performance and nutrient composition were better than the cage. The result provides important basic support for the research and promotion of the aquaculture ship. However, the specific impact of environmental conditions on the large yellow croaker was unclear. Further research is necessary to evaluate the regulatory mechanisms of growth and provide a basis for the improvement of the management of fish in ships.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jmse11010101/s1, Figure S1: Wave height (A) and wind scale (B) in the nearshore cages (denoted in orange) and offshore ship (denoted in blue) throughout the experiment period.

Author Contributions: Conceptualization, Y.Y., H.L. and M.C.; Data curation, W.H.; Funding acquisition, M.C.; Investigation, W.H.; Methodology, Y.Y., W.H. and H.L.; Project administration, H.L.; Software, M.C.; Validation, M.C.; Writing—original draft, Y.Y.; Writing—review and editing, F.Y., H.L. and M.C. All authors have read and agreed to the published version of the manuscript.

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References

1. FAO. *The State of World Fisheries and Aquaculture 2020: Sustainability in Action*; FAO: Rome, Italy, 2021.
2. World Bank. *Fish to 2030: Prospects for Fisheries and Aquaculture*; FAO: Rome, Italy, 2013.

3. Di Trapani, A.M.; Sgroi, F.; Testa, R.; Tudisca, S. Economic comparison between offshore and inshore aquaculture production systems of European sea bass in Italy. *Aquaculture* **2014**, *434*, 334–339. [CrossRef]
4. Davies, I.P.; Carranza, V.; Froehlich, H.E.; Gentry, R.R.; Kareiva, P.; Halpern, B.S. Governance of marine aquaculture: Pitfalls, potential, and pathways forward. *Mar. Pol.* **2019**, *104*, 29–36. [CrossRef]
5. Chu, Y.I.; Wang, C.M.; Park, J.C.; Lader, P.F. Review of cage and containment tank designs for offshore fish farming. *Aquaculture* **2020**, *519*, 734–752. [CrossRef]
6. Li, L.; Jiang, Z.; Ong, M.C.; Hu, W. Design optimization of mooring system: An application to a vessel-shaped offshore fish farm. *Eng. Struct.* **2019**, *197*, 109363. [CrossRef]
7. Lester, S.E.; Gentry, R.R.; Kappel, C.V.; White, C.; Gaines, S.D. Opinion: Offshore aquaculture in the United States: Untapped potential in need of smart policy. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 7162–7165. [CrossRef]
8. Kim, D.H.; Lipton, D.; Choi, J.Y. Analyzing the economic performance of the red sea bream *Pagrus major* offshore aquaculture production system in Korea. *Fish. Sci.* **2012**, *78*, 1337–1342. [CrossRef]
9. Aarset, B.; Carson, S.G.; Wiig, H.D.; Maren, I.E.; Marks, J. Lost in translation? Multiple discursive strategies and the interpretation of sustainability in the Norwegian salmon farming industry. *Food Ethics* **2020**, *5*, 1–21. [CrossRef]
10. Cao, L.; Wang, W.; Yang, Y.; Yang, C.T.; Yuan, Z.H.; Xiong, S.B.; Diana, J. Environmental impact of aquaculture and countermeasures to aquaculture pollution in China. *Environ. Sci. Pollut. Res. Int.* **2007**, *14*, 452–462. [PubMed]
11. Schupp, M.F.; Kafas, A.; Buck, B.H.; Krause, G.; Onyango, V.; Stelzenmueller, V.; Davies, I.; Scott, B.E. Fishing within offshore wind farms in the north sea: Stakeholder perspectives for multi-use from scotland and germany. *J. Environ. Manag.* **2021**, *279*, 111762. [CrossRef]
12. El-Thalji, I. Context analysis of offshore fish farming. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *700*, 012065. [CrossRef]
13. Kirchhoff, N.T.; Rough, K.M.; Nowak, B.F. Moving cages further offshore: Effects on southern bluefin tuna, *T. maccoyii*, parasites, health and performance. *PLoS ONE* **2011**, *6*, e23705. [CrossRef] [PubMed]
14. Bjelland, H.V.; Føre, M.; Lader, P.; Kristiansen, D.; Holmen, I.M.; Fredheim, A.; Grøtli, E.I.; Fathi, D.E.; Oppedal, F.; Utne, I.B.; et al. *Exposed Aquaculture in Norway*; IEEE: New York, NY, USA, 2015; pp. 1–10.
15. Holmer, M. Environmental issues of fish farming in offshore waters: Perspectives, concerns and research needs. *Aquac. Environ. Interact.* **2010**, *1*, 57–70. [CrossRef]
16. Goseberg, N.; Chambers, M.D.; Heasman, K.; Fredriksson, D.; Fredheim, A.; Schlurmann, T. Technological approaches to long-line and cage-based aquaculture in open ocean environments. In *Aquaculture Perspective of Multi-Use Sites in the Open Ocean*; Springer: Berlin/Heidelberg, Germany, 2017; pp. 71–95.
17. Soner, B.; Volkan, K.; Ash, M.B. Floating fish farm unit. Is it an appropriate method for salmonid production. *Mar. Sci. Technol. Bull.* **2013**, *2*, 9–13.
18. Sun, P.; Bao, P.; Tang, B. Transcriptome analysis and discovery of genes involved in immune pathways in large yellow croaker (*Larimichthys crocea*) under high stocking density stress. *Fish Shellfish Immunol.* **2017**, *68*, 332–340. [CrossRef]
19. Gui, J.; Tang, Q.; Li, Z.; Liu, J.; Silva, D. *Aquaculture in China: Success Stories and Smodern Trends*; John Wiley & Sons: Hoboken, NJ, USA, 2018; pp. 297–308.
20. Li, Y.; Yang, C.Y.; Zheng, T.L. Bacterial survival modes and community characteristics in natural environment. *Chin. J. App. Environ. Biol.* **2013**, *19*, 553–560. [CrossRef]
21. AOAC. *Official Methods of Analysis of the Association of Official Analytical Chemists*, 17th ed.; Association of Official Analytical Chemists: Arlington, VA, USA, 2003.
22. Folch, J.; Lees, M.; Sloan Stanley, G.H. A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.* **1957**, *226*, 497–509. [CrossRef] [PubMed]
23. Barnes, H.; Black Stock, J. Estimation of lipids in marine animals and tissues detailed investigation of the Sulphophosphovanillin method for total lipids. *J. Exp. Mar. Biol. Ecol.* **1973**, *12*, 103–118. [CrossRef]
24. Chen, Y.; Huang, W.; Shan, X.; Chen, J.; Weng, H.; Yang, T.; Wang, H. Growth characteristics of cage-cultured large yellow croaker *Larimichthys crocea*. *Aquac. Rep.* **2020**, *16*, 100242. [CrossRef]
25. Soto, D.; Wurmann, C. Offshore aquaculture: A needed new frontier for farmed fish at aea. In *The Future of Ocean Governance and Capacity Development*; Brill Nijhoff: Santiago, Chile, 2019; pp. 379–384.
26. Huang, W.; Wang, N. Discussion on relationship between three kinds of parasitic disease outbreaks of large yellow croaker and the water temperature. *Heilongjiang Agricult. Sci.* **2012**, *12*, 71–73. (In Chinese)
27. Dan, X.M.; Yan, G.J.; Zhang, A.J.; Cao, Z.D.; Fu, S.J. Effects of stable and dielcycling hypoxia on hypoxia tolerance, postprandial metabolic response, and growth performance in juvenile qingbo (*Spinibarbus sinensis*). *Aquaculture* **2014**, *428*, 21–28. [CrossRef]
28. Klinger, D.H.; Levin, S.; Watson, J. The growth of finfish in global open-ocean aquaculture under climate change. *Proc. R. Soc. B Biol. Sci.* **2017**, *284*, 20170834. [CrossRef]
29. Du, Z.Y.; Turchini, G.M. Are we actually measuring growth?-An appeal to use a more comprehensive growth index system for advancing aquaculture research. *Rev. Aquac.* **2022**, *14*, 525–527. [CrossRef]
30. Pang, G.W.; Gao, X.L.; Hong, J.W.; Luo, X.; Wu, Y.S.; You, W.W.; Ke, C.H. Growing abalone on a novel offshore platform: An on-site test of the effects of stocking density and diet. *Aquaculture* **2022**, *549*, 737769. [CrossRef]

31. Saravanan, S.; Geurden, I.; Figureueiredo-Silva, A.C.; Nusantoro, S.; Kaushik, S.; Verreth, J.; Schrama, J.W. Oxygen consumption constraints food intake in fish fed diets varying in essential amino acid composition. *PLoS ONE* **2013**, *8*, e72757. [CrossRef] [PubMed]
32. Zhang, X.; Cai, X.; Liu, X.; Zhao, H.; Song, P.; Zhang, J. Proteomics of liver tissue of large yellow croaker (*Larimichthys crocea*) under high temperature stress. *J. Fish. China* **2021**, *45*, 862–870. (In Chinese)
33. Cai, X.; Zhang, J.; Lin, L.; Li, Y.; Liu, X.; Wang, Z. Study of a noninvasive detection method for the high-temperature stress response of the large yellow croaker (*Larimichthys crocea*). *Aquac. Rep.* **2020**, *18*, 100514. [CrossRef]
34. Dabruzzi, T.F.; Fangue, N.A.; Kadir, N.N.; Bennett, W.A. Thermal niche adaptations of common mudskipper (*Periophthalmus kalolo*) and barred mudskipper (*Periophthalmus argentilineatus*) in air and water. *J. Therm. Biol.* **2019**, *81*, 170–177. [CrossRef]
35. Ding, J.; Liu, C.; Luo, S.Y.; Zhang, Y.B.; Gao, X.M.; Wu, X.F.; Shen, W.L.; Zhu, J.Q. Transcriptome and physiology analysis identify key metabolic changes in the liver of the large yellow croaker (*Larimichthys crocea*) in response to acute hypoxia. *Ecotoxicol. Environ. Saf.* **2020**, *189*, 109957. [CrossRef]
36. Grigorakis, K. Compositional and organoleptic quality of farmed and wild gilthead sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) and factors affecting it: A review. *Aquaculture* **2007**, *272*, 55–75. [CrossRef]
37. Rasmussen, R.S. Quality of farmed salmonids with emphasis on proximate composition, yield and sensory characteristics. *Aquac. Res.* **2001**, *32*, 767–786. [CrossRef]
38. Zhu, Z.; Song, B.; Lin, X.; Xu, Z. Effect of sustained training on glycolysis and fatty acids oxidation in swimming muscles and liver in juvenile tinfoil barb *Barbonymus schwanenfeldii* (Bleeker, 1854). *Fish Physiol. Biochem.* **2016**, *42*, 1807–1817. [CrossRef] [PubMed]
39. Palstra, A.P.; Mes, D.; Kusters, K.; Roques, J.A.C.; Flik, G.; Kloet, K.; Blonk, R.J.W. Forced sustained swimming exercise at optimal speed enhances growth of juvenile yellowtail kingfish (*Seriola lalandi*). *Front. Physiol.* **2014**, *5*, 506. [CrossRef] [PubMed]
40. Palstra, A.P.; Planas, J.V. Fish under exercise. *Fish Physiol. Biochem.* **2011**, *37*, 259–272. [CrossRef] [PubMed]
41. Li, X.M.; Yu, L.J.; Wang, C.; Zeng, L.Q.; Cao, Z.D.; Fu, S.J.; Zhang, Y.G. The effect of aerobic exercise training on growth performance, digestive enzyme activities and postprandial metabolic response in juvenile qingbo (*Spinibarbus sinensis*). *Comp. Biochem. Physiol. A Mol. Integr. Physiol.* **2013**, *166*, 8–16. [CrossRef] [PubMed]
42. Song, B.; Lin, X.; Xu, Z. Effects of upstream exercise training on feeding efficiency, growth and nutritional components of juvenile tinfoil barbs (*Barbodes schwanenfeldi*). *J. Fish. China* **2012**, *36*, 106–114. [CrossRef]
43. Liu, G.; Wu, Y.; Qin, X.; Shi, X.; Wang, X. The effect of aerobic exercise training on growth performance, innate immune response and disease resistance in juvenile *Schizothorax prenanti*. *Aquaculture* **2018**, *486*, 18–25. [CrossRef]
44. Harimana, Y.; Tang, X.; Le, G.; Xing, X.; Zhang, K.; Sun, Y.; Li, Y.; Ma, S.; Karangwa, E.; Tuyishimire, M.A. Quality parameters of black carp (*Mylopharyngodon piceus*) raised in lotic and lentic freshwater systems. *LWT-Food Sci. Technol.* **2018**, *90*, 45–52. [CrossRef]