Water Ecological Restoration in the Chishui River Demonstration Area of the Upper Yangtze River: Achievements and Challenges (Postprint)

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Abstract

"Deeply advancing green development demonstration and promoting ecological environmental protection of the Chishui River Basin" constitutes a major strategic decision and deployment articulated in the Outline of the 14th Five-Year Plan for National Economic and Social Development of the People' s Republic of China and the Long-Range Objectives Through 2035. Strengthening the protection of the water ecological environment of the Chishui River holds exemplary and leading significance for preserving fish diversity in the upper Yangtze River, fostering high-quality regional development, and ushering in a new phase of ecological civilization and Beautiful China construction. This article analyzes the ecological functions of the Chishui River in the upper Yangtze River, elaborates on the effectiveness of conservation and restoration measures implemented in recent years—including comprehensive fishing bans and the cleanup and rectification of small hydropower stations on tributaries—and proposes countermeasures and recommendations for further strengthening the protection and restoration of the Chishui River' s water ecological environment from the perspective of holistic basin protection and systematic restoration.

Full Text

Effectiveness and Challenges of Aquatic Ecological Restoration of Chishui River in Upper Yangtze River

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Abstract

"To set an example of green development and strengthen ecological environmental protection in the Chishui River basin" is an important proposal listed in the Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and Vision 2035 of the People' s Republic of China. Strengthening eco-environmental protection in the Chishui River will play an exemplary and leading role in maintaining fish diversity of the upper Yangtze River, promoting regional high-quality development, and creating a new situation of ecological civilization and Beautiful China. This study interprets the ecological functions of the Chishui River in the upper Yangtze River, expounds the effectiveness of ecological protection and restoration measures implemented in recent years such as the complete fishing ban and rectification of small hydropower stations on tributaries, and proposes countermeasures and suggestions to further strengthen the ecological protection and restoration of the Chishui River from the perspective of whole-basin protection and systematic restoration.

Keywords: upper Yangtze River, Chishui River, aquatic ecological restoration, fishing ban, small hydropower stations withdraw

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1. Ecological Status of Chishui River in the Upper Yangtze River

The Chishui River, a first-order tributary on the right bank of the upper Yangtze River, is renowned as an "ecological river," "fine wine river," "scenic river," and "heroic river." It holds a pivotal position in regional socioeconomic development and cultural heritage, while also serving as a vital ecological barrier in the upper Yangtze River with important ecological functions.

1.1 Chishui River as a Mitigation for Adverse Impacts of Hydropower Development in the Lower Jinsha River

The upper Yangtze River is one of China' s most fish-rich regions, harboring 286 fish species, including as many as 124 endemic species

[2,3]. Concurrently, it is also the most concentrated area of hydroenergy resources in China, with a theoretical hydropower potential of $2.19\$\times10^8 kW and a developable capacity of 1.71\times10^8 kW, accounting for 86.8\times\$10\hat{}8$ kW) [4]. With the implementation of cascade hydropower development in the upper Yangtze River, the aquatic ecological environment will undergo profound changes, and the rare and endemic fish species inhabiting this region will be adversely affected to varying degrees [4,5]. To mitigate these adverse impacts, the State Council approved the establishment of the "National Nature Reserve for Rare and Endemic Fishes in the Upper Yangtze River" in 2005 [6]. The Chishui River, whose main stem has not yet been developed for hydropower and still maintains natural flow regimes, has been incorporated into this reserve along with its entire main stem and some headwater tributaries due to its rich fish resources and natural river characteristics [Figure 1: see original paper].

Surveys indicate that the Chishui River basin is home to 150 indigenous fish species, including 2 species under first-class national protection, 9 species under second-class national protection, and 45 endemic fish species of the upper Yangtze River. The number of rare and endemic fish species accounts for approximately two-thirds of the total rare and endemic fish species in the reserve. Among the numerous tributaries and main stem sections in the upper Yangtze River, the Chishui River ranks among the top in terms of both total indigenous fish species and endemic fish species [3,7-11]. Specifically, its total indigenous fish species rank 5th after the Jinsha River, main stem Sichuan River section, Min River, and Jialing River, while its endemic fish species rank 4th after the Jinsha River, Min River, and main stem Sichuan River section . Notably, most rare and endemic fish species affected by hydropower development in the lower Jinsha River, such as *Procypris rabaudi*, *Leptobotia elongata*, *Percocypris pingi*, *Onychostoma angustistomata*, and *Schizothorax grahami*, can complete their entire life history in the Chishui River. Therefore, the Chishui River serves as a critical habitat for mitigating the adverse impacts of hydropower development in the lower Jinsha River and holds significant value for the conservation of rare and endemic fish [5,12].

1.2 Chishui River as an Important Spawning Ground for Fish with Drifting Eggs

The reproduction of fish with drifting eggs requires the stimulus of rising water levels, and the fertilized eggs need sufficient flow distance and velocity in the water to ensure proper incubation and development during downstream drift [13]. If the flow distance is too short or the velocity too low, the eggs may sink to the bottom and die from oxygen deficiency, making these species particularly sensitive to hydropower development and other water-related engineering projects. The Chishui River, with its long course, abundant water volume, and absence of hydropower projects on its main stem, maintains natural hydrological regimes that provide excellent spawning conditions for fish with drifting eggs. Investigations show that the Chishui River can satisfy the reproductive

requirements of over 20 fish species with drifting eggs, with a large average annual spawning scale of 400 million eggs (internal data). As cascade hydropower development in the lower Jinsha River is implemented, the hydrological regime and water temperature conditions in the lower Jinsha River and the main stem of the reserve will change significantly [5], severely affecting the reproduction of fish with drifting eggs. Due to minimal impacts from hydropower development, the Chishui River maintains natural patterns of water temperature and hydrological rhythms, providing spawning conditions for numerous fish species with drifting eggs. Some species that previously spawned mainly in the main stem of the reserve are now seeking new habitats and spawning grounds in the Chishui River [5].

2. Assessment of Chishui River Aquatic Ecological Restoration Effects

In recent years, to improve the ecological environment quality of the Chishui River, central and provincial governments of Yunnan, Guizhou, and Sichuan have implemented a series of ecological protection and restoration measures, including pioneering a complete fishing ban and rectifying small hydropower stations on tributaries, which have effectively promoted ecological recovery.

2.1 Effects of the Complete Fishing Ban

The "10-Year Fishing Ban in the Yangtze River" is a major decision made by the Party Central Committee and the State Council for the long-term benefit of future generations, representing a historic, iconic, and demonstrative project for Yangtze River protection. As a pilot demonstration area for this ban, the Chishui River provides important reference for other key waters in the Yangtze River basin [14,15]. To scientifically evaluate the effectiveness of the fishing ban, this study analyzed monitoring data from five years before (2012-2016) and five years after (2017-2021) the ban at four regular monitoring sites (Potou Town at the source, Chishui Town in the upper reaches, Chishui City in the middle reaches, and Hejiang County in the lower reaches). The analysis examined changes in fish resources from various aspects including species diversity, representative rare fish populations, dominant species population structure, overall resource quantity, and fish reproduction status. The results show that after five years of complete fishing ban, fish resources in the Chishui River have recovered significantly [15], manifested in five main aspects.

First, fish species diversity has steadily improved. The number of fish species collected at different monitoring sites showed an increasing trend [Figure 2: see original paper]. Species that had disappeared for many years, such as *Anguilla japonica*, *Xenophysogobio boulengeri*, *Leptobotia rubrilabris*, *Xenocypris microlepis*, and *Saurogobio gymnocheilus*, have reappeared in the Chishui River. Endemic species previously found mainly in the estuary section, such as *Rhinogobio cylindricus*, *Ancherythroculter nigrocauda*, and *Megalobrama pellegrini*,

have expanded upstream to the Tucheng section in the middle reaches, while *Schizothorax kozlovi* has expanded downstream from the Yudong Village section at the source to the Erlongqiubao section.

Second, populations of some rare fish species have increased significantly. During the monitoring period, nine species of nationally protected wildlife were collected across the four monitoring sites, including *Acipenser dabryanus*, *Myxocyprinus asiaticus*, *Coreius guichenoti*, *Percocypris pingi*, *Onychostoma angustistomata*, *Procypris rabaudi*, *Leptobotia elongata*, *Leptobotia rubrilabris*, and *Pseudexostoma brachysoma*. Using occurrence frequency (the rate of occurrence during total survey days) to characterize population trends, the results show that populations of *Acipenser dabryanus*, *Myxocyprinus asiaticus*, *Procypris rabaudi*, and *Pseudexostoma brachysoma* increased significantly .

Third, the population structure of dominant species has improved markedly. The average body length and weight of dominant species such as *Schizothorax grahami*, *Acrossocheilus yunnanensis*, *Garra pingi*, *Pseudogyrinocheilus prochilus*, *Spinibarbus sinensis*, *Mystus macropterus*, and *Leiocassis crassilabris* increased significantly. Average body length increased by 4.1%-28.8%, and average body weight increased by 5.7%-64.6%. Meanwhile, the proportion of large individuals in populations increased notably, indicating that the trend of fish population miniaturization and younger age structure has been effectively curbed [15].

Fourth, fish resource biomass has increased substantially. Single-vessel monitoring catches at the four sites increased from 4.4 kg/d, 3.7 kg/d, 4.1 kg/d, and 5.0 kg/d during the five years before the ban to 6.3 kg/d, 5.2 kg/d, 8.2 kg/d, and 10.6 kg/d during the five years after the ban, representing growth rates of 40%-110%.

Fifth, fish reproduction status has improved significantly. The number of early-life-stage fish species collected at the Chishui City section increased from 31 species during the five years before the ban to 45 species during the five years after the ban. Grass carp (*Ctenopharyngodon idellus*), *Xenophysogobio boulengeri*, and silver carp (*Hypophthalmichthys molitrix*), which previously spawned mainly in the main stem of the Yangtze River, were monitored spawning in the Chishui River for the first time in 2018, 2020, and 2021, respectively.

2.2 Effects of Small Hydropower Station Rectification

Although the main stem of the Chishui River has no hydropower projects, tributary hydropower development was once severe. Statistics show that by May 2020, there were 373 hydropower stations in the Chishui River basin with a total installed capacity of 4.494$\times$10^5 kW. Intensive tributary hydropower development severely impacted rare and endemic fish and their habitats. In September 2020, the Central Ecological and Environmental Protection Inspection Team identified several problems: overly dense hydropower station development, severe river dewatering and dehydration compressing fish survival space,

and tributary cascade stations affecting the hydrological regime of the main stem reserve.

To mitigate these adverse impacts, Yunnan, Guizhou, and Sichuan provinces have rectified small hydropower stations in the Chishui River basin since September 2020. According to the provincial rectification plans, 301 small hydropower stations will be completely removed and 28 partially removed, achieving an 88.2% removal rate [Figure 3: see original paper]. By December 2022, 270 small hydropower stations had been dismantled, accounting for 72.4% of the total. The lower reaches of first-order tributaries such as the Datong River, Gulin River, Yanjing River, Baisha River, Baohe River, and Tongche River have basically restored natural connectivity.

To scientifically assess fish resource recovery after hydropower station removal, this study analyzed post-removal monitoring data from typical stations on major tributaries like the Xishui River and Datong River. After removal of the Gaodong Station on the Xishui River, dewatering downstream of the dam site was eliminated, and the former reservoir' s static environment upstream was restored to flowing habitat. Both fish species number and resource quantity increased significantly in different river sections. Downstream of the dam site, fish species increased from 10 before removal to 17 in May 2022, and single-vessel monitoring catch increased from 8 kg/d to 11.9 kg/d. Upstream of the dam site, fish species increased from 15 to 16 [Figure 4: see original paper], and catch increased from 8.3 kg/d to 11.8 kg/d [Figure 5: see original paper]. After removal of the Lianghui No. 1 Station on the Datong River, fish species numbers increased in both upstream and downstream sections. Flow-preferring species such as *Onychostoma angustistomata*, *Procypris rabaudi*, and *Bangana rendahli*, as well as the drifting-egg spawner *Botia superciliaris* that requires long-distance migration, have already migrated upstream to the former reservoir area.

3. Challenges Facing Chishui River Aquatic Ecological Restoration

Despite the series of restoration efforts and notable achievements, the Chishui River still faces challenges due to historical ecological debts, blind following of some restoration measures, and lack of basin-wide systematic considerations.

3.1 Slow Recovery of Some Rare Fish Populations

Although fish resources have recovered significantly after five years of complete fishing ban, the occurrence rates and population numbers of some rare and endemic fish species, such as *Coreius guichenoti*, *Rhinogobio ventralis*, and *Onychostoma angustistomata*, have not increased notably, indicating their survival prospects remain concerning. Although nationally protected species like *Acipenser dabryanus* and *Myxocyprinus asiaticus* have been collected more frequently due to continuous large-scale stock enhancement, no natural reproduction in the wild has been observed, and the risk of extinction in the wild persists.

3.2 Lack of Scientific Basis for Some Restoration Measures

Currently, ecological restoration in the Chishui River basin generally suffers from formalism and utilitarianism, with the rationality and scientific basis of relevant measures needing improvement. Due to operational simplicity and high visibility, stock enhancement has long been regarded as the primary or even sole restoration method. After five years of complete fishing ban, most fish populations in the Chishui River have recovered effectively without requiring excessive artificial intervention. However, some localities still treat stock enhancement as the main restoration approach, blindly pursuing release numbers while "selectively ignoring" the species, quality, and effectiveness of releases. Species such as *Schizothorax grahami*, *Acrossocheilus yunnanensis*, *Spinibarbus sinensis*, and *Onychostoma angustistomata* are already dominant in the Chishui River, yet they continue to be massively released because fry are readily available and inexpensive. These fry originate from other basins outside the Chishui River, and their germplasm quality cannot be guaranteed. Such inter-basin releases pose potential threats to the germplasm resources of indigenous fish in the Chishui River. Due to blind stock enhancement, exotic species from northern China such as *Phoxinus oxycephalus* and *Barbatula nuda* have successfully established populations in some Chishui River tributaries, posing serious threats to indigenous species like schizothoracine fishes. Additionally, some localities ignore ecological red lines and construct so-called "ecological embankments," "ecological revetments," and "ecological footpaths" in the core zone of nature reserves under the guise of ecological restoration, resulting in large-scale bank hardening and destruction of fish habitats.

3.3 Insufficient Cross-regional Coordination Mechanisms

Most of the Chishui River main stem consists of provincial boundary rivers, and some tributaries cross multiple counties and cities. The lack of cross-regional communication and cooperation mechanisms results in insufficient systematic and holistic ecological protection and restoration [16], preventing true achievement of "coordinated upstream-downstream action, integrated main stem-tributary management, and joint left-right bank efforts." Taking the Xishui River small hydropower rectification as an example, due to its confluence being close to the Yangtze River main stem, the Xishui River historically served as an important habitat for rare fish such as *Acipenser dabryanus* and *Myxocyprinus asiaticus* [17]. However, due to dam obstruction and other human impacts, these fish disappeared from upstream areas. To mitigate adverse impacts of tributary hydropower development and promote recovery of rare and endemic fish resources, Chishui City in Guizhou Province completely removed the Gaodong and Lizhishu stations in January 2021. However, the rectification progress in Sichuan Province has lagged significantly; the Qianyudong Station in Hejiang County remains unremoved, preventing full connectivity of the Xishui River and continuing to block fish migration, thus hindering the river' s ecological functions. Similar situations exist widely in inter-provincial tributaries such as the

Datong River and Daoliu River.

3.4 Inadequate Basin Ecological Compensation Mechanisms

In 2018, Yunnan, Guizhou, and Sichuan provinces jointly signed the "Chishui River Basin Transverse Ecological Compensation Agreement," the first inter-provincial transverse ecological compensation mechanism in the Yangtze River basin, which plays an important role in promoting Chishui River ecological improvement. However, the current mechanism has several deficiencies: (1) Single compensation subject. The current mechanism is government-dominated, with few participating enterprises and other beneficiaries, failing to leverage market mechanisms. (2) Limited compensation funds. The current funding scale cannot meet subsequent ecological protection and restoration needs. According to the Guizhou and Sichuan small hydropower rectification plans, the budget for small hydropower removal and subsequent restoration alone exceeds 8.5 billion RMB, while the existing ecological compensation mechanism has limited effect in these areas. (3) Absence of market incentive mechanisms. The current mechanism only has reverse constraints without positive incentives. Some counties and cities in the lower Chishui River have made important contributions to protection but receive no compensation funds, resulting in low enthusiasm for ecological protection and restoration.

4. Recommendations for Future Chishui River Aquatic Ecological Restoration

To further improve the water ecological environment quality of the Chishui River, ensure regional ecological security and sustainable development, and consolidate its role as a pilot demonstration area for Yangtze River protection, we recommend problem-oriented and goal-oriented approaches with precise measures and coordinated promotion from the perspective of holistic river ecosystem protection and systematic restoration.

4.1 Strengthen Protection and Restoration of Rare and Endangered Fish

To address the slow recovery of some rare fish populations, we recommend intensifying artificial-assisted species recovery efforts, establishing a conservation center for rare fish to collect and preserve germplasm resources, and focusing on mastering artificial breeding technologies for endangered species such as *Coreius guichenoti*, *Rhinogobio ventralis*, and *Onychostoma angustistomata*, while conducting wild population reinforcement trials for rare and endangered fish. To avoid adverse impacts of blind stock enhancement on indigenous fish germplasm resources, all enhancement activities aimed solely at economic species proliferation should be banned, shifting instead toward promoting recovery of rare and endangered species such as *Acipenser dabryanus*, *Coreius guichenoti*, *Rhinogobio ventralis*, and *Onychostoma angustistomata*.

4.2 Continuously Strengthen Aquatic Ecological Protection and Restoration

According to previously formulated small hydropower rectification plans and waterway improvement plans, we should accelerate the rectification of prominent ecological and environmental issues such as tributary hydropower development and waterway regulation in the Chishui River basin. We should further deepen pollution control in key enterprises such as liquor brewing, coal mining, and paper manufacturing, optimize industrial structure and spatial layout, change the high-input, high-consumption, and high-emission development model, and promote green development transformation and upgrading of typical industries by region [18].

4.3 Innovate Basin Coordination Management Models

We should establish a comprehensive basin management agency to break departmental and regional divisions, provide unified guidance and coordination for Chishui River ecological protection and restoration, and promote unified ecological environment access and exit mechanisms and ecological compensation and penalty standards throughout the basin [19]. From the perspective of holistic river ecosystem protection and systematic restoration, the central government should coordinate the formulation of the "Chishui River Basin Ecological Protection and Restoration Plan" to systematically deploy and scientifically arrange protection and restoration work including tributary small hydropower rectification, ecological waterway transformation, wild population reinforcement of rare fish, and water pollution control.

4.4 Improve Ecological Compensation Mechanisms

We should further improve the ecological compensation mechanism by strengthening central and provincial fiscal support, incorporating beneficiaries such as liquor enterprises in the Chishui River basin and hydropower development enterprises in the upper Yangtze River into the compensation system, and expanding funding sources. Simultaneously, we should extend the compensation period, expand funding scale, and establish more reasonable allocation mechanisms.

4.5 Strengthen Scientific Research and Monitoring

As the only remaining natural river in the upper Yangtze River, the Chishui River has a unique and complete river ecosystem structure and function with abundant aquatic biological resources, providing an ideal experimental field for theoretical river ecology research. Moreover, as a pilot demonstration area for the "10-Year Fishing Ban in the Yangtze River" and small hydropower rectification, it has important exemplary and leading roles. Therefore, we recommend establishing a long-term monitoring network for aquatic biodiversity and water environment covering the Chishui River main stem and major tributaries. Through long-term fixed-point monitoring, we can comprehensively grasp the

population dynamics of rare and endemic fish and the evolution of river ecosystem structure and function, scientifically evaluate the effectiveness of protection measures such as the "10-Year Fishing Ban in the Yangtze River," and systematically conduct research on river connectivity restoration, typical habitat restoration, and artificial breeding and wild population reinforcement technologies for rare and endemic fish, providing scientific theories and technical support for the national strategy of Yangtze River protection.

5. Implications of Chishui River Ecological Restoration for Yangtze River Protection

As a successful case of holistic basin protection and systematic restoration, the Chishui River experience offers important lessons for Yangtze River protection.

5.1 Adhere to Natural Recovery as the Primary Approach and Continue Strict Implementation of the Complete Fishing Ban

Since the Chishui River pioneered the complete fishing ban in 2017, fish resources have recovered notably. Monitoring results confirm that the complete fishing ban is an effective measure for promoting fish resource recovery in the Yangtze River, and that most species can naturally recover their populations through the ban. To effectively promote fish resource recovery in the Yangtze River, particularly to provide adequate recovery time for rare fish species with relatively slow population recovery rates, it is necessary to continue strict implementation of the complete fishing ban policy.

5.2 Adhere to Holistic Protection and Systematic Restoration to Restore River Connectivity

Since 2020, central and local governments have vigorously rectified prominent ecological and environmental issues such as tributary hydropower development and waterway regulation in the Chishui River basin from the perspective of maintaining river ecosystem integrity, greatly restoring river connectivity and effectively promoting fish resource recovery and water environment improvement. We recommend scientifically restoring river connectivity in the Yangtze River basin from a holistic protection and systematic restoration perspective, reconnecting fish migration channels. For example, we should completely remove small hydropower stations on the Anning River (a tributary of the Yalong River), Qingyi River (a tributary of the Dadu River), Shuoluo River (a tributary of the middle Jinsha River), and Zangqu (a tributary of the upper Jinsha River) to restore natural flow regimes and hydrological rhythms, mitigating adverse impacts of main stem hydropower development on flow-preferring rare and endemic fish [5]. Additionally, we should restore connections between some historically connected lakes and the Yangtze River main stem in the middle and lower reaches to ensure normal migration of river-lake migratory fish during different life stages [20].

5.3 Firmly Establish the "Lucid Waters and Lush Mountains are Invaluable Assets" Concept and Actively Explore Mechanisms for Realizing Ecological Product Value

During ecological protection and restoration, the Chishui River basin has consistently adhered to the "lucid waters and lush mountains are invaluable assets" concept and actively explored mechanisms for realizing ecological product value. To address local food fish needs after the complete fishing ban, riparian counties and cities have capitalized on good water resources to develop ecological fisheries according to local conditions. In 2021, Chishui City' s aquaculture production reached 6,700 tons, doubling the 3,140 tons in 2016 before the fishing ban, meeting public demand for high-quality protein. Meanwhile, Chishui City, relying on its 1.328 million mu of bamboo forests, has pursued the path of "ecological industrialization and industrial ecology," with the bamboo industry' s comprehensive income exceeding 8.1 billion RMB in 2020. Additionally, sauce-flavor liquor and eco-tourism industries are maturing. These explorations have transformed ecological value into enormous economic benefits, laying a solid foundation for subsequent protection and restoration.

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Note: Figure translations are in progress. See original paper for figures.