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Improving Abalone Farming in Fujian: Genetic, Environmental, and Disease Management Solutions

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Abstract:

Abalone farming in Fujian, China, is a crucial industry in China's shellfish aquaculture. Currently, it faces significant challenges, including genetic degradation, disease outbreaks, and environmental pollution. This study provides an in-depth analysis of these issues and proposes practical solutions to enhance the sustainability and productivity of abalone farming. Genetic degradation, which leads to slower growth and reduced disease resistance, can be mitigated through hybridization, selective breeding, and genetic engineering. Disease outbreaks, exacerbated by poor environmental conditions, necessitate a comprehensive approach that combines selective breeding for disease resistance with improved environmental management practices. Environmental pollution, driven by industrial and agricultural discharges, deteriorates water quality, impacting the health and growth of abalones. The study suggests implementing advanced water filtration systems, strict pollution control measures, and developing resilient abalone strains through selective breeding. Addressing these challenges is crucial for promoting the sustainable development and international competitiveness of Fujian's abalone farming industry. This research underscores the importance of integrated strategies to overcome the current obstacles and ensure the long-term viability of the abalone industry in Fujian.

Keywords: Abalone Farming, Sustainable Development, Genetic Degradation, Disease Outbreaks, Environmental Pollution.

1. Introduction

Abalone is a high-quality seafood that meets modern nutritional demands, offering high protein and low fat. In China, there are over ten species of abalone distributed across natural marine areas, among which the small abalone (Haliotis diversicolor) and the Pacific abalone (H. discus hannai) are the primary economic species due to their favorable market size and suitable farming cycles [1,2]. Since 2000, Pacific abalone has been introduced to the Fujian sea area, resulting in explosive growth in farming areas and production, making it the dominant species for cultivation in both northern and southern China [1]. By 2019, China's abalone farming production accounted for over 90% of the global total, with Fujian province contributing 79.3% of China's output [1].

However, China's abalone farming faces multiple threats, including genetic degradation, disease outbreaks, and environmental pollution. First is the genetic degradation problems. Current abalone breeding research focuses primarily on hybrid breeding, selective breeding, and molecular breeding [1]. Hybrid breeding can enhance the growth rate and disease resistance of offspring through crossbreeding between different populations. Selective breeding improves germplasm by continually selecting superior individuals. Molecular breeding utilizes modern biotechnologies, such as gene editing and marker-assisted selection, to enhance breeding efficiency and precision[3]. Xiao, et al.'s results indicate that hybrid abalone exhibits significant trait segregation, with superior growth rates and disease resistance compared to pure strains[4]. These hybrid populations may be valuable for developing improved abalone strains through selective breeding programs. However, the lack of sustainable farming sources might be a reason for the failure to utilize hybrid vigor in China's aquaculture industry. Although China is a major abalone producer, the inability to cultivate large abalone requires the importation of large abalone every year [1], which poses new challenges, such as the natural distribution of Pacific abalone (H. discus hannai) along the East Asian coasts of China, Korea, and Japan [5]. Aquaculture of this species is a booming industry in China, but wild Pacific abalone resources in China have been drastical-

ly reduced because wild Pacific abalone populations in northeastern Japan were affected by the 2011 tsunami [5]. Therefore, cultivating new high-yield, resilient, and high-quality abalone varieties is crucial for enhancing the advancement and international competitiveness of China's abalone farming industry.

On the other hand, disease outbreaks, and environmental pollution have also caused poor growth and breeding conditions for abalone. For example, in 1999, the southern small abalone experienced severe winter mortality and juvenile "shell drop syndrome," potentially caused by water quality issues and viral infections [1]. Additionally, with the rapid growth of the abalone industry, the conflict between genetic improvement and production needs has become increasingly prominent, including serious inbreeding issues due to prolonged self-breeding. Problems such as smaller individual size, weaker resilience, and lower production performance are becoming more evident [1]. In recent years, due to lifestyle restrictions and frequent extreme weather events, the summer survival rate of farmed abalone in Fujian has been low, leading to significant economic losses. Environmental factors, including water quality and pollution, have a major impact on the growth and survival of abalone. Poor water quality can lead to higher disease prevalence and slower growth rates [3]. Improving water quality and reducing pollution are crucial for sustainable abalone farming.

This paper aims to provide an in-depth analysis of the current state of abalone farming in Fujian, China, addressing the primary challenges faced by the industry. By examining issues such as genetic degradation, disease prevalence and environmental pollution, this paper attempts to provide practical solutions to improve the sustainability and productivity of abalone farming in the region.

2. Current situation and difficulties of abalone cultivation in Fujian province

2.1 Basic situation of abalone culture in Fujian province

Fujian Province is one of the most important abalone farming regions in China, primarily cultivating Pacific abalone (H. discus hannai). Its excellent growth performance and market value make it the dominant farming species [1]. The natural conditions along the Fujian coast, such as suitable water temperatures and abundant food resources, provide favorable conditions for large-scale abalone farming. In recent years, the scale of abalone farming in Fujian has continuously expanded, accounting for a significant proportion of the country's total production [1]. However, the abalone farming industry in Fujian also faces several challenges, including genetic degradation, disease outbreaks, and environmental pollution.

2.2 The main problems of abalone cultivation in Fujian: genetic degradation, disease prevalence and environmental pollution

The rapid development of Fujian's abalone farming industry has been accompanied by issues of genetic degradation. Long-term reliance on artificial breeding has led to a decline in germplasm quality, resulting in slower growth rates, reduced disease resistance, and lower reproduction rates [5]. Hybrid abalones (such as H. discus hannai × H. gigantea) exhibit better growth rates and environmental adaptability compared to purebred abalones [4], demonstrating the potential for germplasm improvement. However, genetic degradation significantly impacts farming efficiency and economic benefits.

Diseases are another major challenge for abalone farming in Fujian. Common diseases include bacterial infections, viral diseases, and parasitic diseases, which not only affect the growth and survival rates of abalones but can also lead to large-scale mortality, causing substantial economic losses for farmers. Environmental factors such as water quality and temperature significantly influence the occurrence and severity of diseases. Although selective breeding can improve disease resistance to some extent, environmental management remains crucial [6].

Environmental pollution poses a serious threat to abalone farming in Fujian. Industrial and agricultural discharges deteriorate water quality in farming areas, directly impacting the growth and health of abalones [5]. Additionally, overfeeding and high-density farming exacerbate water quality deterioration. Studies indicate that improving water quality and reducing pollution are essential for achieving sustainable abalone farming [5].

In conclusion, while Fujian's abalone farming industry benefits from favorable natural conditions and market demand, it faces severe challenges such as genetic degradation, disease outbreaks, and environmental pollution. Optimizing germplasm, enhancing disease prevention, and improving environmental management can improve farming efficiency and economic benefits, promoting the sustainable development of Fujian's abalone farming industry.

3. Analysis of genetic degradation, disease prevalence and environmental pollution

As the main abalone breeding land in China, Fujian is still facing problems including genetic degradation, disease

outbreaks and environmental pollution. These problems have seriously plagued the yield and quality of abalone products.

3.1 Genetic degradation: effects on growth, disease resistance and survival of Abalone

Current abalone breeding research mainly focuses on hybrid breeding and selective breeding [1]. However, in artificial cultivation, small population sizes and the lack of appropriate gene introduction can exacerbate inbreeding issues.

To meet the growing commercial demand, China began large-scale cultivation of Pacific abalone in the late 1980s and has entered a stage of rapid development over the past two decades [6]. Studies have shown that hybrids exhibit significant trait segregation, with better growth rates and disease resistance compared to pure breeds [4]. Selecting growth-related traits can significantly promote genetic improvement, incorporating economically valuable traits as genetic progress advances [6]. However, inappropriate hybrid breeding can lead to genetic degradation.

Genetic degradation refers to the decline in the genetic quality of organisms due to changes or reductions in the gene pool, affecting growth, disease resistance, adaptability, and survival rates. This degradation can result from various factors, including environmental stress, genetic drift, inbreeding, and poor breeding practices. Inbreeding increases the likelihood of expressing deleterious recessive genes, leading to slow growth, poor disease resistance, and low survival rates. Particularly in breeding and cultivation, overemphasizing certain economic traits (e.g., rapid growth or high yield) while neglecting genetic diversity and disease resistance can cause genetic degradation. For example, if selective breeding focuses solely on growth speed while ignoring other traits, it can reduce genetic diversity in the gene pool. Genetic degradation can slow down the growth rate of organisms, with certain traits such as shell color or morphology associated with a decline in growth performance [7]. The degradation of the gene pool can affect individual survival rates; for instance, in some hybrid abalone populations, individuals with specific genetic markers (e.g., black spots) are fewer, indicating a survival disadvantage [4]. Reduced genetic diversity lowers disease resistance, making populations more susceptible to diseases. For example, abalone with black spots in their viscera shows poorer heat tolerance under heat stress conditions [4].

Additionally, genetic degradation reduces genetic diversity, making populations more sensitive to environmental changes, thereby affecting trait performance and breeding outcomes. For instance, heritability estimates for weight and shell length are highest at early stages and decrease with age. The genetic correlations for weight and shell length are high and positive across all age groups, indicating that selecting one trait will result in correlated responses in the other. However, phenotypic correlations decrease over time, suggesting that environmental influences become more pronounced as abalone age [3]. This decline in phenotypic correlations over time highlights the increasing impact of environmental factors on traits. This is especially critical for populations experiencing genetic degradation, as they may become more sensitive to environmental changes, leading to unstable trait performance, which in turn affects growth and survival rates.

In conclusion, genetic degradation is a complex issue involving environmental impacts, genetics, and breeding management. To mitigate or prevent genetic degradation, maintaining genetic diversity within populations, implementing scientific breeding practices, and ensuring proper environmental management are crucial.

3.2 Disease outbreaks: common types of diseases and their transmission routes

Abalone, as an important marine aquaculture species, faces significant disease challenges that greatly affect its yield and quality. Disease outbreaks in abalone farms are a major constraint for the industry [8]. Common diseases include bacterial infections, viral diseases, and parasites. Environmental stress factors, such as poor water quality and temperature fluctuations, can significantly influence the prevalence and severity of diseases in abalone populations [8]. Therefore, genetic improvement for disease resistance presents a promising solution to these challenges.

In the breeding process, abalone commonly encounters pathogens including bacteria, viruses, parasites, and fungi. Among these, the abalone herpesvirus (AbHV) is particularly prevalent and impactful [8]. In southern China, AbHV-induced low-temperature viral disease has repeatedly broken out since the early 21st century, severely affecting the abalone farming industry [8]. Studies indicate that AbHV easily infects abalone in water temperatures below 23°C, leading to mortality rates as high as 100% [8]. The virus can infect multiple organs of the abalone, causing slow growth, increased mucus secretion, abdominal hardening and darkening, and rapid death [9]. In addition to low-temperature viral disease, high summer temperatures are also a significant cause of abalone mortality. Research in Australia shows that as sea surface temperatures rise, the summer mortality rate of abalone increases significantly. This increase is related to a complex interplay of biological, environmental, management, and nutritional factors [9].

Research has shown that disease-resistance traits exhibit moderate heritability, suggesting that selective breeding for these traits could be effective [8]. However, environmental factors such as water quality and temperature significantly affect the prevalence and severity of diseases in abalone. Therefore, a combined approach of improved environmental management and selective breeding might be the most effective [9]. Additionally, another study estimated the genetic parameters of growth-related traits in adult Pacific abalone. The findings indicate moderate to high heritability for growth traits, with significant genetic correlations between growth and disease-resistance traits [9]. These results highlight the potential for improving disease resistance through selective breeding.

Enhancing abalone growth rates and energy utilization efficiency is also crucial for improving abalone production. Studies on several abalone species have estimated high potential responses to selection for growth traits, although the genetic basis underlying individual differences in physiological performance remains unclear [7]. One study aimed to estimate the heritable variation of physiological traits associated with energy intake and allocation in red abalone (Haliotis rufescens), and the potential correlated responses to selection between growth and physiological traits at three developmental stages [10].

In summary, genetic improvement of disease resistance and growth performance in abalone holds great potential. By combining selective breeding with improved environmental management, it is possible to enhance the production efficiency and disease resilience of abalone, thus advancing the aquaculture industry.

3.3 Environmental pollution: current situation and its impact on abalone aquaculture

Abalone farming faces challenges including water quality degradation and frequent disease outbreaks caused by high-density farming. As the scale of farming expands, the carrying capacity of the environment becomes limited, exacerbating pollution issues. Environmental factors, such as water quality and pollution, have significant impacts on the growth and survival of abalone. In high-density farming environments, waste and leftover feed lead to eutrophication, which further deteriorates water quality and triggers disease outbreaks [1]. Abalone is particularly sensitive to changes in water quality; poor water quality can slow their growth and even cause mass mortality. Environmental pollution also fosters the proliferation of pathogenic microorganisms, such as Vibrio bacteria and viruses, which can lead to large-scale abalone deaths [1], severely affecting the economic viability of the farming industry.

With the acceleration of industrialization, the levels of heavy metal pollution, pesticides, and other organic pollutants in marine environments have increased, introducing toxic and harmful substances into the ecosystem [1]. These substances not only directly affect the health of abalone but also accumulate in the food chain, posing risks to the entire ecosystem and potentially endangering human health through the food chain.

Moreover, poor water quality can disrupt genetic linkages and affect trait expression [11], leading to increased disease prevalence and reduced growth rates [3].

4. Suggestion

According to the problems of abalone cultivation and breeding mentioned above, this paper will follow the principles of germplasm improvement, disease prevention and control, and the classification of improvement of breeding environment gives suggestions.

4.1 Germplasm Improvement

To address the issue of genetic degradation, the introduction of high-yield, disease-resistant superior strains can enhance the gene pool of existing populations, thereby improving the production performance of abalone. Techniques such as hybridization, selective breeding, and genetic engineering can be employed to develop abalone strains that exhibit rapid growth, strong disease resistance, and high environmental adaptability [10]. Studies have shown that hybrid abalone demonstrates superior growth rates and disease resistance, which can be further enhanced through selective breeding [4]. Therefore, by leveraging the heterosis (hybrid vigor) through crossbreeding between different strains, the growth rate and disease resistance of abalone can be significantly improved.

4.2 Disease Prevention and Control

To address the issue of disease transmission in abalone farming, it is crucial to strengthen the management of the farming environment. Controlling water temperature and improving water quality management is essential, as environmental factors like water quality and temperature significantly affect the occurrence and severity of abalone diseases [3]. Measures such as reducing farming density, regularly monitoring, and adjusting water parameters can prevent disease spread. Additionally, routine health checks of abalone to detect and address diseases early are necessary. Introducing vaccines and antibiotics can also reduce the impact of diseases on farming. Furthermore, hybrid abalone exhibits noticeable trait segregation, with hybrids showing better growth rates and disease resistance compared to pure strains [4]. Selective breeding can enhance

abalone disease resistance, as disease resistance traits in abalone have moderate heritability, making it possible to improve these traits effectively through selective breeding [3]. Therefore, for common diseases in abalone farming and the impact of environmental factors on disease outbreaks, genetic improvement and environmental management are effective solutions.

4.3 Improvement of the breeding environment

First, overcrowded farming conditions can lead to poor water quality and increased disease outbreaks. Reducing stocking density helps alleviate the environmental load.

Second, improving water quality is essential. Deploying advanced water filtration and recycling systems can remove excess nutrients, waste, and harmful substances, maintaining a healthy environment for the abalone. Controlling pollutant input is crucial, including using eco-friendly feed, minimizing chemicals and antibiotics, and ensuring proper waste disposal. Regular monitoring of water parameters (temperature, pH, dissolved oxygen, and pollutants) and strict maintenance schedules are necessary for early detection and correction of deviations.

Moreover, developing abalone strains resilient to environmental stress, diseases, and pollution can enhance survival rates and productivity. Selective breeding programs can focus on traits like high-temperature tolerance, disease resistance, and efficient nutrient utilization [6]. Implementing Integrated Multi-Trophic Aquaculture (IMTA) systems, combining abalone farming with species like seaweed and filter feeders, can naturally balance the ecosystem and reduce environmental impact [10].

5. Conclusion

This study highlights the importance of integrated strategies to address these challenges. Implementing these recommendations is crucial for enhancing the sustainability, productivity, and international competitiveness of Fujian's abalone farming industry. Future research should focus on cost-effective and scalable methods for genetic improvement, disease control, and environmental management to ensure long-term viability and growth. The abalone farming industry in Fujian, China, faces significant challenges, including genetic degradation, disease outbreaks, and environmental pollution, which threaten its sustainability and productivity.

Genetic degradation, due to long-term artificial breeding, has led to slower growth rates, reduced disease resistance, and lower reproduction rates in abalones. Advanced breeding techniques such as hybridization, selective breeding, and genetic engineering are essential to address these issues, enhancing growth, disease resistance, and production efficiency. Disease outbreaks, particularly bacterial and viral infections, have severely impacted yields. The prevalence and severity of these outbreaks are closely linked to environmental factors. Combining selective breeding for disease resistance with improved environmental management practices, such as controlling water temperature, reducing farming density, and routine health checks, is crucial to mitigate these impacts. The introduction of vaccines and antibiotics can further help control diseases. Environmental pollution from industrial and agricultural discharges deteriorates water quality, affecting abalone growth and increasing disease susceptibility. Implementing advanced water filtration and recycling systems, along with strict pollution control measures, is vital for maintaining a healthy farming environment. Developing resilient abalone strains through selective breeding is also beneficial.

Future research should focus on cost-effective and scalable methods for genetic improvement, disease control, and environmental management. Exploring innovative technologies and fostering collaboration between researchers, farmers, and policymakers will be essential for overcoming current challenges and driving sustainable growth in the abalone farming industry.

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