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Prospects for conserving freshwater fish biodiversity in the Anthropocene: A view from Southern China

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Abstract
Globally, population declines of freshwater animals have been consistently greater than counterparts in other realms, making fresh waters hot spots of endangerment—particularly for larger species. Furthermore, biotas have become increasingly homogenized as invasions by non-native species proceed. These trends are particularly evident in Anthropocene China, where humans have profoundly altered freshwater ecosystems, with serious consequences for fishes and other aquatic vertebrates. Here, I examine the prospects for 'bending the curve' or reversing the trend of freshwater fish biodiversity loss in China, focusing on examples from the Yangtze and further south. Much of China's rich fish biodiversity is threatened, but a lack of contemporary surveys means that the conservation status of many species is uncertain, and ~40% of fishes are data deficient. Although nutrient pollution of major rivers has abated recently, poor water quality remains a concern, and the widespread proliferation of emerging contaminants and microplastics can be expected to have unpredictable (but detrimental) effects on the biota. Warmer temperatures will exacerbate the toxicity of micropollutants, and facilitate the spread of non-native species that have been supplanting native fishes. Extensive dam construction has fragmented major rivers, and has blocked fish migrations, preventing access to spawning sites and leading to population extirpations. Dams limit the ability of fishes to adjust their ranges to compensate for global warming, with increased drought severity and frequency under climate change representing an existential threat. Overexploitation will be reduced by the recent introduction of a 10-year fishing ban in the Yangtze basin, but dams, flow regulation, emerging contaminants and continuing habitat degradation will stymie any population recovery or significant recovery of biodiversity as a result of the ban. Furthermore, captive breeding and release programmes have failed to restore populations of threatened fishes because poor management of breeding stock has allowed inbreeding or hybridization leading to genetic pollution of wild populations. Other anthropogenic activities, such as large-scale mining of river sand on the Yangtze flood plain—exacerbated by the sediment-trapping effects of upstream dams—are persistent obstacles to reversing the trend of fish biodiversity loss in China.

KEYWORDS
bending the curve, dams, micropollutants, non-native species, overexploitation, sand mining, Yangtze

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Plain language summary
China has a rich freshwater fish fauna, but many species are threatened by human activities that compromise water quality and habitat conditions. Using a series of case studies, I describe how fishes in the Yangtze and further south have been affected, and the prospects for restoring this biodiversity. Freshwater animals face a combination of multiple threats: pollution by microplastics, pharmaceuticals and other novel compounds; flow alteration and population fragmentation by some of the world's largest dams; habitat destruction by river-sand mining; overexploitation; the spread of non-native species that supplant native counterparts; and ill-conceived captive-breeding and release programmes that have led to genetic pollution of wild populations. Some large iconic species (the Yangtze dolphin, Chinese paddlefish, and Yangtze sturgeon) have become extinct, and the abundance of others has declined greatly. Although a 10-year fishing ban has been implemented in the Yangtze basin, it will not mitigate the prevalence and intensity of other human-caused threats to freshwater biodiversity. Warming temperatures will increase pollution burdens and facilitate the spread of non-native species in southern China. When combined with longer, more frequent and intense droughts under climate change, the prognosis for freshwater fish biodiversity appears bleak.

Practitioner points

- China's rich freshwater fish biodiversity faces multiple anthropogenic threats: for example, historic overexploitation of fishes has led to stock collapses, but the imposition of a 10-year fishing ban in the Yangtze will do little to restore populations because a cascade of dams has fragmented connectivity, impeding breeding migrations and preventing recruitment.
- The proliferation of emerging contaminants and microplastic pollution will offset recent improvements in water quality, and interactions between them will lead to 'ecological surprises' that will be amplified by warmer temperatures and higher contaminant burdens during droughts or periods of water scarcity as the climate changes.
- The spread of non-native species and local losses of ecologically specialized native species in dammed rivers has homogenized fish communities, and can be expected to continue because climate warming and habitat degradation will facilitate the establishment of non-native 'winners' at the expense of native 'losers'.

1 | INTRODUCTION

Globally, populations of freshwater animals have undergone declines in abundance, or a 'great thinning' in numbers, as well as a 'great shrinking' in body size as larger species and individuals are overexploited, in combination with a 'great mixing' of biotas as freshwater invasions proceed (for details, see Dudgeon, 2020). These developments show no signs of slowing or reversing (Reid et al., 2019). Population trend data summarized in the Living Planet Index (LPI) reveal that annual declines of freshwater animal populations (3.9%) have been consistently greater than for terrestrial species (1.1%), falling 83% since 1970 (WWF, 2022). Almost a quarter (22.2%) of freshwater animals are categorized as threatened (i.e., critically endangered, endangered or vulnerable) on the IUCN Red List (www.redlist.org; IUCN, 2024), including 21% of fishes and 32% of frogs. Furthermore, 40% of critically endangered animals live in fresh water, so these ecosystems are hotspots of endangerment.

China has experienced significant species losses from its largest river—notably, the endemic Yangtze river dolphin or baiji (*Lipotes vexillifer*), the Yangtze sturgeon (*Acipenser dabryanus*), and the Chinese paddlefish (*Psephurus gladius*) which, in body-length terms, was the biggest freshwater fish in the world (Zhang, Wu, et al., 2020). The Chinese sturgeon (*A. sinensis*) is predicted to become extinct between 2026 and 2030 (Huang & Li, 2024; Huang & Wang, 2018) while the last known female of the world's largest freshwater turtle, the Yangtze giant softshell (*Rafetus swinhoei*), died in 2019 rendering it functionally extinct. The critically endangered Chinese alligator (*Alligator sinensis*), has been almost extirpated in the wild, occupying a fragment of its former range in the lower Yangtze basin (Jiang & Wu, 2018). Also at risk is the endemic Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*), it is likewise critically endangered (Han et al., 2023). The disappearance of these large freshwater animals has important implications, given their role in trophic cascades and promotion of overall biodiversity (He et al., 2024).

I have written extensively—others might say interminably—on declines in freshwater biodiversity both globally and in tropical East Asia (e.g., Dudgeon, 2020, 2023). Some of that work has been well cited (e.g., Dudgeon et al., 2006), and these declines are now receiving due attention (e.g., Albert et al., 2021; Darwall et al., 2018; He et al., 2019; Reid et al., 2019). The Convention on Biodiversity has set out the key components of a Sustainable Freshwater Transition (Table 1), but '… progress on more sustainable policies and practices related to freshwater ecosystems has remained low …' (CBD, 2020; p.153). One noteworthy accomplishment has been the incorporation of fresh waters (as 'inland waters'—the preferred CBD terminology) in Targets 2 and 3 of the 2022 Global Biodiversity Framework (see Cooke, Harrison, et al., 2023). These, respectively, refer to the protection of 30% of land, sea and inland waters, and the restoration of 30% of degraded ecosystems by 2030. The addition of fresh waters was significant because they had not been mentioned among the targets of the Strategic Plan for Biodiversity 2011–2020.

An Emergency Recovery Plan (ERP; Tickner et al., 2020) to 'bend the curve' or reverse the trend of global freshwater biodiversity loss builds on the Sustainable Freshwater Transition, and is intended to enhance or restore populations rather than merely decelerate the rate of decline. It comprises six elements (see Table 1), but they must be accompanied by comprehensive measures to limit global warming to less than 2°C above preindustrial levels—preferably, no more than 1.5°C. The ERP has been welcomed by practitioners, with the reception bolstered by a series of reviews elaborating the precepts, implementation and potential resilience of the Plan (e.g. Arthington et al., 2024; Cooke, Piczak, et al., 2023; Lynch et al., 2023; Thieme et al., 2024). While there is general consensus on what needs to be done—and done urgently—political resolve and agency are mostly lacking (Darwall et al., 2018; Maasri et al., 2022). This will limit the application of solutions at sufficient scale and speed in the many places they will be needed (Dudgeon & Strayer, 2024). Nonetheless, whenever and wherever political commitment can be found, the ERP and supporting papers offer guidance for policy makers and managers tasked with restoring freshwater biodiversity. Not knowing what to do can no longer be used as an excuse for lack of action.

In this article, I assess the likelihood of successfully reversing declines in the biodiversity of Chinese fishes. They are the best-studied group of freshwater animals in China, where much of the landscape is human-dominated. A summary of the variety of threats to Chinese fishes categorized according to Cao et al. (2024), is indicative: habitat degradation and loss (by pollution, land reclamation, reduced floodplain connectivity, dredging and sand mining, channelization and urbanization) affect 69% of at-risk species; dams along rivers affect 34%; overexploitation, 41%; invasive species, 15%; another 14% have become rare for reasons that have not yet been identified. Because some fishes are influenced by more than one type of threat (see Figure 1), the proportions add up to over 100%. The threats prevailing in China are similar to those documented globally: for instance, a recent

TABLE 1 Key components of the five-point Sustainable Freshwater Transition (CBD, 2020) and the six priority actions of the Emergency Recovery Plan to bend the curve of freshwater biodiversity loss (Tickner et al., 2020). The combination of measures used in particular cases will depend on the local context.

Sustainable Freshwater Transition	Emergency Recovery Plan
1. Integrate environmental flows into water-management policy and practice	1. Accelerate implementation of environmental flows though environmental water allocations or reserves, and appropriate design and operation of water infrastructure such as dams
2. Combat pollution and improve water quality	2. Improve water quality through water treatment, regulation of polluting industries, better agricultural practices, and market instruments
3. Prevent overexploitation of freshwater species	3. Manage exploitation of freshwater species through science- and community-based initiatives, and reduce the demand and regulate the extraction of riverine aggregates such as sand and gravel
4. Prevent introductions and control invasive alien species in fresh waters	4. Prevent and control of invasions by alien species, especially by hindering invasion pathways
5. Protect and restore critical habitats	5. Protect and restore critical habitats by designation and management of protected areas, restoration of degraded habitats, and expansion of markets for ecosystem services (e.g., provision of clean water)
	6. Safeguard and restore freshwater connectivity by removing or re-engineering dams and levees to improve the passage of material and animals, and through the adoption of holistic planning at the catchment level

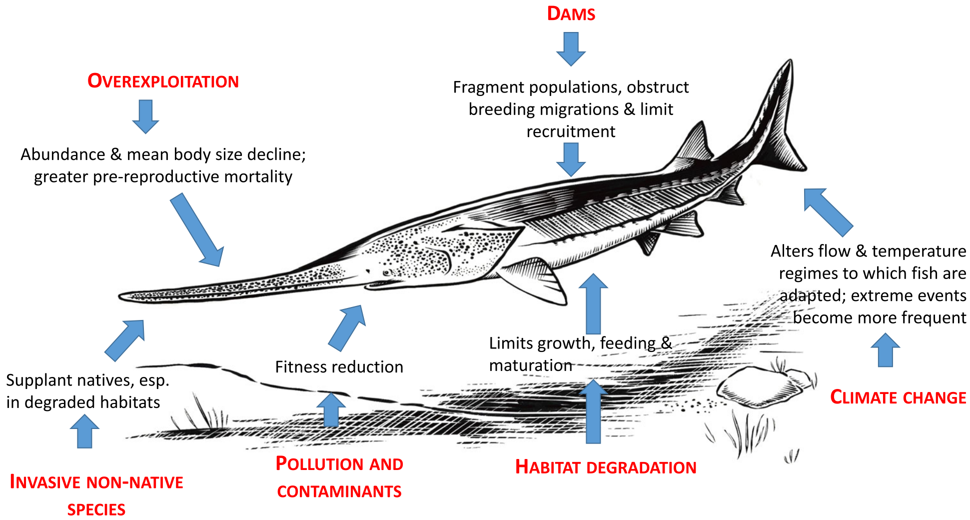

FIGURE 1 Multiple threats deplete populations of river fishes in China through a variety of pathways and modes of action (for details, see Dudgeon, 2023; Stokes et al., 2024). Paddlefish drawing by Nicole T.K. Kit.

analysis has shown that pollution, dams and overexploitation are the most commonly reported direct threats to fishes, and are (respectively) strongly linked to declines in fitness, altered reproduction, and higher mortality (Stokes et al., 2024). Space precludes an exhaustive account of the past and potential trajectories of change in Chinese freshwater fishes during the Anthropocene. Instead, I use a series of examples of the threats to fishes to assess the prospects or likelihood of reversing observed trends. In deference to my geographic location, the place where *Integrative Conservation* is published, and the rapid environmental change that has taken place in this part of the country, most examples are drawn from the Yangtze and southern China.

2 | SOME OF THE THINGS THAT WE DON'T KNOW, AND SOME THAT WE DO

The ERP sets out the suite of actions that will be needed to reverse the trend, underscoring the fact that practitioners know—in general terms—how to improve conditions in freshwater ecosystems. However, some of the detailed, species-specific information needed to conserve freshwater animals is lacking. Globally, one fifth of freshwater species on the IUCN Red List are 'data deficient' (DD), without enough information to permit assessment of their conservation status. (In comparison, only 13% of land animals are DD.) The proportion of DD species is particularly high in parts of Asia: nearly one-third (31%) of fishes in the Indomalayan (or Oriental) realm are DD, far more than their Nearctic (4%) and Palaearctic (10%) counterparts (IUCN, 2024). The LPI includes few freshwater species from China (or elsewhere in East Asia), where annual declines might have exceeded the global average. Fish communities in European, North American and Australian rivers have experienced rapid changes in composition (~30% per decade): reductions in richness and abundance caused by anthropogenic factors have been offset by introductions of non–native species (Danet et al., 2024). It is unclear if these rapid changes have been mirrored in China, in part because the number of freshwater fishes has continued to rise as new species are described. The national total was 1591 at the end of 2020 (Zhang & Cao, 2021), and might eventually reach 1700 species—nearly 10% of freshwater fishes globally (Cao et al., 2024).

Despite such richness, the third red list assessment for China (Zhang & Cao, 2021) exposes the 'grim situation' facing freshwater fishes, with almost a quarter (22%) at risk of extinction (Cao et al., 2024). While this is less than in Europe (37%; Freyhof & Brooks, 2011), the extent of the threat is masked by the high proportion (39%) of DD species (compared to 5% in Europe). This information gap is due to a lack of contemporary, national-scale field surveys of species richness and occurrence, with conservation assessments relying on outdated or incomplete information (Cao et al., 2024). This could mean that the population status of many fishes is less secure than currently supposed. Furthermore, 11% of Chinese fishes are Near Threatened, and could face a worrisome future; only around one quarter (23%) are of Least Concern. The list of wild animals under state protection in China was expanded in 2021 to include 164 freshwater fishes (nine Class I and the rest Class II), but this will do little to ameliorate threats from habitat degradation or transformation. Moreover, protection has been offered principally to large species (such as the two Yangtze sturgeons mentioned above) or those of economic importance (e.g., Reeves' shad, *Tenualosa reevesii*); smaller, less charismatic, fishes have received insufficient attention or have been ignored completely (Li et al., 2020). And unsurprisingly, far more is known about the conservation status of fishes in China than any of the freshwater invertebrates.

3 | POOR WATER QUALITY, AND THE RISKS POSED BY EMERGING CONTAMINANTS AND MICROPLASTICS

Until recently, fresh waters in China were seriously and extensively polluted (reviewed by Han et al., 2016) by a combination of sewage, municipal and industrial wastewater discharge, pesticides, and agricultural fertilizers. At the turn of the century, nitrogen applications were more than three times higher than global average rates (Li & Zhang, 1999), and over half China's population drank water contaminated with levels of animal and human excreta exceeding permissible levels (Wu et al., 1999). Furthermore, ~80% of the 50,000 km of major rivers were too polluted to sustain commercial fisheries, and fish had been eliminated entirely from >5% of the total river length (FAO, 1995). There has been significant progress in abating pollution during the last 20 years. Annual reports produced by the Ministry of Environmental Protection (consolidated within the Ministry of Ecology and Environment since 2018) show improvements in the water quality of major rivers (e.g., MEE, 2020). They reflect growth in collection and treatment capacity for wastewater, although shortfalls in dealing with domestic sewage remain (Tang et al., 2022). Smaller tributaries tend to have higher pollution concentrations than river mainstems because they have lower dilution capacity (Xue et al., 2008), particularly during the dry northeastern monsoon, and pollution blackspots remain (Cao et al., 2024; Li et al., 2020; Wang et al., 2022). They could account for the recurring view that industrial and municipal discharges to rivers, as well as agricultural runoff, are 'essentially unregulated' in China (Chen et al., 2020).

Nitrogen levels in Chinese fresh waters remain high; around 60% is represented by discharge from agricultural (cropland and livestock) sources, with most of the rest attributable to sewage (Yu, Huang, et al., 2019). Domestic wastewater treatment has helped reduce nitrogen loads but the monetary and energy costs have been high. Better management of fertilizer application is needed, together with a substantial boost in nutrient recycling rates nationally—a goal that is technologically achievable, but will require a substantial investment in capital and operating costs (Yu, Huang, et al., 2019). Undoubtedly, further improvements will be necessary to restore ecosystem health: comparisons of drainage basins across China reveal that the taxonomic and functional diversity of freshwater macroinvertebrates has declined, and communities have become more homogeneous, due to high levels of nutrients and organic matter compromising water quality (Farooq et al., 2024). To date, there is no national legislation setting specific goals or targets for dischargers and receiving waters, nor any routine biological assessment of water quality, and there are shortcomings in the management, coordination and sharing of water-quality data (Zhang & Hughes, Davis, et al., 2017, 2021). Some of the necessary legislative improvements could be accommodated under the 2021 Yangtze River Protection Law (Qiu et al., 2021)—the first ruling to address conservation, restoration or sustainable development of any Chinese river basin.

As urban populations have increased—growing from 234 million to 340 million in the Yangtze basin between 2005 and 2016—pollution burdens in parts of the river have become heavier, reflecting shortfalls in sanitation capacity and greater runoff from impervious surfaces (Chen et al., 2020). Economic growth, rather than rising populations, could also have impeded control of water pollution (Tang et al., 2022), but these alternatives are not mutually exclusive. In addition, there has been a world-wide expansion in the variety of contaminants in fresh waters, such as pharmaceuticals, hormones, personal-care products, narcotics, cleaning agents, flame retardants, per- and polyfluoroalkyl compounds, and nanomaterials (e.g., Reid et al., 2019; Sauvé & Desrosiers, 2014; Wilkinson et al., 2022). Rates of production, diversification and release of these emerging contaminants have risen steadily, outpacing other drivers of global change (Bernhardt et al., 2017), without adequate testing of potential acute or chronic biological effects, nor development of the necessary environmental monitoring capacity (Persson et al., 2022). For this reason, pollution-related fitness reduction is the most prevalent anthropogenic threat to freshwater fishes worldwide (Stokes et al., 2024).

A global survey of active pharmaceutical ingredients (APIs) in rivers of 104 countries underscores the risks posed: levels unsafe for aquatic organisms were recorded at 26% of 1054 sites, with 34 APIs were detected at a single location in a Hong Kong (Wilkinson et al., 2022). Antibiotics and their residues are pervasive in Asia (reviewed by Anh et al., 2021), particularly in China where per-capita antibiotic use is six times that in the United States (Zhang et al., 2015). Rivers affected by megacities such as Guangzhou are hotspots of pollution by APIs and personal care products (Bu et al., 2013), and since 2021, assessment of threats from emerging contaminants has been a priority of the Ministry of Ecology and Environment (Wang, Wang et al., 2024). The greatest number of hazardous substances has been recorded from the Pearl River (Li et al., 2019), where 20 out of 50 compounds screened posed significant risks (Wang, Li et al., 2024). While only a small proportion of the more than 1000 emerging contaminants detected in rivers across China present unacceptable ecological risks to aquatic biota when presented individually, exposure to combinations of these compounds produced acute and chronic effects among most (75%) of freshwater organisms tested (Guo et al., 2023). The ever-expanding array of novel compounds (Bernhardt et al., 2017) exposes the biota to unique cocktails of contaminants, and interactions among these stressors can have unexpected outcomes (Birk et al., 2020; Craig et al., 2017).

APIs and other emerging contaminants are not among the pollutants used to assess river water quality in China, which relies on indicators such as nitrogen loads and chemical oxygen demand (Han et al., 2016; Tang et al., 2022). Furthermore, there has been no long-term biomonitoring linking changes in water quality to responses of biodiversity in Chinese rivers, so we cannot assess whether the proliferation of emerging contaminants has thwarted whatever recovery might have been taken place after the water-quality improvements documented by the MEE. Comparison with findings from rivers in Europe may be instructive: time-series data from 22 countries indicate that taxonomic and functional richness of macroinvertebrates increased from 2000 until around 2010 as water quality improved, but decelerated after 2010 and then largely halted (Haase et al., 2023; Sinclair et al., 2024). The conclusion—that efforts to protect rivers are no longer sufficient to mitigate anthropogenic effects—could reflect the variety of novel contaminants to which the freshwater biota are exposed.

Pollution by plastics has become pervasive in most rivers globally (Dris et al., 2015; Lebreton et al., 2017; Reid et al., 2019), particularly in Asia where most (86%) of the transport of plastics by rivers takes place. Loads in the Yangtze (0.33 million t/y) far exceed those of the second-ranked Ganges (0.12 million t/y), and the combined inputs from the three main tributaries of the Pearl River (0.11 million t/y) occupy third position (Lebreton et al., 2017; see also Fok & Cheng, 2015). Pollution by plastic fragments or microplastics (1 μm–1 mm in size) is ubiquitous in China (Zhao et al., 2022), and correlated with the burden of other pollutants, particularly in drainages that are densely settled, have significant industrial activity, or inefficient waste management (or all three). Microplastics ingested by fishes and other animals have potential ecotoxicological effects, due to additives released from the plastic as well as the toxins adsorbed on their surfaces (Zhao et al., 2022). They also bioaccumulate along food chains, to the detriment of biodiversity and ecosystem services (reviewed by Azevedo-Santos et al., 2021). Little is known about how microplastics combine with other contaminants to affect biodiversity (Reid et al., 2019), but interactions have been documented (Mora-Teddy et al., 2024).

4 | THE CONSEQUENCES OF CLIMATE CHANGE

Freshwater biodiversity will be hostage to global climate change comprising multiple stressors, such as hotter conditions, greater variability and more extreme precipitation events that increase the frequency and severity of drought (IPCC et al., 2021; Qi et al., 2022). Prolonged dry spells resulting in the loss of surface flows will have severe (sometimes irreversible) repercussions for fishes, presenting existential risks for species that are narrowly distributed (restricted to single drainages or water bodies) and cannot disperse overland.

Extreme events associated with climate change have become progressively more evident in China. The most severe heatwaves and precipitation deficits on record occurred during 2022 (European Commission, Joint Research Centre, 2022) when flows in the Yangtze to fell to less than half the long-term average, and hydropower shortages forced factory closures. China's two largest lakes are on the Yangtze flood plain: the biggest, Poyang Lake, almost dried up with levels lower than at any time in recorded history; conditions in Dongting Lake were equally dire (European Commission, Joint Research Centre, 2022). In contrast, northern China experienced major flooding and the heaviest rainfall in 140 years during 2023 (Ripple et al., 2023). Much of China experienced record-breaking temperatures between March and May 2023 (Ripple et al., 2023); extreme heat waves occurred again in 2024, with severe floods in parts of the country. Abrupt changes in flow or temperature can substantially reduce species richness in freshwater ecosystems (Sabater et al., 2023), but pulse disturbances have more influence than trend effects associated with continuous or gradual change. Since shortages are more harmful to freshwater fishes than deluges, the effects of droughts are more foreseeable than those of floods (Sabater et al., 2023). Regardless, changes in surface flow regimes will shift conditions away from those to which the biota are adapted.

As climate change proceeds, the prognosis for freshwater biodiversity becomes bleaker. Warming will increase the toxicity of certain contaminants (Wang et al., 2019) and, as mentioned above, human responses to hotter and drier conditions will limit the capacity of rivers to dilute pollutants (Wen et al., 2017). Moreover, food chains become shorter as temperatures rise and will combine with nutrient enrichment to amplify the on-going simplification of freshwater food webs (Bonnaffé et al., 2024). Opportunities for reversing the trend will diminish accordingly.

Although the changing climate is having various direct effects on freshwater biodiversity (Baranov et al., 2020; Haase et al., 2019), it is not merely another of the multiple threats to fishes. Instead, it is better seen as a barrier preventing the realization of conservation goals. For example, readiness to allocate water (or environmental flows) to protect ecosystems will be reduced by climate change, with both the quantities and quality of surface fresh waters declining due to continued human misuse of the freshwater commons (Dudgeon, 2020). Adherence to national and international commitments that limit the greenhouse gas emissions causing climate change will be fundamental to safeguarding freshwater biodiversity (Barbarossa et al., 2021), but even if China can realize domestic targets, global emissions must fall if we hope to reverse the trend significantly. Some changes made nationally, such as improvements in water quality, could benefit biodiversity by enhancing adaptive capacity. Nonetheless, the pursuit of economic growth that depends mainly on burning fossil fuels will soon put climate and biodiversity goals out of reach.

5 | DAMS AND RIVER FRAGMENTATION: THE CASE OF THE YANGTZE

Worldwide, there were more than 37,600 dams higher than 15 m in 2014 (Zarfl et al., 2015), and the number has grown since—particularly in Asia (Zhang & Gu, 2023). By the end of 2015, China had around 22,000 such dams—more than half the global total—and 6500 dams >30 m tall (Xu & Pittock, 2021). The number of large dams has risen rapidly since 2000, and rivers in China are so fragmented that connectivity cannot be reduced much further (Barbarossa et al., 2020). Increases in completion of smaller dams have increased more steeply but their impacts, including those of the uncounted number of micro-hydropower dams that have burgeoned during the last two decades, have not been adequately investigated. There is evidence that even the smallest dams obstruct fish movement (e.g., Chan et al., 2024) and, per unit of electricity generated, dams 4–20 m high are more damaging than taller structures (Kibler & Tullos, 2013).

In China, as elsewhere, river fragmentation by dams limits longitudinal connectivity within ecosystems, preventing the movement of animals and the transport of organic matter and sediment.

The extent of river fragmentation in China will greatly limit the ability of fishes shift their ranges upstream to compensate for warming (Barbarosa et al., 2021); unless they can adapt to higher temperatures, we can expect population declines or local extinctions. These will add to the significant reductions in fish richness that have already taken place in the Yangtze basin, where construction of the Gezhouba Dam, Three Gorges Dam (TGD) and 10 more dams along the Yangtze-Jinsha River mainstem (comprising the Jinsha cascade; see Figure 2) have transformed habitat conditions. Rapidly flowing river reaches have been replaced by large impoundments ranging from 41 to 207 km in length, although they are dwarfed by the 663 km-long Three Gorges Reservoir (dimensions from Huang & Li, 2024). Habitat loss due to the Jinsha cascade has affected at least 46 endemic fishes, blocking breeding migrations by 35, and disrupting recruitment of 26 species with drifting eggs that can no longer float long enough to complete development (Cheng et al., 2015). The number of fishes in the basin fell from 353 species before 2003, when the TGD was completed, to 277 species in 2018 (Liu et al., 2019). Over the same period, the fauna became more homogeneous, reflecting losses of endemics and species with narrow niches,

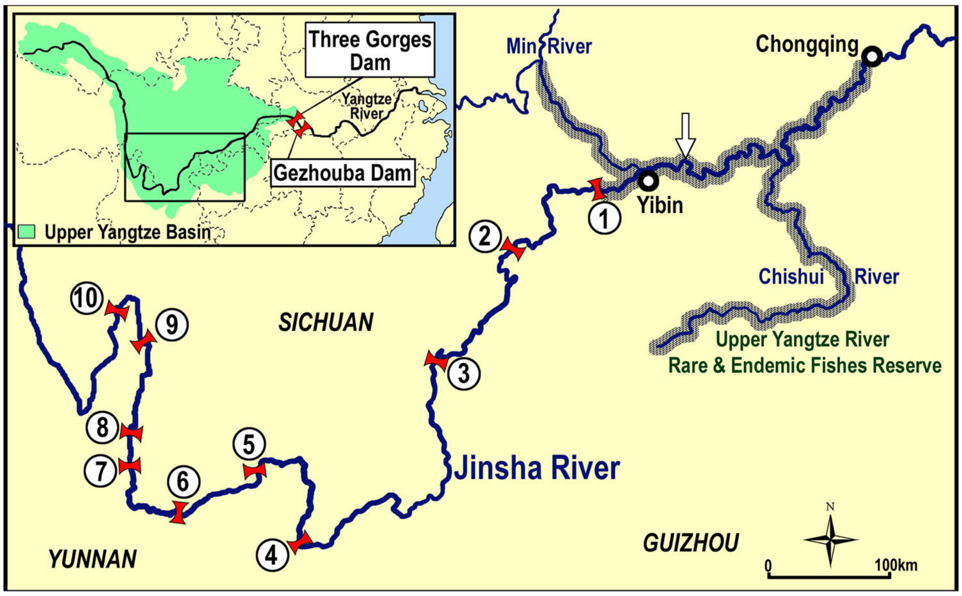

FIGURE 2 The Jinsha (upper Yangtze) River in China shows the location of 10 dams above the Three Gorges Dam and Gezhouba Dam (see inset). The Yangtze transitions to the Jinsha River at Yibin. The boundaries of the Upper Yangtze Rare and Endemic Fishes Reserve, designated in 1987, are also shown; they were adjusted in 2005 to permit the construction of the Xiangjianba Dam. The arrow indicates the only known breeding site of *Psephurus gladius*. The Three Gorges Dam is the largest hydropower project in the world, and the Jinsha cascade includes three more of the tallest dams in China. 1, Xiangjiaba Dam (161 m high); 2, Xiluodu Dam (286 m); 3, Baihetan Dam (289 m); 4, Wudongde Dam (240 m); 5, Guanyinyan Dam (159 m); 6, Ludila Dam (120 m); 7, Longkaikou Dam (119 m); 8, Jin'anqiao Dam (160 m); 9, Ahia Dam (157 m); 10, Liyuan Dam (155 m). Map updated and redrawn from Dudgeon (2010).

an increase in generalists, and the establishment of non-native fishes (Liu et al., 2019). The effects of dams have been especially detrimental to fishes that undertake long-distance breeding migrations (Huang & Li, 2024). Some species with protracted lifespans persist in the Yangtze, despite being unable to access spawning grounds or breed, representing an extinction debt that will be 'paid' upon their eventual disappearance.

After the Yangtze mainstem was initially fragmented by the closure of the Gezhouba dam in 1981, the Institute of Hydrobiology (IHB) of the Chinese Academy of Sciences, advocated for the Chinese sturgeon (Figure 3) to become the primary focus of conservation efforts for river fishes. Subsequently, in 1987, the State Council of China designated sections of the upper Yangtze and its main tributaries (the Chishui and Min rivers) as a reserve intended to protect the sturgeon, the paddlefish, and 69 other endemic or valuable fishes from potential adverse effects of the TGD. After its completion in 2003, when the Jinsha dam cascade had been commisioned, the IHB broadened its focus beyond the Chinese sturgeon to include four more flagship species—the Yangtze sturgeon, the paddlefish (Figure 3), the Chinese sucker (*Myxocyprinus asiaticus*; Figure 4 and Box 1), and the largemouth bronze gudgeon (*Coreius guichenoti*). Unfortunately, the rescue programmes for these species, which include the largest Yangtze fishes, have been described as a 'failure' in need of 'fundamental change' (Huang & Li, 2024) for two reasons. First, there was limited understanding that dams had fragmented fish populations and obstructed breeding migrations, thereby hampering recruitment; second, there was a mistaken assumption that overfishing had been the primary cause of population declines (Huang & Li, 2024). The latter was incorrect, even though some reductions attributable to overfishing had taken place before 1981: for instance, stocks of the paddlefish, which had been exploited for its caviar, had dwindled before the 1970s (Wei et al., 1997; Zhang et al., 2009).

Most river fishes are subject to a simultaneous array of range of threats (see Figure 1), and although flow regulation and dam construction have a lengthy history in China (Dudgeon, 1995), dams have undoubtedly been the major cause of recent population declines of the five flagship species. They share the habit of breeding in the fast-flowing, food-poor upper reaches of the Yangtze-Jinsha River while growing and maturing primarily in the food-rich middle and lower reaches (Huang & Li, 2024). Installation of fish passes can improve connectivity and mitigate river fragmentation due to dams; however, success cannot be guaranteed (Thieme et al., 2024). Passes are often ineffective in rivers with diverse or abundant migratory fish assemblages (e.g. Silva et al., 2018), downstream passage (through reservoirs) representing an almost insurmountable obstacle for many species. Furthermore, fish-pass installation requires recognition of the need for connectivity, which is often limited: for example, only 14 of the 52,000 dams of various sizes in the Yangtze basin have fish passes (Xu & Pittock, 2021). This is despite a government policy requiring that dams built after 2000 install fish passes. That policy,

FIGURE 3 Three Yangtze species were featured on a special issue of postage stamps highlighting 'rare and valuable large fishes in China' issued by the Ministry of Posts and Telecommunications in March 1994. All were Class I nationally protected species, but dam construction prevented recruitment and populations diminished subsequently. Only *Acipenser sinensis* persists in the wild, but numbers are low and the population is expected to become functionally extinct within the next decade. *Psephurus gladius* and *A. sinensis* were featured on stamps of Class I protected species again in 2010 by which time the paddlefish would have been extinct.

FIGURE 4 *Myxocyprinus asiaticus* (Catostomidae): juveniles (body length 14 cm; foreground) differ in appearance from the adult (body length 90 cm; background), and are occasionally available in the aquarium trade as novelty items. Illustration by Nicole K. Kit.

BOX 1 Going, going, gone: The fate *Myxocyprinus asiaticus*

Whereas a considerable literature has been devoted to sturgeons in the Yangtze, much less attention has been devoted to another of the flagship species, *M. asiaticus* (Figure 4); it is the sole catostomid found in China, and the only one that does not occur in North America. Also known as the Chinese sucker, this fish has been a Class II nationally protected species since 1988. It was initially categorized as Vulnerable on the China red list (Wang et al., 1998) but has since been upgraded to Critically Endangered (Zhang & Cao, 2021). When first assessed for the IUCN Red List in 2022, *M. asiaticus* was considered as Vulnerable (Zhao et al., 2023), which seems unduly conservative given that it is confined to the Yangtze, and is a species of critical concern under the Yangtze River Protection Law. A recent population analysis concluded that '… no juveniles have been produced naturally in the Yangtze River since 2010 …' (Huang & Li, 2024), with only hatchery-bred individuals surviving in the river, mostly the highly distinctive juvenile stages (see Figure 4). If this diagnosis is correct, then *M. asiaticus* is extinct in the wild.

Declines in abundance and range occupancy of *M. asiaticus* have been attributed to a combination of pollution, overfishing and dam construction despite (as mentioned above) some dispute over the relative importance of each. Certain species-specific attributes made *M. asiaticus* liable to overexploitation: large body size (almost 1 m in length), late maturity (requiring at least 6 years of growth) and a long life (~25 years; Gao et al., 2008); breeding migrations (of up to 2800 km in some cases; Huang & Li, 2024) increased its susceptibility to population fragmentation by dams. The Chinese sucker formerly constituted over 10% of fishery landings in parts of the upper Yangtze; in the Min River tributary (Figure 2), it constituted 13% of the catch in 1958 but only 2% in 1974, and <1% a decade later (Fan et al., 2006). Because commercial fishing of this protected species had been proscribed, artificial propagation of *M. asiaticus* was initiated in the 1970s, and attempts to boost wild stocks began with the release of hatchery-reared juveniles in 1996 (Gao et al., 2008). Since then, millions of individuals from several hatcheries have been stocked in the Yangtze. After the practice had continued for some years, genetic studies of hatchery fish revealed that broodstock variability was dangerously low (e.g., Cheng et al., 2016; Wan et al., 2015; Xu et al., 2013), compromising the adaptive capacity of stocked individuals. Matters might be improved by exchanging broodstock among hatcheries or using wild individuals to supplement them (Liu et al., 2018; Wan et al., 2015), so avoiding further genetic attrition.

Unfortunately, the feasibility of supplementing broodstock with wild *M. asiaticus* is constrained by the paucity of these fish. Cheng et al. (2016) collected 59 individuals upstream of the TGD between 2009 and 2013, and 112 'wild' fish were obtained by Wu et al. (2016) over a similar period. However, given the magnitude of releases into the upper Yangtze, these fish could well have originated from hatcheries. A recent comparison of the genetic variability of 112 wild *M. asiaticus* from three locations along the upper Yangtze confirmed that inbreeding has resulted in heterozygote deficiency; inter-population genetic differentiation was no longer detectable, and wild populations resembled hatchery fish (Wu et al., 2022).

If the *M. asiaticus* population is no longer self-sustaining, then improved management of the stocking programme may do little to serve conservation ends, although continued releases might safeguard the persistence of a nonbreeding (or 'invalid', *sensu* Huang & Li [2024]) population in the river. If hatchery fish could establish a breeding population in the remaining free-flowing section of the river—between the western end of the Three Gorges Reservoir (near Chongqing) and the Xiangjiaba Dam (adjacent to Yibin; see Figure 2)—there might be a conceivable future for *M. asiaticus* in the Yangtze. But this 400-km section represents a greatly curtailed migration corridor. It might not provide adequate feeding grounds for *M. asiaticus*, which may not adapt to these straitened conditions.

which is seldom followed or enforced, facilitates upstream migration by spawning stock but ignores downstream movement by returning adults and new recruits (Huang & Li, 2024).

Unaccountably, fish passes were not installed in any of the 12 mainstream dams along the Yangtze, thereby disrupting the connectivity of flagship fishes needed to complete their lifecycles. The barrier effects would have been the main cause of population collapses, but there was no implementation of environmental flows to ameliorate hydrological shifts downstream of dams, including elevated temperatures that inhibited breeding by Chinese sturgeon (Zhang et al., 2019). The failure to enforce the national fish-pass policy apparently reflected a consensus in the IHB and the hydropower sector that because the Gezhouba Dam and TGD lacked fish passes, dams in the Jinsha cascade would not require them either (Huang & Li, 2024). Retrofitting Yangtze mainstem dams with fish passes would present huge technical obstacles, even if it were possible to ensure that their design would be effective.

A better way of mitigating the impacts of dams would be to remove them entirely. Most such interventions have involved rather small dams (Ryan Bellmore et al., 2017; but see McCaffery et al., 2024), and removal of dams of (any size) in China has scarcely begun (Ding et al., 2019). No dam removals anywhere have approached the scale of the massive hydropower structures along the Yangtze, and the feasibility or wider acceptability of such action has yet to be assessed. Proposals to demolish dams have been made by some hydropower proponents in China, but are regarded as a stipend to gain approval from the central government to construct larger (and more damaging) structures (Xu & Pittock, 2021). Furthermore, the number of dams in China and the size of many of them far exceed what might be practical to remove, even if agreement could be reached on the desirability of such action. Decommissioning obsolete dams, or those that are no longer able to fulfil their primary function, might offer scope for the restoration of connectivity of Chinese rivers, assuming the difficulty of returning a huge sediment-filled impoundment to its free-flowing state could be overcome.

The threats dams pose to fishes along the Yangtze are alarming, and population collapses of the Yangtze flagship species does not inspire confidence in the efficacy of the fish reserve established upstream of the TGD (see also He et al., 2011). Matters could be worse elsewhere in China. For instance, the upper basins of the Yangtze and Pearl rivers are both major centres of fish diversification in China, but there are 112 species from the Pearl River on the China red list, substantially more than the 80 Yangtze species (Cao et al., 2024). Conditions in parts of the lower Yangtze are certainly far from satisfactory (Li et al., 2020): ecological engineering of habitats with the aim of protecting fishes are often ill-conceived, carried out without regard for basin-scale integrity or river ecology, and results in further population declines. Hard-engineering and artificial wetlands have improved riverscapes for humans in urban areas, but degrade—rather than restore—conditions for fishes. In other words, there has '... been a serious lack of scientific basis and truly ecological action for sound river basin management' (p. 6; Li et al., 2020).

6 | RESTOCKING HAS FAILED TO RESTORE DEPLETED POPULATIONS, AND AGGRAVATED 'GENETIC POLLUTION'

With very few exceptions (see Cao et al., 2024), captive breeding and release is not a viable strategy for restoring the populations of freshwater fishes in China (Huang & Li, 2024). Forty-years of artificial propagation and release of Chinese and Yangtze sturgeons have not supplemented their populations—even though they were combined with proscriptions on fishing these protected species. Full-cycle artificial breeding of the Chinse sturgeon was achieved in 2009, and more than 7 million individuals of different sizes had been released by 2018 (Zhang, Wu, et al., 2020). None of the stocked fish returned to spawn, and this effort has been characterized as '... inadequate and unsustainable' (Huang & Wang, 2018). The Yangtze sturgeon is also readily propagated in captivity; while it has been the subject of restocking attempts since 2007, no natural recruitment has occurred—an indication that '... population supplementation was not very effective' (Wu et al., 2014).

As the case of *Myocyprinus asiaticus* indicates (Box 1), the propagation and release of in-bred hatchery-reared individuals has been detrimental to the genetic diversity of the wild population. There has been little oversight of artificial propagation and fish stocking programmes in China. They are seldom adequately monitored (or monitored at all), do not make sufficient use of genetic information, nor do they have specific objectives or follow agreed guidelines (Cao et al., 2024). This is despite the scale of the enterprise: the Ministry of Agricultural and Rural Affairs released around 190 million hatchery-reared fish fry to fresh waters throughout China during the 13th 5-year plan (2016–20), and another 150 billion will have been stocked by 2025 (http://www.moa.gov.cn/govpublic/YYJ/202201/t20220127_6387852.htm). Thus far, restocking has not restored the populations of any Chinese river fishes (Cao et al., 2024; Huang & Li, 2024). It has also been detrimental for other kinds of threatened freshwater animals (e.g., Chai et al., 2022; Dudgeon, 2023).

7 | THE PROLIFERATION OF NON-NATIVE SPECIES

The combination of climate change, poor water quality, dams and flow modification facilitates the establishment, spread and performance of non-native freshwater species (e.g., Liew et al., 2016; Strayer, 2010), with degraded sites more liable to invasion (see Pilotto et al., 2020). Native species can be expected to be climate-change 'losers' compared to their non-native counterparts, which tend to be less susceptible to extreme weather (Gu et al., 2023), and will be 'winners' with an escalated invasive capacity. China has more non-native freshwater fishes than any other country: 439 non-native alien (or exotic) species, plus 91 native species that have been translocated to parts of China outside their natural range (Cao et al., 2024; see also Kang et al., 2022). Although at least 10% (53 out of 530) of them have become established in rivers in China (Xu et al., 2024), the status of most non-native fishes in China is uncertain (Xiong et al., 2015). However, one estimate is that 200 non-native species (84 alien and 116 translocated fishes) are now breeding in the nation's fresh waters (Xiang et al., 2021)—far fewer than the number of non-native fishes present in China that have not (yet) established self-sustaining populations. For instance, more than 100 species have been introduced from abroad for aquaculture (Kang et al., 2022), but many may be unable to breed in the wild.

The difference between the numbers of non-native species present (530) and those that are established (200) could be an indication of the large potential 'introduction debt' China would face if all non-native species became established. In comparison, 49 non-native fishes have found breeding populations in Hong Kong alone (Chan et al., 2023). While the potential introduction debt of that relatively small (~1000 km^2) territory is far less than China, 100 non-native species (including five hybrids) have been recorded from Hong Kong, far exceeding the number of natives fishes (65 species; Chan et al., 2023). Furthermore, half of the non-native species in Hong Kong are breeding in the wild; if the same thing occurred across the rest of China, ~270 species might become established, suggesting that there may be a sizeable introduction debt.

Among the many biodiversity impacts of non-native fishes in China (see Cao et al., 2024), the introduction of 42 species to 15 lakes on the Yunnan-Guizhou plateau is egregious: it led to the disappearance of 59 native species (including 28 endemics)—more than half of 103 fishes initially present (Ding et al., 2017). Extinction debts were evident and some extirpations of native fishes occurred many years after the introductions. In addition, assemblages became more homogeneous, with a reduced turnover of native species among lakes (Ding et al., 2017; see also Kang et al., 2022). Such homogenization has been reported throughout China, attributed mostly to invasions by non-natives translocated for aquaculture (Liu et al., 2017), and is evident also in rivers worldwide (Su et al., 2021; Villéger et al., 2011). At the same time, local richness of fishes in many rivers has increased because invasions have (thus far) exceeded extinctions (Su et al., 2021; see also Danet et al., 2024). Nonetheless, the proportion of threatened native species in drainages is correlated with the percentage of non-natives present (Leprieur et al., 2008)—indicative of an unrealized extinction debt.

As freshwater ecosystems in China continue to be transformed by humans, conditions will favour tolerant non-native species that may supplant indigenous fishes. In southern China, for example, six African tilapias (species of *Oreochromis, Coptodon* and *Saratherodon*) have been introduced for aquaculture. China is the world's largest producer of tilapias, with around half cultivated in Guangdong Province, and feral populations are widespread, particularly in places where native fishes have declined due to overexploitation, dams or pollution (Gu et al., 2019, 2020). A combination of omnivory and phenotypic variability allows tilapias (chiefly *O. niloticus* and *Coptodon zilli*) to maintain high population densities, transforming communities and food webs (Gu et al., 2018; Shuai et al., 2019). Tilapias are mouthbrooders without strict habitat requirements for breeding, and a single female with a mouthful of eggs can find a new population. Moreover, *Oreochromis* spp. hybridize readily, likely facilitating population establishment when abundance is low. As well as displacing natives, tilapias have intense interspecific interactions: *O. niloticus* dominates *C. zilli* in the extreme south of China, with the outcome reversed further north (Gu et al., 2018). Although current climatic conditions in China constrain the distribution of tilapias, they will spread northward as warming proceeds.

Habitat degradation is detrimental to native fishes, irrespective of the presence of non-native species, so studies of their distribution or relative abundance do not provide sufficient evidence that the former are displaced by the latter. The mrigal carp (*Cirrhinus mrigala*), which established feral populations in Guangdong after introduction from India for aquaculture, is one instance where the necessary confirmation has been forthcoming. Mrigal carp are more tolerant of low water quality and grow faster than native mud carp (*C. molitorella*), competing for food and supplanting them (Yu, Gu et al., 2019). While the replacement of one mud carp by another may have little effect on ecosystem services such as fishery yields, the consequences for ecosystem functioning are not known. African *Clarias gariepinus* catfish have been displacing (and hybridizing with) native congeners in China, and the proliferation of these fast-growing predators, which tolerate poor water quality, might have far-reaching impacts. Tilapias, which are ranked among the 100 'world's worst' invaders (ISSG, 2024), could have a greater influence because these cichlids represent a family that does not occur naturally in China. South American loricariid armoured catfishes (*Pterygoplichthys* spp.) are likewise well established in rivers in Guangdong (Wei et al., 2019), where ecologically analogous native counterparts are lacking. Tilapias and armored catfishes will hinder efforts to reverse the trend of (native) biodiversity loss because—as with extinction—the establishment of non-native species is generally irreversible.

8 | OVEREXPLOITATION OF FISH STOCKS

Populations of many freshwater animals in China have been seriously depleted by overexploitation, with most of the turtles and many amphibians (frogs and salamanders) now absent from large parts of their former ranges, including some protected areas (for details, see Dudgeon, 2023). Freshwater capture fisheries have also been seriously overexploited: landings from the Yangtze peaked (at 427,000 t) in 1954 but declined by nearly 85% (to only 66,000 t) in 2016 (Wang et al., 2022). These changes have been thoroughly reviewed by Kang et al. (2017) and Chen et al. (2020) (see also Zhang, Jarić et al., 2020), so need not be repeated here.

The Yangtze capture fishery was entirely unregulated before the introduction of a seasonal moratorium in 2003 (since extended to seven major river basins), and destructive fishing practices involving the use of fine-meshed nets, electricity, dynamite and poisons were rife. They led to significant declines in species richness, abundance, body size and age at maturity; to give one example, lucrative fisheries for Reeves' shad in the Yangtze and Pearl rivers were eradicated (Wang, 2003). From 2021, the seasonal fishing moratorium in the Yangtze was expanded into a 10-year ban, covering the entire basin—a scale that is unprecedented globally (Chen et al., 2020). A year-round ban had been in place since 2017 along the Chishui River tributary of the upper Yangtze (Figure 2), and has been accompanied by signs of recovery of heavily exploited species (Cao et al., 2024). Similarly, stocks of anadromous *Coilia nasus* (Engraulidae) in Poyang Lake had increased 2 years after a 2019 proscription on their capture (see Jiang et al., 2022).

Will the 10-year ban restore the Yangtze fishery? Much of the decline in fishery yields coincided with a period (1950–70) when around 40% of the area of floodplain lakes was reclaimed and extensive construction of weirs separated the river channel from these lakes, preventing fish migration between them (Wang et al., 2022). This lateral connectivity was vital for important fishery species, such as Chinese major carp, which feed in the lakes but breed in the river. To restore the full complement of floodplain fishes, it has been estimated that the 5500 km^2 of floodplain lakes that remain connected to the Yangtze must be augmented by reconnecting at least 8900 km^2 of isolated lakes (Liu & Wang, 2010); an increase of 168%. Since a 10-year ban will not alleviate the river-lake disconnect, it is unlikely to restore fish stocks fully. Elsewhere, fishing moratoria combined with proscriptions on the use of unselective fishing gear might allow exploited populations to recover, so long as habitat conditions permit. However, year-round bans may not be necessary in all habitat types; seasonal bans could be appropriate in productive lowland rivers, with more flexible proscriptions allowing for sustainable utilization of fishery resources (Cao et al., 2024).

9 | UNSUSTAINABLE EXPLOITATION OF RIVER SAND

Sand mining, or the extraction of alluvial aggregates such as sand and gravel from rivers, is rampant in Asia and has a range of detrimental effects on freshwater ecosystems (reviewed by Koehnken et al., 2020). For instance, dredging has deepened channels, causing water levels to drop, while reduced sediment delivery to deltas has slowed rates of aggradation, increasing the risks of sea-level intrusion. China has the largest construction market in the world and uses more sand in glass, concrete and asphalt than any other country; demand grew by five times between 1995 and 2020, accounting for nearly half of global consumption in 2012 (Wang, Wang et al., 2024). The nation consumed more concrete—and, hence, sand—between 2011 and 2013 than the United States used during the entire twentieth century (Gavriletea, 2017).

Habitat destruction by sand mining on the Yangtze flood plain has been devastating for sedentary, benthic infauna, greatly reducing their diversity, abundance and biomass (Meng et al., 2021; Zou et al., 2019); fishes must have been affected by the alteration of habitat topography and loss of feeding grounds (e.g., Han et al., 2023). Sand mining also increases the turbidity and degrades the quality of adjacent undisturbed sites (Li et al., 2019; Zou et al., 2019). Some curbs on the practice were introduced in 2000 and again in 2021, when sand-mining areas and periods when mining is allowed were designated under the Yangtze River Protection Law, with mining proscribed in some parts of the lower course. Despite periodic prohibitions, the demand for sand and gravel has continued to grow, and mining is not likely to be banned completely (Ma et al., 2022). Removal of vast amounts of sediment has lowered lake-bed levels (and hence water levels) in Poyang Lake—regarded as the world's biggest sand mine (de Leeuw et al., 2010)—by 20 m or more. The mining is unsustainable because the amounts removed exceed the natural supply from upstream. The discrepancy between supply and demand grew substantially after 2003, when an average of 77% of sediment inflows were trapped behind the TGD (Ma et al., 2022). Because of its scale and intensity, sand mining has left a conspicuous Anthropocene fingerprint on freshwater ecosystems in China, such as the Yangtze flood plain, where the damage has been exacerbated by the presence of large dams that have reduced downstream sediment transport. Additional physical transformation of the lower Yangtze—the world's busiest waterway—has been brought about by dredging to facilitate shipping, and the construction of port and berthing facilities for bulk carriers (Dudgeon, 2010).

Even if the other threats facing freshwater biota are disregarded, reversing the trend of freshwater biodiversity loss in places such as the Yangtze flood plain will be challenging. However, there has been a significant rise in the use of artificial sand, produced by mechanically crushing and sieving rock or mine tailings, since 2010 (Wang, Wang et al., 2024); along with tightened proscriptions on sand mining, this shift has the potential to reduce exploitation of riverine aggregates in China. While undoubtedly welcome, such changes will not ameliorate the despoliation of riverine habitat that has taken place already, nor offset sediment trapping by upstream dams.

10 | LOOKING FORWARD

Changes in China's constitutional principles during the past decade reflect the government's commitment to holistic stewardship of natural resources. The objective is to transition toward a more balanced and sustainable development model, by building an ecological civilization (for details, see Hanson, 2019). This key ideology is encapsulated in President Xi Jinping's phrase 'clear waters and green mountains are as valuable as gold and silver mountains' (sometimes paraphrased as 'clear waters and green mountains are invaluable assets'), acknowledging the interconnected social, economic, and ecological value of nature. The transition has been manifested in more stringent environmental regulations, improved institutions and incentives for enhancing environmental health, and an intention to limit the environmental impacts of continued growth. A series of policy instruments relevant to fresh waters are contained within the national *Master Plan for the Protection and Restoration of Key Ecosystems (2021–2035)*, and the three ministries of Ecology and Environment, and Water Resources, and Agriculture and Rural Affairs (MARA) share a work plan for the *Conservation of Aquatic Biodiversity in Key River Basins* (http://www.gov.cn/gongbao/content/2018/content_5327473.htm). That plan will establish a series of systems for observing and assessing aquatic biodiversity, controlling water use, and monitoring in situ conservation; by 2030, improvements in policies and legal instruments for the protection and sustainable use of biodiversity will have been put in place. This work complements the implementation of the Yangtze River Protection Law and the 10-year fishing ban in the river. Efforts to restock freshwater fishes could represent a component of these restoration measures but only if, as mentioned above, outcomes are monitored so that genetic pollution is avoided and conservation objectives are met.

While a fishing ban and appropriately managed restocking will likely benefit the populations of certain Yangtze fishes, the post-1980 commissioning of multiple mainstem dams has stymied the recovery of large-bodied species that can no longer undertake spawning migrations along the river. Prohibitions on exploitation will do nothing to reestablish flow regimes and longitudinal or lateral connectivity; nor can a ban reduce levels of micropollutants or rehabilitate degraded habitat. Most anthropogenic threats to freshwater biodiversity in China became more severe following the collapse of Yangtze fisheries that began in the 1950s, so measures to address overexploitation are unlikely to reverse the population decline trend unless they are combined with measures that moderate other factors contributing to biodiversity loss.

The *Environmental Protection Law of the People's Republic of China* includes the general requirement that natural resources should be developed in a way that protects biodiversity and ensures ecological security. Although there have been attempts to bring iconic Yangtze fishes to public attention (see Figure 3), they have not been a resounding success. Unfortunately, freshwater animals do not receive much consideration from the public or policy makers compared to threatened terrestrial animals, such as the emblematic pandas, primates, Asian elephant, and so on. Enhancement of science-based popularization and education campaigns about freshwater animals is needed to 'mainstream' their protection, and to increase stakeholder engagement. Protection of freshwater biodiversity along the Yangtze is further complicated by the huge size of the drainage basin (nearly 1,810,000 km^2), which depends on communication, coordination and compromise among the governments of 11 provinces, autonomous regions and municipalities, as well as county-level administrations in other provinces. The Yangtze River Protection Law envisages that provincial and governments within the basin shall implement the decisions of a National Yangtze River Basin Coordination Mechanism, set up by the State Council, and protect biodiversity in their respective administrative areas in accordance with the division of responsibilities (see https://english.mee.gov.cn/Resources/laws/environmental_laws/202104/t20210407_827604.shtml). The Coordination Mechanism appears to be envisaged as a type of basin management authority. It is intended to ensure that administrative divisions under the State Council monitor and regulate land-use and hydrological changes in ways that secure ecosystem services and biodiversity conservation on the flood plain and throughout the upper catchment. However, integrating or trading-off the diverse interests of different parties will present major challenges to the conservation or restoration of freshwater biodiversity, especially if it is not accompanied by a significant increase in stakeholder and citizen engagement.

One barrier to coordinated action is the likelihood that different parts or levels of government will have disparate views on the benefits and costs of particular management actions or objectives, and may not take adequate account of biodiversity conservation. For instance, the central government may have priorities that differ from those of provincial authorities, especially in instances where the costs and benefits of dams and other projects must be raised or will accrue locally. Furthermore, in China, as elsewhere, the task of ensuring the ecological health of rivers and their fauna usually cross-cuts the remit of different agencies. For instance, the conservation of river fishes requires integrated catchment management (maintaining forest cover, preventing erosion), controlling rates of exploitation (usually the bailiwick of fisheries authorities), preventing pollution and maintaining water quality (which involves environmental regulatory agencies), and maintaining downstream flows and connectivity (necessitating collaboration between water-resource and energy-generating authorities). The lack of such integration is one explanation for the failure of ecological engineering intended to restore biodiversity in parts of the lower Yangtze (see Li et al., 2020). It may also account for the disregard of the national fish-pass policy since agencies with responsibility for power generation would have been unlikely to consider the needs of their counterparts responsible for conservation or fisheries management.

Reconciling the views of different parts of government is a significant but relatively small, challenge compared to that arising when a wider group of stakeholders must be consulted. For instance, proposals to construct dams intended to enhance human water security, increase energy security and reduce dependence on fossil fuels are potential sources of discord within and outside government: supporters would include the Ministry of Water Resources, the National Office of Energy, the some parts of MARA, together with local governments and hydropower developers; among those who might prefer to limit such projects are the Ministry of Environment and Ecology, the Ministry of Natural Resources, other parts of MARA, 'green' non-government organizations, and academics with environmental or social expertize. Furthermore, the central authorities establish policies for biodiversity conservation that are to be implemented by local governments in provinces and municipalities. This does not facilitate adaptation of national programmes to local constraints and opportunities, and can give rise to disagreement between different levels of administration. Any disparity of views, especially when reflected at a ministerial level, is likely to obscure—rather than highlight—awareness about the need to protect China's neglected freshwater biodiversity, nor can it be expected to result in the endorsement or implementation of measures at sufficient scale or urgency to reverse the trend.

It is difficult to be optimistic about the likely success of applying the Emergency Recovery Plan for freshwater biodiversity (see Table 1) in Anthropocene China. Admittedly, it offers grounds for hope that local-scale improvements might be possible with the application of best-practice approaches to re-establishing or maintaining connectivity, allocating environmental flows, and reducing overfishing. But the widespread and sustained degradation of freshwater ecosystems, continued overexploitation of amphibians and aquatic reptiles and, particularly, the loss of freshwater connectivity attributable to dams that have driven declines of river fishes, does not bode well for the persistence of many threatened species—far less recovery of their numbers. As anthropogenic transformation of drainage basins continues, contaminant burdens diversify, and the climate becomes hotter with more frequent droughts, continued impoverishment of what remains of China's rich fish biodiversity seems inevitable.

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The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ETHICS STATEMENT

This manuscript was prepared in accordance with established principles regarding the ethical treatment of humans and animals and research integrity.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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