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Analyzing the applicability of wetland ecological modes in the Minjiang Estuary wetland

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Wetlands are badly damaged in many parts of the world. The wetland management of Minjiang Estuary wetland has achieved remarkable results. This provides valuable experience for wetland management in other areas. Minjiang Estuary wetland can achieve the effect, mainly because of the adoption of the water quality management, ecological restoration, and ecological tourism development. However, different management modes have their own scope of application. In order to spread its successes, three differential game modes related to Minjiang Estuary wetland management are constructed, and their equilibrium results are compared and analyzed. Finally, research shows that the amount of water quality control by governments is directly proportional to the resilience of wetlands. The amount of social organization culture is proportional to the degree of better water quality. The amount of development by the government and social organizations is directly proportional to the decrease of investment in the spontaneous tourism industry. When the loss caused by flood or the ecological restoration effect is large, the wetland should adopt the ecological restoration mode. When the increased income or reputation of ecotourism is large, the ecotourism development mode should be adopted. This provides a reference for how to manage wetlands and how to promote the management mode of Minjiang Estuary wetland to other areas more effectively.

KEYWORDS

Minjiang Estuary, differential game, wetland management, different modes, social benefit

1 Introduction

Wetland is an important part of ecosystem, which has important ecological, economic and social value. However, many wetlands have suffered serious damage due to human activities (Tendar and Sridith, 2021). For the needs of human activities such as agriculture, urbanization and industrialization, many wetlands have been filled and reclaimed, leading to the disappearance and reduction of wetlands (Rashid et al., 2023).

With the development of industry and urbanization, many wetlands have been polluted, such as industrial wastewater and agricultural pollution (Anza et al., 2019). Due to the development and utilization of water resources, the water source of many wetlands is divided and cut off, which leads to the destruction of wetland ecosystem. At the same time, many wetland resources are over-exploited, leading to the imbalance and destruction of wetland ecosystem. Wetlands are seriously damaged, and it is necessary for the government and all sectors of society to work together to strengthen the protection of wetlands and prevent further destruction and disappearance of wetlands.

Minjiang Estuary wetland, located at the mouth of Minjiang River in Fuzhou, Fujian Province, is one of the important ecological protection areas in Fujian Province (Tao et al., 2015). The wetland is well protected, mainly in the following aspects: first, strong protection consciousness. The local government and all walks of life attach great importance to the protection of Minjiang Estuary wetland, constantly increase the input, strengthen the publicity of wetland protection, and improve the public awareness of protection. Second, the ecological environment is good. Minjiang Estuary wetland ecological environment is relatively good, the water is clear, the air is fresh, the ecosystem is complete, the biodiversity is rich. Third, ecological restoration measures have been improved: the local government and relevant departments have formulated a series of ecological restoration measures, such as setting up protected areas, strengthening inspection and monitoring, and prohibiting the destruction of wetlands. This can effectively restore the ecology of Minjiang Estuary wetland. Fourth, the development of ecotourism: The wetland ecotourism of Minjiang Estuary develops rapidly. Tourism income promotes the development of local economy, and also promotes the implementation of wetland protection. In short, the Minjiang Estuary wetland has been well protected, and has made positive contributions to the sustainable development of local society, economy and ecological environment.

The successful experience and practice of Minjiang Estuary wetland management provides useful reference for other wetland management, and is of great significance for the protection of global wetland ecological environment. However, different wetlands have their own unique characteristics. For example, wetland types, ecosystems, geographical locations, hydrological conditions, biodiversity, socio-cultural background and other aspects are different. The management mode of Minjiang Estuary wetland may not be completely suitable for the management of other areas. In order to learn from the management mode of Minjiang Estuary wetland more effectively, it is necessary to analyze the applicable scope of different wetland management modes. According to different wetland types and ecological environment to formulate corresponding protection and management measures.

Wetland ecosystem is very fragile and easily affected by many factors. Some scholars have studied the factors affecting these wetlands. For example, Guo et al. (2021) studied the effects of land use intensity, grazing, fire and other factors on wetland ecosystem. Bonetti et al. (2021) analyzed how viruses affect gas emissions in wetlands. Boone et al. (2022) studied how shrubs affect wildlife in wetlands. Hrach et al. (2022) studied how tree shade affects wetland ecosystems in the Canadian Rockies. These studies cover the main factors affecting wetland ecosystems.

Some scholars have studied how to analyze wetland ecosystem. Chen et al. (2021) analyzed how to use remote sensing technology and data modeling to analyze the water balance of wetland ecosystem. Lamb et al. (2021) studied the use of radar optics to map wetlands in the mid-Atlantic and Gulf Coast of the United States. Grotelueschen et al. (2021) used experimental and simulation methods to assess the impact of wetland management on rice in East Africa. These studies mainly analyze the wetland ecosystem from the perspectives of computer algorithm, technology and management.

In order to play the role of wetland ecosystem, it is necessary to manage wetland ecosystem effectively. Some scholars study how to manage wetland ecosystems. Bloomer et al. (2022) analyzed how to effectively manage crayfish and waterfowl in wetland ecosystems. Aung et al. (2021) analyzed how to develop policies to manage wetlands in Myanmar. Lin et al. (2021) studied how to control oxygen and temperature to effectively control rice paddy wetland. Liu (2021) used remote sensing technology and neural networks to analyze how to manage saline-alkali wetlands.

However, there are some research gaps in other scholarly studies. Firstly, the earth has the ability to repair itself, and decisions on wetland management are constantly changing. As a result, the status of wetland ecosystem is constantly changing. These studies do not paint a clear picture of this ongoing change. Secondly, while studies by other scholars have summarized suitable wetland governance models from the successful experiences of other wetlands, they have not analyzed the scope of application of different governance models. Only by analyzing the scope of application of different wetland governance models can the successful experience of wetland governance be popularized.

In order to make up for the shortcomings of the above studies, this paper uses a time-continuous differential game to analyze the wetland governance problem. Applying differential games to wetland governance problems has the following advantages. First, differential games can depict the dynamic evolution of wetland resources and the way participants make decisions over time, which helps to express the time-dependence of wetland systems and the continuity of participants' behaviors. Second, wetland governance usually involves multiple participants, such as government, farmers, and enterprises. Differential games can accurately simulate the interactive behaviors of these participants and analyze how various decisions affect each other. Third, in wetland governance, participants may react according to each other's behaviors, and differential games can capture such strategic interactions and help design cooperative mechanisms to improve overall social welfare (Wu and Zhang, 2022). Fourth, wetland ecosystems are complex, and differential games can help to understand the ecosystem's response to external shocks and thus develop more flexible and adaptive wetland governance methods. Applying differential games to the study of wetland governance can provide a comprehensive and in-depth analytical framework, which can help to coordinate the needs of various resource uses and conservation, and realize the sustainable management and long-term protection of wetland ecosystems. However, it should be noted that building accurate and effective differential game models requires rich data support and high level of mathematical and simulation skills.

Meanwhile, this paper draws on the successful experience of Minjiang Estuary wetland management in Fujian province. The successful experience of wetland management in Minjiang Estuary of Fujian Province has different applicability and influence on the judgment result in different regions. Here are some possible scenarios and implications. First, the geographical environment is different. Geographical differences in different regions may lead to different applicability of wetland management experience. For example, wetland topography, climate, hydrological conditions and other factors may have an impact on the implementation and effectiveness of wetland management programs. Therefore, when applying the experience of Minjiang Estuary wetland management in Fujian province to other areas, the local geographical environment should be fully considered. Second, social and economic background differences. The different socio-economic backgrounds of different regions may also affect the applicability of wetland management experience. For example, the successful experience of wetland management at the mouth of the Minjiang River in Fujian Province may have challenges in applicability in developing countries or economically underdeveloped regions. This is because these areas may face limited economic resources, insufficient technical capacity, and unstable social and political conditions, which may make it difficult to effectively implement and promote relevant wetland management measures. Third, manage objectives and resource priorities. The objectives and resource priorities of wetland management may also be different in different regions. The management objectives of the Minjiang Estuary wetland in Fujian Province may focus on ecological restoration and protection, while other areas may pay more attention to flood prevention and agricultural development. Therefore, when applying wetland management experience, it is necessary to determine the appropriate management objectives according to the specific conditions of the region and ensure the priority allocation of resources. In general, the successful experience of wetland management in the Minjiang Estuary of Fujian Province can provide reference for other regions, but it needs to take various local factors into consideration and adapt to local conditions. In the process of implementation, local geographical, social, economic and other characteristics should be considered to ensure that the selected wetland management measures are in line with local needs and conditions to achieve better results.

This paper divides the wetland management mode into three types: water quality management mode, ecological restoration mode and ecological tourism development mode. The balance results of different wetland management modes were compared and analyzed. Finally, the applicable scope of various wetland management modes is obtained. It provides theoretical basis for more effective management of wetland ecosystem.

2 Methodology

2.1 Problem description, hypothesis, and variable definition

2.1.1 Problem description

Minjiang Estuary Wetland is located in the Minjiang Estuary of Fuzhou City, Fujian Province. It is a wetland protection area with coastal salt marsh, intertidal zone, mangrove and sandy beach as its main landscape, and is also an important habitat for migratory birds and fish breeding ground. The Minjiang Estuary wetland covers an area of about 30 km^2, which is one of the largest mangrove wetlands in the east coast of China. There are seven wetland types including estuarine waters, intertidal beaches and mangrove swamps. The wetland park is dominated by estuarine shallows, consisting of eel beaches and surrounding intertidal and estuarine waters, which are formed by the siltation of sediment carried from upstream by the Minjiang River in Meihua Waterway. Fuzhou has an oceanic subtropical monsoon climate, with short winters and long summers throughout the year, warm and humid, with a frost-free period of 326 days, and an average annual sunshine of 1,700 to 1,980 hours; an average annual precipitation of 900 to 2,100 millimeters; and an average annual temperature of 16 to 20 degrees Celsius (Lai et al., 2023). In order to protect this precious wetland resource, Fuzhou Municipal government has established a nature reserve in the Minjiang Estuary wetland and taken a series of measures to protect and restore the wetland ecological environment, including:

(1) Water quality management mode. Wetlands are natural water purification systems, but if they are polluted, they need to be treated. Specific water quality control measures include several types. For example, artificial increase of wetland vegetation, increase wetland area, artificial ventilation, artificial increase of microorganisms, artificial increase of oxygen, etc. This measure has the advantages of nature, environmental protection, water conservation and treatment costs. However, this mode of governance requires a large amount of land, is susceptible to weather conditions, and its effectiveness is not stable. The impacts of anthropogenic activities when using the water quality management model in the wetland conservation and management process can be positive or negative, depending on the nature of these activities and the effectiveness of the management. The positive impacts of anthropogenic activities include the following. First, improved agricultural practices. By reducing the use of pesticides and fertilizers, as well as adopting organic agricultural practices, excess nutrient inputs (especially nitrogen and phosphorus) to wetlands can be reduced, which in turn can positively impact water quality. Second, wastewater treatment upgrades. Construction and upgrading of wastewater treatment facilities can effectively remove harmful substances from wastewater and reduce pollution pressure on wetlands. Third, forest and buffer zone construction. Planting trees and establishing buffer strips around wetlands can filter and absorb pollutants to protect wetland water quality (Chen et al., 2021).

Fourth, watershed management. Adopting watershed management strategies, such as controlling upstream pollution sources and rationally planning land use, can reduce negative impacts on downstream wetlands. The negative impacts of anthropogenic activities mainly include the following aspects. First, over-development and land use change. For example, industrialization, urbanization and intensive agriculture may lead to excessive nutrient and pollutant inputs into wetlands and deteriorate water quality. Second, drainage and disturbance. Changes in wetland drainage and hydrologic conditions may reduce the ability of wetlands to treat pollutants, thus affecting water quality. Third, illegal discharge. Industrial and domestic wastewater is directly discharged into the wetland without treatment, which can seriously affect the water quality of the wetland. Fourth, tourism and recreational activities. If not properly managed, high-intensity tourism and recreational activities may lead to eutrophication of water bodies, littering problems and disturbance of wildlife habitats. Taken together, to ensure that water quality in wetlands is well managed, appropriate anthropogenic activities need to be designed and implemented through scientific planning and integrated multi-stakeholder efforts. This often includes enforcement of laws and regulations, public education and participation, and ongoing monitoring and management.

(2) Ecological restoration mode. The main purpose of this mode is to restore wetland ecosystems. For example, the restoration and reconstruction of wetland ecosystem can be promoted by increasing vegetation, restoring hydrological conditions and improving soil quality (Magnússon et al., 2021). At the same time, this mode can also restore wetland soil. For example, through biological remediation, chemical remediation and other ways to reduce the content of harmful substances in wetland soil, improve soil fertility. Wetlands buffer floods and mitigate their effects. Restoring and rebuilding wetlands can improve flood protection in areas. When adopting the ecological restoration model in the process of wetland protection and management, anthropogenic activities can bring the following positive impacts on the protection and management of wetlands. First, biodiversity restoration. By introducing locally planted species and restoring the structure of wetland biological communities, the natural stability of the ecosystem and its ability to resist diseases and pests can be enhanced. Second, re-establishment of hydrological cycle. By repairing water conservancy facilities such as dams and embankments, or redirecting water flow, the original hydrological cycle of the wetland can be restored and the wetland environment can be improved. Third, soil improvement. Restore the organic matter content and structure of wetland soil to improve habitat conditions, which is beneficial to plant growth and water purification. Fourth, discharge load management. Controlling and managing the pollutant loads entering the wetland can reduce the environmental pressure on the wetland. Fifth, environmental monitoring. Through regular monitoring of ecological changes and water quality conditions in wetlands, possible environmental problems can be detected and responded to in a timely manner. When the ecological restoration model is used in the process of wetland protection and management, anthropogenic activities can have the following negative impacts on wetland protection and management. First, excessive restoration. If the restoration work does not fully consider the natural conditions and ecological characteristics of the wetland, it may lead to the disruption of the ecological balance, for example, the excessive introduction of non-native species may lead to the problem of invasive species. Second, anthropogenic interference. If the restoration process is not managed properly, a large number of anthropogenic activities may disturb the wetland ecology, e.g., the use of heavy machinery may destroy the soil structure and plant and animal habitats. Third, maintenance and management problems. If there is no proper maintenance and management after ecological restoration, the wetland may be degraded back to its original damaged state (Liu, 2021). To summarize, ecological restoration requires careful planning and scientific management to ensure that anthropogenic activities bring positive rather than negative impacts to the protection and management of wetlands. The positive effects of anthropogenic activities can be maximized and the sustainable conservation and utilization of wetlands can be achieved through in-depth study of the ecological processes of wetlands, rational formulation of restoration plans, strengthening of supervision and management during project implementation, and ensuring continuous management and support after restoration.

(3) Ecotourism development mode. This mode mainly uses wetland resources, develops ecological tourism, promotes local economic development, and improves the social influence of wetland protection. Wetland ecotourism development can promote the development of local economy, increase employment opportunities and improve the living standards of local people. Wetland ecotourism development can also enrich tourism products, provide tourists with unique tourism experience and improve tourism attraction. Thus promoting the sustainable development of ecotourism. In the process of wetland protection and management, the adoption of the ecotourism development model may bring two-fold impacts. Its positive impacts mainly include the following aspects. First, environmental education and awareness enhancement. Ecotourism can provide a platform for tourists to enhance their awareness of the value of wetland ecosystems and the importance of conservation. Through interpreters' presentations, educational activities and displays, tourists can learn about ecological conservation. Second, economic incentives. Ecotourism provides an economic mechanism to incentivize local communities to participate in wetland conservation by generating employment opportunities and income, thereby reducing destructive economic activities (e.g., overfishing, agricultural development, etc.) on wetlands. Third, resource inputs. Tourism revenues can be reinvested into wetland conservation and management to improve the infrastructure of protected areas and enhance conservation capacity. Its positive impacts mainly include the following aspects. First, ecological damage. If poorly managed, the influx of tourists may cause disturbance and damage to the vegetation, soil and wildlife of the wetland, including trampling, garbage problems, noise pollution and so on. Second, overuse of resources. The construction of facilities (e.g., trails, viewing platforms, lodging facilities) and daily operations (e.g., water and energy use) may put pressure on wetland resources. Third, management challenges. Effective planning and management are needed to limit the number of visitors, regulate their behavior, and

ensure the sustainability of ecotourism activities (You et al., 2022). In summary, ecotourism development models can have positive impacts on wetland conservation and management, but proper management and control tools are needed to circumvent potential negative impacts. Sustainable ecotourism can be developed by planning reasonable visitor capacity, establishing environmental education programs, guaranteeing environmental monitoring and scientific research excavation, and reinforcing the behavioral norms of tourists, so as to achieve a balance between wetland conservation and rational use.

In the process of wetland management, water quality management, ecological restoration and eco-tourism development are three different management modes, which are interconnected and influence each other. The following are the main relationships between these three modes. First, water quality management is the foundation for ensuring a healthy wetland ecosystem. The water quality of a wetland area directly affects its biodiversity, ecological structure and function, including the removal of harmful substances, nutrient cycling and microbial activity. Effective implementation of water quality management provides the basis for wetland ecological restoration and can maintain wetland landscapes, thus creating conditions for ecotourism. Secondly, ecological restoration aims to repair and rebuild the ecosystems of damaged or degraded wetlands in order to restore their natural functions and biodiversity. Ecological restoration projects often rely on good water quality management as a prerequisite, while successful ecological restoration projects can improve the ability of wetlands to purify water quality, creating a positive cycle. At the same time, ecological restoration helps to enhance the tourism attractiveness of wetlands, making them quality locations for ecotourism. Thirdly, ecotourism refers to tourism activities that develop and utilize natural resources without destroying the environment (You et al., 2022). The development of ecotourism can raise public awareness of the importance of wetlands and public consciousness to support wetland conservation, thus providing social and economic support for water quality management and ecological restoration of wetlands. However, ecotourism, if not properly managed, may also put pressure on the wetland environment, and thus needs to be closely integrated with water quality management and ecological restoration to ensure the sustainability of tourism activities. In summary, these three models should be complementary and mutually supportive. An ideal wetland management strategy would integrate these three aspects to achieve sustainable utilization and conservation of wetlands.

The relationship between the three wetland management modes is shown in Figure 1.

2.1.2 Hypothesis

(1) Wetlands have a certain ability to self-repair

Wetland ecosystem is a complex biodiversity system, which contains a variety of vegetation, animals and microorganisms. The biological populations and species in wetland system depend on each other, forming a relatively stable ecological balance. When a wetland is disturbed or damaged by external factors, such as overdevelopment, pollution, water level changes, etc., the self-healing ability of the wetland will be activated and begin to operate. Here are some examples of the self-healing capabilities that wetlands have: First, the ability to restore vegetation. Wetland vegetation has the ability of rapid growth, reproduction and regeneration. When vegetation is damaged, the seed bank and root system in wetland can quickly recover and spread, fill the

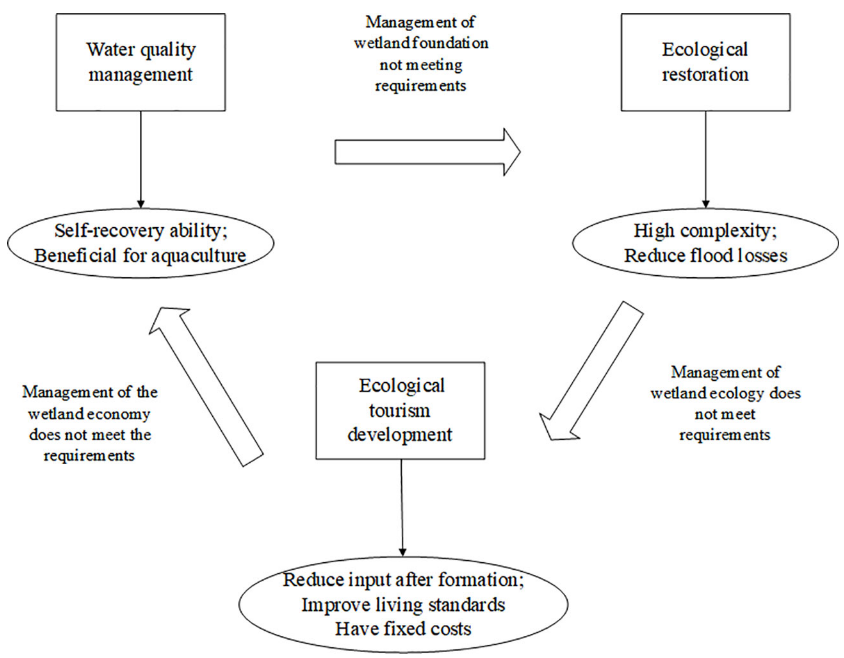

FIGURE 1
Relationship between these three modes of wetland management.

damaged part, and restore the ecological function of wetland vegetation. Second, water self-purification ability. Wetlands have a certain self-purification ability, and plants and microorganisms in the water can absorb and degrade harmful substances and purify the water. Wetlands can play a role in filtering and absorbing pollutants to improve water quality. Third, biogeographic processes. There is a complex interaction between animal community and environment in wetland. When wetlands are destroyed, some animal populations may suffer, but other species with adaptive abilities may take up the slack and restore the balance of animal communities. Fourth, soil retention capacity. The vegetation and root structure of the wetland can effectively fix the soil, reduce soil erosion and sediment deposition, and thus maintain the topographic and geomorphic characteristics of the wetland. However, wetlands are also limited in their ability to repair themselves, especially when faced with large-scale destruction and constant stress. In order to protect wetland ecosystems, effective conservation and management measures need to be taken, including limiting development, reducing pollution, and maintaining normal water levels. The involvement of the government and the public, as well as the support of scientific research, is also crucial to protect and restore the ecological functions of wetlands.Wetland management decisions are constantly changing.

(2) Investment will be reduced after the formation of wetland tourism

The development of wetland tourism can bring economic benefits and employment opportunities, and attract more tourists to spend money. With the gradual maturity of wetland tourism market, investment of government and social organizations can be gradually reduced. First of all, the rapid development of wetland tourism will drive the development of related industries, including hotels, catering, transportation and so on. The growth of these industries will lead to an increase in tax revenue, thereby reducing the financial pressure on the government. In addition, wetland tourism can also attract foreign tourists to come and spend, increase the total income of tourism, and further improve the local economic conditions. Secondly, the development of wetland tourism will create a lot of job opportunities. The increase in the number of tourists will promote the development of tourism-related enterprises, requiring more employees to engage in tour guides, hotel services, scenic area management and other work. These new jobs can reduce local unemployment and reduce government spending on employment assistance. Finally, with the increasing competition in the wetland tourism market, tourism enterprises will pay more attention to improving service quality and saving costs. The government can achieve more stable and sustainable development by reducing direct investment in wetland tourism and encouraging enterprises to innovate and improve efficiency. To sum up, the formation and development of wetland tourism will reduce investment of government and social organizations to a certain extent. However, it should be noted that the government still plays an important role in the regulation and planning of wetland tourism to ensure the sustainable use of wetland resources and environmental protection.

(3) The difficulty of wetland ecological restoration mode is more complex, and the difficulty is the highest.

Wetland restoration modes can be very complex and are often considered to be one of the most difficult ecological restoration tasks. The following are some of the main reasons leading to the difficulty of wetland ecological restoration. First, complex biodiversity. A wetland is a highly complex ecosystem containing a variety of plant, animal and microbial communities. There are intricate interactions and dependencies between different species, so diversity restoration and balance need to be taken into account. Second, the ecological functions of wetlands. Wetlands serve multiple ecological functions, such as water purification, habitat for species, and risk mitigation (such as floods and hurricanes). To restore the ecological function of wetland, various factors should be considered comprehensively to ensure that it can assume the original ecological role. Third, the complexity of hydrological conditions. Water is one of the core elements of wetland ecosystem. Restoring wetland hydrological conditions may involve adjustments in water volume, level and flow, but these adjustments must be based on detailed understanding and modeling of the wetland. Fourth, restoration cost and time: Wetland ecological restoration requires considerable economic and time investment. The restoration process is usually a long-term task, requiring long periods of monitoring and management, and often with limited funds. Fifth, the lack of a complete repair mode. Due to the complexity and diversity of wetlands, there is no universal restoration mode that applies to all wetlands. Each wetland has unique characteristics and challenges, so each restoration plan needs to be carefully researched and customized. In the face of these challenges, wetland ecological restoration requires interdisciplinary research and cooperation, integrating expertise and technology from multiple fields such as ecology, hydrology, and soil science. At the same time, it is also very important to strengthen monitoring and evaluation work and continuously improve repair strategies and methods.

2.1.3 Variable definition

When constructing the differential game model in this article, many parameters and variables are designed. These parameters and variables are defined as shown in Table 1.

2.2 Differential game of three wetland management modes

Differential game has the goal of optimizing the independence and conflict of each player, and can finally obtain the strategy of each player evolving over time and reach the Nash equilibrium. At present, the differential game it is mainly applied in the fields of advertising decision (Viscolani and Zaccour, 2009), logistics management (Bai et al., 2022), supply chain (Zhu et al., 2021), etc. Forest pests and diseases are constantly changing with the change of climate. At the same time, forest pests and diseases will be constantly changed by the governance decisions of governments

TABLE 1 The main definition of variables and parameters in this article.

Variables and parameters	Specific meaning
Y={W,B,T}	three wetland management modes (water quality management, ecological restoration, ecological tourism development)
Independent variable	
$F_{Y1}(t)$	government control degree under wetland management mode Y
$F_{Y2}(t)$	the control degree of social organizations under wetland management mode Y
$B_{W2}(t)$	the amount of aquaculture invested by social organizations under the water quality management mode
$x_{Y1}(t)$	the reputation of the government under the wetland management mode Y
$x_{Y2}(t)$	the reputation of social organizations under wetland management mode Y
Parameter	
ρ	the discount rate occurring over time, $0\leq\rho\leq1$
δ	decay of reputation, $\delta>0$
a_F	income obtained per unit amount of wetland treatment, $a_F>0$
a_B	the income generated per unit of breeding input, $a_B>0$
a_T	income increased by unit tourism investment, $a_T>0$
c_F	cost per unit of wetland management degree, $c_F>0$
c_B	unit cost of farming, $c_B>0$
c_1	the amount of damage per unit of flood, $c_1>0$
C_T	the cost of ecological tourism development in the early stage, $C_T>0$
l	the positive impact of the organization's reputation, $l>0$
α_W	the positive effect of the unit degree of self-resilience of wetlands, $\alpha_W>0$
α_r	positive effects of better water quality on aquaculture, $\alpha_r>0$
β	correlation coefficient of the positive effect of ecological restoration on flood, $\beta>0$
r_W	the degree to which the water quality has improved, $r_W>0$
r_B	the difficulty coefficient of ecological restoration, $r_B>0$
r_T	reduced government input due to the spontaneous formation of tourism industry, $r_T>0$
b_F	the positive reputational impact of wetland management, $b_F>0$
b_B	adverse effects of farming on the reputation of social organizations, $b_B>0$
b_{FT}	the social prestige that the improvement of people's living standard increases, $b_{FT}>0$
b_{FB}	impact coefficient of ecological restoration on flood reduction, $b_{FB}>0$

(Continued)

TABLE 1 Continued

Variables and parameters	Specific meaning
Parameter	
I_F	self-healing capacity of wetlands, $I_F>0$
Function	
$J_{Y1}(t)$	the government's social welfare function under wetland management mode Y
$J_{Y2}(t)$	social welfare function of social organization under wetland management mode Y
$V_{Y1}(t)$	social benefits of the government under wetland management mode Y
$V_{Y2}(t)$	social benefits of social organizations under wetland management mode Y

and social forces. In order to describe this change clearly, this article uses differential game to study forest pest management.

Under the water quality management mode, the social welfare functions of the government and social organizations are as Equation 1 and Equation 2:

$$J_{W1} = \int_0^{\infty} \left[a_F F_{W1}(t) - \frac{c_F}{2\ln(e+\alpha_W I_{F1})} F_{W1}^2(t) + l x_{W1}(t) \right] e^{-\rho t} dt \quad (1)$$

$$J_{W2} = \int_0^{\infty} [a_F F_{W2}(t) - \frac{c_F}{2} F_{W2}^2(t) + a_B(1+\alpha_r r_W) B_{W2}(t) - \frac{c_B}{2} B_{W2}^2(t) + l x_{W2}(t)] e^{-\rho t} dt \quad (2)$$

In the above formula, $a_F F_{W1}(t)$ represents the benefits the government gains from cleaning up the water quality of wetlands. $\frac{c_F}{2\ln(e+\alpha_W I_{F1})} F_{W1}^2(t)$ represents the cost of government's treatment of wetland water quality. $l x_{W1}(t)$ represents the positive impact of reputation on government. $\ln(e+\alpha_W I_{F1})$ represents the reduced investment in water quality management due to the self-recovery ability of wetlands. $a_F F_{W2}(t)$ represents the benefits gained by social organizations to control the water quality of wetlands. $\frac{c_F}{2} F_{W2}^2(t)$ represents the management cost of wetland water quality by social organizations. $a_B(1+\alpha_r r_W) B_{W2}(t)$ represents the income from breeding. $\frac{c_B}{2} B_{W2}^2(t)$ represents the cost of farming. $l x_{W2}(t)$ represents the positive influence of reputation on social organization.

Changes in the reputation of the government and social organizations can be expressed as Equation 3 and Equation 4:

$$\dot{x}_{W1}(t) = b_F F_{W1}(t) - \delta x_{W1}(t) \quad (3)$$

$$\dot{x}_{W2}(t) = b_F F_{W2}(t) - b_B B_{W2}(t) - \delta x_{W2}(t) \quad (4)$$

In the above formula, $b_F F_{W1}(t)$ represents the increased reputation of the government for water management. $\delta x_{W1}(t)$ represents the decline in the government's reputation. $b_F F_{W2}(t)$ represents the increased reputation of social organizations for water quality management. $\delta x_{W2}(t)$ represents a decline in the reputation of social organizations. $b_B B_{W2}(t)$ represents decrease in reputation as a result of farming.

Under the ecological restoration mode, the social welfare functions of the government and social organizations are as Equation 5 and Equation 6:

$$J_{B1} = \int_0^{\infty} \left[a_F F_{B1}(t) - \frac{c_F(1+r_B)}{2} F_{B1}^2(t) + l x_{B1}(t)\right] e^{-\rho t} dt \quad (5)$$

$$J_{B2} = \int_0^{\infty} [a_F F_{B2}(t) - \frac{c_F(1+r_B)}{2} F_{B2}(t) - \frac{c_1}{\beta F_{B2}(t)} + l x_{B2}(t)] e^{-\rho t} dt \quad (6)$$

In the above formula, $a_F F_{B1}(t)$ represents the revenue the government receives from ecological restoration of wetlands. $\frac{c_F(1+r_B)}{2} F_{B1}^2(t)$ represents the cost to the government of ecological restoration of wetlands. $l x_{B1}(t)$ represents the positive influence of reputation on government under ecological restoration mode. The social welfare function of the government under ecological restoration mode is different from that under water resource management. This is because the above hypothesis assumes that the water quality of wetlands has the ability of self-recovery, and the complexity of ecological restoration mode is the highest among the three modes. Therefore, under the same governance degree, the unit cost of wetland management under the water resources management and governance mode is divided by the parameters related to wetland restoration. However, the cost of governance in the ecological restoration mode needs to be multiplied by the parameters related to governance difficulty. $a_F F_{B2}(t)$ represents the income from ecological restoration of wetland by social organizations. $\frac{c_F(1+r_B)}{2} F_{B2}(t)$ represents the cost of ecological restoration by social organizations. $l x_{B2}(t)$ represents the positive influence of reputation on social organization under ecological restoration mode. $\frac{c_1}{\beta F_{B2}(t)}$ represents the damage caused by the flood. The social welfare function of the social organization under the ecological restoration mode is different from that under the water resources management. This is mainly because under good water quality conditions, social organizations will increase investment in aquaculture. Ecological restoration plays a positive role in reducing flood losses. Therefore, under the water quality management mode, the government's social welfare function involves the cost and benefit of aquaculture. Under the ecological restoration mode, the government's social welfare function involves flood related benefits.

Changes in the reputation of the government and social organizations can be expressed as Equation 7 and Equation 8:

$$\dot{x}_{B1}(t) = (b_F + b_{FB}) F_{B1}(t) - \delta x_{B1}(t) \quad (7)$$

$$\dot{x}_{B2}(t) = b_F F_{B2}(t) - \delta x_{B2}(t) \quad (8)$$

In the above formula, $(b_F + b_{FB}) F_{B1}(t)$ represents the increased reputation of the government for ecological restoration. $\delta x_{B1}(t)$ represents the decline of the government's reputation. $b_{FB} F_{B1}(t)$ represents an increased reputation for ecological restoration to reduce flooding. $\delta x_{W2}(t)$ represents a decline in the reputation of social organizations. The reputation of the government and social organizations under the ecological restoration mode is different from that under the water resources management. This is mainly because the ecological restoration mode can reduce the flooding, and the government will increase the reputation of flood management. On the other hand, under the water resources management mode, aquaculture by social organizations may lead to environmental damage, which will have a negative impact on the reputation of social organizations.

Under the mode of ecotourism development, the social welfare functions of the government and social organizations are as Equation 9 and Equation 10:

$$J_{T1} = \int_0^{\infty} [a_F F_{T1}(t) - \frac{c_F(1-r_T)}{2} F_{T1}^2(t) - C_{T1} + l x_{T1}(t)]\, e^{-\rho t} dt \quad (9)$$

$$J_{T2} = \int_0^{\infty} [a_F F_{T2}(t) - \frac{c_F(1-r_T)}{2} F_{T2}^2(t) - C_{T2} + a_T F_{T2}(t) + l x_{T2}(t)]\, e^{-\rho t} dt \quad (10)$$

In the above formula, $a_F F_{T1}(t)$ represents the income obtained by the government from ecological tourism development of wetland. $\frac{c_F(1-r_T)}{2} F_{T1}^2(t)$ represents the cost of ecotourism development. C_{T1} is the fixed cost of the government's upfront investment. $l x_{T1}(t)$ represents the positive influence of reputation on the government under the ecotourism development mode. $a_F F_{T2}(t)$ represents the benefits of environmental improvement. $a_T F_{T2}(t)$ represents the income from tourism. $\frac{c_F(1-r_T)}{2} F_{T2}^2(t)$ represents the cost of ecotourism development by social organizations. C_{T2} represents the fixed cost of early input of social organization. $l x_{T2}(t)$ represents the positive influence of reputation on social organizations under the mode of ecotourism development.

According to hypothesis 2, when wetland tourism is formed, the investment of government and social organizations will decrease. Therefore, compared with the previous two wetland management modes, the cost of government and social organizations in this mode will be reduced. However, this reduction in investment is predicated on the fact that the ecotourism development mode has certain upfront fixed costs. Therefore, the ecotourism development mode has one more upfront fixed cost than the previous two modes.

Changes in the reputation of the government and social organizations can be expressed as Equation 11 and Equation 12:

$$\dot{x}_{T1}(t) = (b_F + b_{FT}) F_{T1}(t) - \delta x_{T1}(t) \quad (11)$$

$$\dot{x}_{T2}(t) = b_F F_{T2}(t) - \delta x_{T2}(t) \quad (12)$$

In the above formula, $(b_F + b_{FT}) F_{T1}(t)$ represents the increased reputation of the government for ecotourism development. $\delta x_{T1}(t)$ represents the decline of the government's reputation. $b_{FT} F_{T1}(t)$ represents increased reputation for promoting the local economy, increasing employment opportunities and improving the living standards of local people. $b_F F_{T2}(t)$ represents the reputation of social organizations increased by ecotourism development. $\delta x_{T2}(t)$ represents the decay of the reputation of social organizations under the mode of ecotourism development. Different from the previous two modes, under the ecotourism development mode, the government can improve the income and living standards of local residents. Therefore, under this mode, the government will gain some reputation for improving the living standards of its residents.

3 Results

In the differential game, the social welfare of government and social forces when forest pests and diseases occur is not only affected by control variables and parameters, but also changes over time. In order to better calculate the amount of control and social benefits, the HJB (Hamilton-Jacobi-Bellman) formula is adopted. HJB formula is a partial differential equation, which is the core of optimal control.

In the problem of selecting the optimal mode of Minjiang Estuary wetland, we hope to find the optimal strategy under different conditions to maximize the social utility function of a mode. To achieve this goal, we introduce a function *V*(t, x) that represents the optimal value for state *x* at time *t*. The HJB equation describes the evolution of this function. It can be written in the following form: After subtracting a tiny time step dt from the optimal value *V*(*t*, *x*) at time *t*, it is equal to the minimization operation on the value of control variable *u*, that is, to find the *u* that minimizes the optimal value *V*(*t*+*dt*, *f*(*t*, *x*, *u*)) at the next time within the range of the value of control variable *u*. Add it to the immediate utility function *L*(*t*, *x*, *u*, *V*(*t*+*dt*, *f*(*t*, *x*, *u*)), which equals 0. This equation can be understood as, at each time *t*, we consider all possible control strategies *u* and calculate the state and optimal value at the next time after using each control strategy, and then choose the control strategy that makes the optimal value at the next time minimum. By iteratively solving this equation, we can gradually determine the optimal control strategy to maximize the utility function of the system.

The logical relationship between these equations is mainly as follows. The state equation describes the dynamic behavior of the system; the objective function specifies the goal that the participants want to achieve; the Hamiltonian contains the system dynamics and performance indicators; in order to find the optimal control, the participants need to derive the covariance equation based on the Hamiltonian function and the state equation, and apply the principle of minimization to determine the optimal policy (Zhou et al., 2022). This is an interdependent and simultaneous problem.

3.1 HJB formula

Under the water quality management mode, the HJB equation of the social welfare function of the government and social organizations as Equation 13 and Equation 14:

$$\rho V_{W1} = \max_{F_{W1}(t)}\left\{\left[a_F F_{W1}(t) - \frac{c_F}{2\ln(e+\alpha_W I_{F1})}F_{W1}^2(t) + l x_{W1}(t)\right] + \frac{\partial V_{W1}}{\partial x_{W1}}\left[b_F F_{W1}(t) - \delta x_{W1}(t)\right]\right\} \tag{13}$$

$$\begin{aligned}\rho V_{W2} = \max_{F_{W2}(t),B_{W2}(t)}&\left\{\left[a_F F_{W2}(t) - \frac{c_F}{2}F_{W2}^2(t) + a_B(1+\alpha_r r_W)B_{W2}(t) - \frac{c_B}{2}B_{W2}^2(t) + l x_{W2}(t)\right]\right.\\ &\left.+\frac{\partial V_{W2}}{\partial x_{W2}}\left[b_F F_{W2}(t) - b_B B_{W2}(t) - \delta x_{W2}(t)\right]\right\}\end{aligned} \tag{14}$$

Under the ecological restoration management mode, the HJB equation of the social welfare function of the government and social organizations as Equation 15 and Equation 16:

$$\rho V_{B1} = \max_{F_{B1}(t)}\left\{\left[a_F F_{B1}(t) - \frac{c_F(1+r_B)}{2}F_{B1}^2(t) + l x_{B1}(t)\right] + \frac{\partial V_{B1}}{\partial x_{B1}}\left[(b_F + b_{FB})F_{B1}(t) - \delta x_{B1}(t)\right]\right\} \tag{15}$$

$$\rho V_{B2} = \max_{F_{B2}(t)}\left\{\left[a_F F_{B2}(t) - \frac{c_F(1+r_B)}{2}F_{B2}(t) - \frac{c_1}{\beta F_{B2}(t)} + l x_{B2}(t)\right] + \frac{\partial V_{B2}}{\partial x_{B2}}\left[b_F F_{B2}(t) - \delta x_{B2}(t)\right]\right\} \tag{16}$$

Under the mode of ecotourism development, the HJB equation of the social welfare function of the government and social organizations as Equation 17 and Equation 18:

$$\rho V_{T1} = \max_{F_{T1}(t)}\left\{\left[a_F F_{T1}(t) - \frac{c_F(1-r_T)}{2}F_{T1}^2(t) - C_{T1} + l x_{T1}(t)\right] + \frac{\partial V_{T1}}{\partial x_{T1}}\left[(b_F + b_{FT})F_{T1}(t) - \delta x_{T1}(t)\right]\right\} \tag{17}$$

$$\rho V_{T2} = \max_{F_{T2}(t)}\left\{\left[a_F F_{T2}(t) - \frac{c_F(1-r_T)}{2}F_{T2}^2(t) - C_{T2} + a_T F_{T2}(t) + l x_{T2}(t)\right] + \frac{\partial V_{T2}}{\partial x_{T2}}\left[b_F F_{T2}(t) - \delta x_{T2}(t)\right]\right\} \tag{18}$$

3.2 Result of equilibrium

Proposition 1: Under the water quality management mode, the governance quantity and social benefits of government and social organizations are respectively (the specific solving procedure is shown in Appendix 1) Equations 19–22:

$$tF_{W1}^{*}(t) = \frac{1}{c_F}\left(a_F + b_F\frac{l}{\rho+\delta}\right)\ln(e+\alpha_W I_{F1}) \tag{19}$$

$$tF_{W2}^{*}(t) = \frac{1}{c_F}\left(a_F + b_F\frac{l}{\rho+\delta}\right) \tag{20}$$

$$tB_{W2}^{*}(t) = \frac{1}{c_B}\left[a_B(1+\alpha_r r_W) - b_B\frac{l}{\rho+\delta}\right] \tag{21}$$

$$\begin{aligned}V_{W1}^{*} = &\tfrac{l}{\rho+\delta}x_{W1} + \tfrac{1}{\rho}a_F\tfrac{1}{c_F}\left(a_F + b_F\tfrac{l}{\rho+\delta}\right)\ln(e+\alpha_W I_{F1}) - \tfrac{1}{2}\tfrac{1}{\rho}\tfrac{1}{c_F}\left(a_F + b_F\tfrac{l}{\rho+\delta}\right)^2\ln(e+\alpha_W I_{F1})\\ &+\tfrac{1}{\rho}\tfrac{l}{\rho+\delta}b_F\tfrac{1}{c_F}(a_F + b_F\tfrac{l}{\rho+\delta})\ln(e+\alpha_W I_{F1})\end{aligned} \tag{22}$$

$$\begin{aligned}V_{W2}^{*} = &\tfrac{l}{\rho+\delta}x_{W2} - \tfrac{1}{\rho}\tfrac{1}{2}\tfrac{1}{c_F}\left(a_F + b_F\tfrac{l}{\rho+\delta}\right)^2 + \tfrac{1}{\rho}a_B(1+\alpha_r r_W)\tfrac{1}{c_B}\left[a_B(1+\alpha_r r_W) - b_B\tfrac{l}{\rho+\delta}\right]\\ &+\tfrac{1}{\rho}a_F\tfrac{1}{c_F}\left(a_F + b_F\tfrac{l}{\rho+\delta}\right) - \tfrac{1}{2}\tfrac{1}{\rho}\tfrac{1}{c_B}\left[a_B(1+\alpha_r r_W) - b_B\tfrac{l}{\rho+\delta}\right]^2\\ &+\tfrac{1}{\rho}\tfrac{l}{\rho+\delta}\left[b_F\tfrac{1}{c_F}\left(a_F + b_F\tfrac{l}{\rho+\delta}\right) - b_B\tfrac{1}{c_B}a_B(1+\alpha_r r_W) + b_B\tfrac{1}{c_B}b_B\tfrac{l}{\rho+\delta}\right]\end{aligned} \tag{23}$$

Conclusion 1: The amount of water quality control of wetland by the government is proportional to the restoration ability of wetland. At the same time, it is directly proportional to the income obtained by the unit governance, and inversely proportional to the unit governance cost. The amount of breeding in social organizations is directly proportional to the degree of better water quality. At the same time, it is proportional to the income per unit of breeding degree, and inversely proportional to breeding cost.

Proposition 2: Under the ecological restoration mode, the governance quantity and social benefits of government and social organizations are respectively (the specific solving procedure is shown in Appendix 2) Equations 23–26:

$$F_{B1}^{\star}(t) = \frac{a_F + (b_F + b_{FB})\frac{l}{\rho+\delta}}{c_F(1 + r_B)} \tag{24}$$

$$F_{B2}^{\star}(t) = \left(\frac{c_1}{\beta}\right)^{\frac{1}{2}}\left[\frac{c_F(1 + r_B)}{2} - a_F - \frac{l}{\rho + \delta}b_F\right]^{-\frac{1}{2}} \tag{25}$$

$$\begin{aligned} V_{B1}^{\star} = {} & \frac{l}{\rho+\delta}x_{B1} + \frac{1}{\rho}a_F\frac{a_F+(b_F+b_{FB})\frac{l}{\rho+\delta}}{c_F(1+r_B)} - \frac{1}{2}\frac{1}{\rho}\frac{\left[a_F+(b_F+b_{FB})\frac{l}{\rho+\delta}\right]^2}{c_F(1+r_B)} \\ & + \frac{1}{\rho}\frac{l}{\rho+\delta}(b_F + b_{FB})\frac{a_F+(b_F+b_{FB})\frac{l}{\rho+\delta}}{c_F(1+r_B)} \end{aligned} \tag{26}$$

$$\begin{aligned} V_{B2}^{\star} = {} & \frac{l}{\rho+\delta}x_{B2} + \frac{1}{\rho}a_F\left(\frac{c_1}{\beta}\right)^{\frac{1}{2}}\left[\frac{c_F(1+r_B)}{2} - a_F - \frac{l}{\rho+\delta}b_F\right]^{-\frac{1}{2}} - \left[\frac{c_F(1+r_B)}{2} - a_F - \frac{l}{\rho+\delta}b_F\right]^{-\frac{1}{2}} \\ & \frac{1}{\rho}\frac{c_F(1+r_B)}{2}\left(\frac{c_1}{\beta}\right)^{\frac{1}{2}} - \frac{1}{\rho}\frac{c_1}{\beta}\left(\frac{c_1}{\beta}\right)^{-\frac{1}{2}}\left[\frac{c_F(1+r_B)}{2} - a_F - \frac{l}{\rho+\delta}b_F\right]^{\frac{1}{2}} \\ & + \frac{1}{\rho}b_F\left(\frac{c_1}{\beta}\right)^{\frac{1}{2}}\left[\frac{c_F(1+r_B)}{2} - a_F - \frac{l}{\rho+\delta}b_F\right]^{-\frac{1}{2}}\frac{l}{\rho+\delta} \end{aligned} \tag{27}$$

Conclusion 2: Under the ecological restoration mode, the amount of wetland ecological restoration by the government is proportional to the degree of flood reduction caused by the restoration. At the same time, it is directly proportional to the benefits of ecological restoration and inversely proportional to the unit restoration cost. The amount of ecological restoration of social organizations is proportional to the losses caused by floods. Meanwhile, it is inversely proportional to the difficulty and cost of ecological restoration.

Proposition 3: Under the ecotourism development mode, the governance quantity and social benefits of government and social organizations are respectively (the specific solving procedure is shown in Appendix 3) Equations 27–30:

$$F_{T1}^{\star}(t) = \frac{a_F + (b_F + b_{FT})\frac{l}{\rho+\delta}}{c_F(1 - r_T)} \tag{28}$$

$$F_{T2}^{\star}(t) = \frac{a_F + a_T + b_F\frac{l}{\rho+\delta}}{c_F(1 - r_T)} \tag{29}$$

$$\begin{aligned} V_{T1}^{\star} = {} & \frac{l}{\rho+\delta}x_{T1} + \frac{1}{\rho}a_F\frac{a_F+(b_F+b_{FT})\frac{l}{\rho+\delta}}{c_F(1-r_T)} - \frac{1}{2}\frac{1}{\rho}\frac{\left[a_F+(b_F+b_{FT})\frac{l}{\rho+\delta}\right]^2}{c_F(1-r_T)} - \frac{1}{\rho}C_{T1} \\ & + \frac{1}{\rho}\frac{l}{\rho+\delta}(b_F + b_{FT})\frac{a_F+(b_F+b_{FT})\frac{l}{\rho+\delta}}{c_F(1-r_T)} \end{aligned} \tag{30}$$

$$\begin{aligned} V_{T2}^{\star} = {} & \frac{l}{\rho+\delta}x_{T2} + \frac{1}{\rho}a_F\frac{a_F+a_T+b_F\frac{l}{\rho+\delta}}{c_F(1-r_T)} - \frac{1}{2}\frac{1}{\rho}\frac{\left[a_F+a_T+b_F\frac{l}{\rho+\delta}\right]^2}{c_F(1-r_T)} - \frac{1}{\rho}C_{T2} \\ & + \frac{1}{\rho}a_T\frac{a_F+a_T+b_F\frac{l}{\rho+\delta}}{c_F(1-r_T)} + \frac{1}{\rho}b_F\frac{a_F+a_T+b_F\frac{l}{\rho+\delta}}{c_F(1-r_T)}\frac{l}{\rho+\delta} \end{aligned} \tag{31}$$

Conclusion 3: Under the ecotourism development mode, the amount of development by the government and social organizations is proportional to the reduced investment caused by the spontaneous formation of the tourism industry. The amount of tourism the government develops is directly proportional to the increased reputation of the people as a result of the improvement of their living standards. The amount of development of social organizations is proportional to the increased income from tourism investment.

3.3 Numerical analysis

In order to describe the change of social utility of government and social organization in more detail, numerical analysis is used in this article. Parameter values are usually estimated based on existing theoretical knowledge and literature studies. Given initial parameter values, a sensitivity analysis is performed to assess the effect of parameter changes on the model. If the model is very sensitive to certain parameters, then these parameters must be set very carefully and may need to be supported by more accurate data.

The discounting rate ρ over time is 0.9. The discount rate is greater than 0 and less than 1. It is mainly determined by the proximity of time and risk-based considerations. The discount rate is used to measure the present value of future cash flows, which, according to the principle of time value, decrease in value over time. Therefore, the discount rate is generally less than 1 to reflect the discount effect of cash flows. The discount rate is also affected by risk factors. Generally, people demand a higher rate of return on investments or cash flows that are risky. Therefore, the higher the risk, the higher the discount rate, and vice versa.

Reputation decay rate δ is 0.1. This is based on the time factor and the degree of trust. The decay of reputation usually occurs gradually over time. If the reputation decay rate is 0.1, it means that the reputation will decrease by 10% every certain period of time. This decay rate may be based on past experience or industry conventions. Reputation is based on trust, and the degree of trust people have in an individual or organization may decrease over time. By setting the reputation decay rate, it can take into account that people. This is based on the time factor and the degree of trust. The decay of reputation usually occurs gradually over time. If the reputation decay rate is 0.1, it means that the reputation will decrease by 10% every certain period of time. This decay rate may be based on past experience or industry conventions. Reputation is based on trust, and the degree of trust people have in an individual or organization may decrease over time. By setting the reputation decay rate, it can take into account that people may give lower weight to past reputation over time.

It is a common situation that the cost of wetland management is relatively low and the benefit of wetland management is relatively high. The cost of wetland management includes the costs required for the protection, restoration and management of wetlands, such as vegetation restoration, water resource management and ecological monitoring. The benefit of wetland management includes the provision of ecosystem services and the creation of economic value. When the cost of wetland management is relatively low, it is easier to implement management measures to protect and restore the wetland ecosystem. The relatively high benefit of wetland management means that the wetland management can obtain greater returns (Lv et al., 2022). In this case, the cost of wetland management is less than the benefit of wetland management, which is beneficial to the sustainable development of society, economy and ecological environment in the long run. Therefore, the cost c_F paid by unit wetland management degree is 2. The unit cost c_B of breeding is 2. The income a_F obtained by unit wetland management degree is 3.

It is a common situation that the cost of wetland management is relatively low and the benefit of wetland management is relatively high. The cost of wetland management includes the costs required for the protection, restoration and management of wetlands, such as vegetation restoration, water resource management and ecological monitoring. The benefit of wetland management includes the provision of ecosystem services and the creation of economic value. When the cost of wetland management is relatively low, it is easier to implement management measures to protect and restore the wetland ecosystem. The relatively high benefit of wetland management means that the wetland management can obtain greater returns (Bi et al., 2022). In this case, the cost of wetland management is less than the benefit of wetland management, which is beneficial to the sustainable development of society, economy and ecological environment in the long run. Therefore, the correlation coefficient of the positive effect of ecological restoration on flood is smaller than that of the positive effect of the self-recovery capacity of wetland unit and water quality improvement on aquaculture. Therefore, the positive effect of unit degree of self-recovery ability of wetland α_W is 2. The positive effect α_r of improved water quality on

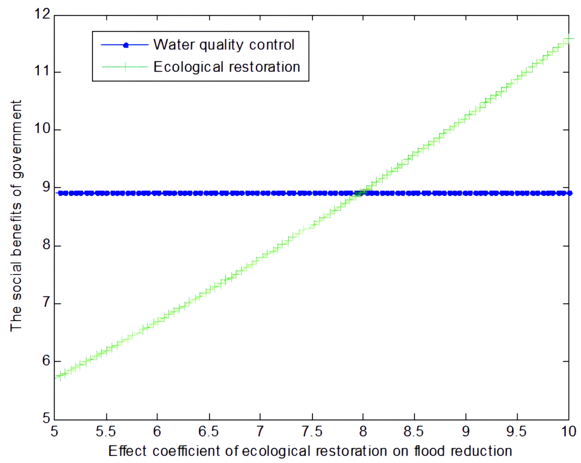

FIGURE 2
The impact of reduced flooding on government revenues due to ecological restoration.

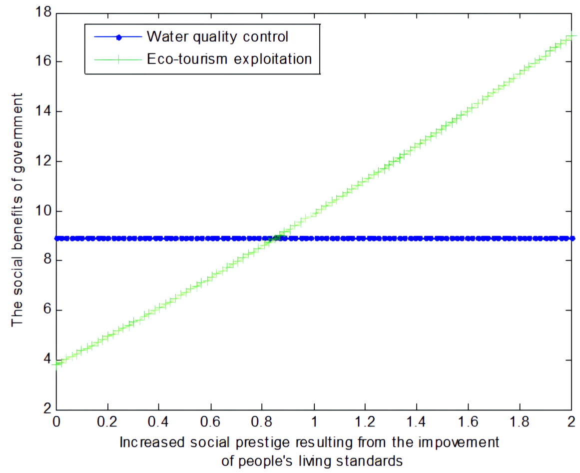

FIGURE 3
The effect of prestige on the government's social benefits.

culture is 2. The correlation coefficient β of the positive effect of ecological restoration on flood is 1.

The initial cost of ecotourism development is usually large. The development process of ecotourism involves many aspects of investment and expenses, such as infrastructure construction costs, ecological protection and restoration costs, publicity and promotion costs, personnel training and management costs, environmental monitoring and protection costs. It should be noted that although the initial cost of ecotourism development is large, with the development of tourism and the increase of passenger flow, ecotourism can also produce considerable economic and social benefits (You et al., 2022). As the activity matures and stabilizes, it can gradually recover costs and reap long-term benefits. Therefore, the cost C_T of ecotourism development in the early stage is 10. The government decreased input r_T due to the spontaneous formation of tourism industry is 0.5.

In general, the restoration of entire ecosystems is more difficult than simply improving water quality. Therefore, the water quality improvement r_W is 1.5. The difficulty coefficient r_B of ecological restoration is 5. Environmental protection is very important to social organizations. If the wetland is cultivated, it will destroy the ecological environment. Thus, the reputation of social organizations is affected to some extent. The positive influence l brought by unit reputation is 1. The negative impact b_B of farming on the reputation of social organizations is 1.5.

Flooding is a common problem around wetlands. This is because wetlands are often located near bodies of water such as rivers, lakes, and swamps. These bodies of water can cause flooding when there is too much rainfall or when the snow melts. If the damage caused by flooding is greater than the benefit of breeding, then there is no need to breed. Therefore, the yield a_B for each unit of breeding input is 5. The loss of c_1 per unit level of flood is 4. The positive impact b_F of wetland management on reputation is 2. The resilience of wetlands is very poor. The self-recovery ability I_F of wetland is 0.2.

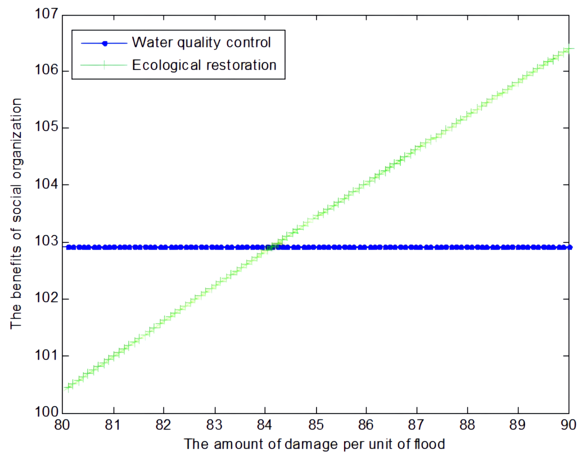

FIGURE 4
The impact of unit flood damage on the benefits of social organization.

Therefore, this article can calculate Equations 31–33:

$$V^{*}_{W1} = 8.92 \tag{32}$$

$$V^{*}_{B1} = 1 + 0.047(5 + b_{FB})^{2} \tag{33}$$

$$V^{*}_{T1} = -10.11 + (5 + b_{FT})(2.78 + 0.55b_{FT}) \tag{34}$$

The following graph (named Figures 2, 3) can also be produced:

Conclusion 4: When the flood is less affected by ecological restoration, the water quality control of wetlands can obtain greater benefits. However, as the flood is more and more affected by ecological restoration, the ecological restoration of wetlands can achieve better results.

Conclusion 5: When the improvement of people's living standard increases the reputation of the government, the government can get more benefits for wetland water quality control. With the improvement of people's living standards and the increase of the government's reputation, the government can obtain greater benefits for the development of wetland ecotourism. This article can also calculate Equations 34–37:

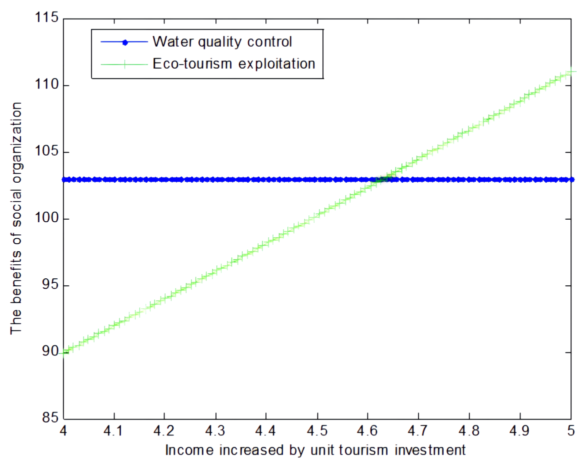

FIGURE 5
Impact of the income from the unit tourism investment on the benefits of social organization.

$$V^{*}_{W2} = 102.91 \tag{35}$$

$$V^{*}_{B2} = 1 + 11.11c_{1}^{\frac{1}{2}} \tag{36}$$

$$V^{*}_{T2} = 1.11(5 + a_{T})^{2} \tag{37}$$

The following graph (named Figures 4, 5) can also be produced:

Conclusion 6: When the loss caused by flood to social organization is small, social organization can get more benefits in water quality control. With the increase of losses caused by flood to social organization, the ecological restoration of social organization can obtain greater benefits.

Conclusion 7: When the income increased by the unit tourism investment is small, social organization can obtain greater benefits in water quality management. However, with the increase of income from the unit tourism investment, social organization can obtain greater benefits in ecotourism development.

4 Discussion

Due to the influence of human activities and natural factors for a long time, the ecological environment of Minjiang Estuary wetland has been seriously damaged and its ecological function has been degraded day by day. In order to protect and restore the ecological environment of Minjiang Estuary wetland, Fuzhou Municipal government has taken a series of measures to strengthen water quality management, ecological restoration and ecological tourism development, and achieved certain results. The management mode of Minjiang Estuary wetland in Fujian province can be used as a reference for other damaged wetlands around the world. However, the specific situation of wetland ecological environment in each place is different. In the process of promoting the Minjiang Estuary wetland management mode, it is necessary to consider the local situation. Therefore, this paper builds a differential game mode of water quality management, ecological restoration and ecotourism development, and makes a comparative analysis of the equilibrium results to obtain the applicable scope of various wetland management modes. It provides a theoretical basis for the successful promotion of Minjiang Estuary wetland management mode in the world.

According to conclusion 1, the amount of governmental treatment of wetland water quality is directly proportional to the restoration capacity of the wetland. At the same time, it is directly proportional to the benefit per unit of treatment and inversely proportional to the cost per unit of treatment. Water quality control is an important part of wetland restoration. Only through water quality control can we reduce the pressure of wetland ecosystem and improve the resilience of wetland. On the one hand, the government's treatment of wetland water quality can reduce pollutants in wetland water, improve water quality, and enhance the stability and recovery ability of wetland ecosystem (Ban et al., 2021). This is different from the research of Messer et al. (2021). Messer et al. (2021) believes wetlands play an important role in improving water quality. This is mainly because his method is mainly experimental, through which the role of wetlands in improving water resources can be obtained. This paper mainly analyzes the significance of water resources improvement to wetland ecological environment and aquaculture through modeling. The situation in conclusion 1 is mainly due to the fact that decisions on wetland management are usually influenced by the following factors. First, the self-purification and restoration capacity of a wetland refers to the ability of a wetland to treat and absorb pollutants, including physical, chemical and biological processes. A wetland system with a high natural resilience may be able to remove pollutants more effectively through its own biogeological processes, reducing the difficulty and cost of treatment. Therefore, the amount of wetland treatment is often preferred to be invested in wetlands with high resilience in order to maximize the benefits of treatment. Second, the benefits per unit of treatment reflect the economic and ecological benefits obtained from treating a wetland. This may include improved water quality, increased biodiversity, enhanced recreational value and possible carbon sink benefits. The greater the benefits of wetland management, the greater the willingness of the government and the society to invest, and thus they are often willing to invest more resources in wetland management. Thirdly, the cost of governance includes direct financial expenditure as well as other social and ecological costs that may arise during the governance process (Jiang et al., 2023). If the unit cost of governance is high, it may weaken the incentive to govern, especially when resources are limited. Therefore, ensuring that governance costs are kept under control is a key factor in ensuring that wetland governance can be carried out. Taken together, an ideal wetland governance strategy should be able to effectively match the natural resilience of the wetland and ensure that each unit of input to governance brings maximum benefits and is financially viable. In other words, policy makers will often consider the restoration capacity of the wetland and the cost-benefit ratio of the management to determine the priority of the management and the allocation of resources, so as to make effective use of the resources and achieve a balance between wetland protection and socio-economic activities.

Meanwhile, according to conclusion 1, the amount of socially organized farming is directly proportional to the degree of water quality improvement. Also, it is directly proportional to the income per unit of farming volume and inversely proportional to the cost of farming. When the amount of social organization aquaculture increases, its pollutant emissions will increase accordingly, such as organic matter in aquaculture wastewater, nitrogen, phosphorus, etc. If these pollutants cannot be properly treated, they will cause pollution to the water, destroy the water ecological environment, and affect the survival and reproduction of aquatic organisms. On the contrary, when the amount of breeding in social organizations is reduced, the amount of pollutants produced will be reduced accordingly, which is conducive to the improvement of water quality and the restoration of ecological environment. By adopting scientific and reasonable aquaculture management measures, such as establishing reasonable aquaculture density, strengthening feed management, and adopting ecological aquaculture, social organizations can effectively control the discharge of pollutants in aquaculture wastewater, reduce the negative impact on water environment, and improve the degree of water quality. Therefore, the amount of breeding in social organizations is proportional to the degree of better water quality, which shows that the aquaculture industry should pay attention to environmental protection while developing, take effective measures to reduce the discharge of pollutants, protect the water ecological environment, and achieve sustainable development. This is different from the studies on the water quality parameters of freshwater fish, freshwater prawn, marine fish and marine prawn (Ziemann et al., 2010). They believe that in each category, the concentration of most water quality parameters is lognormally distributed and spans one to two orders of magnitude. This is mainly because the wetlands studied in this paper are heavily polluted wetlands, and this level of pollution is not conducive to aquaculture. Ziemann et al. (2010) mainly studies areas with less water pollution. In less polluted water, it may mean that there is not enough plankton, benthic organisms or suspended particulate matter in the water, which are the food resources on which the fish depend. The situation in conclusion 1 is mainly due to the fact that decisions on wetland management are usually influenced by the following factors. First, the scale of socially organized aquaculture activities is dependent on water quality conditions. Ideal water quality is conducive to the health and growth of aquatic organisms and therefore supports larger scale aquaculture activities. If aquaculture activities involve filtering aquatic organisms, such as certain shellfish or plants, these species can improve water quality through their physiological processes (e.g., by reducing suspended solids and nutrients in the water), which in turn can support larger farming volumes. Therefore, when farming aquatic products, social organizations tend to prefer wetlands with better water quality, or invest resources in the farming process to improve water quality and increase the scale and sustainability of farming. Second, the income generated per unit of aquaculture volume characterizes the economic efficiency of aquaculture activities. Higher levels of income can provide stronger economic incentives for social organizations to expand the scale of farming or improve farming techniques in order to increase production and yields (Bloomer et al., 2022). Higher incomes likewise mean that more resources are available for management of farmed waters and water quality improvement, which in turn can support more farming activities. Thirdly, aquaculture costs refer to the various expenditures required in the aquaculture process, including the costs of aquaculture facilities, feeds, labor, and water quality management. If the cost of farming is too high, it will reduce the profit margin of the farming industry and inhibit the expansion of farming scale. Therefore, when deciding on the scale of aquaculture activities, social organizations are bound to consider the cost factor and select those wetlands where aquaculture can be carried out under cost-controllable and economically efficient water quality conditions. In this case, social organizations need to assess and balance the water quality conditions, the benefits of aquaculture activities and the corresponding costs when considering the expansion of aquaculture scale. Through measures such as increasing farming efficiency, improving water quality management, and reducing operating costs, the overall profitability of the farming industry can be enhanced, while the increase in scale can be realized with the support of the environment. Reflected at the level of wetland management, this implies the need to develop policies and measures that promote the economic development of social organizations while focusing on ecological protection and the sustainable improvement of water quality.

This paper next explains conclusion 3. Ecotourism has many advantages, including protecting the ecological environment, promoting social and economic development, and improving people's quality of life. There are several reasons why ecotourism development should be strengthened when the increased revenue from ecotourism is greater. First, to promote economic development. The development of ecotourism can promote the development of local economy, increase the income of local residents and improve the living standard of local residents. When the income of ecotourism increases, the attraction and competitiveness of ecotourism can be further enhanced by measures such as increasing investment and improving service quality, so as to attract more tourists, increase tourism income and drive the development of local economy. Second, protect the ecological environment. Strengthening ecotourism development can promote the protection and restoration of local ecological environment. Through the development of ecotourism, people can be encouraged to protect the ecological environment, reduce the consumption and destruction of natural resources, and protect the stability and sustainability of the ecosystem (Sierra et al., 2021). Third, raise public awareness. The development of ecotourism can improve the public's awareness and understanding of the ecological environment, enhance people's awareness of environmental protection, promote people's protection and attention to the ecological environment, so as to promote the sustainable development of the society. In conclusion, when ecotourism gains more revenue, the development of ecotourism should be strengthened, which cannot only promote economic development, but also protect the ecological environment, raise public awareness and achieve the goal of sustainable development. But some studies hold a different view. Lonn et al. (2018) believe that ecotourism cannot achieve the goal of reducing poverty and improving livelihoods of local residents. This is mainly due to the following reasons. First, inadequate infrastructure: Some ecotourism areas in Cambodia have inadequate infrastructure, such as transportation, accommodation, sanitation facilities, etc. This affects the tourists' travel experience, making ecotourism less attractive and competitive. Second, lack of promotion and marketing. Many potential tourists may not know that Cambodia has rich ecotourism resources or have limited knowledge of the country's ecotourism options. Lack of publicity and promotional activities limits the development and attractiveness of ecotourism. Third, environmental issues and sustainable development challenges. Over-development and improper management may lead to the destruction of ecosystems, destroying the originality and beauty of tourism resources. This may reduce tourists' interest and affect the sustainability and long-term development of ecotourism. Fourth, inadequate education and training. Cambodia may face inadequate education and training, lacking opportunities to provide practitioners with the necessary training and expertise. Fifth, social and political factors. Issues such as the instability of government policies, social instability and corruption may limit the development of ecotourism and affect the willingness to invest and cooperate. In order to solve these problems, Cambodia can take the following measures: improve infrastructure construction and enhance the level of tourism services; strengthen the promotion and marketing of ecotourism to enhance visibility; formulate and implement environmental protection policies and sustainable development strategies; strengthen relevant education and training; improve the social and political environment to enhance the reliability of investment and cooperation. In this way, more revenue and sustainable development opportunities can be created for Cambodia's ecotourism.

The reason why the government's investment in wetland development is directly proportional to the spontaneous reduction of tourism investment is that the government's investment and policy will affect the development of wetland and tourism. First of all, government investment will affect the development of wetlands. The government's development policies and financial support for wetlands will have an impact on the utilization and development of wetlands. If the government is limited in the amount of wetland development, then developers will be forced to reduce the development of wetlands, thus reducing the destruction of wetlands. Secondly, the government's investment will also affect the development of tourism. Government's policy and investment in tourism will have an impact on the development of tourism. If government investment in tourism is reduced, the development of tourism will be limited, thus reducing the number of visitors to and damage to wetlands (Dushani et al., 2021). Therefore, the amount of wetland development by the government is directly proportional to the spontaneous reduction of tourism investment, which indicates that the government's policies and capital investment have an important impact on wetland protection and tourism development. The government should take positive measures to strengthen the protection and management of wetlands, and at the same time, formulate policies and invest enough funds to facilitate the development of tourism. This cannot only protect the wetland ecological environment, but also promote the sustainable development of tourism. This is somewhat different from some studies. For example, Ji and Wang (2022) believe that with the increase of capital investment, the tourism development level of China's coastal cities will show a pattern of first decline and then increase from 2010 to 2019. This is mainly because a variety of factors will play a role in the development of tourism. Specifically, the following factors can affect it. First, economic fluctuations. This period just includes the period of impact of the global financial crisis and economic recession. The economic recession may lead to a decrease in the demand for tourism, and many people may cut their spending on tourism. This may lead to the impact and decline of tourism in coastal cities. Second, natural disasters and environmental problems. China's coastal areas are seriously threatened by natural disasters such as typhoons and floods. Disaster and environmental problems may lead to damage to tourism facilities and scenic spots, a decrease in tourists, and an impact on the development of tourism. Third, policy adjustment. The Chinese government may have carried out adjustment and reform of tourism-related policies during this period. Some policy adjustments may have an impact on the tourism industry of coastal cities, such as adjusting the openness of tourism destinations, tourism visa policies, etc. Fourth, city image improvement and tourism promotion measures. With the gradual development of China's domestic tourism market, some coastal cities may have adopted a series of city image improvement and tourism promotion measures. These measures may include upgrading tourism facilities, carrying out promotional activities, holding events and exhibitions, etc., to attract tourists and promote the development of tourism. Fifth, domestic population flow and consumption upgrading. With the acceleration of urbanization and consumption upgrading of China's population, more and more people begin to attach importance to the demand for leisure and tourism. This trend may partly offset the adverse impact of economic fluctuations and other factors on tourism, and promote the rebound of tourism development in coastal cities. However, the research of this paper involves the impact of global wetlands, which is more extensive than the study of the Ji and Wang (2022). Global wetland tourism is less affected by the policies, nature, population and other factors of a single country. This is the reason for the difference in the results of the two studies.

5 Conclusion

The ecological environment and local economic development level of different wetlands in the world are different. In order to better extend the successful experience of Minjiang Estuary wetland management to other wetlands, this paper constructs the differential game model of three control modes: water quality management, ecological restoration and ecotourism development, and obtains the applicable scope of each mode. The research shows that when the loss caused by flood or the effect of ecological restoration is large, ecological restoration mode should be adopted for wetland; the ecotourism development mode should be adopted when the increased income or reputation of ecotourism is greater. The conclusion of this paper can help managers to formulate clearer and more targeted management goals according to the actual situation of different wetlands. It provides a simple guiding principle to help decision makers make a more reasonable choice between ecological restoration and ecotourism development. Wetland management should be flexible and changeable, and should be analyzed according to specific environmental and socio-economic conditions. At the same time, it is necessary to consider both the long-term environmental benefits provided by wetland ecosystems, as well as the short-term economic gains and social impacts.

We can also expand on this study. For example, this paper only considers that wetlands are close to people's living areas, governance decisions are in constant change, and governments and social organizations can clearly grasp the situation of local wetlands. In future studies, it is possible to consider that wetlands are far away from people's living areas, management decisions are fixed, and local wetland conditions are partially grasped to study related issues. At the same time, this study cannot only provide reference for wetland governance in other parts of the world, but also provide reference for cross-border river governance and transnational dust storm governance.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Author contributions

YB: Investigation, Methodology, Software, Supervision, Writing – original draft, Writing – review & editing. LW: Software, Supervision, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Anza, M., Salazar, O., Epelde, L., Alkorta, I., and Garbisu, C. (2019). The application of nanoscale zero-valent iron promotes soil remediation while negatively affecting soil microbial biomass and activity. *Front. Environ. Sci.* 7, 19. doi: 10.3389/fenvs.2019.00019

Aung, T., Kyi, S. W., Suzue, K., Theint, S. M., Tsujita, K., Yu, T. T., et al. (2021). Rapid ecosystem service assessment of a protected wetland in Myanmar, and implications for policy development and management. *Ecosyst. Serv.* 50, 101336. doi: 10.1016/j.ecoser.2021.101336

Bai, Y., Gao, Y., Li, D., and Liu, D. (2022). Coordinated distribution or client introduce? Analysis of energy conservation and emission reduction in canadian logistics enterprises. *Sustainability* 14, 16979. doi: 10.3390/su142416979

Ban, J., Ling, B., Huang, W., Liu, X., and Zhang, J. (2021). Spatiotemporal variations in water flow and quality in the sanyang wetland, China: implications for environmental restoration. *Sustainability* 13, 4637. doi: 10.3390/su13094637

Bi, X., Wu, Y., Meng, L., Wu, J., Li, Y., Zhou, S., et al. (2022). Integrating two landscape connectivity models to quantify the priorities of wetland conservation and reclamation restoration at multiple scales: a case study in the yellow river delta. *Ocean Coast. Manage.* 229, 106334. doi: 10.1016/j.ocecoaman.2022.106334

Bloomer, C. C., Taylor, C. A., and Distefano, R. J. (2022). Integrating burrowing crayfish and waterfowl conservation management on moist-soil wetlands. *Environmen. Conserv.* 49, 130–135. doi: 10.1017/S0376892922000078

Bonetti, G., Trevathan-Tackett, S. M., Carnell, P. E., and Macreadie, P. I. (2021). The potential of viruses to influence the magnitude of greenhouse gas emissions in an inland wetland. *Water Res.* 193, 116875. doi: 10.1016/j.watres.2021.116875

Boone, W. W., Albrecht, A. A., Conrad, J. R., Lechowicz, C. J., Hellgren, E. C., and Mccleery, R. A. (2022). Shrub encroachment threatens persistence of an endemic insular wetland rodent. *J. Mammal.* 5, 1182–1193. doi: 10.1093/jmammal/gyac058

Chen, S., Glamore, W., and Johnson, F. (2021). Integrating remote sensing and numerical modeling to quantify the water balance of climate-induced intermittent wetlands. *Water Resour. Res.* 57, e2020WR029310. doi: 10.1029/2020WR029310

Dushani, S. N., Aanesen, M., and Vondolia, G. K. (2021). Balancing conservation goals and ecotourism development in coastal wetland management in Sri Lanka: a choice experiment. *Ocean Coast. Manage.* 210, 105659. doi: 10.1016/j.ocecoaman.2021.105659

Grotelueschen, K., Becker, M., Gaydon, D. S., Whitbread, A. M., Ziegler, S., Senthilkumar, K., et al. (2021). Assessing the effects of management and hydro-edaphic conditions on rice in contrasting east african wetlands using experimental and modelling approaches. *Agric. Water Manage.* 258, 107146. doi: 10.1016/j.agwat.2021.107146

Guo, Y., Boughton, E. H., and Qiu, J. (2021). Interactive effects of land-use intensity, grazing and fire on decomposition of subtropical seasonal wetlands. *Ecol. Indic.* 132, 108301. doi: 10.1016/j.ecolind.2021.108301

Hrach, D. M., Petrone, R. M., Green, A., and Khomik, M. (2022). Analysis of growing season carbon and water fluxes of a subalpine wetland in the canadian rocky mountains: implications of shade on ecosystem water use efficiency. *Hydrol. Process* 1), 36. doi: 10.1002/hyp.14425

Ji, J., and Wang, D. (2022). Regional differences, dynamic evolution, and driving factors of tourism development in chinese coastal cities. *Ocean Coast. management.* 226, 106262 doi: 10.1016/j.ocecoaman.2022.106262

Jiang, W., Liu, B., Peng, X., Shu, L., Li, S., and Shen, Y. (2023). Groundwater response to water diversion and surface-water management scenarios in the yellow river delta wetland reserve, China. *Hydrogeol. J.* 31, 1829–1846. doi: 10.1007/s10040-023-02664-z

Lai, X., Zeng, C., Su, Y., Huang, S., Jia, J., Chen, C., et al. (2023). Vulnerability assessment of coastal wetlands in minjiang river estuary based on cloud model under sea level rise. *Acta Oceanol. Sin.* 42, 160–174. doi: 10.1007/s13131-023-2169-7

Lamb, B. T., Tzortziou, M. A., and Mcdonald, K. C. (2021). A fused radar-optical approach for mapping wetlands and deepwaters of the mid-atlantic and gulf coast regions of the United States. *Remote Sens* 13, 2495. doi: 10.3390/rs13132495

Lin, X., Eguchi, S., Maeda, S., Yoshida, K., and Kuroda, H. (2021). Combined effects of oxygen and temperature on nitrogen removal in a nitrate-rich ex-paddy wetland. *Sci. Total Environ.* 779, 146254. doi: 10.1016/j.scitotenv.2021.146254

Liu, D. (2021). Soil moisture and salinity inversion based on new remote sensing index and neural network at a salina-alkaline wetland. *Water* 13, 2762. doi: https://doi.org/10.3390/w13192762

Lonn, P., Mizoue, N., Ota, T., Kajisa, T., and Yoshida, S. (2018). Evaluating the contribution of community-based ecotourism (cbet) to household income and livelihood changes: a case study of the chambok cbet program in Cambodia. *Ecol. Economics* 151, 62–69. doi: 10.1016/j.ecolecon.2018.04.036

Lv, M., Zhang, D., Niu, X., Ma, J., Lin, Z., and Fu, M. (2022). Insights into the fate of antibiotics in constructed wetland systems: removal performance and mechanisms. *J. Environ. Manage.* 321, 116028. doi: 10.1016/j.jenvman.2022.116028

Magnússon, R., Limpens, J., Kleijn, D., Huissteden, K. V., and Heijmans, M. (2021). Shrub decline and expansion of wetland vegetation revealed by very high resolution land cover change detection in the siberian lowland tundra. *Sci. Total Environ.* 782, 146877. doi: 10.1016/j.scitotenv.2021.146877

Messer, T. L., Moore, T. L., and Nelson, N. (2021). Constructed wetlands for water quality improvement: a synthesis on nutrient reduction from agricultural effluents. *Trans. ASABE* 2), 64. doi: 10.13031/trans.13976

Rashid, I., Aneaus, S., Dar, S., Javed, O., Khanday, S., and Bhat, S. (2023). A novel gis-based multicriteria analysis approach for ascertaining the catchment-scale degradation of a himalayan wetland. *Environ. Res.* 229, 115967. doi: 10.1016/j.envres.2023.115967

Sierra, L., Marin, W., and Castro, L. G. (2021). Economic valuation of benefits in freshwater ecosystems: complex wetlands system belonging to the san juan river in the magdalena medio region, Colombia. *Sustainability* 13, 5374. doi: 10.3390/su13105374

Tao, L. A., Xla, B., Hz, A., Cya, B., Gsa, B., and Wl, A. (2015). Distribution of trace metals and the benthic foraminiferal assemblage as a characterization of the environment in the north minjiang river estuary (fujian, China). *Mar. pollut. Bull.* 90, 227–241. doi: 10.1016/j.marpolbul.2014.10.047

Tendar, P., and Sridith, K. (2021). Vegetation structure of wetlands in eastern himalayan highlands of gasa, Bhutan. *ScienceAsia* 47, 78–85. doi: 10.2306/scienceasia1513-1874.2021.007

Viscolani, B., and Zaccour, G. (2009). Advertising strategies in a differential game with negative competitoral interference. *J. Optim. Theory Appl.* 140, 153–170. doi: 10.1007/s10957-008-9454-7

Wu, Z., and Zhang, F. (2022). Maximum principle for discrete-time stochastic optimal control problem and stochastic game. *Math. Control Relat. F.* 12, 475–493. doi: 10.3934/mcrf.2021031

You, S., Zheng, Q., Chen, B., Xu, Z., Lin, Y., Gan, M., et al. (2022). Identifying the spatiotemporal dynamics of forest ecotourism values with remotely sensed images and social media data: a perspective of public preferences. *J. Clean. Prod.* 341, 130715. doi: 10.1016/j.jclepro.2022.130715

Zhou, B. X., Liu, C., Zhou, Z., and Zhang, X. (2022). Minimal m-symmetric periodic solutions of general hamiltonian systems and delay differential equations. *J. Differ. Equations* 329, 1–30. doi: 10.1016/j.jde.2022.04.039

Zhu, S., Xie, K., and Cui, P. (2021). Dynamic adjustment mechanism and differential game model construction of mask emergency supply chain cooperation based on covid-19 outbreak. *Sustainability* 13, 1115. doi: 10.3390/su13031115

Ziemann, D. A., Walsh, W. A., Saphore, E. G., and Kim, F. (2010). A survey of water quality characteristics of effluent from hawaiian aquaculture facilities. *J. World Aquaculture Soc.* 23, 180–191. doi: 10.1111/j.1749-7345.1992.tb00767.x

Appendix 1

Take the derivatives of F_{W1} with respect to (13), and take the derivatives of F_{W2} and B_{W2} with respect to (14), and set them equal to zero, we can get:

$$F^*_{W1}(t) = \frac{1}{c_F}(a_F + b_F \frac{\partial V_{W1}}{\partial x_{W1}}) \ln (e + \alpha_W I_{F1}) \tag{38}$$

$$F^*_{W2}(t) = \frac{1}{c_F}(a_F + b_F \frac{\partial V_{W2}}{\partial x_{W2}}) \tag{39}$$

$$B^*_{W2}(t) = \frac{1}{c_B}[a_B(1 + \alpha_r r_W) - b_B \frac{\partial V_{W2}}{\partial x_{W2}}] \tag{40}$$

Substituting (38) into (13) and substituting (39) and (40) into (14), we can get:

$$\begin{aligned}\rho V_{W1} = & a_F \tfrac{1}{c_F}(a_F + b_F \tfrac{\partial V_{W1}}{\partial x_{W1}}) \ln (e + \alpha_W I_{F1}) \\ & - \tfrac{1}{2}\tfrac{1}{c_F}(a_F + b_F \tfrac{\partial V_{W1}}{\partial x_{W1}})^2 \ln (e + \alpha_W I_{F1}) \\ & + l x_{W1}(t) + [b_F \tfrac{1}{c_F}(a_F + b_F \tfrac{\partial V_{W1}}{\partial x_{W1}}) \\ & \ln (e + \alpha_W I_{F1}) - \delta x_{W1}(t)] \tfrac{\partial V_{W1}}{\partial x_{W1}}\end{aligned} \tag{41}$$

$$\begin{aligned}\rho V_{W2} = & a_F \tfrac{1}{c_F}(a_F + b_F \tfrac{\partial V_{W2}}{\partial x_{W2}}) - \tfrac{1}{2}\tfrac{1}{c_F}(a_F + b_F \tfrac{\partial V_{W2}}{\partial x_{W2}})^2 \\ & + a_B(1 + \alpha_r r_W)\tfrac{1}{c_B}[a_B(1 + \alpha_r r_W) - b_B \tfrac{\partial V_{W2}}{\partial x_{W2}}] \\ & - \tfrac{1}{2}\tfrac{1}{c_B}[a_B(1 + \alpha_r r_W) - b_B \tfrac{\partial V_{W2}}{\partial x_{W2}}]^2 + l x_{W2}(t) \\ & + \tfrac{\partial V_{W2}}{\partial x_{W2}}[b_F \tfrac{1}{c_F}(a_F + b_F \tfrac{\partial V_{W2}}{\partial x_{W2}}) - b_B \tfrac{1}{c_B} a_B(1 + \alpha_r r_W) \\ & + b_B \tfrac{1}{c_B} b_B \tfrac{\partial V_{W2}}{\partial x_{W2}} - \delta x_{W2}(t)]\end{aligned} \tag{42}$$

Let $V^*_{W1} = k_1 x_{W1} + k_2$, $V^*_{W2} = k_3 x_{W2} + k_4$, wherein, k_1, k_2, k_3 and k_4 are all constants. The parameters of the optimal social welfare function can be obtained by calculation as follows:

$$\begin{cases} k_1 = \tfrac{l}{\rho+\delta} \\ k_2 = \tfrac{1}{\rho} a_F \tfrac{1}{c_F}(a_F + b_F \tfrac{l}{\rho+\delta}) \ln (e + \alpha_W I_{F1}) \\ \quad - \tfrac{1}{2}\tfrac{1}{\rho}\tfrac{1}{c_F}(a_F + b_F \tfrac{l}{\rho+\delta})^2 \ln (e + \alpha_W I_{F1}) \\ \quad + \tfrac{1}{\rho}\tfrac{l}{\rho+\delta} b_F \tfrac{1}{c_F}(a_F + b_F \tfrac{l}{\rho+\delta}) \ln (e + \alpha_W I_{F1}) \end{cases} \tag{43}$$

$$\begin{cases} k_3 = \tfrac{l}{\rho+\delta} \\ k_4 = \tfrac{1}{\rho} a_F \tfrac{1}{c_F}(a_F + b_F \tfrac{l}{\rho+\delta}) - \tfrac{1}{\rho}\tfrac{1}{2}\tfrac{1}{c_F}(a_F + b_F \tfrac{l}{\rho+\delta})^2 \\ \qquad + \tfrac{1}{c_B}[a_B(1 + \alpha_r r_W) - b_B \tfrac{l}{\rho+\delta}] \\ \quad \tfrac{1}{\rho} a_B(1 + \alpha_r r_W) - \tfrac{1}{2}\tfrac{1}{\rho}\tfrac{1}{c_B}[a_B(1 + \alpha_r r_W) - b_B \tfrac{l}{\rho+\delta}]^2 \\ \quad + \tfrac{1}{\rho}\tfrac{l}{\rho+\delta}[b_F \tfrac{1}{c_F}(a_F + b_F \tfrac{l}{\rho+\delta}) \\ \quad - b_B \tfrac{1}{c_B} a_B(1 + \alpha_r r_W) + b_B \tfrac{1}{c_B} b_B \tfrac{l}{\rho+\delta}] \end{cases} \tag{44}$$

Therefore, it can be concluded that:

$$\begin{aligned}V^*_{W1} = & \tfrac{l}{\rho+\delta} x_{W1} + \tfrac{1}{\rho} a_F \tfrac{1}{c_F}(a_F + b_F \tfrac{l}{\rho+\delta}) \\ & \ln (e + \alpha_W I_{F1}) - \tfrac{1}{2}\tfrac{1}{\rho}\tfrac{1}{c_F}(a_F + b_F \tfrac{l}{\rho+\delta})^2 \ln (e + \alpha_W I_{F1}) \\ & + \tfrac{1}{\rho}\tfrac{l}{\rho+\delta} b_F \tfrac{1}{c_F}(a_F + b_F \tfrac{l}{\rho+\delta}) \ln (e + \alpha_W I_{F1})\end{aligned} \tag{45}$$

$$\begin{aligned}V^*_{W2} = & \tfrac{l}{\rho+\delta} x_{W2} - \tfrac{1}{\rho}\tfrac{1}{2}\tfrac{1}{c_F}(a_F + b_F \tfrac{l}{\rho+\delta})^2 \\ & + \tfrac{1}{\rho} a_B(1 + \alpha_r r_W)\tfrac{1}{c_B}[a_B(1 + \alpha_r r_W) - b_B \tfrac{l}{\rho+\delta}] \\ & + \tfrac{1}{\rho} a_F \tfrac{1}{c_F}(a_F + b_F \tfrac{l}{\rho+\delta}) - \tfrac{1}{2}\tfrac{1}{\rho}\tfrac{1}{c_B}[a_B(1 + \alpha_r r_W) - b_B \tfrac{l}{\rho+\delta}]^2 \\ & + \tfrac{1}{\rho}\tfrac{l}{\rho+\delta}[b_F \tfrac{1}{c_F}(a_F + b_F \tfrac{l}{\rho+\delta}) \\ & - b_B \tfrac{1}{c_B} a_B(1 + \alpha_r r_W) + b_B \tfrac{1}{c_B} b_B \tfrac{l}{\rho+\delta}]\end{aligned} \tag{46}$$

In this case,

$$F^*_{W1}(t) = \frac{1}{c_F}(a_F + b_F \frac{l}{\rho+\delta}) \ln (e + \alpha_W I_{F1}) \tag{47}$$

$$F^*_{W2}(t) = \frac{1}{c_F}(a_F + b_F \frac{l}{\rho+\delta}) \tag{48}$$

$$B^*_{W2}(t) = \frac{1}{c_B}[a_B(1 + \alpha_r r_W) - b_B \frac{l}{\rho+\delta}] \tag{49}$$

Appendix 2

Take the derivatives of F_{B1} with respect to (15), and take the derivatives of F_{B2} with respect to (16), and set them equal to zero, we can get:

$$F^*_{B1}(t) = \frac{a_F + (b_F + b_{FB})\frac{\partial V_{B1}}{\partial x_{B1}}}{c_F(1 + r_B)} \tag{50}$$

$$F^*_{B2}(t) = (\frac{c_1}{\beta})^{\frac{1}{2}}[\frac{c_F(1 + r_B)}{2} - a_F - \frac{\partial V_{B2}}{\partial x_{B2}} b_F]^{-\frac{1}{2}} \tag{51}$$

Substituting (50) into (15) and substituting (51) into (16), we can get:

$$\begin{aligned}\rho V_{B1} = & a_F \frac{a_F + (b_F + b_{FB})\frac{\partial V_{B1}}{\partial x_{B1}}}{c_F(1+r_B)} - \frac{1}{2}\frac{[a_F + (b_F + b_{FB})\frac{\partial V_{B1}}{\partial x_{B1}}]^2}{c_F(1+r_B)} + l x_{B1}(t) \\ & + \frac{\partial V_{B1}}{\partial x_{B1}}[(b_F + b_{FB})\frac{a_F + (b_F + b_{FB})\frac{\partial V_{B1}}{\partial x_{B1}}}{c_F(1+r_B)} - \delta x_{B1}(t)]\end{aligned} \tag{52}$$

$$\begin{aligned}\rho V_{B2} &= a_F\left(\frac{c_1}{\beta}\right)^{\frac{1}{2}}\left[\frac{c_F(1+r_B)}{2}-a_F-\frac{\partial V_{B2}}{\partial x_{B2}}b_F\right]^{-\frac{1}{2}}\\ &-\frac{c_F(1+r_B)}{2}\left(\frac{c_1}{\beta}\right)^{\frac{1}{2}}\left[\frac{c_F(1+r_B)}{2}-a_F-\frac{\partial V_{B2}}{\partial x_{B2}}b_F\right]^{-\frac{1}{2}}\\ &-\frac{c_1}{\beta}\left(\frac{c_1}{\beta}\right)^{-\frac{1}{2}}\left[\frac{c_F(1+r_B)}{2}-a_F-\frac{\partial V_{B2}}{\partial x_{B2}}b_F\right]^{\frac{1}{2}}+lx_{B2}(t)\\ &+\left[\frac{c_F(1+r_B)}{2}-a_F-\frac{\partial V_{B2}}{\partial x_{B2}}b_F\right]^{-\frac{1}{2}}\\ &b_F\left(\frac{c_1}{\beta}\right)^{\frac{1}{2}}\frac{\partial V_{B2}}{\partial x_{B2}}-\delta x_{B2}(t)\frac{\partial V_{B2}}{\partial x_{B2}}\end{aligned} \quad (53)$$

Let $V_{B1}^{\star}=k_5x_{B1}+k_6$, $V_{B2}^{*}=k_7x_{B2}+k_8$, wherein, k_5, k_6, k_7 and k_8 are all constants. The parameters of the optimal social welfare function can be obtained by calculation as follows:

$$\begin{cases} k_5=\frac{l}{\rho+\delta}\\ k_6=\frac{1}{\rho}a_F\frac{a_F+(b_F+b_{FB})\frac{l}{\rho+\delta}}{c_F(1+r_B)}-\frac{1}{2}\frac{1}{\rho}\frac{\left[a_F+(b_F+b_{FB})\frac{l}{\rho+\delta}\right]^2}{c_F(1+r_B)}\\ \quad+\frac{1}{\rho}\frac{l}{\rho+\delta}(b_F+b_{FB})\frac{a_F+(b_F+b_{FB})\frac{l}{\rho+\delta}}{c_F(1+r_B)}\end{cases} \quad (54)$$

$$\begin{cases} k_7=\frac{l}{\rho+\delta}\\ k_8=\frac{1}{\rho}a_F\left(\frac{c_1}{\beta}\right)^{\frac{1}{2}}\left[\frac{c_F(1+r_B)}{2}-a_F-\frac{l}{\rho+\delta}b_F\right]^{-\frac{1}{2}}\\ -\left[\frac{c_F(1+r_B)}{2}-a_F-\frac{l}{\rho+\delta}b_F\right]^{-\frac{1}{2}}\\ \frac{1}{\rho}\frac{c_F(1+r_B)}{2}\left(\frac{c_1}{\beta}\right)^{\frac{1}{2}}-\frac{1}{\rho}\frac{c_1}{\beta}\left(\frac{c_1}{\beta}\right)^{-\frac{1}{2}}\left[\frac{c_F(1+r_B)}{2}-a_F-\frac{\partial V_{B2}}{\partial x_{B2}}b_F\right]^{\frac{1}{2}}\\ \quad+\frac{1}{\rho}b_F\left(\frac{c_1}{\beta}\right)^{\frac{1}{2}}\\ \quad\left[\frac{c_F(1+r_B)}{2}-a_F-\frac{l}{\rho+\delta}b_F\right]^{-\frac{1}{2}}\frac{l}{\rho+\delta}\end{cases} \quad (55)$$

Therefore, it can be concluded that:

$$\begin{aligned}V_{B1}^{\star}&=\frac{l}{\rho+\delta}x_{B1}+\frac{1}{\rho}a_F\frac{a_F+(b_F+b_{FB})\frac{l}{\rho+\delta}}{c_F(1+r_B)}-\frac{1}{2}\frac{1}{\rho}\frac{\left[a_F+(b_F+b_{FB})\frac{l}{\rho+\delta}\right]^2}{c_F(1+r_B)}\\ &+\frac{1}{\rho}\frac{l}{\rho+\delta}(b_F+b_{FB})\frac{a_F+(b_F+b_{FB})\frac{l}{\rho+\delta}}{c_F(1+r_B)}\end{aligned} \quad (56)$$

$$\begin{aligned}V_{B2}^{*}&=\frac{l}{\rho+\delta}x_{B2}+\frac{1}{\rho}a_F\left(\frac{c_1}{\beta}\right)^{\frac{1}{2}}\left[\frac{c_F(1+r_B)}{2}-a_F-\frac{l}{\rho+\delta}b_F\right]^{-\frac{1}{2}}\\ &-\left[\frac{c_F(1+r_B)}{2}-a_F-\frac{l}{\rho+\delta}b_F\right]^{-\frac{1}{2}}\\ &\frac{1}{\rho}\frac{c_F(1+r_B)}{2}\left(\frac{c_1}{\beta}\right)^{\frac{1}{2}}-\frac{1}{\rho}\frac{c_1}{\beta}\left(\frac{c_1}{\beta}\right)^{-\frac{1}{2}}\left[\frac{c_F(1+r_B)}{2}-a_F-\frac{l}{\rho+\delta}b_F\right]^{\frac{1}{2}}\\ &+\frac{1}{\rho}b_F\left(\frac{c_1}{\beta}\right)^{\frac{1}{2}}\left[\frac{c_F(1+r_B)}{2}-a_F-\frac{l}{\rho+\delta}b_F\right]^{-\frac{1}{2}}\frac{l}{\rho+\delta}\end{aligned} \quad (57)$$

In this case,

$$F_{B1}^{*}(t)=\frac{a_F+(b_F+b_{FB})\frac{l}{\rho+\delta}}{c_F(1+r_B)} \quad (58)$$

$$F_{B2}^{\star}(t)=\left(\frac{c_1}{\beta}\right)^{\frac{1}{2}}\left[\frac{c_F(1+r_B)}{2}-a_F-\frac{l}{\rho+\delta}b_F\right]^{-\frac{1}{2}} \quad (59)$$

Appendix 3

Take the derivatives of F_{T1} with respect to (17), and take the derivatives of F_{T2} with respect to (18), and set them equal to zero, we can get:

$$F_{T1}^{*}(t)=\frac{a_F+(b_F+b_{FT})\frac{\partial V_{T1}}{\partial x_{T1}}}{c_F(1-r_T)} \quad (60)$$

$$F_{T2}^{*}(t)=\frac{a_F+a_T+b_F\frac{\partial V_{T2}}{\partial x_{T2}}}{c_F(1-r_T)} \quad (61)$$

Substituting (60) into (17) and substituting (61) into (18), we can get:

$$\begin{aligned}\rho V_{T1}&=a_F\frac{a_F+(b_F+b_{FT})\frac{\partial V_{T1}}{\partial x_{T1}}}{c_F(1-r_T)}-\frac{1}{2}\frac{\left[a_F+(b_F+b_{FT})\frac{\partial V_{T1}}{\partial x_{T1}}\right]^2}{c_F(1-r_T)}-C_{T1}\\ &+lx_{T1}(t)+\frac{\partial V_{T1}}{\partial x_{T1}}\left[(b_F+b_{FT})\frac{a_F+(b_F+b_{FT})\frac{\partial V_{T1}}{\partial x_{T1}}}{c_F(1-r_T)}-\delta x_{T1}(t)\right]\end{aligned} \quad (62)$$

$$\begin{aligned}\rho V_{T2}&=a_F\frac{a_F+a_T+b_F\frac{\partial V_{T2}}{\partial x_{T2}}}{c_F(1-r_T)}-\frac{1}{2}\frac{\left[a_F+a_T+b_F\frac{\partial V_{T2}}{\partial x_{T2}}\right]^2}{c_F(1-r_T)}\\ &-C_{T2}+a_T\frac{a_F+a_T+b_F\frac{\partial V_{T2}}{\partial x_{T2}}}{c_F(1-r_T)}\\ &+lx_{T2}(t)+\left[b_F\frac{a_F+a_T+b_F\frac{\partial V_{T2}}{\partial x_{T2}}}{c_F(1-r_T)}-\delta x_{T2}(t)\right]\frac{\partial V_{T2}}{\partial x_{T2}}\end{aligned} \quad (63)$$

Let $V_{T1}^{\star}=k_9x_{T1}+k_{10}$, $V_{T2}^{*}=k_{11}x_{T2}+k_{12}$, wherein, k_9, k_{10}, k_{11} and k_{12} are all constants. The parameters of the optimal social welfare function can be obtained by calculation as follows:

$$\begin{cases} k_9=\frac{l}{\rho+\delta}\\ k_{10}=\frac{1}{\rho}a_F\frac{a_F+(b_F+b_{FT})\frac{l}{\rho+\delta}}{c_F(1-r_T)}-\frac{1}{2}\frac{1}{\rho}\frac{\left[a_F+(b_F+b_{FT})\frac{l}{\rho+\delta}\right]^2}{c_F(1-r_T)}-\frac{1}{\rho}C_{T1}\\ \quad+\frac{1}{\rho}\frac{l}{\rho+\delta}(b_F+b_{FT})\frac{a_F+(b_F+b_{FT})\frac{l}{\rho+\delta}}{c_F(1-r_T)}\end{cases} \quad (64)$$

$$\begin{cases} k_{11}=\frac{l}{\rho+\delta}\\ k_{12}=\frac{1}{\rho}a_F\frac{a_F+a_T+b_F\frac{l}{\rho+\delta}}{c_F(1-r_T)}-\frac{1}{2}\frac{1}{\rho}\frac{\left[a_F+a_T+b_F\frac{l}{\rho+\delta}\right]^2}{c_F(1-r_T)}\\ \quad-\frac{1}{\rho}C_{T2}+\frac{1}{\rho}a_T\frac{a_F+a_T+b_F\frac{l}{\rho+\delta}}{c_F(1-r_T)}\\ \quad+\frac{1}{\rho}b_F\frac{a_F+a_T+b_F\frac{l}{\rho+\delta}}{c_F(1-r_T)}\frac{l}{\rho+\delta}\end{cases} \quad (65)$$

In this case,

$$\begin{aligned}V_{T1}^{\star}&=\frac{l}{\rho+\delta}x_{T1}+\frac{1}{\rho}a_F\frac{a_F+(b_F+b_{FT})\frac{l}{\rho+\delta}}{c_F(1-r_T)}\\ &-\frac{1}{2}\frac{1}{\rho}\frac{\left[a_F+(b_F+b_{FT})\frac{l}{\rho+\delta}\right]^2}{c_F(1-r_T)}-\frac{1}{\rho}C_{T1}\\ &+\frac{1}{\rho}\frac{l}{\rho+\delta}(b_F+b_{FT})\frac{a_F+(b_F+b_{FT})\frac{l}{\rho+\delta}}{c_F(1-r_T)}\end{aligned} \quad (66)$$

$$V_{T2}^{*} = \frac{l}{\rho+\delta} x_{T2} + \frac{1}{\rho} a_F \frac{a_F + a_T + b_F \frac{l}{\rho+\delta}}{c_F(1-r_T)} - \frac{1}{2}\frac{1}{\rho} \frac{\left[a_F + a_T + b_F \frac{l}{\rho+\delta}\right]^2}{c_F(1-r_T)} - \frac{1}{\rho} C_{T2} + \frac{1}{\rho} a_T \frac{a_F + a_T + b_F \frac{l}{\rho+\delta}}{c_F(1-r_T)} + \frac{1}{\rho} b_F \frac{a_F + a_T + b_F \frac{l}{\rho+\delta}}{c_F(1-r_T)} \frac{l}{\rho+\delta} \tag{67}$$

In this case,

$$F_{T1}^{*}(t) = \frac{a_F + (b_F + b_{FT}) \frac{l}{\rho+\delta}}{c_F(1 - r_T)} \tag{68}$$

$$F_{T2}^{*}(t) = \frac{a_F + a_T + b_F \frac{l}{\rho+\delta}}{c_F(1 - r_T)} \tag{69}$$