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Impacts of Yangtze Cascade Dams on Migratory Fishes and Restoration

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Abstract. As the river basin with the highest freshwater biodiversity in China, the Yangtze River has seen its hydrological rhythms and habitat connectivity in both its main and tributary streams profoundly reshaped by the extensive construction of cascade dams. This paper aims to systematically analyze the chain of threats posed by cascade barriers to key migratory fish species, such as the Chinese sturgeon and the 'Four Major Carp Species', and to objectively evaluate the effectiveness and limitations of existing ecological restoration technologies. The research findings indicate that physical barriers and the absence of hydrological signals have led to a reduction of approximately 99% in the natural spawning grounds of the Chinese sturgeon, whilst the natural spawning output of the 'Four Major Carp Species' has fallen by more than 98%. Artificial flood pulse creation under ecological water regulation can effectively trigger spawning of semi-anadromous fish, yet conventional fish passage facilities achieve less than 5% passage efficiency for large benthic migratory fish. This study provides crucial theoretical grounds and decision-making support for refining coordinated protection strategies across the main and tributary rivers of the entire basin, and for optimizing the joint regulation system of multiple dams, against the backdrop of the 'Ten-Year Fishing Ban on the Yangtze River'.

Keywords: Yangtze river basin, cascade dams, migratory fish, habitat restoration, ecological restoration

1. Introduction

As a center for the evolution of China's endemic and rare aquatic species, the Yangtze River has given rise to typical migratory fish species of significant ecological and economic value, such as Acipenser sinensis, Acipenser dabryanus and the 'Four Major Carp' (black carp, grass carp, silver carp and bighead carp). However, since the completion of the Gezhouba and Three Gorges hydropower schemes—and particularly in recent years with the successive full-scale commissioning of the cascade of large dams on the lower reaches of the Jinsha River (Wudongde, Baihetan, Xilodu and Xiangjiaba)—the longitudinal connectivity and natural hydrological rhythms of the Yangtze River's main and tributary streams have undergone drastic physical restructuring. The continuous development of this series of high-head cascade dams has directly severed the natural migration routes used by migratory fish to travel between their spawning grounds, feeding grounds and

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overwintering grounds, and has become the core driving factor behind the current decline in aquatic biodiversity in the Yangtze River.

The reproduction and survival of migratory fish are highly dependent, from a biological perspective, on the continuity of river habitats and specific hydrological pulse signals. Cascade dams not only create absolute physical barriers in space, but also—through the regulation of water storage and discharge in reservoirs—lead to the stagnation of water within the reservoir, a reduction in downstream flow velocity, and the 'thermal lag effect' characteristic of deep-water reservoirs. These alterations in the hydrological and physical environment have directly eliminated the flood peak signals required to trigger gonadal development and ovulation in fish, whilst severely compromising the hatching conditions for both benthic adhesive eggs and drifting eggs. For example, research the Gezhouba Dam diversion clearly indicated that the dam severed the Chinese sturgeon's sole upstream migration route, leading to extreme compression and habitat degradation of its natural spawning grounds. Research on the Three Gorges Dam also confirmed that the loss of hydrological signals and the reduction in flow velocity caused by water impoundment were the direct causes of the precipitous decline in natural spawning volumes of the 'Four Major Carp Species' in the middle reaches of the Yangtze River.

In recent years, scholars both in China and abroad have conducted extensive research into the impact of the cascade development of the Yangtze River on aquatic ecosystems. Through long-term community monitoring, Dam operations are driving the fish communities in the middle reaches of the Yangtze River towards a succession towards species adapted to still waters, whilst the diversity of species adapted to fast-flowing waters has declined sharply [1, 2]. Meanwhile, the current state of conservation in the Yangtze River basin, pointing out that, under the influence of the barrier effect, conventional fish passage facilities face technical bottlenecks [3, 4]. Whilst ecological regulation—represented by 'artificial peak creation'—has demonstrated restoration potential in reshaping hydrological signals in certain river sections [5, 6].

Although the academic community has accumulated a wealth of empirical data on the ecological response mechanisms of individual hydropower projects or specific protected species—such as assessments of the Three Gorges Dam's impact on the 'Four Major Carp' or the barrier effect of the Gezhouba Dam on the Chinese sturgeon—there remains a lack of systematic analysis of the 'cumulative threat effect' arising from the entire cascade of dams along the main and tributary rivers of the Yangtze. Furthermore, with the large-scale application of various ecological restoration technologies—such as fish passage facilities, ecological water allocation and fully artificial restocking programmes—there is an urgent need for an objective assessment of the overall effectiveness and practical limitations of these interventions within complex real-world habitats.

In light of this, this paper focuses on the core context of the construction of cascade dams on the Yangtze River, systematically integrates multi-source monitoring data from recent years, and conducts an in-depth analysis of the 'compound threat mechanism' resulting from the combined effects of physical barriers, the absence of hydrological signals and the thermal lag effect. At the same time, it focuses on evaluating the practical effectiveness and limitations of current mainstream ecological restoration techniques—namely, connectivity restoration, hydrological remodelling and artificial stock enhancement—in the conservation of key migratory fish species. This paper aims to provide a scientific theoretical basis and decision-making guidance for optimising joint ecological scheduling mechanisms across multiple dams and formulating long-term strategies for the restoration of aquatic biodiversity throughout the entire basin, against the backdrop of the 'Ten-Year Fishing Ban on the Yangtze River' strategy

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2. Characteristics of changes in aquatic habitats under cascading development

2.1. Disruption of vertical connectivity and attenuation of hydrological processes

The primary ecological impact of multi-stage high dams lies in the complete disruption of a river's natural physical continuity, forcibly dividing what was once a swift and continuous flowing water habitat into alternating 'reservoir' and 'downstream of the dam' zones characterized by semi-still water conditions. Routine reservoir operations significantly dampen the natural flood peak pulses that occur in spring and summer, leading to a substantial reduction in both discharge volume and flow velocity in the downstream sections of the river. The cold-water release effect from deep large reservoirs lowers spring downstream water temperature by 2–4 °C relative to natural conditions and delays warming progress, disrupting fish life-cycle phenology. Furthermore, during high-water discharge in the flood season, the high-head outflow causes intense aeration, which readily leads to supersaturation of total dissolved gas (TDG) in the water (typically exceeding 120 %), completely altering the physicochemical characteristics of the water downstream of the dam [7].

2.2. Degradation of key habitats and spawning sites

Hydrodynamic alteration triggers cascading degradation of benthic habitats. Rapid-flow habitat depth declines significantly. Flow velocity within reservoirs drops sharply from 1.5–2.5 m/s pre-dam construction to 0.1–0.3 m/s, submerging original historic fast-flow spawning grounds under deep reservoir water. Reduced flow velocity also causes massive suspended sediment deposition at reservoir tails and backwater zones; sediment deposits bury original gravel substrates and remove essential attachment and hatching substrate for adhesive-egg spawners. At the eco-physiological level, weakened hydrological rhythms erase spring flood peaks that act as critical reproductive triggers. Species dependent on flow surges and rising temperature cues fail to complete gonadal maturation and ovulation. Cold-water effects delay the date when downstream water reaches the 18 °C threshold required for four major carp spawning by 15–25 days, shortening the effective breeding window. Total dissolved gas supersaturation during large flood discharges exposes incubating larvae and juveniles to lethal risks of gas bubble disease [8].

3. Mechanisms of threat to migratory fish and diagnosis based on empirical data

3.1. Spatial compression and genetic decline—taking the Chinese sturgeon as an example

Acipenser sinensis is selected as the key case species for evaluating dam barrier impacts, as this large anadromous spawner demands intact habitat connectivity across its life cycle. Its long-distance migration makes it ideal to quantify the endangerment pathway: dam physical barriers → habitat spatial compression → shrinking breeding adult populations → loss of genetic diversity. As an iconic Yangtze anadromous fish, Chinese sturgeon reproduction relies on extremely long migration routes. The Gezhouba Dam cut off its roughly 3,300 km upstream migration pathway, confining spawning activity to a narrow 78 km river segment downstream of the dam. Contemporary field surveys show spawning ground area has collapsed from over 600 hm^2 pre-dam construction to approximately 5 hm^2, representing a 99% reduction of functional spawning habitat. Severe habitat compression and fragmentation create an irreversible genetic bottleneck. Wild breeding population size has fallen from 2000–10000 individuals in the 1970s to fewer than 100 mature individuals at present, placing the species in critical endangerment. Continuous molecular monitoring confirms

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disrupted gene flow within wild populations, with effective population size and expected heterozygosity gradually declining, pushing the natural self-sustaining capacity of wild populations close to collapse [9].

3.2. Loss of hydrological pulses and failure of compensatory mechanisms—taking the four major Chinese carp species as an example

Different from the physical barrier mechanism observed in Chinese sturgeon, the four major carp species (black carp, grass carp, silver carp and bighead carp) serve as another representative case, as these mid-Yangtze semi-anadromous fish produce drifting eggs and are highly sensitive to hydrodynamic and flood pulse conditions. They enable quantitative diagnosis of this core pathway: reservoir water stagnation and lost hydrological signals → sinking and suffocation of drifting eggs → breakdown of natural population replenishment.

The four major Chinese carp species (black carp, grass carp, silver carp and bighead carp) are semi-anadromous fish; their reproduction is heavily dependent on hydrological pulses, and the drifting eggs they lay must be suspended in water flowing at a suitable velocity of >1.0 m/s in order to hatch successfully. The drastic reduction in flow velocity in the reservoir and backwater areas caused by dam operations results in vast quantities of drifting eggs sinking to the reservoir bed before their membranes have ruptured, where they suffocate due to oxygen deprivation.

Long-term hydrological and ecological monitoring data reveal the devastating consequences of this process: between 2003 and 2009, following the filling of the Three Gorges Dam, the average annual spawning output of the 'Four Major Carp' at the Yichang section of the middle reaches of the Yangtze River fell to approximately 42 million eggs. Compared with historical data—over 10 billion eggs prior to dam construction (in the 1960s) and approximately 2.5 billion eggs during the early years of the Gezhouba Dam's operation (in the 1980s)—the decline in natural spawning output has exceeded 98 %, signalling that the natural replenishment mechanism of the wild population has become severely compromised [10].

3.3. Community homogenization and the evolution of diversity

The evolution of the habitat from a 'rapid-flow, erosion-dominated' type to a 'still-water, sedimentation-dominated' type has inevitably driven macro-level homogenization of the fish community structure. Long-term fishing statistics on the evolution of fish communities in the middle reaches of the Yangtze River indicate that the proportion of fast-flowing fish species, which are suited to flowing water habitats, in the total catch has declined sharply from 40.5 % prior to dam construction to 12.3 %. At the same time, the proportion of euryoecious fish species adapted to still waters, such as crucian carp and silver bream, expanded rapidly, surging from 21.8 % to 68.2 %. The Shannon–Wiener diversity index for the overall community fell from 2.85 prior to dam construction to 2.12, and the resilience of the river ecosystem to disturbances has been significantly reduced

4. Application of ecological restoration technologies and assessment of their effectiveness

4.1. Restoration of vertical connectivity: the effectiveness and bottlenecks of fish passage facilities

To mitigate habitat fragmentation caused by physical barriers, fish passage structures including vertical slot fishways, fish lifts and fish collection-transport systems have been widely constructed

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along Yangtze mainstem and tributaries. Monitoring of fishways at Jinsha cascade hydropower stations shows these facilities benefit small and medium-sized cyprinids, achieving 15–35% passage success. Nevertheless, large migratory fish such as Chinese sturgeon have large body size, complex swimming kinematics and strict requirements for induced flow fields, resulting in passage efficiency below 5%. Engineering constraints such as complex turbulent flow downstream of dams and difficult intake positioning mean current fishways cannot restore historic migration routes for large migratory fish.

4.2. Hydrological signal reshaping: a breakthrough in ecological dispatch

Ecological dispatch has been proven to be the most effective technical measure currently available for mitigating changes in hydrological rhythms. Since 2011, the Three Gorges Project has conducted ongoing 'artificial peak creation' trials targeting drifting egg-laying fish species: during the peak spawning season, artificial flood peaks are released, causing the discharge flow to surge by 2,000–5,000 m^3/s, thereby ensuring that the flow velocity in local river sections is restored to above 1.5 m/s and maintaining a suitable discharge water temperature. Field assessments have confirmed that the more than 15 ecological regulation operations carried out between 2011 and 2021 precisely triggered mass spawning among the four major carp species, with the maximum spawning output recorded in a single monitoring event exceeding 3 billion eggs. The recent deepening of joint regulation between the main and tributary rivers has further confirmed the decisive value of hydrological pulse restoration for the recovery of semi-anadromous fish populations.

4.3. Direct population replenishment: the potential and risks of stocking programmed

Through a combination of fully artificial breeding and stocking programmed, millions of Chinese sturgeon fry and the 'Four Major Carp Species' are released annually at designated sites into the main and tributary rivers of the Yangtze, directly alleviating the crisis of wild populations being reduced to zero. Although stocking techniques have achieved breakthroughs in terms of scale, their underlying limitations cannot be overlooked. On the one hand, the long-term survival and establishment rates of artificially released individuals in complex natural habitats remain low; on the other hand, the heavy reliance on a very small number of wild broodstock for large-scale breeding is steadily increasing the risk of genetic homogenization, which, in the long term, may accelerate the depletion of genetic diversity across the entire wild population.

4.4. Development strategies for an integrated restoration system

At present, ecological restoration projects are largely confined to the isolated management of individual reservoirs, and a coordinated ecological mechanism involving multiple dams within a cascade system has yet to become standard practice. In future, the protection and restoration of the Yangtze River Basin must involve the integration of the macro-scale water network. The primary measure is to establish a three-dimensional integrated ecological scheduling model covering 'water temperature, flow rate and velocity' across the entire basin, based on the Jinsha River–Three Gorges cascade of reservoirs. At the same time, there is an urgent need to introduce molecular genetic techniques, such as eDNA, to track released populations throughout their entire life cycle and quantify their actual contribution to the recovery of wild populations.

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5. Conclusion

The construction of the cascade of dams on the Yangtze River has profoundly reshaped the river's ecosystem. This study has identified that the chain of events leading to ecological crisis exhibits a complex interplay characterized by 'physical barriers + stagnation in reservoir waters + loss of hydrological signals + temperature retention in downstream flows. This compound disturbance has not only led to a drastic reduction of over 99 % in the natural spawning grounds of long-distance migratory fish such as the Chinese sturgeon, triggering profound population genetic decline, but has also directly caused a sharp drop in flow velocity within the reservoir areas. Consequently, large numbers of the drifting eggs of the 'Four Major Carp' have sunk to the riverbed and suffocated, rendering the natural population replenishment mechanism ineffective.

About the evaluation of restoration techniques, ecological management centred on 'artificial peak creation' has achieved substantial and significant results in restoring hydrological pulses and stimulating the spawning of the four major carp species; it is currently the most effective habitat intervention method. By contrast, engineered fish passage facilities remain constrained by hydrodynamic bottlenecks, resulting in persistently low passage efficiency for large migratory fish; whilst artificial restocking techniques, whilst effective in species conservation, still face underlying challenges such as low survival rates in the wild and a decline in genetic diversity.

A limitation of this study is that, due to constraints on the availability of long-term monitoring data, the quantitative assessment model for the 'cumulative critical effect' of the joint operation of multiple dams on the main and tributary rivers still requires further refinement. Future research and conservation practices should make full use of the historic opportunity presented by the 'Ten-Year Fishing Ban on the Yangtze River' to accelerate the establishment of a coordinated ecological scheduling system for multiple dams across the main and tributary rivers. Furthermore, modern molecular tracking technologies, such as high-throughput sequencing, should be utilized to deepen the monitoring of the basin-wide ecological network, thereby providing long-term, precise scientific safeguards for the comprehensive recovery of aquatic biodiversity in the Yangtze River.

References

[1] Wang, L., & Huang, Z. (2020). What is actually the main cause for the survival crisis of Chinese sturgeon? *Journal of Lake Sciences, 32*(4), 924-940.

[2] Wei, Q. (2020). Conservation of Chinese sturgeon (Acipenser sinensis) based on its life history: Dilemma and breakthrough. *Journal of Lake Sciences, 32*(5), 1297-1319.

[3] Yang, H., Shen, L., He, Y., et al. (2023). Status of aquatic organisms resources and their environments in the Yangtze River system (2017—2021). *Journal of Fisheries of China, 47*(2), 029301.

[4] Akstinas, V., Virbickas, T., Meilutytė-Lukauskienė, D., Šarauskienė, D., Vezza, P., Kriaučiūnienė, J., Rakauskas, V., Steponėnas, A., Jurgelėnaitė, A., Jakimavičius, D., & Nazarenko, S. (2024). Multicomponent assessment of the impact of hydropower cascade on fish metrics. *Science of the Total Environment, 906*, 167541.

[5] Huang, A., Gao, G., Yao, L., Yin, S., Li, D., Xuan Do, H., & Fu, B. (2024). Spatiotemporal variations of inter- and intra-annual extreme streamflow in the Yangtze River Basin. *Journal of Hydrology, 629*, 130634.

[6] Chen, Q., et al. (2023). River damming impacts on fish habitat and associated conservation measures. *Reviews of Geophysics*.

[7] Hong, Y., et al. (2022). Effects of fish habitat substitution in tributaries under the cascade hydropower development of Lancang River. *Acta Ecologica Sinica*.

[8] Li, M., Liu, Z., Yu, Q., & Chen, Y. (2021). Exploratory analysis on spatio-seasonal variation patterns of hydro-chemistry in the upper Yangtze River basin. *Journal of Hydrology, 597*, 126217.

[9] Chen, Y., Wu, X., Liu, X., Lai, J., Liu, Y., Song, M., Li, F., & Gong, Q. (2023). Biochemical, transcriptomic and metabolomic responses to total dissolved gas supersaturation and their underlying molecular mechanisms in Yangtze sturgeon (Acipenser dabryanus). *Environmental Research, 216*, 114457.

DOI: 10.54254/2753-8818/2027.38400

[10] Guo, C., Jin, Z., Liang, D., Nones, M., & Zhou, Y. (2024). Spatiotemporal evolution and influencing factors of flood control storag4e sedimentation in the Three Gorges Reservoir, Changjiang River, China. *Catena, 243*, 108214.