PNAS OPINION

To save sturgeons, we need river channels around hydropower dams

Liang Zhang[a,b], Haijun Wang[a], Jörn Gessner[b,c], Leonardo Congiu[b,d], Tim J. Haxton[b,e], Erik Jeppesen[f,g,h,i], Jens-Christian Svenning[j], and Ping Xie[a,k,1]

Sometimes the best, most cost-effective way to preserve fish habitats is to dismantle an existing dam, such as this dam on the Minjiang River, a major tributary of the Yangtze River in Sichuan Province, China. Image credit: Wei Zhao (Affair Center for Protection and Management of Rivers and Lakes in Sichuan Province).

On the white sand of the bottom
Lay the monster Mishe-Nahma,
Lay the sturgeon, King of Fishes;
Through his gills he breathed the water,
With his fins he fanned and winnowed,
With his tail he swept the sand-floor.

—From "The Song of Hiawatha," an 1855 epic poem by Henry Wadsworth Longfellow (1807–1882) inspired by Native American legends.

Sturgeon, a flagship taxon for functional rivers and adjacent seas, have existed for more than 200 million years (1). Around since the time of dinosaurs, they have survived at least two mass extinction events (2). However, all contemporary sturgeon species are now endangered, the result of human activities on rivers that have taken place during the last two centuries. The consequences of these effects are now becoming apparent.

In July of 2022, the International Union for Conservation of Nature (IUCN) confirmed the extinction of the Chinese paddlefish (*Psephurus gladius*), whereas Yangtze sturgeon (*Acipenser dabryanus*) has moved from the category "Critically

The authors declare no competing interest.

[1]To whom correspondence may be addressed. Email: xieping@ihb.ac.cn.

This article contains supporting information online at https://www.pnas.org/lookup/suppl/doi:10.1073/pnas.2217386120/-/DCSupplemental.

Published March 24, 2023.

Endangered" to "Extinct in the Wild." Only 26 sturgeon species remain, all of which are now threatened with extinction; in 2009, 85% of the species had a similar status (3). Most critically endangered sturgeon species are distributed throughout the Ponto-Caspian area, Europe, and China.

Overharvest, habitat degradation, and water pollution, as well as genetic degradation, all threaten the long-lived (up to 170 years) and late-maturing (8–30 years) sturgeon (4, 5). Managers and researchers could mediate some adverse impacts on sturgeons (e.g., targeted and accidental catch, water pollution) through international and regional conservation efforts (6). However, loss of sturgeon habitats and declining reproductive efficiency, mostly caused by dam operations, blockage of migration routes, and alteration of hydroecology as well as reduced habitat quality below the barrier (e.g., sediment transport, homogenous downstream channels), have led to drastically reduced recruitment as well as genetic degradation of populations since the 19th century when modern dam building began (4, 5, 7, 8).

To restore wild sturgeon populations, we need to restore the historical mitigation routes that have been interrupted as well as the habitats affected by the dams.

Given that the number of hydropower dams will only increase in the coming years, we argue that now is the time to effectively mitigate their effects by building large-size migration channels around the dams. This will conserve and restore the reproductive migration of sturgeons—which would also help other threatened freshwater megafauna as well as migratory species. Such channels should be designed to emulate natural river courses, with sufficient length to resemble the rivers' historic slope and hydrology. The upstream and downstream entrances should be located close to the dam and provide sufficient attraction flow to ensure that sturgeons will find and use them.

Sturgeon and Dams

The negative effects from dams are manifold. They interrupt upstream migrations for reproduction, affect the downstream migrations of juvenile stages, and they alter the ecosystems upstream in the impoundments and downstream through temperature alterations and scouring. These effects also impact the ability to implement remediation measures such as restocking programs (1, 4, 7, 8). The number of hydropower facilities worldwide has been increasing exponentially over the past 100 years, leading to substantial fragmentation of essential sturgeon habitats as well as increased alteration of flow patterns, which serve as a key driver of migration and reproduction (e.g., spawning sturgeon need moderate to high water velocities over coarse gravel or cobble substrate) (5–8). Numerous new dams have been constructed with national or even multinational permits, funded through international agencies and operators. These edifices are typically designed for a life span of 50–100 years of hydropower generation, irrigation, navigation, and flood risk management. Consequently, the environmental impact will accumulate for decades to come, adversely affecting migratory fish populations, with sturgeon being the most endangered (*SI Appendix*, Fig. S1).

In an attempt to cope with the decline of natural populations, ex situ conservation and restocking measures have been introduced in hopes that such mitigation measures would help stabilizing populations. However, even under the best of circumstances, ex situ stocks consist of a small group of wild individuals taken from populations in decline that possess low levels of genetic diversity. Unfortunately, more often these ex situ stocks comprise animals that were themselves propagated and reared under controlled conditions, leading to risks of reduced fitness owing to behavioral deprivation, high relatedness, captive selection, and outbreeding depression (4, 8, 9).

Researchers noted the negative effects of damming as early as in the mid-19th century, but countermeasures to facilitate migration were only introduced in the 1950s in the former Soviet Union (10). Despite continued attempts that have even resulted in several large-scale approaches (building fishways, ladders, lifts, etc.), sturgeon passages have never successfully increased the dam passage rates of sturgeons. Moreover, few sturgeons living in these projects were able to reproduce effectively (8), reflecting conceptual and operational limitations in fish passage facilities and fish lifts. Among the challenges are the size of the facilities in relation to the migration corridor, attraction flows for fish passages or lifts that stimulate entry of large sturgeons, obstacles to orientation upstream of the dams in the reservoirs, and the alteration of reproduction sites (8, 9).

Most fish passage facilities at dams and weirs have been constructed for relatively small and strong-swimming fish species that use small rivers and streams for reproduction (e.g., salmonids). Migrating sturgeons are much larger, live in bigger rivers, and require ample space to navigate migration-assisting structures. Attempts at solutions, including fish lifts and vertical slot passes, have mainly involved modifying devices tested for other fish. The efficiency of such fish passages or lifts is minimal, with less than 2% of sturgeons successfully using them (11); such facilities and passages deviate too much from the natural migrating conditions that the sturgeons have adapted to over millions of years.

Seeking New Options

Dam removal is the most effective way to ensure the return of sturgeons to rivers (6), as demonstrated by the Edwards Dam on Kennebec River in Maine and the Ballville Dam on the Sandusky River in Ohio. In both cases, sturgeons returned almost immediately to the upriver sections of the two rivers after dam removal (12). However, there are of course legitimate societal benefits of dams, such as flood control, hydropower generation, as well as industrial, agricultural, and residential water supply. In these cases, governments and wildlife managers must find ways to effectively allow sturgeons to complete their life cycle beyond manipulated and controlled reproduction and recruitment. The fish must have adequate opportunities to maintain self-sustaining populations of sufficient diversity and size for their long-term viability.

We also need to sustain large wild populations with substantial genetic variability.

Light at the End of the Tunnel

Sturgeons spawn in large rivers as well as in large tributaries with suitable habitats and substantial flowing water quantities and velocities (1, 13, 14). Considering the poor performance of conventional migration assistance, we believe that river-like side channels are the best way to restore sturgeon migration routes and provide alternative habitats in cases where dam removal is not feasible. Several examples of natural-like channels support this claim.

In one case, local government constructed a natural-like channel to allow sturgeon to bypass the Konstantinovskiy Dam on the Don River, Russia. The channel was 6 km long and 22 m wide, and it had an average depth of 2 meters and an elevation of 16 meters from bottom to top of the channel. The flow velocity reached an average of 1.1 m/s. Between 1987 and 1994, researchers recorded the migration of 250 and 2,590 sturgeon individuals in the bypass channel, respectively. In 1999, stellate sturgeon (*Acipenser stellatus*) eggs in the channel indicated its use as a spawning habitat (10). The outcome of this endeavor has resulted in new projects for bypass channels on other dams of River Don by 2022.

On the Namakan River, Ontario, Canada, a natural channel comprises a series of rapids extending over 2 km and with a water depth of about 7 meters (13). Genetic analyses have confirmed that lake sturgeon (*Acipenser fulvescens*) use this back channel to access upstream waters (circumventing the falls on the main channel), helping to maintain their populations in the river (13).

The most recent promising case study is in Montana, where state authorities built a 3.4-km-long side channel to the Lower Yellowstone River at the Intake Diversion Dam in late April 2022. Three wild mature and nine tagged individuals of pallid sturgeon (*Scaphirhynchus albus*) swam through the channel within weeks of channel completion (15).

Circumventing Dams

Channels can serve as a supplementary habitat for the sturgeon reproduction or as a bypass (see *SI Appendix*, Fig. S2). The channel design must consider the historical habitat requirements for sturgeons, such as flowing patterns, water velocity, gradient, river width and depth, and water quality. Properly operating sturgeon migration channels requires a commitment of dam operators, whether via the permitting process or legislative action. In migration and reproduction periods, as well as during the outmigration of spawners and juveniles, the dam and reservoir operators should direct 20–30% of the available discharge to the channel to meet the requirements for sturgeon migration to allow the fish to find the entrance and to provide sufficient incentive to use it (6).

Species conservation is costly, especially when the species has declined and multiple mitigation techniques must be used to restore the population (1, 4, 6, 7). The extinction of Chinese paddlefish as well as the extinction or near extinction of other freshwater fauna in the Yangtze River system, including the Chinese sturgeon (*Acipenser sinensis*) and Yangtze sturgeon (*Acipenser dabryanus*), exemplify the cost of failing to provide effective means for reproduction. Governments should include large fish passages, designed as natural river courses, in the design of new or existing facilities, helping to reach a balance between human benefits and aquatic ecosystem conservation, including sturgeons. Construction of migration channels requires considerable investment and effort; these costs must be included in the overall assessment of hydropower installations (which, right now, often neglect mitigation costs completely). Other costs include maintaining the dam and providing surveillance to prevent sturgeon poaching. The many benefits include the services that a river with longitudinal connectivity provides, not least maintaining diverse, abundant fish stocks that support sustainable fisheries.

Maintaining viable, functional sturgeon populations is a worthy objective not only for the conservation of biodiversity but for the preservation of related cultural practices as well (1, 5, 6). To prevent the extinction of these charismatic and important species, governments and wildlife managers must take more audacious measures to mitigate the negative effects of dams and hydropower.

ACKNOWLEDGMENTS. This research was supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (XDB31000000) and the Yunnan Provincial Department of Science and Technology (202001BB050078 and 202103AC100001). E.J. was supported by the Tübitak Outstanding Researchers Program, BIDEB 2232 (118C250), and J.-C.S. was supported by VILLUM FONDEN (Biodiversity Dynamics in a Changing World, Grant 16549) and Danish National Research Foundation via Center for Ecological Dynamics in a Novel Biosphere (ECONOVO; Grant DNRF173).

Author affiliations: [a]Institute for Ecological Research and Pollution Control of Plateau Lakes, School of Ecology and Environmental Science, Yunnan University, Kunming 650500, China; [b]World Sturgeon Conservation Society, Neu Wulmstorf 48 21629, Germany; [c]Leibniz-Institute for Freshwater Ecology and Inland Fisheries, Berlin 310 12587, Germany; [d]Department of Biology (DiBio), University of Padua, Padua 35121, Italy; [e]Aquatic Research and Monitoring Section, Ontario Ministry of Natural Resources and Forestry, Peterborough, ON K9J 7B8, Canada; [f]Department of Ecoscience, Aarhus University, Aarhus C 8000, Denmark; [g]Danish Centre for Education and Research, Chinese Academy of Sciences, Sino, Beijing 100039, China; [h]Department of Biological Sciences and Centre for Ecosystem Research and Implementation, Limnology Laboratory, Middle East Technical University, Ankara 06800, Turkey; [i]Institute of Marine Sciences Middle East Technical University, Erdemli-Mersin 33731, Turkey; [j]Center for Ecological Dynamics in a Novel Biosphere (ECONOVO) & Center for Biodiversity Dynamics in a Changing World (BIOCHANGE), Department of Biology, Aarhus University, Aarhus C 8000, Denmark; and [k]Donghu Experimental Station of Lake Ecosystems, Institute of Hydrobiology, State Key Laboratory of Freshwater Ecology and Biotechnology of China, Chinese Academy of Science, Wuhan 430072, China

Author contributions: L.Z., H.W., J.G., L.C., T.J.H., E.J., J.-C.S. and P.X. designed research; L.Z., H.W., J.G., L.C., T.J.H., J.-C.S., and P.X. performed research; L.Z., H.W., J.G., L.C., T.J.H., E.J., J.-C.S., and P.X. analyzed data; L.Z., H.W., J.G., L.C., T.J.H., E.J., J.-C.S., and P.X. wrote the paper.

1. W. E. Bemis, B. Kynard, Sturgeon rivers: An introduction to *Acipenseriform* biogeography and life history. *Environ. Biol. Fish* **48**, 167–183 (1997).
2. M. A. D. During *et al.*, The Mesozoic terminated in boreal spring. *Nature* **603**, 91–94 (2022).
3. International Union for Conservation of Nature, *IUCN Red List, Global Sturgeon Reassessment* (International Union for Conservation of Nature, Gland, Switzerland, 2022).
4. R. Billard, G. Lecointre, Biology and conservation of sturgeon and paddlefish. *Rev. Fish Biol. Fish* **10**, 355–392 (2001).
5. J. Gessner, T. Hein, T. Friedrich, Flagship species of the Danube - Will there be sturgeons in the future? *Danube Watch* **1**, 10–11 (2019).
6. World Sturgeon Conservation Society and WWF, Pan-European Action Plan for Sturgeons, Convention on the conservation of European wildlife and natural habitats standing committee, 38th meeting Strasbourg, November 27-30th, 2018. pp. 47–51 (2018).
7. T. J. Haxton, T. M. Cano, A global perspective of fragmentation on a declining taxon–the sturgeon (*Acipenseriformes*). *Endang. Species Res.* **31**, 203–210 (2016).
8. S. J. Cooke *et al.*, Water resource development and sturgeon (*Acipenseridae*): State of the science and research gaps related to fish passage, entrainment, impingement and behavioural guidance. *Rev. Fish Biol. Fish.* **30**, 219–244 (2020).
9. P. Xie, Three-gorges dam: Risk to ancient fish. *Science* **302**, 1149 (2003).
10. D. S. Pavlov, M. A. Skorobogatov (editors), "*Chapter 5 - Fish passages in Russia*" *in Fish Migrations in Regulated Rivers* (Russian Academy of Sciences, KMK Scientific Press, Moscow, 2014) pp. 154–202.

11. J. D. Thiem, "*Behavior and energetics of sturgeon fishway passage*," PhD thesis, Carleton University, Ottawa, Canada (2013).
12. Great Lakes Now, Lake Erie's Sturgeon Revival. https://www.greatlakesnow.org. Accessed 17 March 2023.
13. A. B. Welsh, D. T. McLeod, Detection of natural barriers to movement of lake sturgeon (*Acipenser fulvescens*) within the Namakan River, *Ontario. Can. J. Zool.* **88**, 390–397 (2010).
14. C. J. Perrin *et al.*, White sturgeon spawning habitat in an unregulated river: Fraser River, *Canada. Trans. Am. Fish. Soc.* **132**, 154–165 (2003).
15. B. French, Pallid sturgeon passage: New dam bypass on Yellowstone River luring fish upstream. *The Spokesman-Review*, https://www.spokesman.com/stories/2022/may/23/pallid-sturgeon-passage-new-dam-bypass-on-yellowst (23 May 2022).