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RESEARCH ARTICLE

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RESEARCH ON FISH RESOURCES PROTECTION AND ECOLOGICAL RESTORATION IN THE CONSTRUCTION OF HYDROPOWER STATIONS IN PLATEAU AREAS

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ABSTRACT

The plateau regions are characterized by significant topographic relief, and the construction of hydropower stations has become an effective component of economic development. However, the construction of hydropower stations can lead to damage to fish resources and the aquatic ecological environment. This paper focuses on the protection of fish resources in hydropower stations in plateau regions and finds that dam construction and power plant construction can restrict the migration of fish and affect fish diversity. Water storage during the dry season can increase fish diversity in rivers, but the release of flow in the reduced water section not meeting standards can also have a certain impact on fish diversity. Therefore, this paper suggests that fish resource protection and ecological restoration can be carried out through engineering and non-engineering methods.

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INTRODUCTION

In recent years, with the construction of water conservancy projects, the ecological environment of dammed rivers has been damaged, and the protection of fish resources has become a widely concerned issue in society (Wen *et al.*, 2020). The construction of dams affects the migration of fish, destroys the original spawning grounds, feeding grounds and wintering grounds of fish in the river, and leads to changes in the habitat of fish. At the same time, the construction of dams also changes the connectivity of rivers, causing damage to the migration of fish, hindering the genetic exchange of fish populations and limiting the genetic diversity of fish. The construction of fish passage facilities has become the main measure for the protection of fish resources in water conservancy projects (Lan *et al.*, 2025). Currently, the main methods adopted internationally include the construction of fishways, ecological fishways, fish ladders, fish locks, ship locks, fish lifts and fish collection and transportation facilities. However, most of these facilities are not ideal, so it is necessary to adopt a combination of non-engineering measures to protect fish and restore the ecological environment to achieve the maximum protection of the ecological environment (Chen *et al.*, 2020;). The plateau region has the characteristic of ecological fragility, and large-scale engineering measures may disrupt the original ecological balance. Therefore, non-engineering measures for the protection of fish resources can largely protect the original habitat and promote fish diversity without changing it.

At the same time, a combination of small-scale engineering measures and non-engineering measures can be adopted to effectively protect fish resources.

RESEARCH AREA AND METHODS

Research Area: This study focuses on the LLS hydropower station in the western plateau region of China. The hydropower station is a diversion type, and its working area is composed of the powerhouse (S1), dam site (S2), and the reduced flow section (S3). Sampling points were set up at the dam site, powerhouse, and the reduced flow section respectively, mainly to observe the diversity of fish resources and the current habitat status. The specific sampling points are shown in Table 1.

Table 1. Coordinates of specific sampling points

Sample point	Sample point name	Longitude	Latitude
S1	Powerhouse	99.2481E	30.2366N
S2	Dam site	99.2565E	30.2290N
S3	Reduced flow section	99.2592E	30.2224N

Fish Species Identification: This study mainly employed the methods of on-site fishing, market research supplementation, and environmental DNA (eDNA) sequencing for the investigation of fish resources. This survey was mainly conducted during the dry season,

but the fishing results were not significant. Therefore, the sequencing data of eDNA was mainly used as the main data for this study.

Data Analysis and Visualization: All statistical analyses in this study were conducted using SPSS software. The calculation of fish diversity mainly employed α diversity to represent it, including Simpson index (D'), Pielou evenness index (J), Margalef richness index (M), and Shannon-Wiener diversity index (H). The specific calculation methods are as follows (Shannon, 1948; Simpson, 1949; Jessup et al., 2022):

$$D' = 1 - \sum_{i=1}^S \left(\frac{n_i}{n}\right)^2 \quad (1)$$

In the formula (1) : D' - Simpson's diversity index; n - total number of individuals of large benthic invertebrates; S - number of species of large benthic invertebrates; n_i - number of individuals of the i -th species of large benthic invertebrates.

$$H = - \sum P_i \times \ln P_i \quad (2)$$

$$J = \frac{H}{\ln S} \quad (3)$$

$$M = \frac{S-1}{\ln N} \quad (4)$$

In the formula(2) (3) and (4), P_i represents the proportion of the number of individuals of the i -th species to the total number of individuals, S is the number of species that have been surveyed, and N is the total number of species that have been discovered.

RESULTS

Fish Collection Results: A total of 3 species of fish were collected, amounting to 232 individuals. They belong to 1 order, 2 families, and 3 genera, including 2 specimens of Shi's Plateau Loach, 35 specimens of Fine-tailed Plateau Loach, and 195 specimens of Schizopygopsis malacanthus fish. Among the catch, there is 1 species of fish endemic to the upper reaches of the Yangtze River, which is Schizopygopsis malacanthus fish. From the proportion of the catch, the affected sections of the river mainly have Cyprinidae fish as the main species, and Cyprinidae fish are medium and small-sized fish. Among them, Schizopygopsis malacanthus fish has the largest number and is the dominant species (as shown in Table 2).

Table 2. Data of On-site Fish Collection

Species	Quantity	Mean weight (g)	Mean body length (mm)
Schizopygopsis malacanthus	195	7.4	84.8
Triplophysa stenura	35	14	112.1
Triplophysa stoliczkai	2	13.3	119

Environmental DNA Test Results: Through eDNA testing, it was found that there were 21 species of fish in S3, 25 species in S1, and 21 species in S2. The majority of the fish species were of the Cypriniform order (as shown in Figure 1).

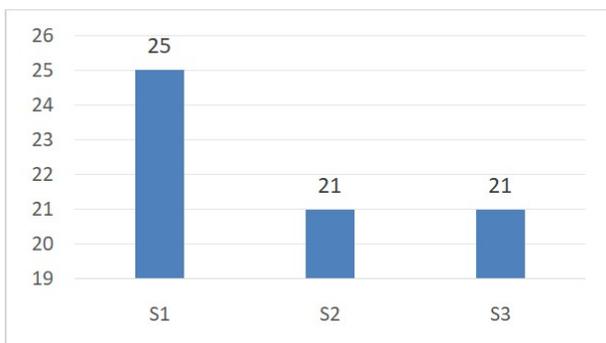


Figure 1. Results of fish environmental DNA testing at LLS Hydropower Station

Analysis of Fish Diversity: As shown in Table 3, the results of fish species diversity at the LLS hydropower station indicate that the fish diversity at this station is quite good. The fish diversity was the highest at the S2 sampling point, followed by S3, while the species diversity at S1 was relatively lower. From the perspective of the Simpson index, the indicator at the S2 sampling point was higher than that at S3 and S1 sampling points, suggesting that there is a dominant species in the reservoir area. The large presence of the endemic Schizopygopsis malacanthus fish indicates that the riverine habitat still meets the survival requirements of rare fish species. The number of abundant fish species detected by eDNA reflects that the operation of the power station has not caused a devastating impact on the fish community in the basin. However, the fish diversity at the S1 sampling point was relatively lower, suggesting that the construction and operation of the power station may have caused certain disturbances to the fish habitat in this area. Attention should be paid to optimizing the habitat suitability.

Table 3. Calculation Results of Fish Diversity

Sample point	H	D'	J	M
S1	2.68	0.16	0.83	2.15
S2	2.98	0.20	0.98	2.04
S3	2.81	0.16	0.92	1.97

Protection Measures and Suggestions

Protection Principles

(1) Principle of Effective Stakeholder Participation: River ecological protection not only requires maintaining the ecological balance of the river itself, but also needs to gain public recognition and support. Therefore, the principle of effective stakeholder participation should be integrated throughout the entire process of river protection, fully reflecting the needs of various stakeholders, ensuring the health and stability of the river ecosystem, promoting the implementation of the ecological protection plan, and effectively coordinating the interests of all parties.

(2) Principle of Maximizing Comprehensive Benefits: River ecological restoration has the characteristics of high investment, high risk, and long cycle. Due to the complexity of the river ecosystem, the direction of succession and the effectiveness of restoration are uncertain. Therefore, it is necessary to base on the overall system of the river basin, conduct comprehensive analysis of costs and benefits under the current monetary conditions, take into account both short-term and long-term interests, combine the actual situation of the river and the restoration goals to formulate the optimal restoration plan, achieve the maximum restoration effect, and comprehensively enhance the comprehensive benefits of the economy, society, and the environment.

(3) Principle of Biodiversity: Biodiversity is the core foundation for maintaining the balance of the river ecosystem and ensuring the health of the river system. River ecological restoration should follow the biodiversity principle in ecology. Under the premise of preventing biological invasion, introduce native species, build ecological habitat corridors, and effectively protect and enhance the biodiversity level of the river system.

(4) Principle of Dividing River Sections: Based on the differences in river section morphology and river gradient, a single river can be divided into different river sections. The degree of ecological damage and the restoration goals of each river section are significantly different. Therefore, the division of river sections should be carried out according to the principle of dividing river sections, prioritize selecting river sections with higher restoration priority, match appropriate restoration technical means, and achieve the expected restoration effect through the combination of overall optimization and local refinement.

(5) Principle of Considering Different Time Periods: The ecological restoration of river system functions is a long-term process and cannot be accomplished in one step. In different time periods, due to changes in the dominant function of the system, adjustments in external conditions, etc., the river system presents different dynamic change characteristics. The restoration work needs to be planned and implemented in a reasonable way based on the actual situation of each stage, clearly define the positioning and governance goals of the current restoration stage, and take scientific and appropriate restoration measures in a targeted manner.

(6) Principle of Multi-functional Coordination: The requirements for the health and stability of the river ecosystem for various functional indicators are different. Therefore, the principle of multi-functional coordination should be followed. Based on the analysis of individual functional indicators one by one, comprehensively consider the correlation and coordination among various indicators to achieve the overall consideration and coordinated improvement of various functions of the river.

(7) Principle of Prioritizing Main Functions: The importance of various functions of the river system varies in different river sections and at different times. It is necessary to follow the principle of prioritizing main functions based on the actual situation and implement policies flexibly. For areas with relatively light pollution and higher economic development levels, the river ecosystem structure and function can be optimized to meet the ecological function requirements; for areas with excessive development and prominent pollution problems, the self-purification function of the river needs to be guaranteed. When various functions cannot be achieved simultaneously, the main function of the river should be prioritized.

(8) Principle of Natural Circulation: The principle of natural circulation is the fundamental principle for river ecological restoration. The natural circulation of rivers is constrained by multiple factors such as population and society, urban planning, industrial structure, land use, river conditions, pollution characteristics, geological and geomorphic conditions, vegetation conditions, climate environment, and management mechanisms. It is necessary to comprehensively analyze various influencing factors, accurately assess the causes and extent of river ecological damage, and accordingly formulate targeted restoration and remediation measures. Fully leveraging the self-purification and self-regulation capabilities of the river ecosystem, combined with ecological theories and supplemented by scientific and moderate artificial intervention, promote the restoration of the river ecosystem towards a healthy and natural direction, and construct a river ecological environment where humans and nature coexist harmoniously.

Protection Countermeasures

Engineering Measures

(1) Horizontal Section Deepening Channel: In the reduced-flow sections, the flow decreases, and the river is mostly in a low-flow state. Under low-flow conditions, the width-to-depth ratio of the water passage is large, presenting a very wide and shallow form, which is extremely unfavorable for the survival of fish. By locally deepening the cross-section to form a deep channel, a compound cross-section can be constructed. The deep channel will have a larger water depth, which is conducive to the survival of fish.

(2) Vertical Section Setting of Water Retaining Weirs: On the vertical section of the reduced-flow river, setting water-retaining weirs at certain intervals can increase the cross-sectional water depth and increase the water surface area. The local upstream water level will rise, forming a deep pool, while the downstream part may cause a fast-flowing habitat.

(3) Cross-section Layout of Artificial Steps - Deep Pools: Referring to the structure and morphology characteristics of the natural steps -

deep pools system in mountainous rivers, artificial steps - deep pools are arranged in the reduced-flow river section.

(4) Construction of Fish Migration Channels: Build fish migration channels to restore the seasonal migration of fish between blocked river sections. The construction of fishways should be based on a thorough understanding of the river flow characteristics and ecological protection issues, combined with the migration habits of fish, to make them as close as possible to the migration of fish. For example, to avoid affecting the smooth entry of fish into the fishway, the design position of the fishway entrance should be far away from existing water conservancy projects, and the shape of the fishway section should not be built as a regular rectangle or trapezoid, and the curvature of the fishway should be close to that of the natural river. In addition, shallow banks should be set in the river to provide resting places for fish during migration.

Non-Engineering Measures

(1) River Ecological Diversions: River ecological diversions are an important measure for river ecological restoration. The purpose is to meet the ecological water demand of the river ecosystem, restore or partially restore the natural ecological laws of the river. Ecological diversions aim to regulate the water demand contradiction between humans and nature, attempting to find a balance point for water resource allocation between humans and the environment.

(2) River Section Water Supply: The methods of river section water supply mainly include natural precipitation and dam discharge. During the dry season, precipitation is scarce, and most of the water from the upstream of the river is used for power generation, resulting in a decrease in the flow of the reduced-flow sections and threatening the ecosystem (Ji et al., 2026). Forced discharge of a certain flow is the most direct and effective remediation method for the river ecosystem of the reduced-flow sections. According to the actual conditions of the river, based on the calculated ecological flow required by the reduced-flow sections, holes should be drilled on the dam to release the corresponding flow, which is of great significance for restoring the river ecosystem of the reduced-flow sections (Wang, 2024).

(3) Ecological supplementation: Properly supplement the release of fish in the upstream area of the hydropower station. When conducting the release, it is essential to introduce native species to prevent the invasion of alien species or their becoming dominant species, which could cause harm to the local biodiversity. Carry out the breeding and release of endemic fish species: artificially breed the *Schizopygopsis malacanthus* fish, and release juvenile fish with a size of $\geq 38\text{mm}$ in the reservoir area and the reduced-flow sections every year to replenish the population and enhance the fish diversity downstream of the power station.

(4) Restoration of fish feeding ground habitats: The riverbed downstream of the factory building was subjected to ecological renovation. Pebbles and gravel were laid down, and the riverbed substrate was restored by adding artificial substrates (such as ecological concrete and bamboo fiber bundles), providing attachment and breeding sites for the benthic animals that fish need.

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