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Original Research Articles

Construction and reflections on the disease prevention and control system of aquatic organisms based on management perspective

Cai-Yun Li[1], Xiao-Ai Li[2], Li Li[3], Yi-Chun Lou[4], Cheng-Song Yu[5], Hui-Ping Xu[6a], Tao Xu[2b]

[1] Jinan Vocational College, [2] General Station of Fishery Development and Resource Conservation in Shandong Province, [3] Shandong Institute of Land Spatial Data and Remote Sensing Technology, [4] Jinan Agricultural Technology Extension and Service Center, [5] Yushan City Marine and Fisheries Supervision and Inspection Brigade, [6] Laixi City of agriculture and rural affairs

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Disease prevention and control are a crucial aspect of fishery management, as they ensure the sustainability of aquacultural systems. With a specific focus on Shandong Province, China, this study outlines the occurrence of diseases in aquatic organisms. It summarizes dynamics that drive disease prevention and control and supports technology, work mode, and emergency prevention and control. In addition, this study also delves into the role of epidemic prevention and control institutions, the upgrading of the social service of disease prevention systems, and insufficient technical support for new species and models. Overall, the findings outlined in this study are intended to achieve the following aims: enhance organizational management of disease prevention and control, standardize the implementation of social services, improve research into prevention and control technologies, and highlight the importance of information technology in disease prevention and control. Based on practical aquaculture production, our aim is to comprehensively analyze the situation of the construction of a disease prevention and control system, strengthen guidance on epidemic prevention technologies, establish a robust animal epidemic prevention system, and propose development strategies, serving as a reference for competent authorities to enhance the disease prevention and control of aquatic organisms.

INTRODUCTION

Research on diseases of aquaculture animals in China started in the late 1950s and early 1960s. Prior to that, the focus was primarily on parasitic diseases, including protozoa, helminths, and crustaceans. The emphasis has shifted to other diseases in recent years. With the development of aquaculture, especially the rise of marine animal farming, the scope of disease research has expanded to include shrimp, crabs, shellfish, reptiles, amphibians, and other aquaculture species.[1] This research has largely focused on disease prevention and control in aquatic animals. After more than a decade of joint efforts, disease researchers and aquaculture workers have achieved remarkable results in the prevention and control of disease. Specifically, there has been an improvement in the creation of disease prevention and control systems.

Aquaculture disease prevention and control work is essential for ensuring the safety and stability of the industry, as well as the quality and safety of its products. It also supports and guarantees environmentally friendly production processes. On one hand, the fishery plays an increasingly prominent social role in the construction of a large food concept, the implementation of the rural revitalization strategy, and the stable production and supply of fish. This includes increasing the income of fishermen and other related aspects. Shandong Province is known for its specialization in aquaculture, with a workforce of 294,000 people. The province's per capita income of fishermen is 25,179.22 yuan, which is 7 percentage points higher than the national average. Additionally, diseases in aquatic organisms have become an increasingly prominent problem with aquaculture development. According to Aquatic Animal Health in China, in recent years, the direct economic losses caused by diseases in China's aquaculture industry are estimated at approximately RMB 50 billion annually (Data from Health in China). Diseases have prompted aquaculture practitioners to indiscriminately use medications for disease prevention, posing risks to aquatic products' quality, safety, and ecological and biological security.[2] Currently, diseases have

a Corresponding author. Hui-Ping Xu, E-mail:lxscj0532@163.com

b Corresponding author. Tao Xu, E-mail: xutao_78@126.com

become a significant bottleneck hindering the normal development of aquaculture, making disease prevention an urgent priority.

The issuance and implementation of the *Several Opinions on Accelerating the Environmentally Friendly Development of Aquaculture* by China have made environmentally friendly development a trend in industry growth and a focal point of societal concern. Under the development model of environmentally friendly and quality-oriented fishing, disease prevention and control will intertwine with various aspects of the industry chain, such as seedling breeding, feed nutrition, and environmental regulation. This integration further highlights its societal significance.

As a leading province in fisheries, Shandong began establishing key monitoring points for diseases in major aquaculture species and constructing institutions for aquatic animal disease prevention and control as early as 2000 (Grazieli et al., 2023). So far, the province has preliminarily formed a three-tiered network system for disease prevention and control of aquatic organisms across provincial, municipal, and county levels. This paper elaborates on the current status of the disease prevention and control system for aquatic organisms in Shandong Province. It provides development suggestions, aiming to offer guidance for disease prevention and healthy aquaculture in the province.

CATEGORY AND INCIDENCE OF DISEASE

CATEGORY OF DISEASE

In 2022, among the monitored dominant aquaculture species in the province, 24 diseases were identified. Bacterial diseases accounted for 50.00% of the cases, followed by diseases of unknown causes at 20.83%. Parasitic diseases, viral diseases, fungal diseases, and non-pathogenic diseases accounted for 12.50%, 8.33%, 4.17%, and 4.17% respectively(Data from Shandong Province Aquatic Animal Health Status Report 2022).

INCIDENCE OF DISEASE

June and July recorded a high incidence of aquaculture diseases, while fewer disease occurrences were observed in April and October. Bacterial diseases in freshwater fish peaked during the summer (Hetron et al., 2023). Among them, red-skin disease(*Pseudomonas fluorescens*), enteritis (*Aeromonas*), and bacterial septicemia(*Aeromonas hydrophila*) pose severe threats to the "four major cultured fish" (*Mylopharyngodon piceus, Hypophthalmichthys molitrix, Aristichys nobilis, and Ctenopharyngodon idella*). Among marine fish, *Cynoglossus semilaevis* mainly suffered from scuticociliatosis while *Scophthalmus maximus* was affected by vibriosis. Acute hepatopancreatic necrosis and vibriosis were prevalent in *Litopenaeus vannamei* and *Fenneropenaeus chinensis*, respectively, whereas exoskeletal disorders occurred in *Procambarus clarkii*. Ostreid herpesvirus was a significant threat during the breeding and cultivation periods of arcadioidea shellfish. *Stichopus japonicus* mainly faced ailments like swollen mouth disease and skin ulceration syndrome. Diseases prevalent among reptiles include turtle perforation disease and turtle ulceration disease (Purabi et al., 2021). Kelp seedlings were predominantly affected by algal hookworm infestation. Overall, diseases in some aquaculture species persist throughout the production process, evolving from single-pathogen infections to multiple-pathogen directions.

CURRENT STATUS OF AQUATIC ORGANISM DISEASE PREVENTION AND CONTROL SYSTEM IN SHANDONG PROVINCE

The aquatic organism disease prevention and control system in Shandong Province centers around regional aquatic organism safety. It integrates provincial, municipal, county, and enterprise resources, emphasizing proactive measures such as disease monitoring, inspection, quarantine, scientific research, technology dissemination, and emergency support. This integrated approach aims to establish a robust disease prevention and control network that ensures vertical and horizontal coordination, efficient operation, and effective safeguards.

ORGANIZATIONAL STRUCTURE FOR PREVENTION AND CONTROL

Sticking to the principle of "regional development with emphasis," the province has enhanced a four-tier aquatic animal disease diagnosis and treatment system, emphasizing coverage of key areas, real-time monitoring, and early warning. Disease monitoring systems have been established in key aquaculture areas across various prefectures, monitoring and reporting sites for dominant breeding species. The total coverage of the monitoring systems reached nearly 40,000 hectares.[3] Outstanding disease monitors and reporters were selected and assigned to over 400 key aquaculture enterprises and seedling centers across 114 fisheries counties (cities/districts), achieving complete coverage of priority regions and aquatic seedling farms.

Adhering to the principle of "collective action for prevention, creating a unified effort," the province has established an expert consultation system for aquatic animal disease prevention. Specifically, 30 experts were invited to form China's first provincial-level aquatic animal disease prevention and control committee. This committee comprises subgroups focusing on marine fish, freshwater fish, *Stichopus japonicus*, shrimps and crabs, and shellfish and algae. In addition, an "online" team of 11 provincial experts and 164 county-level experts in aquatic animal disease prevention and control was assembled. Disease monitoring and prevention initiatives were carried out across 104 counties (cities/districts). 10 prefectures and 48 counties (cities/districts) have established aquatic animal disease detection labs. Collaborative research and international exchanges on disease prevention and control techniques were conducted by 20 universities and institutes stationed in the province or owned by the province, such as the Yellow Sea Fisheries Research Institute and Shandong Freshwater Fisheries Research Institute. Expert committees and online teams pro-

vide technical support and guidance to laboratories to improve disease detection and diagnosis. The committees and online expert team collaborate to enhance the efficiency and effectiveness of disease control by exchanging experience and technology. Disease prevention and control committees, online expert teams, and disease detection laboratories are interdependent and mutually reinforcing. Together, they constitute an important force in aquaculture disease control.

THE FOUNDATION OF PREVENTION AND CONTROL

The province has printed and issued the *Shandong Provincial Trial Measures for Aquatic Seedling Quarantine at Origin* and developed an electronic certification system for this work. Creating the Yuyetong (literally Fishery Pass) information platform, integrating modules like Yudaifu (literally Doctor Fishery) and Precision Monitoring and Reporting, facilitated real-time data sharing among provincial, municipal, and county-level monitoring and reporting agencies. The province has also standardized protocols for disease monitoring and reporting. In addition, a framework for the disease standard system of fishery in Shandong was formulated, outlining the practical requirements for disease prevention and control standards. Besides, a compendium titled *Shandong Catalog of Aquaculture Disease Prevention and Control* has been compiled, summarizing over 80 common diseases and more than 200 disease maps. Moreover, disease control maps and a series of short Douyin educational videos on disease prevention and control techniques have been created for six major aquaculture species, including *S. japonicus* and *L. vannamei*.

SUPPORTING TECHNOLOGIES FOR PREVENTION AND CONTROL

Prioritizing the high-quality development of Shandong's aquaculture industry, over 100 innovative technologies, novel models, and new applications promoting environmentally friendly aquaculture development were consolidated from various fishery-related colleges, institutes, and key enterprises across the province. Manuals such as the *Handbook for Environmentally Friendly Development of Aquaculture: Shandong Provincial Scientific Research Innovations and Environmentally Friendly Development Practices* and the *Shandong Provincial Technical Guide for Aquatic Animal Disease Prevention and Control*, which guide the prevention and control of aquaculture animal diseases, were compiled. The "135" two-crop graded sequential aquaculture model for *L. vannamei* is to create a specialized workshop for roughening shrimp seedlings to a size of 1.5cm or larger before releasing them into the ponds. Inland freshwater aquaculture ponds have created a new culture mode. Indoor shrimp seedlings undergo desalination roughness for 10 days and are then moved into a shrimp fry temporary incubation greenhouse for 30 days of intermediate centralized cultivation. After intermediate temporary cultivation, the shrimp seedlings reach about 5cm and are distributed outside the pond for 50 days of aquaculture. It enables the cultivation of two crops per year and significantly reduces the risk of disease in pond culture, resulting in a survival rate of over 90%.[4] Techniques like the "Integrated High-Temperature Disaster Defense Technology for Pond Breeding of *S. japonicus*" have been established. This technology involves selecting anti-reverse and high-temperature resistant seedlings, using hierarchical culture methods, standardizing pond transformation, controlling the environment with micro-ecological preparations, and installing cold energy air suspension cooling devices with shade nets. The result is an integrated technology system that includes 'anti-reverse new varieties + environmental control + process optimization'. The model demonstrated a total area of 26,000 acres for integrating new varieties of antiretroviral drugs, environmental control, and process optimization with high-temperature disaster prevention and control technology, *r*aised average survival rates by 23%, and increased profitability by over 40%. Demonstrations of healthy breeding techniques for new oyster species, including expanding row and rope spacing and the use of polyethylene ecological floats, effectively enhanced survival rates and plumpness.

MODES OF PREVENTION AND CONTROL

Firstly, a "Three-Link-One-Delivery" working mechanism was established, achieving three interlocking aspects: the synchronization between disease monitoring and reporting and disease prevention and control; the collaborative governance between disease prevention and control institutions and experts; the linkage between industrial entities and the research system. This aims to promote the development of a working model emphasizing prevention as a priority, tracking services, and innovative applications. Secondly, seven provincial disease prevention and control service bases were established, extending services to grassroots promotion agencies for regionalized disease prevention and control technical services. Disease monitoring and warning technical services were carried out on a regional basis, and eco-friendly disease prevention and control technologies within the industry were summarized.[5] Thirdly, the province implemented localized services. A four-dimensional approach has been taken, including disease prevention and control services via mobile units, technical services at grassroots levels, expert disease prevention and control visits, and live-streamed training sessions on disease prevention and control techniques. The recipients of these services have expanded from solely aquaculture enterprises to cover grassroots technical promotion personnel, lab testing staff, and students from fisheries-related universities and institutes, broadening the scope of disease prevention and control services effectively.

EMERGENCY DISEASE PREVENTION AND CONTROL

The Shandong Provincial Emergency Plan for Typhoon Prevention issuance aims to establish and improve a responsive mechanism for fishery typhoon prevention, actively addressing typhoon disasters to minimize casualties and

property losses. Leveraging the role of the Provincial Committee of Aquatic Disease Prevention and Control, horizontal linkages have been established with innovative fisheries teams involved in *S. japonicus*, shrimps, and crabs. Meanwhile, vertical collaborations have been initiated to capitalize on the advantages of fishery technical promotion systems. New business entities were mobilized to jointly carry out disease detection and epidemiological investigations in key aquaculture areas, providing fundamental support for emergency disease prevention and control of key species. Furthermore, the province has established routine and emergency disease detection and prevention technical guidance services, directing focus on the occurrence and prevalence of six diseases, such as white spot syndrome and Enterocytozoon hepatorenal, during critical aquaculture periods.[9]

PROBLEMS IN SYSTEM CONSTRUCTION

INADEQUATE ROLE PLAYED BY EPIDEMIC PREVENTION AND CONTROL INSTITUTIONS

At the municipal and county levels, aquatic animal epidemic prevention and control institutions face challenges such as staff shortages, lack of technical expertise and training, unstable operational funding, and absence of specific tasks. These impede the effective functioning of lab testing capabilities and diminish their initiative and capacity for social services. Inadequate monitoring, early warning, prevention, and control of aquatic animal diseases directly impact disease transmission and cause serious economic losses.

SOCIALIZATION OF DISEASE PREVENTION AND CONTROL SYSTEMS NEEDS ENHANCEMENT

There is a lack of organized mechanisms for differentiated hierarchical prevention and control services at regional levels within the disease prevention and control system. Persisting contradictions involve both repetitive and insufficient services. The service system lacks linkage mechanisms with practitioners, requiring further expansion in the breadth and depth of technical dissemination. Irrational allocation of prevention and control resources can result in a waste of resources and reduced efficiency. Additionally, it is not conducive to long-term prevention and control of aquatic animal diseases, which can negatively impact the sustainable development of the fishery industry.

INSUFFICIENT TECHNICAL SUPPORT FOR NEW SPECIES AND MODELS

Disease prevention and control technologies primarily focus on traditional aquaculture species and models, with inadequate innovation in technical integration and relatively low standardization levels. Insufficient progress tracking in new species and models leads to a low application rate of disease prevention and control technologies. This may limit the effectiveness of disease prevention and control, increase the risk of disease outbreaks, hinder the further development of aquatic animal disease prevention and control technology, and affect the scientific and technological level of the entire industry.

SUGGESTIONS ON DEVELOPMENT

ENHANCE ORGANIZATIONAL MANAGEMENT OF DISEASE PREVENTION AND CONTROL

Strengthen monitoring and early warning systems in key aquaculture areas and establish a coordinated prevention and control system. Improve aquatic animal disease monitoring networks and emergency plans to ensure comprehensive monitoring of key aquaculture species in advantageous regions. Realize coordinated actions for disease prediction, assessment, scientific prevention, and emergency response. Solve the "last-mile" problem of disease prevention and control in aquaculture by incorporating new economic entities, such as professional cooperatives and family farms, into the construction of disease prevention and control systems. Leverage their role in collective and joint disease prevention and control, establishing a linkage and influence.

STANDARDIZE THE IMPLEMENTATION OF SOCIALIZED SERVICES

Establish a hierarchical and regional socialized service model led by competent fishery authorities. Coordinate multiple entities in academia, industry, research, and commerce to promote relevant work, forming a step-wise work mechanism of "demand + response" across counties, cities, and provinces.[10] Transform provincial-wide scattered social services into regional, targeted interventions. Through pond circulation and rural collective property rights reforms, the interest's linkage mechanism between professional cooperative societies and "enterprise + farmers is improved." This fosters their role as the foundation for mutual production assistance, demand collection and aggregation, and the point of origin for social service undertakings and expanded outreach.

RESEARCH AND APPLY KEY DISEASE PREVENTION AND CONTROL TECHNOLOGIES

Proactively track advanced models, development trends, and technology teams. Leverage intermediary organizations to connect universities, institutes, and industry entities, systematizing innovative research and demonstrating resistance-oriented excellent breeds, eco-friendly management modes, and aquaculture technologies. Summarize eco-healthy aquaculture models like integrated rice-fish culture, factory-scale recirculating aquaculture, and high-temperature summer cultivation of *S. japonicus*, creating typical cases and practices for eco-friendly disease prevention.[11] Establish the foundation for standardized support systems in fishery disease prevention and control, shifting the emphasis from drug dependency to compliance with disease prevention and control standards.

Table 1. Species monitored at the monitoring and reporting sites (2018–2022)

Year	Participation in Local Government	Number of measurement points	Measured varieties
2018	DongYing、BinZhou、WeiFang、JiNing、WeiHai、TanAn、LiaoCheng、LinYi、RiZhao、HeZe、YanTai 11 cities and 28 counties	484	Black carp、Grass carp、Silvercarp、bighead、Common carp、Goldfish、Pond loach、Rainbow trout、Snakehead、Tilapia、sturgeon、Redfin culter、Turbot、Bastard halibut、Tongue Sole、righteye flounders、Northern pike、Sea perch、Pufferfish、Snapper、Epinephelusspp、Whiteshrimp、kuruma prawn、Fenneropenaeus chinensis、Red Swamp Crayfish Chinese mitten crab、swimming crab、Scallop、Oyster、clam、Abalone、Tegillarca granosa、kelp、Sea mustard、Gracilaria、Soft-shell Turtle、sea cucumber
2019	DongYing、BinZhou、WeiFang、JiNing、WeiHai、ZaoZhuang、LiaoCheng、LinYi、RiZhao HeZe、YanTai、DeZhou 12 cities and 29 counties	488	Black carp、Grass carp、Silvercarp、bighead、Common carp、Goldfish、Pond loach、Silurus asotus、Aucha Perch、Snakehead、Tilapia、Northern pike、sea perch、Grouper、Snapper、Tongue Sole、Whiteshrimp、Fenneropenaeus chinensis、kuruma prawn、Penaeus monodon、Red Swamp Crayfish、Australian Spiny lobster、Chinese Mitten Crab、swimming crab、Scallop、Oyster、clam、kelp、Gracilaria、Soft-shell Turtle、sea cucumber
2020	DongYing、ZiBo、BinZhou、WeiFang、JiNing、TanAn、WeiHai、ZaoZhuang、LiaoCheng、LinYi、RiZhao、HeZe、YanTai、DeZhou 14 cities and 36 counties	451	Grass carp、Silvercarp、bighead、Common carp、Goldfish、Pond loach、Aucha Perch、Snakehead、Tilapia、sturgeon、Redfin culter、Northern pike、sea perch、Turbot、Bastard halibut、righteye flounders、Snapper、Tongue Sole、pufferfish、Korean rockfish、Litopenaeus vannamei、Fenneropenaeus chinensis、Penaeus japonicus、Red Swamp Crayfish、Chinese Mitten Crab、swimming crab、Oyster、Abalone、Scallop、clam、Lamarck、kelp、Gracilaria、Soft-shell Turtle、sea cucumber
2021	JiNan、ZiBo、ZaoZhuang、DongYing、YanTai、WeiFang、JiNing、TaiAn WeiHai、RiZhao、BinZhou、DeZhou、LiaoCheng、LinYi、HeZe 15 cities and 40 counties	475	Grass carp、Silvercarp、bighead、Common carp、Goldfish、Pond loach、Letalurus Punetaus、Amur catfish、Tilapia、sturgeon、Redfin culter、Northern pike、Turbot、Bastard halibut、pufferfish、righteye flounders、Snapper、Tongue Sole、Korean rockfish、Litopenaeus vannamei、Fenneropenaeus chinensis、Penaeus japonicus、Red Swamp Crayfish、Chinese Mitten Crab、swimming crab、Chinese Softshell、sea cucumber、Oyster、Abalone、Scallop、clam、lobster、Lamarck、kelp、Gracilaria
2022	JiNan、ZiBo、ZaoZhuang、DongYing、YanTai、WeiFang、	443	Grass carp、Silvercarp、bighead、Common carp、Goldfish、Pond loach、Letalurus Punetaus、Amur catfish、Aucha Perch、Tilapia、sturgeon、Redfin culter、Northern pike、Turbot、Bastard halibut、sea perch、pufferfish、Epinephelusspp、Snapper、Tongue Sole、Korean rockfish、Black Scraper、Litopenaeus vannamei、Fenneropenaeus chinensis、Penaeus japonicus、Red Swamp Crayfish、Chinese Mitten Crab、swimming crab、Chinese Softshell、

JiNing、TaiAn WeiHai、RiZhao、 BinZhou、DeZhou、 LiaoCheng、 LinYi、HeZe 15 cities and 44 counties	sea cucumber、Oyster、Abalone、Scallop、clam、kelp、Gracilaria

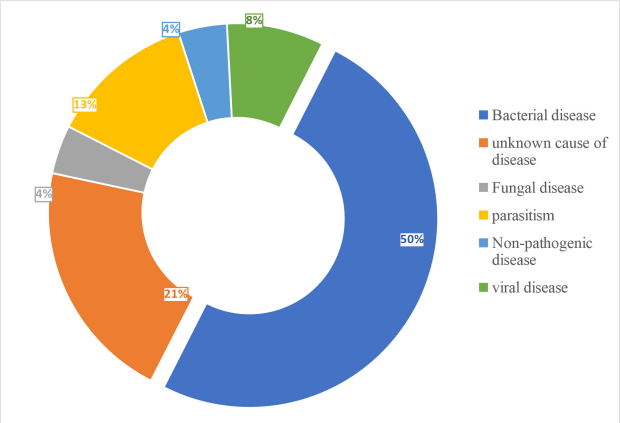

Figure 1. Proportion of aquatic animal diseases in 2022.

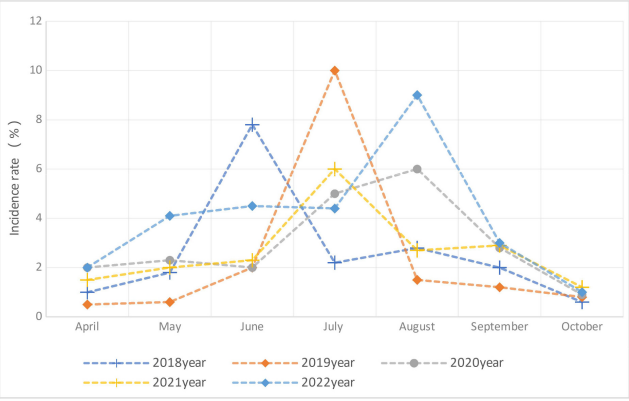

Figure 2. Average monthly disease incidence rates in fish (2018–2022)

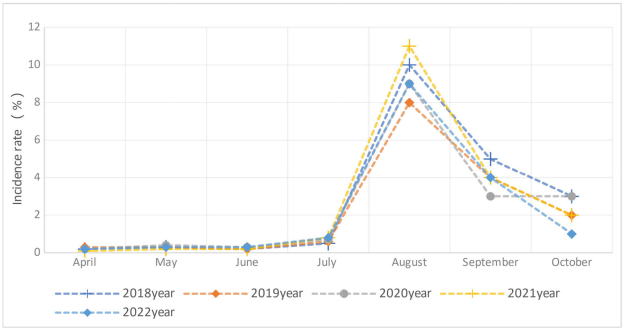

Figure 3. Average monthly disease incidence rates in *Stichopus japonicus* (2018–2022)

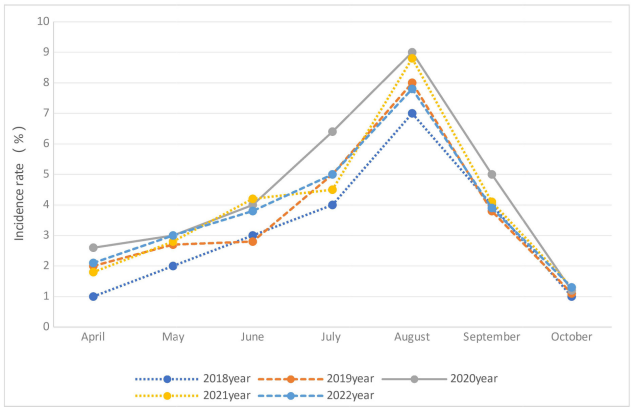

Figure 4. Average monthly disease incidence rates in shrimps (2018–2022)

LEVERAGE THE ADVANTAGES OF INFORMATION TECHNOLOGY FOR PREVENTION AND CONTROL

Establish a technical support platform for aquatic animal health supervision and management. Integrate information technology with inputs in aquaculture, disease monitoring, and quality safety, enabling aquaculture enterprises to monitor input, directly report diseases, record processes, and trace quality. Improve the construction of a self-diagnosis database for aquatic animal diseases, integrate disease series maps and cases for specific species and regions, and enhance the effectiveness of disease diagnosis, prevention, and control. Develop an "online" team of disease prevention and control experts, offering remote technical consultation services for aquaculture entities.[12] Produce informative videos on typical diseases, utilizing multiple channels, multimedia, and diverse platforms to enhance the comprehensibility and guidance of disease prevention and control.

UTILIZE THE FULL POTENTIAL OF THE ORGANIZATION

Aquatic technology extension agencies and other professional organizations should be used to enhance aquaculture personnel's training and technical guidance. This will improve their ability to prevent and control epidemics. Mobilize local and grassroots activism, clarify the responsibil-

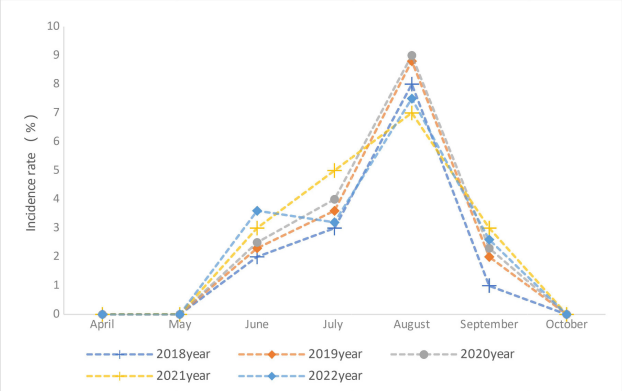

Figure 5. Average monthly disease incidence rates in crabs (2018–2022)

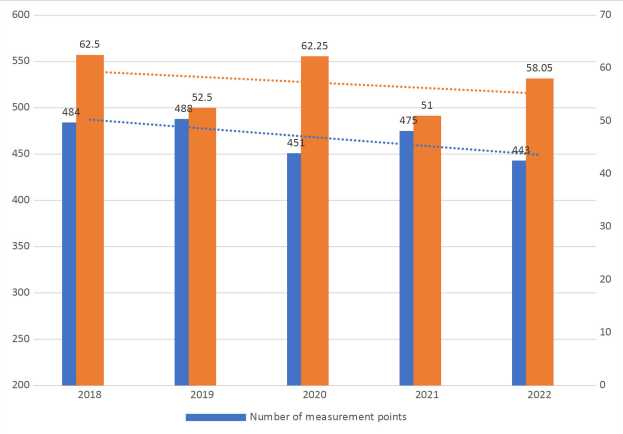

Figure 6. Number of disease monitoring and reporting sites (2018–2022)

ities and tasks of relevant units at the local level in the prevention and control of aquatic animal diseases, encourage grassroots aquaculture units and individuals to actively participate in prevention and control work, and provide necessary support and incentives. We propose integrating existing resources for aquatic animal disease monitoring, quarantine, and research to enhance resource integration and information sharing. This will improve the efficiency of resource utilization. An information-sharing platform will release real-time information on epidemics, prevention and control techniques, policies, and regulations. This will improve the transparency and timeliness of information.

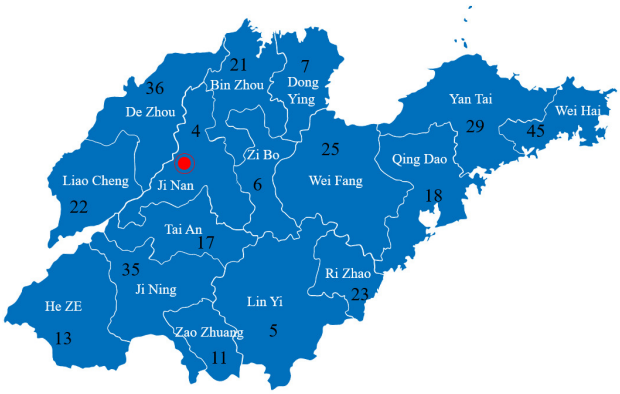

Figure 7. The distribution of disease Reporter across different cities in Shandong Province

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AUTHOR CONTRIBUTIONS

Data curation: Cai-Yun Li (Equal), Xiao-Ai Li (Equal), Li Li (Equal). Methodology: Cai-Yun Li (Equal), Hui-Ping Xu (Equal). Formal Analysis: Xiao-Ai Li (Lead). Investigation: Xiao-Ai Li (Lead). Writing – original draft: Xiao-Ai Li (Equal), Yi-Chun Lou (Equal). Supervision: Xiao-Ai Li (Equal), Tao Xu (Equal). Resources: Yi-Chun Lou (Lead). Writing – review & editing: Cheng-Song Yu, Tao Xu (Equal). Funding acquisition: Hui-Ping Xu (Lead). Conceptualization: Tao Xu (Lead).

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