

Original Research Articles

Investment risks and control measures in aquaculture projects – based on PEST analysis

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Aquaculture has emerged as a pivotal sector in addressing global food security, promoting rural development, and supporting sustainable economic growth, especially in coastal and developing regions of China. However, investment projects in aquaculture are increasingly exposed to multifaceted risks stemming from dynamic external environments. This study employs the PEST (political, economic, social, and technological) analysis framework to systematically identify, categorize, and analyze these external risks. Through a combination of policy reviews, expert interviews, and industry data analysis, this paper provides a comprehensive risk profile across four dimensions: policy uncertainty and regulatory constraints, economic volatility and market competition, social resistance and labor shortages, and technological gaps and disease vulnerability. Based on the PEST analysis, a set of tailored risk mitigation strategies is proposed, including policy adaptation, financial hedging, community engagement, and technological upgrading. The findings not only offer a structured approach to investment risk assessment in aquaculture projects in China but also provide practical recommendations for stakeholders seeking to enhance project resilience, improve investment efficiency, and achieve long-term sustainability. This paper contributes to the growing body of literature on aquaculture economics and risk governance by offering a macro-environmental perspective grounded in empirical insight.

INTRODUCTION

Aquaculture has become a vital component of the global food production system, especially in light of the stagnation in wild fishery yields and the increasing demand for seafood driven by population growth and changing dietary preferences (FAO, 2020).¹ According to the Food and Agriculture Organization of the United Nations, aquaculture now provides more than half of the fish consumed worldwide, with global aquaculture production reaching 87.5 million tonnes in 2020, a sharp rise from the 32.4 million tonnes reported in 2000 (FAO, 2022).² In particular, emerging economies in Asia, led by China, have seen rapid growth in both freshwater and marine aquaculture driven by favorable policies, technological advancements, and market incentives (Wang & Cheng et al., 2015; Zhang & Gui, 2023).^{3, 4}

Despite its rapid growth and significant economic contributions, aquaculture remains a sector with considerable

investment risk. These risks stem from a variety of factors, including disease outbreaks, environmental degradation, market volatility, regulatory uncertainties, and the high capital intensity of infrastructure (Bostock et al., 2010; Liu & Sumaila, 2007).^{5,6} For instance, large-scale aquaculture projects often face difficulties in site selection, licensing, and compliance with environmental standards, especially in coastal areas where spatial competition with tourism, shipping, and urban development is intense (Naylor et al., 2021).⁷ Furthermore, the biological nature of aquaculture production, characterized by long cycles, biological hazards, and sensitivity to environmental changes, introduces unique uncertainties that differ from traditional industrial investments (Aljehani & N'Doye et al., 2023).⁸

To better understand and manage these complex risks, researchers and practitioners have called for more systematic risk identification frameworks that integrate macro-environmental factors into aquaculture project assessments. The PEST analysis model—standing for Political, Economic,

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Social, and Technological factors—has been widely used in strategic planning and investment risk evaluation across industries (Yüksel, 2012).⁹ However, its application to the aquaculture sector remains relatively limited, especially in the context of analyzing investment risks and control strategies in different political and regulatory environments.

This paper aims to fill this paucity of research by applying the PEST framework to assess investment risks in aquaculture projects and to identify targeted control measures. We examine the specific challenges and risk exposures faced by investors from four dimensions: policy and regulatory uncertainty (P), market and financial volatility (E), labor and community relations (S), and production and technological uncertainty (T). Based on field interviews, case studies, and secondary data collected from selected coastal regions in China, we explore how different risk factors manifest across contexts and what mitigation mechanisms have proven effective in practice. In doing so, we aim to offer a comprehensive analytical lens and practical insights to guide stakeholders—including investors, project managers, and policymakers—in designing more resilient and sustainable aquaculture ventures.

LITERATURE REVIEWS

Although the number of studies on aquaculture risk management has significantly increased in recent years, existing research has primarily focused on operational or biological risks, such as disease outbreaks, fluctuations in feed quality, and changes in water quality conditions (Cahill & Davidson et al., 2022; Campbell & Kambey et al., 2020; Adnan & Xicang et al., 2024; Rahman & Nielsen et al., 2021).¹⁰⁻¹³ While these studies provide valuable insights into the direct risks associated with aquaculture operations, they often overlook the impact of macro-environmental factors on the investment risks of aquaculture projects. Macro-environmental factors, including government policies, economic conditions, social dynamics, and technological advancements, have a profound influence on the success of aquaculture projects yet have not received sufficient attention.

Government policy uncertainty, economic volatility (Valderrama & Hishamunda et al., 2015),¹⁴ societal acceptance of aquaculture projects, and the pace of technological advancement are all key factors influencing the investment risks associated with aquaculture projects (Luna & Llorente et al., 2023).¹⁵ For example, policy instability may lead to delays in project approvals or increased costs, economic fluctuations may affect market demand and financing channels, social resistance may hinder project implementation, and technological lag may limit production efficiency and disease control capabilities.

In this context, the PEST analysis framework provides a systematic method for comprehensively assessing the external risks faced by aquaculture projects, covering four dimensions (Khalid & Zhang et al., 2020).¹⁶ The PEST framework has been widely applied in strategic planning and risk analysis across multiple industries, such as manufacturing, energy, and healthcare, with its effectiveness in identifying,

classifying, and addressing macro-environmental risks having been validated. However, the application of this framework in the field of aquaculture investment research remains relatively limited, particularly in emerging markets or highly regulated regions, where its potential has yet to be fully realized.

Specifically, existing literature on the application of the PEST framework in the aquaculture sector is limited, with most studies remaining theoretical in nature and lacking empirical research and specific case analyses. This results in investors often lacking effective risk prediction and response strategies when faced with changes in the macro environment, thereby limiting their ability to make wise investment decisions in complex and dynamic market conditions. Therefore, this study aims to address this research gap by applying the PEST framework to systematically identify, classify, and analyze the external risks faced by aquaculture projects and propose corresponding control measures to enhance the projects' risk resilience, improve investment efficiency, and achieve long-term sustainable development.

RESEARCH METHODS

RESEARCH FRAMEWORK: PEST MODEL

In order to analyze the investment risks of aquaculture projects from a macro-environmental perspective, this study adopted the PEST analysis framework, which breaks down external factors into four main dimensions, as shown in Table 1:

(1) Political factors: Political factors primarily refer to the impact of government policies, regulatory frameworks, and administrative procedures on aquaculture investment decisions. Key elements include 1) policy uncertainty: frequent changes in fisheries and environmental protection policies may erode investor confidence and disrupt long-term planning; 2) regulatory constraints: strict regulations on environment, land use and marine space driven by policies may restrict industrial development by limiting the selection of breeding sites or increasing compliance costs. 3) Complex administrative approval processes: Lengthy and multi-tiered bureaucratic approval procedures may delay project initiation and increase transaction costs. These factors can significantly impact the feasibility, cost, and timeline of aquaculture projects, particularly in countries or regions with decentralized governance structures or inconsistent policy enforcement.

(2) Economic factors: Economic factors encompass financial and market-related elements that directly impact the profitability and sustainability of aquaculture investments. Key factors include 1) price volatility: the prices of aquaculture products (such as fish, shellfish, and seaweed) are subject to significant volatility due to factors such as seasonal supply, global trade dynamics, and import competition. Such fluctuations may lead to unstable income and increase financial risks for investors. 2) Market demand uncertainty: Changes in consumer preferences, health trends, and domestic or international market demand may result in

uncertainty regarding product sales. Unexpected declines in demand may lead to oversupply, price declines, and inventory buildup. 3) Limited access to financing: Many aquaculture projects, particularly those led by small and medium-sized enterprises, face difficulties in accessing stable and affordable financing. High initial capital requirements, lack of collateral, and recognition of industry risks often limit access to bank loans or investment capital. These economic factors play a critical role in the risk-return profile of aquaculture enterprises, and if not properly managed or mitigated, may hinder long-term investment.

(3) Social factors: Social factors refer to social and human capital-related influences that affect the acceptability, operation, and sustainability of aquaculture investments. Key elements include 1) labor shortages: the aquaculture industry often struggles to attract and retain skilled workers due to factors such as high work intensity, production facilities located in rural areas, and limited training opportunities. Labor shortages may reduce operational efficiency and limit production capacity; 2) insufficient community support: local communities may oppose aquaculture projects due to concerns about environmental impacts, noise, odors, or disruptions to traditional livelihoods, which may lead to social resistance, legal challenges, or reputational risks, thereby hindering project implementation. 3) Land use conflicts: Competition with tourism, agriculture, conservation, or urban development for coastal or inland water resources may trigger land use conflicts. Such disputes may limit access to suitable aquaculture sites and create long-term operational uncertainties. These social dynamics impact the social operating license of aquaculture enterprises and must be carefully managed through stakeholder engagement, transparent communication, and inclusive development practices.

(4) Technical factors: Technical factors relate to the level of innovation, infrastructure, and technical capabilities that support efficient and sustainable aquaculture. Key factors include 1) inadequate disease prevention and control: outbreaks of fish and shellfish diseases pose significant risks to production and profitability. Limited access to vaccines, biosecurity protocols, and veterinary expertise increases vulnerability to biological threats; 2) outdated production technologies: in many regions, aquaculture production still relies on outdated farming systems and manual processes, leading to low productivity, poor resource utilization, and significant environmental impacts. 3) Lack of data management and digital tools: The absence of robust data collection, monitoring, and digital management systems hinders decision-making, traceability, and performance optimization. This technological gap reduces the ability to adapt to changing market and environmental conditions.

Overcoming these technical limitations is critical to sustainably expanding aquaculture scale, improving competitiveness, and keeping pace with global trends toward smart and precision aquaculture.

The PEST model provides a systematic perspective for assessing the external environment of aquaculture investments, enabling comprehensive identification and classification

of potential risks and their root causes. It is particularly suitable for early strategic planning and risk screening for large and medium-sized aquaculture projects.

RESEARCH DESIGN AND PROCESS

This study combines qualitative analysis with semi-quantitative evaluation. Specifically, we integrated document reviews and expert interviews with risk scoring to comprehensively and systematically evaluate the investment risks of aquaculture projects. The specific research process is as follows:

STEP 1: DETERMINE EVALUATION INDICATORS

Based on extensive reading and in-depth analysis of relevant literature, policy documents, and actual project cases, we have carefully constructed a risk assessment indicator system based on the PEST framework. This system not only covers the four main dimensions at the macro level but also further breaks down each dimension into 3-5 specific sub-factors to ensure the comprehensiveness and detail of the assessment. Specifically, in the political dimension, we considered factors such as policy continuity, regulatory strictness, and administrative efficiency; in the economic dimension, we focused on input cost volatility, the diversity of financing channels, and the uncertainty of market demand; in the social dimension, we analyzed conflicts over land and water resource use, labor shortages, and changes in consumer preferences; and in the technological dimension, we emphasized the assessment of disease control capabilities, automation levels, and the effectiveness of data management.

STEP 2: DATA COLLECTION

To ensure the accuracy and reliability of the assessment results, we collected a wealth of data through multiple channels. Specifically, in terms of policy analysis, we conducted a detailed review of regulations, five-year development plans, and environmental guidelines related to aquaculture at the national and regional levels; in terms of industry reports, we made full use of authoritative data provided by the Food and Agriculture Organization (FAO), the National Bureau of Statistics, and industry associations; in the expert interview phase, we conducted in-depth semi-structured interviews with 12 stakeholders from various fields. These interviewees included aquaculture investors, project managers, policy experts, and technical advisors; for the case study component, we carefully selected four representative aquaculture investment projects in China, covering both successful and failed cases, to draw lessons from them.

STEP 3: RISK IDENTIFICATION AND CLASSIFICATION

After collecting a large amount of data, we used scientific methods to systematically identify and classify risks under each dimension of PEST. For each risk, we conducted an in-depth analysis, including its likelihood of occurrence, potential impact on project success, and interrelationships

Table 1. PEST Analysis framework diagram

Political	Economic	Social	Technological
policy uncertainty	price volatility	labor shortages	inadequate disease control
regulatory restrictions	fluctuating market demand	insufficient community support	technological backwardness
complex administrative approval processes	limited financing	land use conflicts	lack of data management

Table 2. Risk level classification matrix (risk probability × impact)

	Low impact	Moderate impact	High impact	Extremely high impact
High probability	moderate risk	high risk	extremely high risk	extremely high risk
Moderate probability	low risk	moderate risk	high risk	extremely high risk
Low probability	low risk	low risk	moderate risk	high risk

with other risks. For example, we explored how policy risks could indirectly increase project financial risks by affecting the financing environment. Subsequently, we categorized risks into four levels—low, medium, high, and critical—using a risk matrix (as shown in Table 2) to more intuitively illustrate the severity of risks.

STEP 4: VALIDATION AND STRATEGY DEVELOPMENT

To ensure the robustness and credibility of the research results, we organized an expert consultation meeting, inviting several experts with extensive experience and deep professional knowledge in the field of aquaculture to conduct a detailed verification and discussion of the risk list and classification. Based on the valuable opinions and suggestions from the experts, we made necessary adjustments and improvements to the risk assessment results. Subsequently, we proposed targeted control measures for each risk category, such as early policy engagement to mitigate risks arising from policy uncertainty, the use of financial hedging tools to mitigate the impact of market volatility, the development of stakeholder communication strategies to enhance social acceptance, and the adoption of resilient technologies to enhance the project's risk resilience. These measures aim to help investors and stakeholders better address various risk challenges in aquaculture projects and ensure the project's long-term sustainable development.

REASONABLENESS OF RESEARCH METHODS

This study used the PEST analysis method as its core research tool, based on the following considerations of rationality:

(1) **Comprehensiveness.** The success of aquaculture investment projects does not depend solely on technical or operational factors but is greatly influenced by broader external environmental factors. The PEST analysis method systematically covers key dimensions such as regulatory environment, economic conditions, social dynamics, and technological advancements, which collectively form the

complex external risk network faced by aquaculture investment projects. Through PEST analysis, we can comprehensively identify and assess the potential impacts of these external factors on project investment returns, operational efficiency, and sustainability, thereby ensuring the completeness and accuracy of risk assessments.

(2) **Strategic relevance.** For investors, especially institutional investors seeking long-term stable returns, macro-level analytical tools are crucial. The PEST analysis method provides investors with a more comprehensive perspective, enabling them to conduct strategic screening and evaluation at the early stages of a project. Through this framework, investors can gain a clear understanding of the political stability, economic development trends, social acceptance, and technological level of the project's location, thereby assessing the project's long-term feasibility and potential risks. This strategic insight helps investors make more informed investment decisions and avoid falling into potential risk traps.

(3) **Adaptability.** The aquaculture industry exhibits significant regional and policy sensitivity, with investment projects in different regions and policy environments facing distinct risk characteristics. A key advantage of the PEST model lies in its high adaptability and flexibility, enabling it to be customized according to specific research subjects and contexts. Whether it is marine aquaculture projects in coastal areas, freshwater aquaculture projects in inland regions, or various projects influenced by different policy environments, the PEST model can adjust its analytical dimensions to tailor a risk assessment framework for each project. This adaptability makes the PEST analysis method an ideal choice for risk assessment in aquaculture investment projects.

(4) **Practicality of decision support.** Another major advantage of the PEST analysis method is its ability to organically combine qualitative and semi-quantitative analysis, providing decision-makers with actionable recommendations and risk prioritization. In terms of qualitative analysis, the PEST model delves into external factors from political, economic, social, and technological dimensions to

reveal the various potential risks faced by the project. In terms of semi-quantitative assessment, we employ a data-driven approach to quantitatively evaluate the probability of occurrence and potential impact of each risk. By combining these two methods, we can not only clearly identify key risk points but also prioritize them based on their probability of occurrence and urgency, thereby providing robust support for the development of targeted risk control measures. This decision-support functionality makes the PEST analysis method indispensable in risk assessment for aquaculture investment projects.

RESULTS AND DISCUSSION

POLITICAL RISKS AND CONTROL MEASURES

As an industry highly dependent on government approvals, land and water usage rights, and strict compliance with environmental regulations, aquaculture projects are inevitably subject to significant influence from the political environment. This study employs the PEST analysis framework to conduct a comprehensive analysis and identification of the primary political risk factors faced by aquaculture projects and proposes corresponding control measures.

POLITICAL RISKS

(1) POLICY VOLATILITY AND INCONSISTENCY

Policy fluctuations and inconsistencies are one of the primary political risks faced by aquaculture projects. Frequent changes in environmental protection policies, subsidy standards, and administrative priorities create significant compliance uncertainties for investors. Such uncertainties not only increase compliance costs but may also lead to sudden project stagnation due to policy adjustments, resulting in substantial economic losses. For example, in recent years, as global environmental awareness has grown, governments worldwide have introduced stricter environmental regulations. The Chinese government issued the “Emission Standards for Aquaculture Water Pollutants,” imposing higher requirements on wastewater discharge and drug use during aquaculture processes. The implementation of this policy forced many traditional aquaculture methods to reform or phase out, with some projects unable to adapt to the new policies in time, leading to forced shutdowns and significant losses for investors. Additionally, in China’s coastal regions, adjustments to ecological zoning have led to the suspension of multiple coastal aquaculture projects, leaving a large amount of investment in limbo. This case clearly demonstrates the severe impact of policy fluctuations on aquaculture projects.

(2) COMPLEX LICENSING AND APPROVAL PROCEDURES

Aquaculture projects frequently encounter complex procedures when obtaining operational licenses and approvals. Multi-agency oversight and inconsistent standards result in delays in obtaining permits, particularly in areas such as

environmental impact assessments, water rights approvals, and construction permits. Such delays not only increase the project’s time costs but may also lead to economic losses due to missing the optimal investment window.

(3) INSUFFICIENT LOCAL GOVERNANCE CAPACITY

In certain regions, local governments may lack the necessary professional skills or resources to sustainably and effectively implement national aquaculture policies. This deficiency in governance capacity may result in ineffective policy implementation, creating a disconnect between planning and implementation, and thereby hindering the smooth progress of aquaculture projects.

CONTROL MEASURES

(1) CONTACT DECISION MAKERS AS EARLY AS POSSIBLE

Investors should actively participate in local planning and regulatory discussions to ensure that project directions remain consistent with upcoming policies. By communicating with decision-makers early on, investors can better understand policy intentions, adjust project plans in advance, and reduce the risks associated with policy fluctuations.

(2) ESTABLISH A LEGAL DUE DILIGENCE MECHANISM

Engage a professional legal advisory team to conduct comprehensive legal due diligence on investment projects. Legal advisors should closely monitor policy developments and promptly provide legal advice to investors to help them maintain compliance in a complex regulatory environment.

(3) ESTABLISH PARTNERSHIPS WITH LOCAL GOVERNMENTS

By promoting joint development models or pilot projects, establish close partnerships with local governments. Such cooperation not only helps investors better understand local policies but also ensures that projects align with local development priorities, thereby securing greater policy support and resource allocation.

ECONOMIC RISKS AND CONTROL MEASURES

ECONOMIC RISKS

Aquaculture projects typically have high capital intensity and long investment payback periods, which expose them to numerous complex and severe economic risk factors. Through in-depth analysis, this study highlights the following key economic risk factors.

(1) VOLATILITY OF INPUT PRICES

Among the various inputs in aquaculture, fluctuations in feed, fish fry, electricity, and fuel prices have a significant impact on aquaculture costs. Taking feed as an example, global soybean prices have surged significantly in recent years. Since soybeans are a key raw material in feed production, their significant price increases have directly led to a significant rise in feed costs. As shown in Figure 1, feed prices exhibited a fluctuating trend of first declining

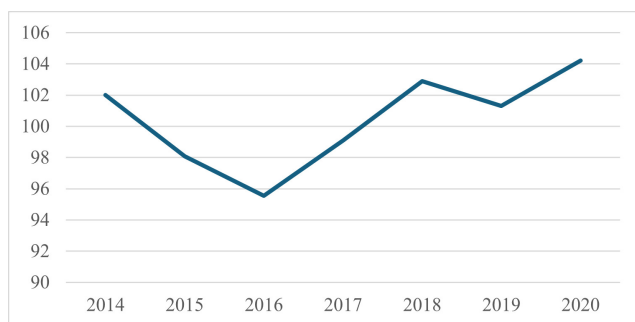


Figure 1. Feed prices from 2014 to 2020

Data source: CSMAR

and then rising between 2014 and 2020. This instability has posed major challenges for cost control in aquaculture projects. Aquaculture farmers and businesses often struggle to accurately predict cost changes resulting from feed price fluctuations, which in turn affects project profitability expectations and financial planning.

(2) EXCHANGE RATE AND TRADE RISKS

For export-oriented farms, currency depreciation or export restrictions in the target market may directly impact revenue. Additionally, exchange rate fluctuations and changes in trade policies are closely linked to the import and export of aquaculture products, as evidenced by the fluctuations in import and export volumes and values of aquaculture products from 2014 to 2023, as shown in Figure 2. During this period, the total volume of imports and exports generally increased, with import and export values fluctuating accordingly. When the currency of the target market depreciates, even if import and export volumes remain stable or increase, the value of imports and exports calculated in local currency may decrease due to exchange rate conversion issues. For example, if the currency of the target market depreciates relative to the local currency during a period of rising import and export volumes, the value of export revenue converted back to local currency will decrease, directly compressing the profit margin of aquaculture projects.

Additionally, changes in trade policies, such as tariff adjustments and the establishment of trade barriers, may also lead to fluctuations in the volume and value of imports and exports. When export restrictions are implemented, the volume of imports and exports may decrease, thereby affecting the value of imports and exports. As shown in Figure 2, the decline in the volume and value of imports and exports in certain years may be related to unfavorable trade policies implemented by target markets at the time. The uncertainty of exchange rates and trade policies increases the unpredictability of project returns, exposing businesses to greater economic risks in international market competition. From the perspective of the exchange rate uncertainty index, this uncertainty further impacts businesses' assessments and decisions regarding international markets, increasing the economic risk exposure of aquaculture projects.

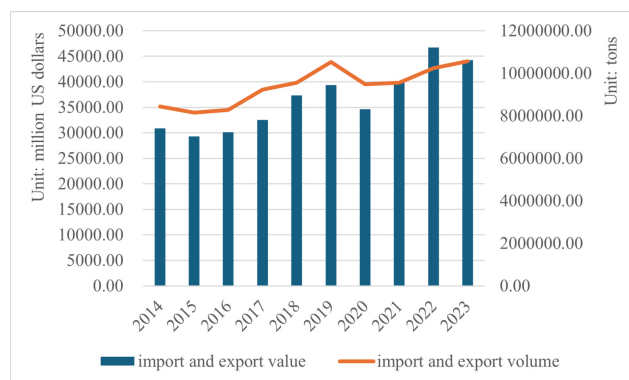


Figure 2. China's aquatic product import and export trade situation

Data source: CHINA FISHERY STATISTICAL YEARBOOK

(3) UNCERTAINTY OF MARKET DEMAND

Changes in consumer preferences and the occurrence of food safety incidents may have sudden and significant impacts on the market demand for aquaculture products. For example, a decline in consumer demand for specific species such as eel or tilapia may lead to a decrease in market prices and sales volumes for these products, thereby affecting the economic viability of aquaculture projects. The impact of food safety incidents is even more far-reaching. Once food safety issues related to aquaculture products arise, consumers often reduce their purchases of such products, leading to a sharp decline in overall market demand. This uncertainty in market demand poses numerous challenges for aquaculture projects in terms of market expansion and sales strategy formulation.

(4) FINANCING CONSTRAINTS

Financial institutions typically classify the aquaculture industry as a high-risk sector when evaluating aquaculture projects, with risk factors including disease outbreaks, natural disasters, and market price fluctuations during the aquaculture process. As a result, aquaculture projects often face challenges such as high borrowing costs or limited access to long-term credit during the financing process. This study adopts the research method proposed by Mu and Liu (2023), selecting the SA index as a proxy variable for financing constraints. To facilitate comparison, we have processed the data using absolute values. As shown in Figure 3, this illustrates the average financing constraints faced by listed fisheries companies in China from 2014 to 2023. The figure indicates that the index shows an overall upward trend, reflecting the increasing pressure faced by fisheries companies during the financing process. A higher SA index implies stricter financing constraints, which will limit project funding sources and hinder project scale expansion and sustainable development.

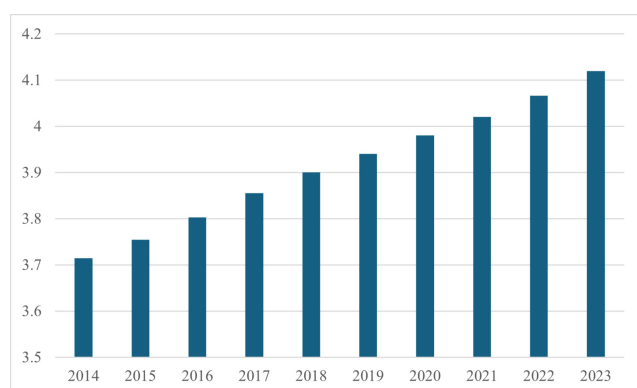


Figure 3. Average financing constraints for listed fishing companies from 2014 to 2023

Data source: CSMAR

CONTROL MEASURES

(1) USE FINANCIAL HEDGING INSTRUMENTS

Stabilize raw material costs by using futures contracts or entering into long-term stable procurement contracts with suppliers. Through hedging operations in the futures market, raw material prices can be locked in to some extent, thereby reducing the risks associated with price fluctuations. For example, livestock and poultry farming companies can purchase corresponding soybean futures contracts in the futures market when feed prices are relatively low. When feed prices rise, the profits from the futures contracts can offset the increase in procurement costs in the spot market, thereby stabilizing farming costs.

(2) DIVERSIFY PRODUCT AND MARKET MIX

Developing a diversified product line helps avoid over-reliance on a single product or export market. By expanding product variety, companies can meet the needs of different consumers and reduce risks associated with a decline in demand for a particular product. Additionally, expanding into diversified market channels, including both domestic and international markets, can reduce reliance on a single export market and mitigate the impact of exchange rate and trade risks on the project.

(3) STRENGTHEN INVESTOR COMMUNICATION

By establishing transparent financial models and conducting third-party project audits, investors can clearly understand the project's actual operational status and financial condition, thereby enhancing their understanding and trust in the project. Transparent financial information enables investors to more accurately assess the project's risks and returns, thereby increasing the project's chances of securing financing. Third-party project audits provide objective and impartial evaluations, further enhancing the project's credibility and facilitating the smooth conduct of financing activities.

SOCIAL RISKS AND CONTROL MEASURES

SOCIAL RISKS

The successful implementation and sustainable development of aquaculture investment projects largely depend on the acceptance of local communities and the stability of the labor force. Numerous factors in the social environment can have a profound impact on aquaculture projects. Through in-depth analysis, this study has identified the following key social risk factors.

(1) CONFLICTS OVER THE USE OF LAND AND WATER

In aquaculture activities, the use of land and water resources often becomes a key factor in triggering conflicts. When aquaculture competes with agriculture, tourism, or local residents' needs, conflicts may arise. Such conflicts are particularly pronounced in ecologically sensitive areas or densely populated regions. Ecologically sensitive areas typically possess unique ecosystems and biodiversity. Aquaculture activities may disrupt local ecosystems to some extent, such as by occupying wetlands or altering water flow, thereby sparking opposition from environmentalists and local residents. Densely populated areas face relative scarcity of land and water resources, and the demand for land and water resources from aquaculture may conflict with the living needs of local residents. For example, in some coastal areas, aquaculture competes with tourism for coastal resources. The construction of aquaculture facilities may affect the aesthetic appeal of coastal landscapes, reducing tourism appeal, and thereby sparking conflicts between tourism operators and aquaculture practitioners.

(2) LABOR SHORTAGES AND SKILLS MISMATCHES

As the automation level of the aquaculture industry continues to improve and biosafety standards become increasingly stringent, the demand for technical talent is growing more urgent. However, traditional non-technical labor can no longer meet the industry's development needs, leading to an imbalance in the supply of rural labor. As shown in Figure 4, although the total number of people engaged in aquaculture-related industries fluctuated between 2014 and 2023, the number of professional personnel has generally been declining. Additionally, the structural distribution of professional staff, part-time staff, and temporary staff may not fully align with the industry's demand for technical talent. The application of automated equipment requires professional technicians for operation and maintenance, while the enhancement of biosecurity standards demands personnel with relevant professional knowledge and skills. However, the rural labor force generally lacks systematic professional training, making it difficult to undertake these technical tasks. This results in challenges for enterprises in recruiting suitable talent, thereby impacting the normal operations and development of projects.

(3) THE MISCONCEPTION OF PUBLIC PERCEPTION AND INFORMATION

Past environmental incidents, such as antibiotic overuse or wastewater discharge, have severely damaged public trust.

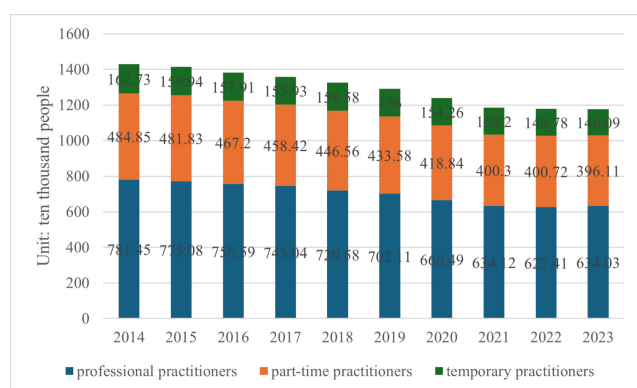


Figure 4. Number and composition of people working in China's fishing industry from 2014 to 2023

Data source: CHINA FISHERY STATISTICAL YEARBOOK

These negative incidents have left a deep impression on the public, leading to skepticism and resistance toward aquaculture projects. Once rumors of similar environmental issues emerge, even without a factual basis, they can quickly trigger public panic and opposition. The spread of such public perceptions and misinformation may severely hinder the project approval process, as government agencies consider public opinion and concerns when approving projects; it may also affect product market acceptance, as consumers may reduce purchases due to concerns about the safety of aquaculture products, thereby negatively impacting the project's economic benefits.

CONTROL MEASURES

In order to effectively address the above social risks and ensure the smooth progress of aquaculture projects, the following control measures can be taken.

(1) CONDUCT A SOCIAL IMPACT ASSESSMENT (SIA)

During the project feasibility study phase, community consultation should be integrated as an essential component of the social impact assessment. Through thorough communication and interaction with local community residents and stakeholders, their needs, concerns, and expectations should be understood, and the potential positive and negative social impacts of the project should be assessed. Based on the assessment results, corresponding mitigation measures and community development plans should be formulated to reduce the project's adverse social impacts and enhance community acceptance of the project.

(2) INVEST IN LOCAL TRAINING PROGRAMS

Establish partnerships with local vocational schools or agricultural universities to jointly develop customized training programs tailored to the aquaculture industry. Design systematic training courses based on industry needs to cultivate talent with professional skills and knowledge. Through this approach, not only can the skill levels of the local workforce be enhanced to meet the project's demand for technical talent, but it also promotes the development of

local human resources, providing a solid talent foundation for the project's long-term development.

(3) ENHANCE ENVIRONMENTAL TRANSPARENCY

Regularly publish environmental monitoring data for aquaculture projects, including information on water quality, soil quality, and antibiotic usage, to enable the public to promptly understand the project's environmental status. Establish a public communication platform to actively address public concerns and questions, thereby enhancing public trust in the project. Through transparent environmental management measures, avoid public opposition caused by information asymmetry and create a favorable social environment for the smooth implementation of the project.

TECHNICAL RISKS AND CONTROL MEASURES

TECHNICAL RISKS

In the field of aquaculture, the maturity and resilience of technology are critical to production efficiency and disease control, directly impacting the economic viability and sustainability of aquaculture projects. Through in-depth analysis, this study has identified the following key technical risk factors.

(1) INADEQUATE BIOSAFETY AND DISEASE CONTROL

One of the major threats facing the aquaculture industry is disease outbreaks. Diseases such as white spot disease and streptococcal infections, once they occur, often result in significant losses of aquatic products. As shown in Figure 5, the proportion of aquatic product losses caused by diseases fluctuated significantly between 2014 and 2023, with particularly high loss rates in years such as 2017 and 2023. Many small and medium-sized aquaculture farms lack adequate quarantine and monitoring systems due to limited funds and outdated technology. This makes it difficult for them to detect diseases early and implement effective control measures, leading to rapid disease spread and severe impacts on aquaculture production. For example, the white spot disease virus spreads rapidly, and once it infects a shrimp farming population, it can cause mass shrimp deaths in a short period, resulting in significant economic losses for farmers.

(2) LAGGING TECHNICAL APPLICATION

The application of new technologies in aquaculture is of great significance for improving production efficiency, reducing costs, and ensuring product quality. However, advanced technologies such as recirculating aquaculture systems (RAS), AI-based monitoring technologies, or genetic breeding have not been widely adopted, primarily due to their high initial investment costs and lack of professional knowledge. Taking RAS as an example, although the system can effectively improve water resource utilization efficiency and reduce dependence on the environment, its high construction and operational costs make it difficult for many small and medium-sized farms to afford. Additionally,

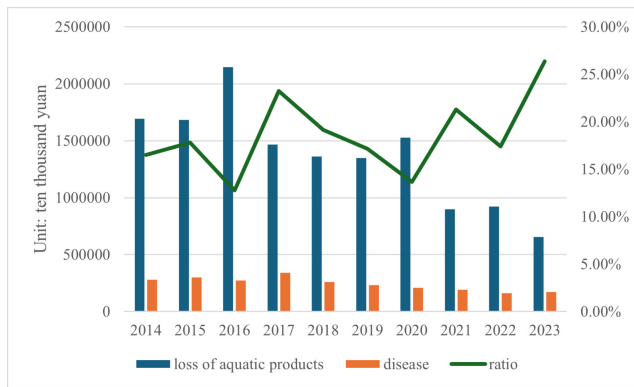


Figure 5. Economic losses caused by fishery disasters in China from 2014 to 2023

Data source: CHINA FISHERY STATISTICAL YEARBOOK

aquaculture personnel lack the necessary expertise to operate and maintain these advanced systems, further limiting the adoption of new technologies. As shown in the data on changes in aquatic product losses in Figure 5, insufficient application of technology may result in an inability to promptly and effectively address preventable risks, thereby causing losses.

(3) GAPS IN DATA INFRASTRUCTURE

Reliable data infrastructure and consistent data collection methods are the foundation for achieving traceability and intelligent aquaculture. Currently, the aquaculture industry has significant shortcomings in this area. The lack of unified data collection standards and regulations leads to inconsistent data formats and quality between different farms, making it difficult to effectively integrate and analyze data. Additionally, insufficient digital infrastructure, such as inadequate network coverage and limited data storage and processing capabilities, hinders real-time data transmission and sharing. This makes it difficult to accurately record and trace information during the farming process, hindering the provision of robust support for production decisions and impeding the development of smart aquaculture technologies. As shown in Figure 6, while the number of patent authorizations has increased in recent years, the number of invention patents remains relatively low, which may indicate that the industry still has significant room for improvement in terms of technological innovation and data infrastructure development.

CONTROL MEASURES

To effectively address the aforementioned technical risks and improve the technical level and risk resistance of aquaculture, the following control measures can be taken.

(1) PRIORITIZE INVESTMENT IN BIOSAFETY

Aquaculture enterprises should establish dedicated funds as early as possible for disease monitoring, water quality control, and health monitoring systems. Establish a comprehensive disease monitoring system, conduct regular

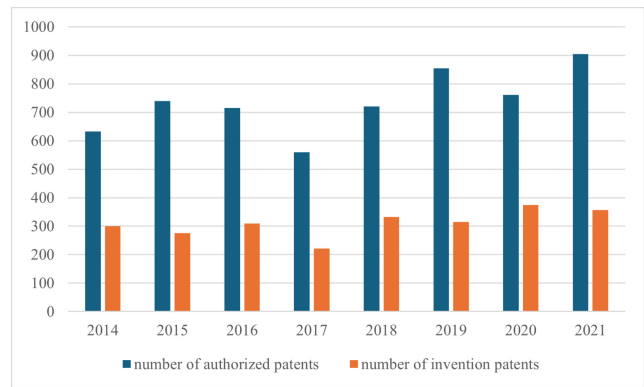


Figure 6. Status of fishery science and technology patents in China from 2014 to 2021

Data source: CHINA FISHERY STATISTICAL YEARBOOK

testing of aquaculture water bodies and organisms, and promptly identify potential disease risks. Strengthen water quality control to ensure a stable and suitable aquaculture environment, thereby reducing the causes of disease outbreaks. Additionally, equip facilities with specialized health monitoring equipment and personnel to monitor the health status of aquaculture organisms in real time, enabling the implementation of effective isolation and treatment measures at the earliest stages of disease outbreaks to minimize losses.

(2) ENCOURAGE TECHNOLOGY TRANSFER PLATFORMS

Establish close cooperative relationships between industry, academia, and government, and build a technology transfer platform. Academia possesses abundant research achievements and cutting-edge technologies but lacks channels to convert these technologies into actual productive capacity; enterprises face technical challenges and innovation needs but struggle to obtain suitable technologies. Through the technology transfer platform, effective collaboration between the two sides can be promoted, accelerating the application of new technologies in the aquaculture sector. The government can introduce relevant policies to provide financial support and tax incentives for technology transfer and collaborative projects, encouraging active participation from all parties.

(3) DEVELOP A DIGITAL TRACEABILITY SYSTEM

Fully leverage advanced technologies such as IoT and blockchain to build a digital traceability system. IoT technology can collect various data in real-time during aquaculture, such as water quality parameters, feed intake, and biological growth conditions, and upload this data to the cloud. Blockchain technology ensures the integrity and traceability of the data. Consumers can scan the product's QR code to obtain detailed information about the entire process from farming to sales, thereby enhancing operational transparency and product value. This not only helps to enhance consumer trust in aquatic products but also helps aquaculture enterprises establish a positive brand image and strengthen their market competitiveness.

Table 3. Summary of major risks and control measures

Risk category	Specific risks	Control measures
political risks	policy fluctuations, complex approval processes, and insufficient local governance capabilities	early policy engagement, legal due diligence, and cooperation with local governments
economic risks	fluctuations in input prices, exchange rate and trade risks, uncertain market demand, and financing difficulties	financial hedging, diversified products and markets, transparent financial communication
social risks	conflicts over resource use, labor shortages, public perceptions, and misinformation	social impact assessment, vocational training, improving environmental transparency
technical risks	inadequate disease control, outdated technology, and poor data infrastructure	investment in biosafety, technology transfer platforms, and digital traceability system construction

CONCLUSIONS AND POLICY RECOMMENDATIONS

CONCLUSIONS

This study employed the PEST analysis framework to systematically and comprehensively identify and assess the political, economic, social, and technological risks faced by aquaculture investment projects. Through in-depth analysis, we have reached the following conclusions:

(1) In terms of political risk, aquaculture investment projects primarily face three challenges: policy instability, complex administrative approval procedures, and uneven local governance capabilities. Policy instability may require projects to frequently adjust strategies during operations to align with new policy requirements, thereby increasing operational costs and uncertainty. Complex administrative approval procedures may lead to inconsistent policy implementation, making it difficult for investors to accurately predict project outcomes and thereby increasing investment risks. Inadequate local governance capacity may result in a disconnect between planning and implementation, thereby impacting the smooth implementation of aquaculture projects.

(2) From an economic risk perspective, aquaculture investment projects are primarily affected by fluctuations in input prices, limited financing channels, and fluctuations in international market demand. Fluctuations in input prices for feed, fuel, and other inputs directly increase production costs, posing a threat to the project's profitability. Furthermore, since aquaculture projects typically have a highly capital-intensive nature, the limited availability of financing channels makes it difficult to secure funds, especially during economic downturns when financing costs may rise further. Additionally, fluctuations in international market demand may also lead to fluctuations in product prices, impacting aquaculture enterprises that rely on exports.

(3) In terms of social risks, conflicts over land and water resource allocation, shortages of skilled workers, and declining public trust due to environmental issues are the primary challenges facing aquaculture investment projects. As urbanization accelerates, the scarcity of land and water resources is intensifying, potentially leading to competition or even conflicts with other industries such as agriculture

and tourism in terms of site selection and water use. Meanwhile, the aquaculture industry's demand for skilled workers is growing, but the shortage of labor and skill mismatches in rural areas are becoming increasingly prominent, hindering the smooth implementation of projects. Additionally, past environmental incidents have eroded public trust in aquaculture projects, resulting in more obstacles in project approvals and product acceptance.

(4) In terms of technical risks, inadequate disease control systems, low adoption rates of advanced aquaculture technologies, and the lack of digital infrastructure for detection and traceability are the main challenges facing aquaculture investment projects. Disease outbreaks can result in significant losses, but many small and medium-sized farms lack robust quarantine and monitoring systems, making it difficult to effectively prevent and control diseases. Additionally, due to high upfront costs or lack of expertise, new technologies such as recirculating aquaculture systems and AI-based monitoring technologies have not been widely adopted, limiting improvements in production efficiency. Furthermore, the absence of reliable digital infrastructure and inconsistent data collection methods hinder the development of traceability and smart aquaculture, making it difficult for projects to respond to market changes and risks.

The interplay of these risks creates a complex and dynamic environment for aquaculture investments. For example, policy uncertainty may lead investors to adopt a cautious attitude toward new technologies, thereby hindering technological innovation and industrial upgrading; simultaneously, insufficient community participation may increase resistance to large-scale infrastructure development, posing additional challenges during project site selection and construction phases. This underscores the need for investors and stakeholders to adopt a comprehensive risk management strategy that addresses multiple PEST factors to ensure the smooth implementation of projects.

Furthermore, the study underscores that risk levels vary across different regions, enterprise sizes, and aquaculture species. For example, aquaculture projects in coastal areas may face stricter environmental regulations and higher land costs; large enterprises may have stronger risk-bearing capacity and more abundant resources to address various challenges; and different aquaculture species have varying

requirements for environmental and technical conditions. Therefore, it is essential to adopt differentiated risk control strategies and develop targeted measures based on specific circumstances, rather than a one-size-fits-all approach. Only in this way can investment risks be effectively managed, thereby enhancing the success rate and sustainability of aquaculture projects.

POLICY RECOMMENDATIONS

Based on this study's in-depth analysis of investment risks in aquaculture projects, the following strategic recommendations are now presented to government decision-makers, investors, and industry stakeholders, with the aim of mitigating investment risks and enhancing the sustainability and resilience of aquaculture investments.

(1) ENHANCE POLICY STABILITY AND REGULATORY TRANSPARENCY

The government should strive to create a stable, transparent, and predictable policy environment to enhance investor confidence and promote long-term planning. Specifically, it should ensure the continuity and consistency of key policies such as environmental protection, land or water resource utilization, and subsidy mechanisms to reduce uncertainty caused by frequent policy adjustments. Furthermore, the government should establish a unified aquaculture licensing and approval platform to integrate functions across multiple departments, streamline approval processes, reduce project startup times, and improve administrative efficiency. Additionally, the government should issue clear policy roadmaps and environmental zoning guidelines to provide investors with clear guidance, reduce investment risks, and prevent asset stranding caused by policy changes.

(2) PROMOTE FINANCIAL INNOVATION AND INVESTMENT FACILITATION

To reduce operational risks in aquaculture projects, the government should actively support financial innovation and establish diversified insurance mechanisms, including index-based weather insurance and disease outbreak insurance, to provide risk protection for investors. Additionally, financial institutions should be encouraged to establish green investment funds and low-interest loan products specifically designed to support the development of sustainable aquaculture projects, thereby reducing financing costs and expanding financing channels. For companies that adopt environmentally friendly or digital aquaculture technologies at an early stage, the government should provide tax incentives and investment credits to encourage technological innovation and industrial upgrading.

(3) DEEPEN COMMUNITY PARTICIPATION AND WORKFORCE DEVELOPMENT

For large and medium-sized aquaculture projects, the government should mandate the conduct of social impact as-

sessments (SIAs) to ensure alignment with local development goals and prevent community opposition. Concurrently, the government should collaborate with vocational schools and agricultural universities to establish an aquaculture training and certification system to enhance labor skills, alleviate labor shortages, and improve employment quality. Additionally, the government should establish a public information platform to disclose environmental performance and food safety data, enhance transparency, and boost consumer confidence and community acceptance, thereby facilitating the smooth implementation of the project.

(4) ACCELERATE TECHNOLOGICAL UPGRADING AND DIGITAL INTEGRATION

To promote technological progress in the aquaculture industry, the government should establish regional aquaculture innovation centers dedicated to research and development in key areas such as disease prevention, aquaculture techniques, and system optimization. Additionally, subsidies or matching funds should be provided to companies adopting advanced technologies such as recirculating aquaculture systems (RAS), smart monitoring devices, and blockchain-based traceability tools to lower the barriers to technology adoption and accelerate their widespread application. Furthermore, the government should establish national standards for aquaculture production data to promote data sharing and interoperability, thereby enhancing the accuracy and efficiency of risk monitoring.

(5) ADOPT AN INTEGRATED RISK MANAGEMENT FRAMEWORK

The government should encourage businesses to establish early warning systems based on PEST analysis, continuously monitor changes in the political, economic, social, and technological environment, and promptly adjust investment strategies. Additionally, risk adjustment factors should be incorporated into investment assessment models to comprehensively consider multi-dimensional uncertainties and resilience factors, thereby enhancing the scientific rigor of investment decisions. Furthermore, the government should promote the development of public-private partnerships (PPPs) in infrastructure-intensive aquaculture development zones, utilizing risk-sharing mechanisms to mitigate project risks and facilitate the smooth implementation and sustainable development of projects.

By promoting clearer regulations, financial innovation, community participation, and technological modernization, stakeholders can build more resilient and adaptive aquaculture systems. In the face of global environmental and socioeconomic challenges, these efforts are not only critical to project success but also contribute to promoting sustainable blue economic growth.

FUTURE RESEARCH DIRECTIONS

Although this study used the PEST framework to conduct a comprehensive analysis of aquaculture investment risks, there are still several areas for future exploration:

(1) Use scenario analysis or Monte Carlo simulation to quantitatively model risk probabilities and economic losses.

(2) Conduct cross-country comparisons to assess how risk profiles differ across different institutional and environmental contexts.

(3) Integrate ESG (environmental, social, and governance) frameworks to align risk control with global sustainability standards.

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DATA ACCESSIBILITY

The datasets generated and analyzed during the current study are available from the corresponding authors upon reasonable request.

CONFLICT OF INTEREST STATEMENT

The authors declare that this article was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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