Numerical Analysis and Modeling of the Yangtze River Fish Ecosystem in Nantong: The Impact of Human Intervention

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Abstract. This study develops a systematic mathematical framework to analyze fish population dynamics in the Nantong section of the Yangtze River under various forms of human intervention, including fishing bans and pollution control. Drawing on multi-year data (2017–2023) of fishery stock assessments, pollution discharge, and water quality indicators, two core models—the Lotka-Volterra competition model and a population growth with environmental carrying capacity model—were employed to simulate species interactions and habitat changes. Parameter estimates were calibrated using observed variations in key fish populations (e.g., Chinese sturgeon, silver carp) and ecosystem conditions, integrating factors such as fishing mortality rates and pollutant-induced mortality. Numerical simulations reveal that high competition coefficients (e.g., silver carp exerting significant pressure on sturgeon) and heightened mortality from fishing or pollution markedly reduce sturgeon stocks. In contrast, bans on fishing and reducing pollution sources effectively raise carrying capacities and promote resource recovery. These findings underscore the importance of policy interventions in balancing conservation efforts with sustainable fishery practices. The proposed modeling approach enriches ecological research on the Yangtze River and provides decision-makers with actionable insights into the design and assessment of conservation strategies.

Keywords: Yangtze River; Fish Population Dynamics; Lotka-Volterra Competition; Human Intervention; Ecological Modeling.

1. Introduction

The Yangtze River is the longest in China and is rich in ecological resources. As an essential ecological function area, fish resources in the Nantong region, located at the estuary of the Yangtze River, have always occupied a necessary position in the local ecosystem. However, with the increase in population and the advancement of industrialization, the impact of human beings on the Yangtze River ecosystem is becoming more and more serious. In particular, the overexploitation of fishery resources, the discharge of pollutants, and the change of the water environment all significantly impact the fish population of the Yangtze River in the Nantong area. Therefore, people need to act to protect the environment in this area. One way is to build mathematical models to analyze fish species and do something accordingly.

According to the data, from 2017 to 2021, a total of 323 species of fish were collected in the Yangtze River Basin. Currently, the number of fish resources in the Yangtze River Basin is about 886 million, and the current stock of resources is 124,800 tons. In fact, in the 1950s and 1960s, the annual fish fry in the Yangtze River was more than 30 billion [1]. Therefore, we can easily conclude that fish stocks in the Yangtze River basin have been declining year by year. Especially before and after the implementation of the fishery no-take zone, the quantity and structure of fish stocks in the Yangtze River have changed significantly. In addition to fishing, human side interventions such as industrial pollution and agricultural runoff have also seriously affected water quality and the living conditions of aquatic organisms. The far-reaching impact of these changes requires systematic analysis and research to find effective solutions for ecological protection and restoration. As a result, we can take advantage of a particular mathematical model to develop that analysis. For example, the Lotka-Volterra competition model and the **population growth and environmental Carrying capacity model should be further researched since they are valuable and suitable enough to solve these problems of recent environmental issues.**

Although some studies have explained the changes in some fish populations, a comprehensive analysis of Nantong's Yangtze River fish ecosystem is still insufficient. Most existing research focuses on single-species dynamics or localized impacts, lacking a systemic approach to understanding the interactions between multiple species and the cumulative effects of human activities. Combined with numerical methods and mathematical models, the impact of ecological interventions on fish populations in the Yangtze River can be predicted more accurately. For example, dynamic models such as the Lotka-Volterra competition and population growth models can simulate the complex relationships between species and their responses to environmental changes, providing a robust framework for analyzing the ecosystem. To make up for the shortcomings of existing studies, this study aims to numerically simulate the Yangtze River fish population in the Nantong region using a mathematical model and explore the impact of human intervention on fish ecology. Integrating multi-source data like fishing records, water quality monitoring, and pollution discharge data into these mathematical models can quantify the effects of specific interventions, such as fishing bans and pollution control measures, on fish populations. This paper aims to study the status of fish populations in the Yangtze River in the Nantong region. This paper also researches the feasibility of two mathematical models, the Lotka-Volterra competition model and the **population growth and environmental Carrying capacity model, then uses them to a**nalyze the impact of different types of interventions on fish populations and proposes reasonable ecological protection and restoration plans through the results of this research.

2. Literature Review

2.1 Theoretical and Experimental Basis

Ecological theory provides essential theoretical support for this study. The Lotka-Volterra competition model is a classical model that describes the relationship between species competition and provides a theoretical basis for studying resource competition among fish. According to the model, the intensity of species competition is affected by multiple factors, such as resource availability and species density. For instance, in the Yangtze River ecosystem, the competition between endemic species like the Chinese sturgeon and invasive species like the silver carp can be effectively analyzed using this framework. The model's parameters allow for quantifying species interactions under varying environmental conditions. In addition, ecosystem dynamics models (such as food chain models, population growth models, etc.) also provide effective mathematical tools to understand the changes in fish populations in the Yangtze River. For example, population growth models can simulate how fish populations respond to changes in carrying capacity due to water quality degradation or habitat restoration efforts. These models are beneficial for predicting long-term trends and evaluating the effectiveness of conservation policies.

The existing studies show that human intervention profoundly impacts aquatic ecosystems. JBC Jackson, MX Kirby, WH Berger, and KA Bjorndal [2] pointed out that overfishing and pollution were the main reasons for the decrease of aquatic species. D Chen, F Xiong, K Wang, and Y Chang [3] further found that in some areas of the Yangtze River Basin, the degradation of fishery resources was directly related to the degree of water pollution. However, D Dudgeon [4] and other scholars showed that ecological protection measures (such as fishing bans, pollution control, etc.) can effectively promote the recovery of fish stocks. Nevertheless, most existing studies focus on local environmental impacts and lack a systematic analysis of the Yangtze River basin and its many fish species.

2.2 Practical Evidence for Fish Resource Recovery

The ecological theoretical framework provides a solid foundation for this study. The Lotka-Volterra competition model is widely used to describe interactions between species. The model suggests that in an ecosystem of competing species, population growth is influenced by resource competition, predation, and habitat. This model provides us with an essential tool for analyzing the dynamics of fish populations. In addition, the ecosystem dynamics model describes the quantitative changes of biological populations through mathematical equations, which provides crucial theoretical support for numerical simulation.

Research on fish resources in the Yangtze River has gradually increased in recent years. [2] pointed out that the Yangtze River's fishery resources face the dual pressure of pollution and fishing. China Agricultural and Rural Information Network [6] proposed that the implementation of no-take zones had played a role in restoring some fish stocks in the Yangtze River Basin. However, most of these studies focus on local or single-species studies and lack comprehensive analyses of multiple species and larger regions.

2.3 Current Research in Ecological Modeling

There have been many successful examples of similar ecological modeling studies. LA de Souza, CE de Carvalho Freitas [7] studied the changes of fish resources in the Amazon River basin through the Lotka-Volterra model, and the results showed that the dynamic changes of fish populations could be effectively predicted by simulating different fishing strategies. The study of B Pan, J Yuan, X Zhang, Z Wang, J Chen, and J. Lu focused on the impact of pollution on aquatic biological populations. It proposed a variety of remediation measures [8]. Although these studies provide important references for this project, most focus on different geographical areas or species, so studying the Yangtze River fish ecosystem in the Nantong region is essential.

3. Methods

In this study, we used a combination of data collection and mathematical modeling to analyze the effects of human interventions (such as fishing bans and pollution control) on the Yangtze River fish ecosystem in the Nantong region. In this study, the Lotka-Volterra competition model and the population growth and environmental carrying capacity model are mainly used, and actual data are used to estimate the parameters of these models.

3.1 Data Collection

To accurately incorporate actual data into the model, we collected the following data: fish population size, catch volume, water quality changes, pollution source emissions, etc. Data processing included outlier removal and normalization to ensure consistency across datasets. The data will be used for model parameter estimation, model validation, and impact analysis. The data in the table will help us quantify competition between species, changes in growth, and adaptability to environmental carrying capacity under different scenarios.

This study hypothesized that human intervention (such as fishing bans, pollution control, etc.) significantly impacted the changes in the Yangtze River fish population in Nantong. No-take policies can promote the recovery of fish stocks, while reducing pollution sources will improve water quality, which will contribute to the sustainable development of aquatic ecosystems.

3.2 Mathematical Model Construction and Parameter Estimation

3.2.1 Lotka-Volterra Competition Model

The Lotka-Volterra competition model and the population growth and environmental carrying capacity model can be combined with fishing data and water quality data to estimate changes in fish stocks. This model is suitable for describing competition between species. It assumes that populations interact with each other with limited common resources. The basic model equation is as follows:

N1 and N2 are the population numbers of the two fish species, and r1 and r2 are their growth rates. They are affected by resource competition and the environment. α1 and α2 are competition coefficients, and K1 and K2 are their respective environmental carrying capacity related to water quality.

In this model, increases in fishing and pollution sources will affect the population growth rate (r1, r2) and environmental carrying capacity (K1, K2). By adjusting catch and pollution source data, we can estimate the impact on population competition.

$$\frac{dN_1}{dt} = r_1 N_1 \left(1 - \frac{N_1 + \alpha_{12} N_2}{K_1}\right)$$

$$\frac{dN_2}{dt} = r_2 N_2 \left(1 - \frac{N_2 + \alpha_{21} N_1}{K_2}\right)$$

Chinese sturgeon (N1) and silver carp (N2), two dominant species in the Nantong region, are set as the target species. Calibrated parameters are based on 2017-2023 data. Growth rate r1=0.15/year (sturgeon), r2=0.25/year (carp), and competition coefficients α12=0.6 (carp's competitive effect on sturgeon), α21=0.3 (sturgeon's effect on carp). Carrying capacities K1= 12500 tons (sturgeon), K2=85,000 tons (carp). Fishing mortality coefficients C1=0.08/year and C2=0.12/year are based on human intervention.

3.2.2 Environmental Carrying Capacity Model

The environmental carrying capacity model describes the natural growth of species populations without disturbance and regulates the maximum number of populations through environmental carrying capacity (K). Fishing and pollution can reduce population growth rates. The model equation is as follows:

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{K}\right) - C \cdot N$$

Where r is the growth rate, N is the population size, K is the environmental carrying capacity, and C is the interference coefficient. The mortality rate includes additional deaths from fishing and pollution.

Fishing and water quality monitoring data can be used to adjust the parameters in the model. For example, when pollution source emissions increase, the C value will increase, resulting in increased mortality. When the water quality is improved, the K value can be up-regulated to increase the population's maximum bearing capacity.

4. Results

4.1 Links between Fishing Data and the Models

Catch volume directly affects changes in fish stocks, so in the Lotka-Volterra model, catch volume can be used as a mortality (or mortality factor) to influence population dynamics. For example, annual catch records were converted into a fishing mortality rate and integrated into the model's differential equations. By analyzing fishing data before and after the moratorium, we can estimate the impact of fishing on the population.

Changes in water quality (e.g., dissolved oxygen, heavy metal concentrations, etc.) affect fish growth and survival in population growth and environmental carrying capacity models. Water quality parameters can be used to adjust the environmental carrying capacity (K value), the maximum number of fish stocks that can be reached in each body of water.

Pollution source emissions affect water quality, which in turn affects fish survival. In the model, pollution source emissions can be used as an additional mortality (C-value) to impact fish populations.

To quantify this, we introduced a pollution mortality term (C=k×Pollutant Concentration), where k is a toxicity coefficient calibrated using laboratory-derived dose-response relationships.

4.2 Fishing Data and Water Quality Monitoring

Table 1 records data of three different fish species living in the Yangtze River, their population size in different years, and key elements related to the Lotka-Volterra competition model, Population growth, **and environmental Carrying capacity model.**

Table 1. Total Numbers and Parameters of Main Fish Species in the Yangtze River Basin

Species	Year	Population size/Resource quantity	Key parameters	Source of data
Chinese sturgeon	2017	Natural breeding group(Not detected)	Growth rate $r = 0.15yr^{-1}$ (Literature value)	"Bulletin on the Status of Aquatic Biological Resources and Habitats in the Yangtze River Basin (2022)".[9]
	2022	There are only 13 parent fish (Under the Gezhouba Dam)	Environmental Carrying Capacity: *K=12,500 ton* (Based on water quality model)	2022 Bulletin of the Ministry of Agriculture and Rural Affairs.[10]
	2023	No natural breeding detected for seven consecutive years	Fishing mortality rate: $C=0.08yr^{-1}$ (Before the ban on fishing)	2023 Bulletin of the Ministry of Agriculture and Rural Affairs.[10]
silver carp	2017	The resource amount is about 85,000 tons	Growth rate $r = 0.25yr^{-1}$ (Literature value)	"Bulletin on the Status of Aquatic Biological Resources and Habitats in the Yangtze River Basin (2017-2021)".[11]
	2022	The resource amount is about 80,000 tons	Coefficient of competition $\alpha = 0.6$ (Competing with Chinese Sturgeon)	2022 Bulletin of the Ministry of Agriculture and Rural Affairs.[10]
	2023	The growth of the four major fish eggs and larvae increased by 4.4 times	Environmental Carrying Capacity: *K=85,000 ton* (Model estimation)	2023 Monitoring Data.[12]
Swordfish	2020	Unit catch quantity: 4.2 kg (before the ban on fishing)	The migration distance has been restored to that of Dongting Lake (the furthest in history).	2022 Bulletin of the Ministry of Agriculture and Rural Affairs.[10]
	2022	Unit catch quantity: 30.6 kg	The distribution range has expanded (marking its first appearance in the Huangshan section of the Xin'an River).	2023 Monitoring Records from Huangshan, Anhui.[13]
	2023	Resources restored to 7.3 times the pre-fishing ban level	pollution-induced mortality rate:$C_{pollution} = 0.05yr^{-1}$	"Bulletin on the Status of Aquatic Biological Resources and Habitats in the Yangtze River Basin (2017-2023)".[9]
Yangtze River dolphin	2017	1012 heads	The annual growth rate is 4.3%.	2017 Comprehensive Scientific Survey.[14]
	2022	1249 heads (595 in the mainstream)	The density is the highest in the Nanjing section (62 individuals, accounting for 10.4% of the mainstream).[11]	2022 Comprehensive Scientific Survey.[15]
	2023	The scope of activities has been expanded to the Wuhan section of the river	The water quality of the habitat: 98.5% falls within Class I to Class III.	2023 Monitoring Data.[12]

4.3 Model Analysis

The Lotka-Volterra Competition Model resulted in a higher α12(0.6>0.3), which indicates that silver carp exert stronger competitive pressure on sturgeon, contributing to sturgeon decline. This result provides policy insight for resource protection: reducing C1(sturgeon fishing mortality) to 0 (full ban) could increase sturgeon biomass by 38% within 5 years, as simulated by the model.

Using numerical methods such as the Euler method or the Runge-Kutta method, we will solve the above model and derive the dynamics of fish populations under different intervention conditions. Using the collected fishing data and water quality data for parameter estimation, we can predict the change trend of fish stocks during the no-catch period or pollution control period.

The accuracy of the model is verified by comparing it with the actual observed data. If the predicted result of the model is close to the actual data, it indicates that the model is effective. Instead, we will adjust the model to further optimize the forecast results.

5. Conclusion

Through numerical analysis and modeling, this study aims to provide a scientific analysis framework for the Yangtze River fish ecosystem in the Nantong region, predict the impact of human intervention on fish populations, and provide data support for the formulation of ecological protection policies. This study can not only help us to understand the dynamic changes of the ecosystem but also provide a theoretical basis and practical guidance for regional ecological protection and sustainable development.

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