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REVIEW

The Extinction of the Chinese Paddlefish *Psephurus gladius*: Transnationalism, Technology Transfer, and Timescape

Dennis L. Scarnecchia

Department of Fish and Wildlife Sciences, University of Idaho, Moscow, Idaho, USA

ABSTRACT

The extinction of the Chinese paddlefish *Psephurus gladius* is examined in the context of transnationalism, technology transfer, and the compressing timescape of human activity, not just from the perspective of *Psephurus*, but also sturgeons and other long-lived, ancient and not-so-ancient declining fish species. Information is presented and questions raised as to why the extinction of *Psephurus* occurred, what broader transnational and technological trends may have led to it, and what can be learned and done to save the remaining Acipenseriform and other vulnerable species. Despite *Psephurus* (and its close relatives) surviving through millions of years of evolutionary time, its rapid descent to extinction, a result of a combination of overharvest, dam construction blocking spawning migrations, and pollution, is best understood in a broader geopolitical context of transfer of technologies for river development and use without adequate concurrent introduction of ecological knowledge needed for species persistence. The slowly developing life histories of *Psephurus* and many other fishes in a rapidly compressing timescape had led to their formerly adaptive life histories becoming maladaptive in the wild. Biologists and managers must start thinking more about what measures must be implemented immediately to maintain biodiversity of these long-lived but now ill-adapted species in the wild in an increasingly human-dominated, timescape-compressed world.

KEYWORDS

Polyodontidae; sturgeon; large rivers; Yangtze River; ancient fishes

> Timescape: The rate of human developmental and technological change impacting a landscape or aquatic system. (Scarnecchia and Schooley 2022).

> We have become accustomed to think of separate, singular events, each dependent upon a unique singular cause….But in the ecosphere every effect is also a cause…Such ecological cycles are hard to fit into human experience in the age of technology. (p. 11–12, Barry Commoner, The Closing Circle (1971))

In the COVID-19 pandemic world of early 2020, little noticed was the formal proclamation, a peer-reviewed, multi-authored, obituary (Zhang et al. 2020), announcing the extinction of the Chinese paddlefish (Polyodontidae: *Psephurus gladius).* One of the largest freshwater fishes globally, *Psephurus* was an ancient Acipenseriform fish closely related to sturgeons, (Grande and Bemis 1991) with a spear-like rostrum (Figure 1), whose family has been traced to the Lower Cretaceous about 115 million years BP in China (Grande et al. 2002) and Upper Cretaceous at least sixty-five million years BP in North America (MacAlpin 1947). The Chinese paddlefish was originally described by western science only a century and a half ago from the Yangtze River of China by Martens in 1861 as *Polyodon gladius* (Handyside 1875) and later placed into its own genus *Psephurus* by Guenther in 1873 (Wu 1930). The last two reported living *Psephurus* were found in December 2002 and January 2003; numerous subsequent searches have failed to find any survivors (Zhang et al. 2016). The extinction of *Psephurus*, proclaimed in early 2020 following modeling and observations, was estimated to have occurred "by 2005, and no later than by 2010" (Zhang et al. 2020).

Despite the proven ability of *Psephurus* and its close relatives to survive through millions of years of evolutionary time (Grande and Bemis 1991; Grande et al. 2002), including cataclysmic events and climate changes, *Psephurus* was unable to survive a mere century and a half of the compressing timescape (Scarnecchia and Schooley 2022) of human activities, including unprecedented human population growth,

CONTACT Dennis L. Scarnecchia scar@uidaho.edu Department of Fish and Wildlife Sciences, University of Idaho, 875 Perimeter Drive, Moscow, ID 83844-1136, USA.

Figure 1. Adult *Psephurus* gladius, Yichang, Hubei Province, 1993. Photo Dr. Q. Wei.

advances in fishing technology, dam construction and river impoundment, and other river alterations. Like other surviving Acipenseriform fishes (i.e., sturgeons), *Psephurus,* a long-lived and late-maturing species, was overharvested (Main 2020) and its large river habitat needed for successful spawning and rearing was impounded by dams and polluted from human industries (Zhang et al. 2020; Narvaez et al. 2021). Many long-lived (e.g., >20 yr; Hamel et al. 2014), late maturing, poorly recruiting fish species, including *Psephurus* and its Acipenseriform relatives, are highly vulnerable to overfishing (Birstein et al. 1997a; Boreman 1997) and habitat loss and are declining in the wild despite conservation efforts (sturgeons: Haxton et al. 2016). Compounding the problem, managers have historically been unaware in many cases of the longevity and erratic recruitment of these fishes (e.g., Scarnecchia et al. 2007, 2014, 2019a,2019b; Lackmann et al. 2019, 2022a,2022b; Daugherty et al. 2020) or ignored the significance of it (Musick 1999), so that conservation of these species in the wild, many of them historically undervalued, is today seriously challenging fisheries management agencies (Scarnecchia and Schooley 2022). For fisheries scientists and managers whose cause is to conserve ancient fishes (so-called "living fossils") for future generations, and for all people who value and are knowledgeable about biodiversity (e.g., Birstein et al. 1997b; Xing et al. 2016), the extinction of *Psephurus* is considered a tragic and irreplaceable loss. Its extinction leaves *Polyodon spathula,* the zooplanktivorous paddlefish native to the Mississippi and Missouri River basins of North America, as the last living species of Polyodontidae (Grande and Bemis 1991).

The Chinese paddlefish departed from an increasingly anthropocentric, industrial, techno-frenetic, climate-altered, timescape-compressed (Scarnecchia and Schooley 2022) world, its extinction formally proclaimed at the time when the spread of COVID-19 was the salient immediate environmental event impacting humans (Shereen et al. 2020). Attempts to save *Psephurus*, it so-happened, were centered at scientific research institutes (Institute of Hydrobiology and Yangtze River Fisheries Research Institute) in the metropolis of Wuhan, (Yu et al. 1985,1986b; Zhang et al. 2020), the same city where COVID-19 is believed to have to have been transferred to humans. As of 2023, some attribute the transfer to the Huanan Wholesale Fish Market, with many scientists concluding that wild animals being sold passed COVID-19 to humans (Worobey et al. 2022). Others attribute its origin as a leak from a high-level laboratory in Wuhan (Gaviria and Martin 2023). Humans then rapidly spread the virus globally. Though pale in comparison to the human tragedy and loss of life, economic and social effects of COVID-19 on fisheries beginning in 2020 were within the year felt widely through myriad supply-chain problems in commercial fisheries and their products (Minahal et al. 2020; He et al. 2021; Alam et al. 2022). COVID-19 also affected recreational fishing; many who had theretofore spent their leisure time watching public athletic events or attending public concerts developed or renewed, at least temporarily, their interest in fishing and other outdoor activities that met their needs of family recreation, social distancing, and open space (Stokes et al. 2020; Midway et al. 2021; Paradis et al. 2021). In the fisheries realm of 2020, as everywhere and everywhen, exigencies in a compressing timescape directly affecting millions of people preoccupied human attention and dwarfed the reporting of the extinction of this ancient, unique, but little-known fish.

This paper considers a range of events leading up to the extinction of the Chinese paddlefish. Transnationalism, technology transfer, and timescape are identified as important driving factors. These same factors also weigh heavily on the status and future prospects of *Polyodon,* closely allied sturgeons, and other long-lived, declining fish species, many of them ancient, that occupy freshwater and marine habitats. Questions are raised as to why the extinction of *Psephurus* occurred, what broader transnational and technological trends led to it and may threaten the extant sturgeons, the extinction of *Psephurus* compared and contrasted to the more favorable, but vulnerable, status of *Polyodon* (Moore and Rider 2022), and what can be learned and done to save the remaining Acipenseriform species and other long-lived fishes (ancient and non-so ancient) attempting to survive in the wild in an ever-compressing timescape of human activity.

The last days of Psephurus

> A new paper published in Science of the Total Environment concludes that the [Chinese paddlefish Psephurus gladius] has gone extinct, mainly due to overfishing and dam construction. It's 'a reprehensible and an irreparable loss' says study leader Qiwei Wei [of the Chinese Academy of Sciences, Wuhan, China] who's been looking for the animal for decades. (Main 2020. National Geographic Society).

> The designing and construction of the [Gezhouba] dam and the installation of the equipment were all undertaken by Chinese personnel. As far as the amount of work and the technical standard are concerned, this cross-river structure ranks first among China's hydropower projects. Apart from economic benefit, the Gezhouba project is a boon to tourism. With its overall completion, a number of gardens will appear along this section of the river together with tree-shaded roads at the sites of the three channels. Chinese and foreign travelers visiting the Three Gorges will be tempted to include Gezhouba project in their itinerary. They will find this man-made wonder a feast to the eye and the imagination, a monument to human ingenuity in taming China's longest river. Yangtze.com Cruise and Tours (https://www.yangtze.com/blog/more-facts-about-the-gezhouba-dam/. . . . .)

In his book *The Freshwater Fishes of China*, Harvard-educated Ichthyologist John Treadwell Nichols (1943) described Psephurus with scientific dispassion as "*Depth in length to base of caudal, 10.3 [mm]; head 1.6; snout in head, 1.5; eye in snout 30 (Small specimen 175 mm long to base of caudal). Dorsal rays, about 70; anal, about 65; no scutes or scales.*" (p. 17). His only remark quoted Ping (1931, p. 190) that *"This fish is valued for food … and may reach a length of 7,000 mm [7 meters]"* (p. 17; Figure 1). Ping (1931) called it the Yangtze Beaked Sturgeon and noted that *"Its snout is produced in a flat blade with its tip pointed and base widened and thickened. It has an inferior mouth with numerous small teeth on both jaws, small eyes, and a heterocercal [uneven-lobed] caudal fin. The color of the fish is grayish brown above and whitish below."* (p. 190). The surviving closeup photographs of *Psephurus* reveal the inferior mouth and protrusible jaws (Chenhan and Yongjun 1988) with teeth (Figure 2A), more closely resembling a bottom-feeding piscivore as opposed to *Polyodon*, its specialized, midwater, zooplankton-eating relative. *Psephurus* also showed characteristic primitive pores (Kistler 1906; Nachtrieb 1910; Figure 2A) associated with the now studied electrosensory system of *Polyodon* used in finding food (Wilkens et al. 2002).

Life history studies on *Psephurus* involved small numbers of mostly younger fish, typically less than 20 years old, suggestive of overharvest of the larger, older specimens (Chenhan and Yongjun 1988; Jun et al. 1996). As with *Polyodon* and sturgeons, females grew to a larger size than males, and matured later in life, although information on maturation is scant. Yu et al. (1986b) reported catching a large female (total length 315 cm; weight 87 kg) with well-developed (Stage 4) ovaries in April 1983; two other mature females were caught in March and April 1986. Fish were caught in the Yangtze below Gezhouba Dam at times and locations when mature fish would be likely to be staging prior to spawning. Maximum lifespan of *Psephurus* was not known. Zhang et al. (2020) reported an estimated lifespan of 29–38 years; this may well be a substantial underestimate, however. Depending on life history, metabolic factors (Scarnecchia et al.

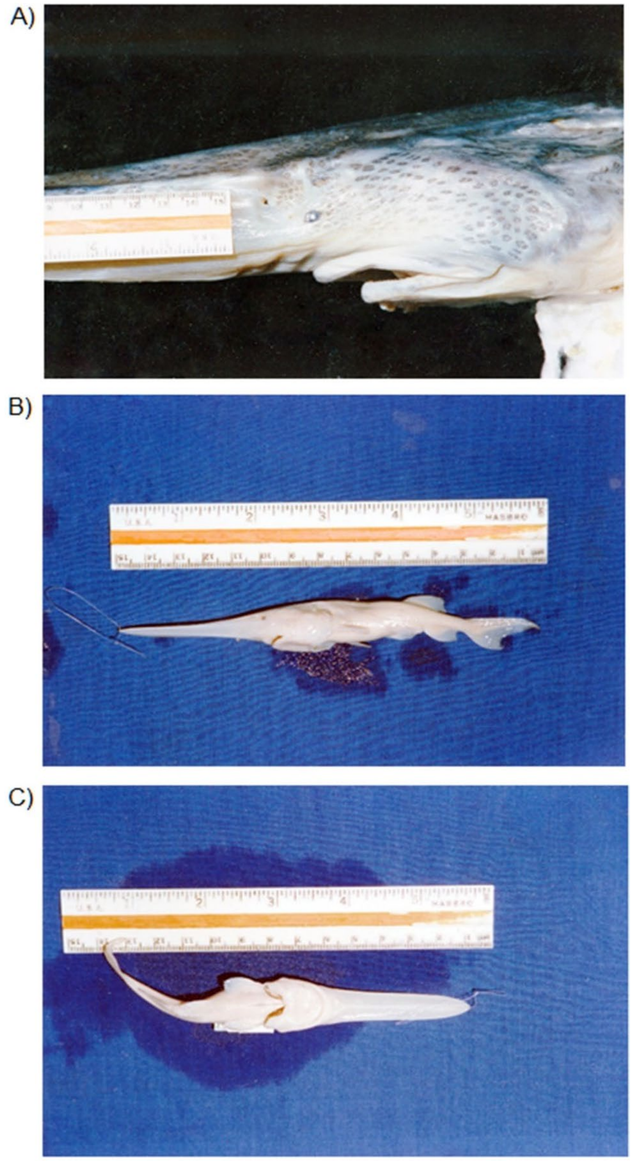

Figure 2. A) Young recruit *Psephurus* showing inferior mouth, teeth on dentary, and primitive pores (Nachtrieb 1910); B) Age-0 Psephurus side view and c) ventral view. Photos of Dr. Todd Georgi, Crete, Nebraska.

2011), and harvest rates, many of its large sturgeon relatives (typically not even as large as *Psephurus*) may approach or exceed 75–100 years in some localities, especially in unfished situations (*Acipenser transmontanus*: Rien and Beamerderfer 1994). Age estimation of *Polyodon* using dentaries (Scarnecchia et al. 2006) and sturgeon using fin sections (*Acipenser fulvescens*: Rossiter et al. 1995) can also underestimate actual ages of the oldest fish as growth slows or ceases and annuli become close together or overlap. Unlike *Polyodon, Psephurus* was adapted to feeding lower in the water column and ate small and mid-sized fishes and crustaceans (Mims et al. 1993). Growth of age-0 fish (Figure 2B and C) was reported to be very rapid (Mims et al. 1993), similar to rapid growth favored for successful recruitment (Figure 3) in *Polyodon* (Scarnecchia et al. 2019b). In addition to its inhabiting the Yangtze River and tributaries (Wei et al. 1997), the species was also known from the Hwang He (Yellow) River (Wei et al. 1997) and several other rivers (Zhang et al. 2020; Figure 4). Though a river species, it had considerable migratory capability, and it was described as anadromous (Wei et al. 1997) or at least euryhaline, moving into the east China and Yellow Seas (Chenhan and Yongjun 1988). Like all of its surviving sturgeon relatives and *Polyodon*, *Psephurus* was a sought-after food fish, and its roe yielded high-quality caviar (Chenhan and Yongjun 1988; Mims et al. 1993). *Psephurus* was never reported by scientists as being abundant (e.g., Kimura 1934); Chenhan and Yongjun (1988) estimated annual harvest of 25,000 kg in the 1970s, modest considering the size of individual fish.

Although some North American scientists, including the author, have weighed, measured, and tagged hundreds, even thousands, of *Polyodon*, few scientists from outside or inside of China had the opportunity to handle *Psephurus*. The closest the author came to seeing *Psephurus* was in preserved specimens. By 1988, it was perhaps already too late for anyone within or

Figure 3. *Psephurus* – a young recruit. Photo of Dr. Todd Georgi, Crete, Nebraska.

outside China to change the extinction trajectory of the species. Nevertheless, in September of that year while researching *Polyodon* in the upper Mississippi River (Scarnecchia et al. 1989; Moen et al. 1992) at Iowa State University, the author was informed that Ms. Yan Zhao, a Chinese Scientist who had sampled, studied, and published on *Psephurus* in its native habitat with Dr. Zhitang Yu of the Institute of Hydrobiology in Wuhan (Yu et al. 1986b), had come to the United States on an academic exchange for fisheries research. She had recently worked at the Center for Limnology at the University of Wisconsin, from where she had contacted the late Dr. William Shelton, a paddlefish expert at the University of Oklahoma (Letter from Zhao to Shelton dated November 9, 1987) inquiring on research possibilities. That year, she instead moved to Mississippi to work with Dr. L. E. Miranda as a visiting research scientist at Mississippi State University. In a September 12, 1988, letter to her, the author expressed interest in collaborating with her, as a visiting scientist, specifically on *Psephurus*. In her September 24th reply it was agreed that funding would be sought for investigations on *Psephurus* in 1989 from selected science organizations and foundations. *Psephurus* was recognized at that time as in critical need of a recovery effort. As she put it, "*I believe that preserving and r[a]ising the [Psephurus] population…is meaningful research work because there are few scientists to do this in China and we have not met success in artificially induced spawning on Psephurus. …the stock decrease[s] year by year.*" (Y. Zhao, Letter of September 24, 1988). In a November 10, 1988, letter, she also indicated that the author had been introduced *via* a letter to her colleague, Dr. Yu, an expert in large river sturgeons and *Psephurus* (Yu et al. 1985; Deng et al. 1985: Yu et al. 1986a 1986b,) in relation to the Gezhouba hydroelectric project on the Yangtze River. Dr. Yu was by that time the Deputy Director and Senior Engineer of the Institute of Reservoir Fisheries, under the Ministry of Water Resources. The Gezhouba Dam, a water-control facility and large hydroelectric power station, had been started in 1970. The project was completed in 1988, but by 1981, spawning migrations which would have taken *Psephurus* up the Yangtze and its upper tributaries previously identified as spawning areas were blocked (Chenhan and Yongjun 1988; Figure 5). Evidence suggested that adult fish used the upper river for spawning and hatched larvae drifted with flows to rear farther down the river (Yu et al. 1986b) and the lack of new fish entering the subadult population (recruitment failure) was suspected (Wei et al. 1997). After blockage of the river,

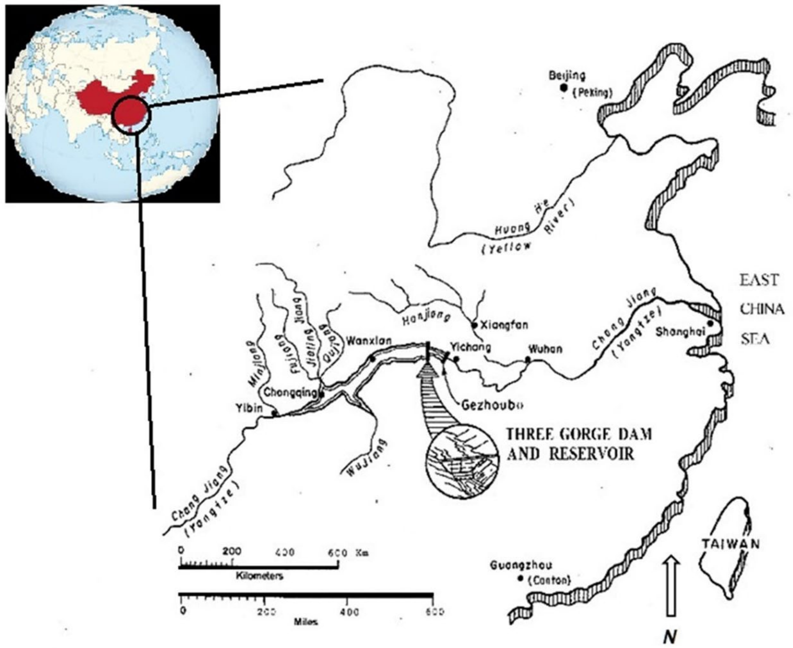

Figure 4. Map of middle and lower Yangtze River, China. Adapted from LaBounty (1984).

Figure 5. Gezhouba Dam, China.

the by-catch of *Psephurus*, always a concern even when the species was protected from targeted harvest, had declined to near zero by the late 1990s.

Wuhan, where Dr. Yu and his Institute of Reservoir Fisheries conducting much of this research were located, was an unknown city at that time to most Americans. In a March 19, 1989, letter, he welcomed the collaboration:

> Dear Prof. Scarnecchia
>
> I am glad to learn from Ms. Yan Zhao's letter that you are interested in Psephurus gladius Martens in the Yangtze River and willing to cooperate with us in studying it. The population of Ps. gladius, a kind of rare animal which is in imminent danger, is small and little biological study has been done. We're continuously studying the artificial propagation of Ps. Gladius in recent years. However, it is difficult to get sexually mature individuals, the result is not satisfying. I'm sure that having your cooperation we'll make great progress in the study of Ps. gladius. You are welcome to visit my institute and give learned report when you come to China. It's a pleasure to host you in Wuhan.
>
> Thank you and best wishes,
>
> Yu Zhitang.

Less than a month later, the week of April 4–6, 1989, a workshop on *Polyodon* was hosted by the Missouri Department of Conservation (MDC) in the southwestern Missouri town of Mt. Vernon. The meeting convened many of the scientists most familiar with *Polyodon* and Mississippi River Basin sturgeon. MDC paddlefish experts such as L. Kim Graham, Thomas Russell (Russell 1986), Jerry Hamilton, as well as scientists from other Mississippi Basin states generously shared their knowledge with the attendees. Jerry Hamilton, hatchery manager, had refined and demonstrated successful Cesarean Section spawning and culture techniques for *Polyodon* at Blind Pony Hatchery, Sweet Springs, Missouri (Graham et al. 1986). His techniques were developed with expert instruction and guidance from Dr. Serge Doroshov, a Russian-born scientist and the foremost sturgeon authority globally, by then located at the University of California, Davis (Conte et al. 1988). We observed the spawning methods and MDC provided informative field trips where we handled live *Polyodon* captured in nearby Table Rock Lake (reservoir). The Workshop was memorable for its efficacy and congeniality and

Figure 6. A) Truckstop where paddlefish Symposium was held, Mt. Vernon Missouri, 1989 and B) Yan Zhao and the author at that meeting.

also as the only scientific meeting the author has attended held in the conference room of a truck stop (Figure 6A), entirely consistent with the plebian status typically afforded *Polyodon* at that time.

In addition to the North American scientists at the meeting, in attendance was Yan Zhao (Figure 6B), who gave a well-received presentation on *Psephurus* biology and conservation. In conversations with her, it was clear that key steps needed to be taken, and soon, to save *Psephurus*. Because research on large rivers is difficult and expensive, the best hope was to find some fish, most likely where they staged seasonally prior to spawning. Once it was known where to locate and capture them, the next planned step was to assist Dr. Yu with culturists such as Dr. Serge Doroshov, Jerry Hamilton, and others in China and the United States in the capture of prespawners, incubation of eggs, and production of young fish from wild-captured broodstock.

Funding was an issue. Later that year, in October 1989, Yan Zhao and the author, with the endorsement and logistical support promised by Dr. Yu, submitted proposals to three conservation organizations: the National Geographic Society, World Wildlife Fund, and Wildlife Conservation International. While waiting for a response, a letter, dated February 16,1990, from Dr. Yu reiterated his invitation to visit and promised a warm reception but expressed well-grounded concerns about being able to find enough mature *Psephurus* at one time to conduct artificial propagation. Mature females were most likely to be the most critical problem, as they mature later in life than males and probably had a longer period of gonadal recrudescence, not spawning every year or perhaps not even every other year, a common pattern in Acipenseriform fish (Roussow 1957; Erickson and Webb 2007; Scarnecchia et al. 2007).

None of the three proposals to the three conservation organizations for work on *Psephurus* were funded that year. Rejection letters did not indicate any particular interest in the species or encourage re-submissions.

Other collaborations between American and Chinese scientists seemed to have potential for a better outcome. Drs. Steven Mims (Kentucky State University) and Todd Georgi (Doane College, Crete, Nebraska) represented the United States and presented papers at the International Symposium on Sturgeons and paddlefishes at Southwest Agricultural University in Beibei, Chongquig, Sichuan Province in June 1992. Unpublished documents from Dr. Georgi's files indicated that he collaborated with Dr. Liu Chenhan in the late 1980s and early 1990s in reciprocal visits in planning a Chinese paddlefish study. Efforts were unsuccessful, however (T. Georgi, Personal Communication). In spring, 1993 Dr. Mims, L. Kim Graham, and three other American scientists undertook a 3-week exploratory tour of the upper and middle Yangtze River to build support for a Chinese and American collaboration to save *Psephurus*. The American contingent learned that the Chinese government was more enthusiastic about culturing *Polyodon* and was not interested in funding such efforts for *Psephurus*. In a brief review of *Psephurus* and its aquaculture prospects in China as a food and caviar fish, Mims et al. (1993), reported that "Collaborative research on paddlefish is planned between the United States and China is being discussed and plans for implementation are underway" (p. 48). He outlined a plausible approach: 1) Receive approval by Chinese government for project; 2) Receive funding for 3–5 years; 3) Prepare fish farms for captured mature fish and for fry and growing fish; 4) capture sexually mature fish and transport to the fish farms; and 5) Start artificial propagation based on American paddlefish/sturgeon techniques, i.e., gonadic stimulation by hormones, collection of sperm and collection [*via* Cesarean Section] of eggs, fertilization, incubation, fry rearing in fertilized ponds, and transfer of fingerlings to stocking sites. In 1995, Dr. Mims submitted a proposal to the National Geographic Society to fund *Psephurus* broodstock capture and begin a propagation program at Southwest University, Beibei, Sichuan Province. This proposal was not funded. (S. Mims, Kentucky State University, Personal communication).

By 1994, however, when the Three Gorges Dam 360 km to the west of Wuhan and just upriver of Gezhouba Dam (Figure 5) was started, Chinese research was becoming more focused on *Polyodon*, which had been introduced into China in 1988 (Ji and Li 2019) and which was much more abundant and more easily reared in captivity (Graham et al. 1986; Semmens and Shelton 1986). Unlike *Polyodon, Psephurus* had not been reared successfully (Wei et al. 1997; Ji and Li 2019). In addition, *Polyodon* was a zooplanktivore (Eddy and Simer 1929; Michaletz et al. 1982) more suited for the pond monoculture and polyculture development (Mims et al. 2009; Mims 2015; Mims and Shelton 2015) well established throughout Chinese freshwaters for many centuries (Hao-Ren 1982).

After the 1981 blockage of spawning migrations at Gezhouba Dam (Figure 5), sightings of *Psephurus* declined rapidly, both above and below the dam (Zhang et al. 2020). Efforts yielded few positive results. By the spring of 1998, for example, Dr. Mims was informed a female and probable male *Psephurus* had been captured and transported to an unidentified hatchery near Wuhan. Two weeks later the fish died due to anoxic conditions (S. Mims, Kentucky State University, Personal communication). The reservoir behind Three Gorges Dam also began filling in 2003 (Yi et al. 2010a). By the twenty first century, *Psephurus* had become so rare that scientific reports on it were mostly documentations of sightings (Chen et al. 2004; Fan et al. 2006; Gao et al. 2009; Zhang et al. 2016), retrospectives using older data (Wu 2005; Zhang et al. 2016), or warnings of impending extinction (http://news.bbc.co.uk/earth/hi/earth_news/newsid_8269000/8269414.stm). Dam construction, overfishing (including by-catch, a frequent problem with rare species (Musick 1999)), and effects of pollution and industrialization along the highly-used Yangtze had taken a combined toll (Narvaez et al. 2021). Wu (2005) compared genetic diversity of archived *Psephurus* samples from 1957–1959 with later samples from 1995 to 1999 and found that a loss of genetic diversity in the latter group. He also suggested that the species may be "at significant risk of extinction" (p. 325) and that artificial rearing was an immediate need. Telemetry studies on Chinese Sturgeon (*Acipenser sinensis*) below Gezhouba Dam showed that fish still tried to ascend the dam-impounded river (Yang et al. 2006) and fisheries investigations in the Yangtze showed major impacts to various fish species (Xie et al. 2007). But by this time, *Psephurus* was too rare to be mentioned. Drifted nets, setlines, and hydroacoustics were yielding no *Psephurus*. In 2009, a few hundred scientists migrated to Wuhan from around the globe and presented more than a hundred papers on sturgeon and paddlefish for the World Sturgeon Conservation Society Sixth International Symposium on Sturgeons. Aquaculture papers dominated the presentations; no papers were focused specifically on *Psephurus*. Just over a decade later, after more futile attempts at finding living *Psephurus*, the species obituary by Zhang et al. (2020) and a note by Mei et al. (2020) summarized the events leading up to the extinction: habitat changes on the Yangtze, especially effects of Gezhouba and Three Gorges dams, serious overfishing, and pollution. They also identified some lessons for conserving Yangtze fauna moving forward: the need for a comprehensive Yangtze faunal survey, the problem of lags in fish responses to human threats, and the need for extinction risk analyses, and the need to identify the most critically imperiled species. The lessons were scientifically supported within the realms of river ecology and fisheries science. But there are also some other, broader lessons involving technological development, ecology and timescape worth considering.

Portents for *Psephurus*: Overfishing, TVA, the Bureau of Reclamation, and the origins of Chinese big dam projects

> The idea of a "Tennessee Valley Authority" on an international scale has spread widely. The term is now so commonly used that it has acquired a meaning of its own, independent of the experiment from which it took its name. The T.V.A., after its first ten years, came to be looked upon as a model and as a preliminary to wider developments elsewhere…. proposals have been made for the Amazon and Yangtze valleys… page i., Finer (1944)

> By 1945, some 50,000 translated copies of [Tennessee Valley Chairman David] Lilienthal's book [TVA: Democracy on the March] had been distributed by the Office of War Information (OWI) in China alone. American advisors there soon found the Chinese quoting the "principles" [of the book] to them. This interest probably had a connection to the hopes of the Nationalist regime for help with post-war reconstruction, which included plans for a "Yangtze River Authority" (p. 346). Ekbladh (2002)

> …'The Bureau [of Reclamation]'s early activities in China augured the emergence of the Chinese state as … the world's preeminent producer of large dams, … (p.46) Sneddon (2015)

Few global successes exist in sustainably managing wild harvest of sturgeon and paddlefish, and almost none outside of North America (Haxton et al. 2016). Most fisheries harvest too many larger individuals, especially females, which may contribute most to reproduction and recruitment (e.g., *Polyodon*; Scarnecchia et al. 2022), exacerbating the habitat problems commonly suffered by Acipenseriform fish populations. It is also well documented that numerous types of fishing technology, including vessels and fishing gear, have increased in efficiency over the past century in China and elsewhere (Huang and He 2019). Nationwide in China, Xing et al. (2016) identified issues including overharvest of mature spawners, fishing down the food web, and illegal fishing (including electrofishing) as badly damaging freshwater fisheries. Inadequate harvest management (including by-catch) has been implicated as a major problem for sustaining native fish and aquatic mammals in the Yangtze River (Mei et al. 2020).

Barring rampant overharvest, however, dams and their effects on spawning habitat have often been implicated as an equally important, and in the long term, a more serious threat to paddlefishes (Sparrowe 1986; Unkenholz 1986; Gerken and Paukert 2009; Hoover et al. 2019), sturgeons (Anders et al. 2002), and other migratory fishes inhabiting large rivers (Jackson and Marmulla 2001; Larinier 2001; Hoover et al. 2019). In investigating the historical role of dams in the extinction of *Psephurus*, evidence immediately surfaces of the twentieth century transnational migration of dam-building philosophies, approaches, and technologies (a process sometimes narrowly termed *technology transfer* but involving much more) from the United States to China. Unlike writings about *Psephurus* or its conservation needs or efforts, which would barely fill a small book, the role of high-technology American dam-building information and technology transfer has been well-studied and documented in scientific literature. Of relevance here are the transnational philosophical and technological transfers, and the resulting dispersal of knowledge, centered around the Tennessee Valley Authority (TVA) and its director, David Lilienthal (Figure 7A), recounted by Ekbladh (2002) and those of the Bureau of Reclamation (hereafter, Bureau) and its representative, John L. Savage, recounted by Sneddon (Sneddon and Fox 2012; Sneddon 2015). The political regime change in China (i.e., Nationalist regime fall and the rise of the People's Republic) in 1949 and the Cold War in the 1950s stifled implementation of the Chinese dam building and development ideas and plans of both TVA and the Bureau. Both agencies nevertheless played key roles in America's geopolitical planning in the 1940s and planted seeds that later bore fruit as Chinese dam building within China and global dominance in dam building and river control worldwide.

The Tennessee Valley Authority was authorized in 1933 as a federal corporation designed to address problems affecting the economically depressed Tennessee River Valley, including lack of rural electrification, flooding, erosion, and deforestation. Electricity from TVA dams was the key component of the program that led to improved quality of life, better farming practices, and more industry in the region. An outcome of the Muscle Shoals Controversy (Hubbard 1959, 1961), TVA rapidly became an American model of regional development of a river basin. Ekbladh (2002) discussed the success of the TVA domestically in the Tennessee River Valley and how its emphasis on involvement of the local populace was promoted by its accomplished Director, David Lilienthal, as not only an economic lifesaver to the impoverished basin but a triumph for American ideals of democracy applicable both domestically and internationally. TVA was described by Lilienthal (1964) as merging philosophy and technology. According to Ekbladh (2002), "perhaps Lilienthal's greatest accomplishment during his tenure with the TVA was his articulation of a clear philosophy for the organization. The essence of this vision was grass-roots democracy, a theme popular with many during the New Deal" (p. 340). The indigenous-population-sensitive, grass-roots emphasis (Selznick 1966) identified in his book *TVA Democracy on the March* (Lilienthal 1944; Figure 7B) was viewed as a "model of global application… and an instrument of transformation of … nature, man and society" (p. 302; Havard 1983) useful to local and regional conditions globally. Much more than a technological recipe book, it extolled a revolutionary view of human regional development and human potential. Within a decade of TVA founding, serious discussion ensued regarding the international application of the TVA model and principal issues to be addressed. Finer (1944) devotes a chapter to some of those issues, including consideration within and among foreign countries and the role of economic agencies in international funding. Such development, it was argued through succeeding years, would not only aid in America's influence and in international security, but also help TVA itself as it would learn to refine its activities based on projects elsewhere. According to Jones and Freeman (2005), by 1953 more than 39 million people had visited the TVA from nations worldwide.

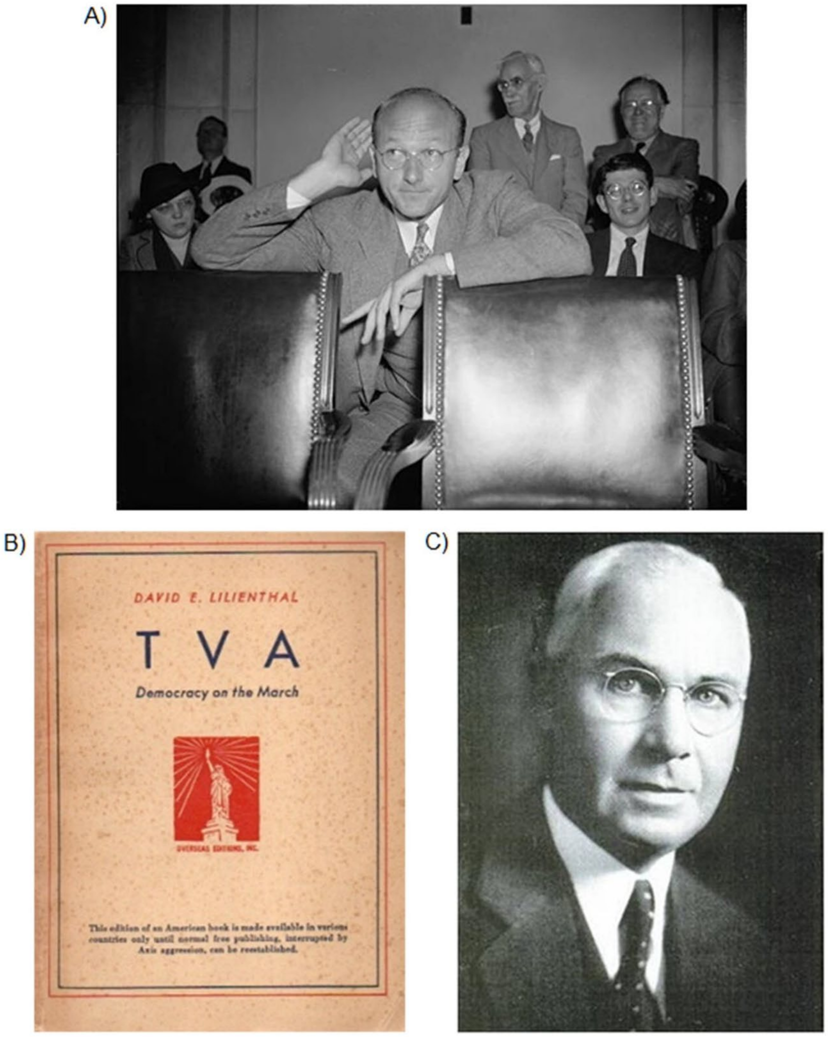

Figure 7. A) David Lilienthal of the Tennessee Valley Authority and B) Lilienthal's book TVA: Democracy on the March; C) John L. Savage of the Bureau of Reclamation.

Not all Americans viewed TVA favorably (e.g., Russell 1949; Williams 1951), citing concerns about socialism and government over-reach (Willkie 1937) and not all TVA initiatives were as successful as sometimes portrayed (Williams 1951). Environmental and societal concerns of the TVA approach and dam construction in the Tennessee River basin were eloquently expressed fairly soon after TVA's establishment (e.g., Davidson 1948). By the 1960s, the environmental movement in the United States led to considerable opposition to new dam construction (e.g., North Carolina: Stewart and Manganiello 2018), leading TVA to develop a much more effective and comprehensive domestic environmental program. In later decades, TVA even conducted research on *Polyodon* ecology in the early 1970s and documented reproduction in the Tennessee and Cumberland Rivers (Pasch et al. 1980; Wallus 1986).

Despite the concerns about overreach and environment, by the 1940s TVA numerous successes included electric power generation, rural electrification, flood control, farm programs coming out of the depression, and aiding the war effort. As the optimistic Lilienthal expressed it in *TVA Democracy on the March*, "There is almost nothing, however fantastic, that (given competent organization) a team of engineers, scientists, and administrators cannot do today. Impossible things can be done, are being done, in this mid-twentieth century" (p. 2–3, Lilienthal 1944).

Lilienthal and the TVA, with federal government approval, decided to extend their domestic agenda globally, delivering America's message of hope around the world for technological development (e.g., Japan: Dinsmore 2013). Its regional scope also contrasted with broader, centralized national planning ideas offered by the Soviet Union. In China, plans for a Yangtze

River Authority in the epigram above were suggested by Ekbladh (2002) as possibly connected with the Nationalist regime of Chiang-Kai-shek for help with post-WWII reconstruction, which served American geopolitical interests as well. Ekbladh (2002) recounts how the Rockefeller Foundation, seeing the potential of the TVA model, "throughout the 1930s and 1940s …sent a number of Chinese engineers and agriculturists to Tennessee to witness the accomplishments of the New Deal effort" (p. 339–340). Lilienthal's TVA message found an enthusiastic audience throughout much of China for immediate economic benefits along the heavily used but naturally unruly, flood-prone, often treacherous Yangtze River (Yin and Li 2001; Wang et al. 2011) to which *Psephurus,* the Chinese sturgeon *Acipenser sinensis* (Deng et al. 1985; Yang et al. 2006) and other long-lived riverine fish species had become well-adapted through evolutionary time.

Other U.S. government-employed, dam-building experts had an interest in China in the 1940s. In his comprehensive look at twentieth century dam-building, *Concrete Revolution*, Sneddon (2015) documents the activities of John L. Savage (Figure 7C), Bureau of Reclamation engineer and (later) private consultant, in promoting American ideals and technology in China to the Nationalist government. As described by Sneddon, "Savage's career with the Bureau [of Reclamation] …embodied the key traits of the idealized technical expert: virtuosity in terms of technical knowledge, a capacity to innovate, and an almost metaphysical understanding of how technology might best be applied to promote human welfare. He was a modest man, but whose life mission revolved around the construction of large dams, and whose belief in the efficacy of these projects and their tremendous capacity to improve the human condition was unshakeable", (p. 36). By 1945, by which time Lilienthal's book on the TVA had been translated into Chinese (Lilienthal 1964), Savage was working with the Nationalist regime planning construction of a Yangtze Gorge Dam, near Yichang, some 320 km from Wuhan. According to Savage, "The Yangtze Gorge Project is a "CLASSIC"… It will be of utmost importance to China. It will bring great industrial developments… It will bring widespread employment. It will bring high standards of living. It will change China from a weak to a strong nation" (1944; quoted in Sneddon 2015).

Even though TVA Lilienthal (1944) mentions the Bureau only twice in his book, the agencies occupied different geographies from each other in the U. S., and coordination between the agencies was not the best as each agency promoted itself, many Bureau goals were similar to those of the TVA (e.g., Swain 1970). In China, Bureau plans for working with the Nationalist regime were consistent with overall TVA philosophy, interests, and proposed outcomes in terms of supporting and stabilizing the political regime and improving living conditions. With a record of successful dam building in difficult terrain (e.g., Hoover Dam (Rowley 2006)), their technical knowledge and engineering competence were well-established. Sneddon (2015) notes that in 1945 "The State Department approved an agreement crafted by …[China's] National Resources Commission and the Bureau of Reclamation for Bureau staff (including Savage) to provide technical support for dam construction in China and, importantly, for the training of several dozen Chinese engineers at the Bureau's headquarters and laboratory in Denver. Savage, after retiring in 1946 at the age of 65, immediately… signed a contract as Bureau consulting engineer to expressly continue planning work on the Yangtze Project" (p. 45; Sneddon 2015).

The TVA plans for the Yangtze River Authority and the Bureau plans for the Yangtze Gorge Dam were soon thwarted by the political instability and regime change in China. Chinese engineers in Denver learning about dam construction were recalled in 1947. By this time, however, the philosophical and technical seeds of dam-building and its benefits had dispersed to China from the TVA and Bureau through technology transfer, to be integrated and reconciled with existing traditional Chinese views of river control (Boxer 1988), cultivated, and refined by the Chinese themselves and in cooperation with others, including the Soviets. Chinese engineers that had traveled to Bureau facilities in Denver returned with state-of-the-science training in engineering to begin bringing some of the international visions of the Bureau and TVA to fruition.

Though the state-of-the-science and competence of TVA and Bureau engineers and administrators then and now are unquestioned, in the 1940s and 1950s, the actions of these agencies had some long-term equivocal implications. In the Tennessee Valley, for example, issues such as displacement of indigenous peoples (e.g, Davidson 1948) had grass roots adherents and were considered but were viewed as a distant second to modernization and development (e.g., Norris Dam, Tennessee: McDonald and Muldowney 1982; Krueger et al. 1985). Scattered minority voices all along expressed concern for maintaining natural rivers (and indigenous human inhabitants), thereby, potentially benefiting *Polyodon*, sturgeons, as well as other fish and aquatic species.

The transnational technology (and world view) transfer from the United States to China clearly showed its strengths in the realms of engineering and river control for geopolitical influence and economic development and just as clearly showed its deficiencies in the areas of ecology and conservation of species biodiversity. One important concept of American thinking that was missing in the transnational transfer of the 1930s and 1940s was the recognition of the intrinsic value of wild (undomesticated) places and wilderness from Transcendentalists onward (Thoreau 1851; Muir 1901; Stegner 1961; Errington 1963), and its relevance to maintaining wildlife populations (Holt and Talbot 1978), including wild fishes and their habitats (e.g., Lichatowich 1999). Its absence was unfortunate because even though China was for centuries agriculture-based and is regarded as the origin and foremost proponent of aquaculture (Nakajima et al. 2019) and polyculture (Hao-Ren 1982), it did not have a comparable ethic toward wildness, wild places, or wild fishes. As described by Tin and Yang (2016), "In the Chinese language, there are no exact equivalents of the word *wilderness*. In modern Chinese, wilderness is commonly translated as *huang yě*…indicating places where plants and animals are not cultivated by humans … and…not subject to human influence… *huang yě* has also adopted the connotation of being savage, violent and dangerous. (p. 35)". Gao (2017) notes that the Chinese appreciation of nature is associated with farming practices (topophilia), making it difficult for them to fully appreciate wild, uncontrolled areas typically associated with species such as *Psephurus* and sturgeons. No perspective was present in the transnational technology transfer on the importance of wild fishes and their habitats to balance the interests of river impoundment and its immediate benefits. Raising fish in aquaculture was a more appreciated approach in China than managing to conserve wild, difficult-to-handle species such as *Psephurus* and their uncontrolled, unpredictable habitats.

The Americans providing information to China did not themselves understand or appreciate issues of aquatic ecology and the effects of river impoundment and modifications on native fishes such as paddlefishes, sturgeons, and other riverine fish species. From the earliest days of the U.S. Fish Commission and its first Commissioner, Spencer Fullerton Baird, there was strong interest in using hatcheries to mitigate and substitute for overharvest and habitat losses associated with development (Allard 1978; Lichatowich 1999). For the TVA Biological Adjustment Division in the Tennessee Valley, "fisheries activities include[d] the establishment of fish hatcheries for stocking the newly created lakes…the construction of small dams around these lakes for…constant level fish rearing ponds, as well as scientific study of…the newly impounded waters as a guide to the attainment of fisheries objectives (p. 95, Hodge 1938). Impoundment was viewed as favorable overall to fisheries; "The waters of the reservoirs and the rivers below them, largely freed from the heavy load of silt are rapidly becoming favorable breeding places for game fish" (p. 127, Hodge 1938). In most locations worldwide, the ecological effects of excessive sedimentation behind dams in the coming century (e.g., Yangtze River: McDonald et al. 2009; Schleiss et al. 2016) was a remote concern. Even more remote were concerns for ancient migratory fishes such as *Polyodon* (in North America), *Psephurus* in China, and sturgeons in both places. The transfer of *ecological* information and knowledge regarding impacts to proposed Yangtze projects on native migratory fishes was nil. In that era, ecological *benefits* of natural silt loads in rivers and unimpeded fish passage and the costs of blockage of fish migrations and inundation of spawning grounds of ancient fish such as *Polyodon* in North America and *Psephurus* in China were alien concepts and not part of project planning. The main domestic aquatic ecological issue that captured TVA attention at that time was the area of immediate human health: the increase in incidence of malaria in the Tennessee River basin associated with dam and reservoir construction (Kitchens 2013) and efforts to control it (Carter 2014).

Lilienthal journals during his years at TVA (1939–1945) understandably focus on the war effort, energy, and strategic resources such as aluminum. Through the Oak Ridge National Laboratory, TVA played a crucial role in winning World War II (Callahan 1980). Emphasis was on immediate human and national survival and the shorter-term economic and political benefits of dams and development over the next few human generations. Lilienthal journals during his TVA years do not mention fish or ecological issues at all (Lilienthal 1964); such issues were typically outside of benefit/cost analyses of that time (Boxer 1988). Unlike the unquestioned expertise in dam construction technology, it was not possible, at this critical time in the nascence of modern technological dam construction and global development, to transfer ecological knowledge of rivers and their migratory fishes either domestically or internationally that had not been adequately invested in, was poorly understood, and remained largely unarticulated.

Even as late as the 1980s, by which time environmental concerns for America's existing and planned dams were taken much more seriously, ecological emphasis on international dam projects was much less pronounced than for domestic dam projects. J. F. LaBounty (1984) of the Bureau assessed environmental effects of the Three Gorges Project as part of a 10-person delegation to China in May-June 1981 and noted that "…*Psephurus gladius* is another large-bodied fish found in the project area that migrates to a yet unknown extent. It seems as if so little may be known on this species' natural habitats that any prediction of effects due to the project is not yet possible. In order to take effective measures to save this fish, ecological studies must be undertaken"(p. 14). In the same report, he recognized the importance of "unobstructed, free flowing" (p. 14) water for some migratory Yangtze River species and also noted that the Chinese Sturgeon "will perhaps be most affected by dam construction" and that "damming the Yangtze without some sort of corrective action will result in loss of this fish species" (p. 14) since it was known to travel to the Upper Yangtze River to spawn. He further stated that "Much interest has been expressed in China for protecting the Chinese Surgeon (sic), mostly in regard to Gezhouba. Design and construction of a fish ladder at Gezhouba and three Gorge has been considered". He concluded, however, that '"the chances of a fish ladder contributing to the survival of this species seem very remote" (p.14), instead promoting trap and haul methods for moving migratory fish above the structures and fish propagation in hatcheries. Similar approaches were favored for the Yangtze sturgeon *Acipenser dabryanus*. He did recommend that "the Three Gorge Project should have the benefit of a careful environmental assessment before it is constructed" (p. 16, LaBounty 1984). Indirect effects on *Psephurus* and river fishes and other aquatic life such as the potential rapid increase in pollution associated with dam-aided industrialization were not discussed. One tepid paragraph-length section voicing nebulous long-term ecological concerns about *Psephurus* and sturgeons was nothing amid well-articulated promotions by the Bureau and other agencies for the more immediate (and shorter-term) economic and geopolitical benefits of river development.

It has also been stated that in the past the Bureau lacked statutory authority to implement much-needed restoration of ecosystem effects of earlier Bureau projects (Benson 2011). Back then, the emphasis of the United States, the TVA, and the Bureau in its technology transfer to China was on engineering for power and flood control while using river development and modernization to mutual geopolitical advantage (Ekbladh 2002; Sneddon 2015) and promoting the American philosophical and technological world view. Additional status benefits accrued to nations taking the step toward western-style modernization by controlling flooding, unpredictable and often dangerous rivers, generating power for industry from them, and putting rivers to a range of immediate human uses. At home and abroad, the immediate, paramount economic and societal needs were winning World War II and the geopolitical positioning for the incipient Cold War. Considered less immediate in importance was displacement of indigenous human cultures. Even less significance was attached to latent ecological issues such as reservoir sedimentation. Of even less concern were the ecological requirements for native migratory fishes and other species, no matter how far back in the fossil record migratory fishes such as *Psephurus* (or sturgeons or *Polyodon*) went and how irreplaceable those species may have been.

The legacy of TVA, the Bureau, and countless other outside influences, governmental and private, that followed into China, including transnational thinking, technology transfer, and extensive national and international funding, collided with and came to completely dominate the long-standing Chinese practice of a water conservation philosophy described by Boxer (1988) as *shuili*, involving over two thousand years of less ambitious but less intrusive engineering of natural and human systems. Over the period 1949 [the founding of the People's Republic of China] to 1998, 84,000 reservoirs of different-kinds were constructed in China (Jiang and Fu 1998). Gezhouba Dam on the Yangtze, a large water control project 330 km west of Wuhan involving hydropower and shipping locks, was begun in 1970 and completed in 1988, with the blockage of the main channel to fish migration thought to be a major contributor to the demise of *Psephurus*. Although Shi et al. (2015) noted that fish passage in some Chinese waters have been attempted since the 1960s, it was not until after 2002 that a federal law required passage. Gezhouba Dam, completed in what Shi et al. (2015) called "an inactive period" of fish passage in China, is a direct descendent of the transnational technology transfer without ecological underpinnings and the prevailing world view of development that accompanied it. Its lack of fish passage reflected low emphasis on environmental concerns related to migratory fish at that time. Chinese governmental authorities, long more focused politically and economically on dam building technology and aquaculture than on rare, wild fish and other aquatic species, demonstrated apathy toward the fate of *Psephurus.*

A broader global outcome of the transnational technology transfer and the values that came with it was the ascendance of China into the premier dam building empire of the twenty first century, both within and beyond Chinese borders (International Rivers 2012; Urban and Nordensvard 2014). In the Yangtze, Gezhouba and Three Gorges dams provide power, flood control, irrigation and facilitate cargo shipments. According to McDonald et al. (2009), "Chinese dam builders have accumulated a vast knowledge base, having constructed almost half of the world's large dams within Chinese borders. The majority of these projects have been built during the past 50 years…. Chinese firms and financiers are currently involved in at least 93 major dam projects abroad."(p. 294). China's expertise has spread to other parts of Asia (Biggs 2006; Urban et al. 2018), in Europe and Latin America (Kirchherr and Matthews 2018), and globally (McDonald et al. 2009). Zhou et al. (2021) reported that by 2008, China led the world in patent applications; by 2017, Chinese patents in the hydropower industry constituted 95% of the world total.

Studies in the early twenty-first century on the effects of Gezhouba and Three Gorges dams on the Yangtze described negative effects of loss of natural river function and habitat connectivity (Yi et al. 2010a,2010b) on carps and other species such as sturgeons (Deng et al. 1985; Yang et al. 2006), as well as the insurmountable problems for *Psephurus* (Cheng et al. 2015). Environmental costs, including needed human population resettlement and concerns over native sturgeon and the Yangtze Dolphin *Lipotes vexillifer*, were long recognized (Ziyun 1986; Liu and Zuo 1987) and voiced as minority opinions (Boxer 1988; Fearnside 1988). Today, Chinese aquatic scientists are well aware of the potential for mass extinctions in the Yangtze. A recent article (Mei et al. 2020) identified a 10-year commercial fishing ban on the Yangtze, its tributaries, and adjoining lakes. With the extinction of *Psephurus* imminent or by then a reality, Cheng et al. (2015) spoke about lessons learned from the Yangtze. For *Psephurus*, an ancient survivor seen as minor, even insignificant collateral damage to many in the broader human trajectory of the early twenty first century, the lessons from ignoring ecology came too late. The article by Mei et al. (2020) in *Science* was entitled *A first step for the Yangtze*. Ironically, it came in the same year as the paper by Zhang et al. (2020) documenting the end of *Psephurus.*

There is evidence that many of the same kinds of geopolitical exigencies and immediate nation-status benefits recognized and applied by TVA and the Bureau domestically in the Depression and war years of the 1930s and 1940s have been more recently and widely applied to Chinese dam building (Boxer 1988), both domestically and abroad, by China and by other nations with emerging economies relying on Chinese dam building technology (Nüsser 2003; Tilt 2015). Meanwhile, the immediate benefits of China's dams in China and elsewhere to some, as well as short- and long-term costs to others (Urban et al. 2018) have continued to create serious ecological problems for many native riverine fish species.

Ecological irony and Wuhan

> By the end of the 1960s, it was obvious that development programs worldwide had displaced hundreds of thousands, exposing these groups to social and cultural turmoil as well as epidemic disease and economic hardship (p. 372) Ekbladh (2002).

> It is now clear that the mysterious respiratory illness in Wuhan is caused by a new type of coronavirus… Viruses emerge and reemerge globally… irrespective of borders. They jump from animal to humans, and they move from one country to another (p. 1–2). Liu and Saif (2020).

In early 2020, while the extinction of venerable but little-known *Psephurus* was being documented in a science-based panegyric out of Wuhan (Zhang et al. 2020), the critical loss of species biodiversity acknowledged, and a path forward proposed (Mei et al. 2020; Zhang et al. 2020), Wuhan itself was ironically the unfortunate epicenter of the initial transfer of COVID-19 to the United States and beyond. The pandemic started as an epidemic (i.e., an outbreak confined to a region or segment of the population) one of many throughout history that have begun *in many different human populations and regions*. The COVID-19 epidemic turning into a pandemic was a not-unimaginable outcome (ecologically speaking) in the world of the early twenty-first century. Future epidemics, wherever they will arise, have increased potential to become pandemics as well. The extinction of *Psephurus* and the concurrent development and spread of COVID-19 into a pandemic, although differing enormously in scope and perceived human significance, shared common roots in transnationalism, technology transfer, a fundamental ignorance of and lack of concern for ecological principles, and the steadily compressing timescape on earth resulting from the accelerating pace and global reach of human activities.

If the rapid dispersal of dam building and its technology around the globe, most notably from the United States to China and from there globally, was an outcome of mid-twentieth century American geopolitical efforts to promote their world view and technological capability, the wide, rapid exchange and dispersal of countless species of organisms, plant and animal (including humans), was occurring concurrently, and had been, for a few centuries. It has just accelerated in the current timescape. The Columbian Exchange (Crosby 1972), described by Nunn and Qian (2010) as "the exchange of diseases, ideas [including technology], food, crops, and populations between the New World and the Old World following the voyage to the Americas by Christopher Columbus in 1492" (p. 163) has led to extensive andmultidisciplinary scholarly work (Milanich and Milbrath 1989; Thomas 1989, 1990, 1991; Viola and Margolis 1991; McCook 2011) documenting "the social, ecological, ideological, and human repercussions of European-Native American Encounters…" (p. xiii; Thomas 1990). Since 1492, technologies, crops, domesticated animals, and diseases have all been exchanged at an accelerating rate. In fisheries, species such as the Common Carp *Cyprinus carpio*, brown trout *Salmo trutta,* and rainbow trout *Oncorhynchus mykiss* were transferred around the world in hopes of providing a valuable crop or fishing opportunity for humans. Many such introductions into and out of the United States, often aided by well-meaning scientists, whether ecologically defensible or not (Sagoff 2005; Gozlan 2008), have continued up to the present (e.g., Grass Carp *Ctenopharyngodon Idella*: Mitchell and Kelly 2006 and other large carps from Asia into North America). Whereas some earlier transfers were intentional and more gradual and occurred over many years or centuries in preindustrial times (e.g., Common Carp: Balon 1995a,1995b; Hoffman 1995), more recent introductions in the 19th and early- and mid-twentieth century were often intentional and their more rapid spread was aided greatly by technology (Common Carp: Cole 1905: Grass Carp: Mitchell and Kelly 2006). Most aquatic transfers in recent decades are unintentional (Mills et al. 1993; Rothlisberger and Lodge 2013) and the timescape of these transfers has been continually compressing up to the present into more rapid and forced species interactions (Johnson et al. 2009). The accelerated time-compressed dispersal of new ideas, technologies, and organisms of all taxa has continued a trend that has expanded far beyond the European-North American transfer. In a period of a mere lifespan or two of *Psephurus*, accustomed like the sturgeons to living and evolving at an almost geological pace, landscapes and riverscapes, including species assemblages, have changed radically. In the rapidly compressing timescape of the late 20th and early 21st centuries, dams and other river modifications fragmented river habitats rapidly, reservoirs flooded spawning areas, and improved fishing methods targeted large old fish. The long, slow-lane life history of *Psephurus* and Acipenseriform relatives, an adaptive asset for millions of years, in evolutionarily terms so long a winner, was suddenly a loser.

If the extinction of an esoteric species such as *Psephurus* from transnational Columbian Exchanges failed to resonate with most twenty-first century people in the globalizing, techno-frenetic, industrial environment of the past century, the introduction and rapid dispersal of COVID-19 and other diseases afflicting those same people *has* resonated. The COVID-19 pandemic, of course, was far from the first problem associated with the Columbian Exchange, human contact, and subsequent epidemics and pandemics (see Dobyns 1993). "Virgin soil" epidemics (Crosby 1976) have been implicated as a major cause of the decline in native (aboriginal) populations in North America. Studies have documented epidemics from introduction of diseases (e.g., smallpox, influenza, malaria, yellow fever, measles, whooping cough, etc.) from Europeans and their slaves from Africa to native tribes in Hispaniola and the Caribbean (malaria: McNeill 2010), Florida (sixteenth century and later; Deagan 1985; Hann 1991), southeastern U. S. Tribes (fifteenth through eighteenth centuries; Kelton 2007 the Northeastern U.S. (Seventeenth Century: Algonquian and Iroquois peoples; Snow and Lanphear 1988), up the Missouri River (seventeenth and eighteenth centuries: Sundstrom 1997), from the Columbia River tribes along the northwest coast and upriver to upper basin tribes (Boyd 1999), to name just a few examples. Kelton (2007, 2015) associates the most serious epidemics in the American southeast among native tribes to English and Spanish colonialism, especially the former, in pursuing trade in native slaves, especially in the mid-seventeenth century. Other epidemics such as yellow fever were recurring problems in the United States: Philadelphia (1793; Foster et al. 1998), Louisiana and Mississippi (1853, 1878; Nuwer 2009). In a book cynically but accurately entitled *The Gifts of Civilization*, Bushnell (1993) documents how a range of introduced diseases, including venereal diseases, tuberculosis, and numerous other diseases that migrated to the islands with Captain James Cook and successors, decimated the population of native Hawaiians. In the early twentieth century (1918–1919), the virulent influenza strain killed 50 million or more people globally, and more than 600,000 in the U. S., as the virus originally spread globally, most likely from U. S. origins, and later returned (Barry 2004). On the Yangtze, J. F. LaBounty of the Bureau (1984), while perhaps understating the potential dam impacts to migratory fishes, including those to *Psephurus* and sturgeons, at the same time acknowledged the potential adverse environmental effect of disease transmission to indigenous peoples living along the river if inundation from the Three Gorges Project forced human displacement. Worldwide, the exchange and increasing levels of domestication led to an increase in zoonoses, such as infectious diseases transmitted between species from animals to humans that contributed to the decimation of native tribes (Martin 1976). COVID-19 may also benefit from rapid domestication of animal carriers (Gao 2021).

In an ecologically vengeful circle worthy of Barry Commoner's (1971) assertion that *everything is connected to everything else*, at the exact time *Psephurus* was declared extinct by scientists in Wuhan, COVID-19, whether originating from a zoonosis at the Wuhan market (Worobey et al. 2022), from inadequate controls in a Wuhan high safety laboratory (Gaviria and Martin 2023), a combination of these events, or a yet-to-be identified cause, was carried by humans into the techno-frenetic, time-compressed, dispersal-oriented world that we in the U.S. helped develop and market, and, as ecology would suggest, came back to us in the form of COVID-19 with much human mortality and suffering. At the core of this event, and events leading up to it, was a long-standing lack of understanding and respect for ecological principles. The COVID-19 virus, not coincidentally, with its rapid transmissibility and ability to rapidly mutate into new forms, is far better adapted to the compressed twenty-first century timescape than a slow-lane, piscine anachronism like *Psephurus*.

The future of sturgeons and other long-lived fishes

> As a species, we have a childlike disinterest and partial disbelief in the time before our appearance on Earth. With no appetite for stories lacking human protagonists, many people simply cannot be bothered with natural history. We are thus intemperate and intemporate - time illiterate. Like inexperienced but overconfident drivers, we accelerate into landscapes and ecosystems with no sense of their long-established traffic patterns, and then reach with surprise and indignation when we face the penalties for ignoring natural laws. (p. 7), Marcia Bjornerud, Timefulness (2018)

> Should conservatism in ecological matters be labelled a vice rather than a virtue? So say the technological optimists. (p. 73), Garrett Hardin, The Limits to Altruism, Ch. 4: Who cares for posterity?

> Technology made large populations possible; large populations now make technology indispensable. Joseph Krutch

> If you don't know where you're going, you'll end up somewhere else – Yogi Berra

For the remaining living Acipenseriform fish and other ancient (and not-so-ancient) fishes that are not short-lived, not easily domesticated, nor pre-adapted to the new human landscapes and riverscapes of dams, impoundments, and aquaculture, it is becoming less likely each decade that there is a place for them as this century progresses. All of a sudden, in geological terms, *Psephurus* is gone, and most of the wild sturgeons are declining, threatened, or endangered and under increasing environmental stress (Haxton et al. 2016), part of a so-called sixth mass extinction threating global fauna and flora (Ceballos et al. 2015). Most management of Acipenseriform species in the wild can be accurately described as salvage efforts with fewer and fewer surplus wild fish for harvest, persisting almost exclusively with the aid of both conservation aquaculture and production aquaculture.

Polyodon, although not thriving, continues to maintain itself, with managers' help, to support a few commercial fisheries (Scholten 2009; Rider et al. 2019) and several important sport harvest fisheries (Mestl et al. 2019). Such fisheries not only provide food and popular recreational benefits (Scarnecchia et al. 2021a,2021b; Scarnecchia and Schooley 2022) but also serve to temporarily assuage our concerns (concerns supported by scientific evidence) about the vulnerability of such species in the wild. Perhaps *Polyodon's* comparative success in the wild is because it is the only fish in the entire Acipenseriform group that is a midwater zooplanktivore (Michaletz et al. 1982) preadapted to many of the new reservoirs, even though those reservoirs are, and will prove to be, mere blips on the geological landscape. Rapid sedimentation of such reservoirs typically occurs (Jiang and Fu 1998; Schleiss et al. 2016), despite engineering efforts to slow it (Ren et al. 2021). Some *Polyodon* populations of the species have even temporarily expanded with reservoir construction, and resulting trophic upsurge, resulting in rapid growth (Fort Gibson, Grand River, Oklahoma: Houser and Bross 1959), and at times substantial fisheries (e.g., Lake Sakakawea, Missouri River, North Dakota: Scarnecchia et al. 1996, 2007). Once the benefits of trophic upsurge dissipate, such increases are expected to decline (Scarnecchia et al. 2009).

Zooplanktivory and adaptability to ponds in *Polyodon* has made it easier than other Acipenseriform species to be mono-cultured or polycultured (Mims

Figure 8. *Polyodon* aquaculture in China.

and Shelton 2015; Yang et al. 2018). As of 2022, *Polyodon* has become widespread in China, the world's leading aquaculture nation, as an aquaculture animal for both meat and caviar since its introduction there in 1988 (He 1999; Tian and Wang 2001; Ji and Wang 2009; Mims 2015; Ji and Li 2019; Figure 8). The Chinese aquaculture success with *Polyodon* and sturgeons is influencing and dominating world caviar markets (https://caviarstar.com/blog/china-has-become-one-of-the-worlds-largest-caviar-producers/). Yang et al. (2018) report that "It took only 20 years for sturgeon farming for(sic) China to become the largest sturgeon nation producer accounting for over 80% of world production (p. 243)". And in the original spirit of the Columbian Exchange, as caviar travels the globe (Fain et al. 2013), so do the fishes like *Polyodon* yielding it. *Polyodon* has been dispersed to Europe and Russia and functions as both an aquaculture species and as a feral inhabitant of large rivers. The species is now reared in hatchery ponds in several European countries for meat and caviar (Billard and Lecointre 2000; Lobchenko et al. 2002; Simonović et al. 2006; Hubenova et al. 2007; Kaczmarczyk et al. 2012; Onders and Mims 2015; Simeanu et al. 2015) and has been found in the Danube River (Simonović et al. 2006; Jelkić and Opačak 2013). Depending on location, *Polyodon* was introduced into the wild from escaping aquacultural operations, releases of aquariasts, or intentionally by professionals, and is now found widely throughout much of central and eastern Europe (Jarić et al. 2019), and in Russian waters (Kharin and Cheblukov 2009), where aquaculture prospects are being explored (Elnakeeb et al. 2021). Its presence has even raised concern that it is a potentially invasive species (Jarić et al. 2019). Despite this concern, its slow-lane life history (Musick 1999), its relative ease of capture, and the economic value for caviar will militate strongly against it ever being abundant enough and sufficiently difficult to remove from a water body to become a serious invasive.

The aquaculture development for *Polyodon* and other Acipenseriform species in many localities inside and outside of species' native ranges (Ethier 2014; Yang et al. 2018; White et al. 2023) portends a troublesome trend in this century, where many fishes will either fully or mostly domesticate (Teletchea 2017), linger as vestiges of wild stocks, or disappear entirely. The domestication effort for Acipenseriform fishes typically involves whatever technologies are available to raise these fishes in as short a time as possible for meat and caviar (Raposo et al. 2023), abbreviating their fundamental life histories (Wei et al. 2004; Dasgupta 2015; see the latest approaches for *Polyodon* in Mims and Shelton 2015; Figure 9). Genetic crosses among species, gynogenesis, and intensive culture methods in farming and ranching situations are just a few of the many methodologies designed to produce quality flesh and caviar with maximum efficiency in the minimum amount of time (Mims and Shelton 2015; Yang et al. 2018; Shelton et al. 2019), by-passing the more cumbersome and inconvenient aspects of their evolved life histories. In an aquaculture-centered fisheries world, it then becomes especially important that adequate consideration be given to both the life history and ecological costs of rapid domestication (Teletchea 2016) and the loss of wildness in species. Regardless of aquacultural successes, for long-term persistence as a wild species and not a domesticated one, *Polyodon* and sturgeons must have suitable, typically free-flowing or quasi-free flowing, large or mid-sized river habitat for natural spawning and stock maintenance (Bemis and Kynard 1997).

In his novel *A Single Pebble* (1956), Chinese-born American Journalist John Hersey (1914–1993) described the struggles of a young American engineer trying to reconcile western ambitions for modernizing

Figure 9. *Polyodon* plate lunch in China. Emphasis is on producing meat and caviar as quickly as possible.

China with dam construction on the Yangtze against centuries-old values of human inhabitants living and working there. Neo-colonial ideas of modernization the young engineer brought with him did not merge harmoniously with those espousing more traditional values (Christie 2011). As Hersey wrote: "I became an engineer… chosen by the big consulting firm…. to go to China and study the river called by the Chinese "the great", the Yangtze, to see whether it would make sense for my company to try to sell the Chinese Government a vast power project in the river's famous gorges. … This was half my life ago, in the century's and my early twenties; the century and I were both young and sure of ourselves then. …I could only think of … [the Yangtze] as a long strip of raw, naked, cruel power waiting to be tamed. I had much yet to learn." (Hersey 1956). Among the many disconnects between modern industrial efforts and indigenous lives in that book and in the real world are their different timescapes. The geologist Bjornerud (2018) discusses how *thinking long-term*, like a geologist, "can help us save the world", and help us in the process, much like she noted that Aldo Leopold talked of "thinking like a mountain". This has not been the pattern of human activity. The expeditious application of virtually any technology to meet short-term political and economic demands at the long-term expense of ecology and the environment (Meffe 1992) has instead become a defining attribute of *Homo sapiens*. The consistent pattern of human political and economic exigencies subverting the longer-term ecological rationale for conserving our biodiversity, in this case of ancient, wild, migratory riverine fishes embodied in *Psephurus* and its relatives, continues to repeat itself globally, increasingly, and more rapidly in an anthropocentric world of more than eight billion humans, most of them impoverished. This pervasive pattern of applying too little ecology in the application of our technologies threatens not only fish like *Psephurus* but our own future as well.

If the lessons of the past century and the extinction of *Psephurus* and other ancient species before their natural ecological time have taught us anything, it is that we must start thinking more about what we need to implement to maintain biodiversity of these long-lived and now ill-adapted species of fish and other taxa in an increasingly human-dominated, techno-frenetic, timescape-compressed world. As transnational exchanges of ideologies, information, people, and other organisms becomes faster and more frequent, as seems inevitable, biotic intermixing will increase, homogenizing the planet and its biota, including fish (Kaufman 1992; Lockwood and McKinney 2001). The human rush toward homogenization and the compressing timescape, both highly detrimental to slow-lane species such as *Psephurus*, *Polyodon*, sturgeons, and other taxa, promises to strain our fish and wildlife management capabilities to the limit. For fisheries biologists charged with conserving ancient fishes, we must take all steps within our control to understand and manage these long-lived fishes and their habitats. Reductions in harvest may also be a necessity in most cases, instead focusing harvest on the more abundant species, especially competing invasives (Scarnecchia and Schooley 2020; Scarnecchia et al. 2021b) while minimizing by-catch. Although the world is far from devoid of highly intelligent ecologists who understand its importance and write erudite, even inspirational, books on the subject, far too little of this ecological knowledge finds its way into sustainable public policies in fisheries or most other realms of human activity. Beyond just *thinking* longer-term, fisheries scientists and managers need to meet the special challenges of conserving our long-lived fishes in their native habitats by proactively *managing* longer term. We must keep our long-lived fishes, some of them "living fossils", from rapidly becoming just fossils and recollections, like *Psephurus* (Figure 10).

Clearly, however, fisheries scientists andmanagers need more help than is being received from other scientists and scholars in other disciplines and from the entire public, in addressing larger, often external human societal issues: our burgeoning human numbers, how far and fast we all move about the earth, how fast we move other organisms around the planet, how we use industry and technology, and how much energy we use in the increasingly frenetic process. Managing our wild fishes and fisheries will become intractable if we cannot develop rational and humane ways of managing ourselves and our activities consistent with not only our values but with ecological

Figure 10. Philatelic remembrance of *Psephurus*.

realities. If fisheries management has often been described as mostly people management, and it often has (e.g., Clay and McGoodwin 1995), then beyond just *thinking* long term (Bjornerud 2018), humanity had better start finding and taking acceptable long-term, ecologically-based management *actions* in both fisheries and human realms, and right away.

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References

Alam GMM, Sarker MNI, Gatto M, Bhandari H, Naziri D. 2022. Impacts of COVID-19 on the fisheries and aquaculture sector in developing countries and ways forward. Sustainability 14(3):1071. doi:10.3390/su14031071

Allard DD.Jr. 1978. Spencer Fullerton Baird and the U. S. Fish Commission. New York (NY): Arno Press.

Anders PJ, Richards DL, Powell MS. 2002. The first endangered white sturgeon population: repercussions in an altered large river floodplain ecosystem. In: Van Winkle W, Anders P, Secor DH, Dixon D. Biology, Management, and Protection of North American Sturgeon. American Fisheries Society Symposium 28. Bethesda, MD. p. 67–82.

Balon EK. 1995a. The common carp, *Cyprinus carpio*: its wild origin, domestication in aquaculture, and selection as colored nishikigoi. Guelph Ichthyol Rev 3:1–55.

Balon EK. 1995b. Origin and domestication of the wild carp, *Cyprinus carpio*: from Roman gourmets to the swimming flowers. Aquaculture 129(1–4):3–48. doi:10.1016/0044-8486(94)00227-F

Barry J. 2004. The great influenza. New York (NY): Penguin Books.

Bemis WE, Kynard B. 1997. Sturgeon rivers: an introduction to acipenseriform biogeography and life history. Environ Biol Fishes. 48(1–4):167–183. doi:10.1023/A:1007312524792

Benson RD. 2011. New adventures of the old Bureau: modern-day reclamation statutes and Congress's unfinished environmental business. Harvard J Legislation 48:137–184.

Biggs D. 2006. Reclamation nations: The U. S. Bureau of Reclamation's role in water management and nation building in the Mekong Valley, 1945–1975. Comp Technol Transfer Soc. 4(3):225–246. doi:10.1353/ctt.2007.0001

Billard R, Lecointre G. 2000. Biology and conservation of sturgeon and paddlefish. Rev Fish Biol Fish. 10(4):355–392. doi:10.1023/A:1012231526151

Birstein VJ, Bemis WE, Waldman JR. 1997. The threatened status of acipenseriform species: a summary. Environ Biol Fishes. 48(1–4):427–435. doi:10.1023/A:1007382724251

Birstein VJ, Waldman JR, Bemis WE. 1997. Sturgeon biodiversity and conservation. Environ Biol Fishes.48(1–4):1–438.

Bjornerud M. 2018. Timefulness. How thinking like a geologist can help save the world. Princeton (NJ): Princeton University Press.

Boreman J. 1997. Sensitivity of North American sturgeons and paddlefish to fishing mortality. Environ Biol Fishes. 48(1–4):399–405. doi:10.1023/A:1007345806559

Boxer B. 1988. China's Three Gorges Dam. Questions and prospects. China Q. 113:94–108. doi:10.1017/S0305741000026424

Boyd R. 1999. The coming of the spirit of pestilence. Seattle (WA): University of Washington Press.

Bushnell OA. 1993. The gifts of civilization. Germs and genocide in Hawaii. Honolulu: The University of Hawaii Press.

Callahan N. 1980. TVA: bridge over troubled waters. South Brunswick (NJ): A. S. Barnes Company .

Carter ED. 2014. Malaria control in the Tennessee Valley Authority: health, ecology, and metanarratives of development. J Hist Geogr. 43:111–127. doi:10.1016/j.jhg.2013.09.002

Ceballos G, Ehrlich PR, Barnosky AD, García A, Pringle RR, Palmer TM. 2015. Accelerated modern human–induced species losses: Entering the sixth mass extinction. Sci Adv. 1(5):e1400253. doi:10.1126/sciadv.1400253

Chen D, Duan X, Liu S, Shi W. 2004. Status and management of fishery resources of the Yangtze River. In: Welcomme RL, Petr T, editors. Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries. Bangkok, Thailand: United Nations Food and Agricultural Organization and the Mekong River Commission. p. 173–182.

Cheng F, Li W, Castello L, Murphy BR, Xie S. 2015. Potential effects of dam cascade on fish: lessons from the Yangtze River. Rev Fish Biol Fish. 25(3):569–585. doi:10.1007/s11160-015-9395-9

Chenhan L, Yongjun Z. 1988. Notes on the Chinese paddlefish, *Psephurus gladius* (Martens). Copeia 1988(2):482–484. doi:10.2307/1445891.

Christie S. 2011. Reading the "gap" in the Chinese gorge: Modernist untranslatability in John Hersey's *A Single Pebble*. Comp Lit East West. 15(1):49–56. doi:10.1080/25723618.2011.12015400

Clay PM, McGoodwin JR. 1995. Utilizing social sciences in fisheries management. Aquat Living Resour. 8(3):203–207. doi:10.1051/alr:1995019

Cole LJ. 1905. German carp in the United States. Washington (DC): U. S. Bureau of Fisheries.

Commoner B. 1971. The closing circle. New York (NY): Alfred A. Knopf.

Conte FS, Doroshov SI, Lutes PB. 1988. Hatchery manual for the White Sturgeon. Davis (CA): University of California Cooperative Extension.

Crosby AW. 1972. The Columbian Exchange. Biological and cultural consequences of 1492. Westport (CT): Greenwood Press.

Crosby AW. 1976. Virgin soil epidemics as a factor in the aboriginal depopulation of America. William Mary Q. 33(2):289–299. doi:10.2307/1922166

Dasgupta S. 2015. The economics of paddlefish aquaculture. In: Mims SD, Shelton WL, editors. Paddlefish aquaculture. Hoboken (NJ). p. 267–290.

Daugherty DJ, Andrews AH, Smith NG. 2020. Otolith-based age estimates of Alligator Gar assessed using bomb radiocarbon dating to greater than 60 years. North Am J Fish Manage. 40(3):613–621. doi:10.1002/nafm.10390

Davidson D. 1948. The Tennessee. (Two Volumes). New York (NY): Rinehart.

Deagan KA. 1985. Spanish-Indian interaction in sixteenth-century Florida and Hispaniola. In: Cultures in contact. Washington, D.C.: Anthropological Society of Washington. p. 281–318.

Deng Z, Z, Yu Y, Xu X, C. Zhou 1985. Age determination and population structure of spawning Chinese sturgeon (*Acipenser sinensis* Gray). Acta Hydrobiol Sin. 9(2):99–111. (in Chinese with English summary).

Dinsmore E. 2013. Concrete results? The TVA and the appeal of large dams in occupation-era Japan. J Jpn Stud. 39:1–38.

Dobyns HF. 1993. Disease transfer at contact. Annu Rev Anthropol. 22(1):273–291. doi:10.1146/annurev.an.22.100193.001421

Eddy S, Simer PH. 1929. Notes on the food of paddlefish. Trans Illinois State Acade Sci. 21:59–68.

Ekbladh D. 2002. Mr. TVA": Grassroots development, David Lilienthal, and the rise of the Tennessee Valley Authority as a symbol for U. S. overseas development, 1933–1973. Diplomatic Hist. 26(3):335–374. doi:10.1111/1467-7709.00315

Elnakeeb MA, Vasilyeva LM, Sudakova NV, Anokina AZ, Gewida AGA, Amer MS, Naiel MAE. 2021. Paddlefish, *Polyodon spathula*: Historical, current status, and future aquaculture prospects in Russia. Int Aquat Res. 13:89–107.

Erickson DL, Webb MAH. 2007. Spawning periodicity, spawning migration, and size at maturity of Green Sturgeon, *Acipenser medirostris*, in the Rogue River, Oregon. Environ Biol Fish. 79(3–4):255–268. doi:10.1007/s10641-006-9072-x

Errington P. 1963. The Pricelessness of untampered nature. J Wildl Manage. 27(2):313–320. doi:10.2307/3798423

Ethier V. 2014. Farmed Sturgeon. Monterey (CA): Monterey Bay Aquarium Seafood Watch.

Fain SR, Straughan DJ, Hamlin BC, Hoesch RM, LeMay JP. 2013. Forensic genetic identification of sturgeon caviars travelling in world trade. Conserv Genet. 14(4):855–874. doi:10.1007/s10592-013-0481-z

Fan X, Wei Q, Chang J, Rosenthal H, He JX, Chen D-Q, Shen L, Du H, Yang D-G. 2006. A review of conservation issues in the Upper Yangtze River- the last chance for a big challenge: Can Chinese paddlefish (*Psephurus gladius*), Dabry's sturgeon (*Acipenser dabryanus*), and other fish species still be saved? J Appl Ichthyol. 22 (Supplement 1):32–39. doi:10.1111/j.1439-0426.2007.00926.x

Fearnside PM. 1988. China's Three Gorges Dam: "Fatal" project or step toward modernization? World Dev. 16(5):615–630. doi:10.1016/0305-750X(88)90190-8

Finer H. 1944. The T. V. A. Lessons for international application. International Labour Office Studies and reports Series B. Number 37. Montreal, Canada.

Foster KR, Jenkins MF, Toogood AC. 1998. The Philadelphia Yellow Fever epidemic of 1793. Sci Am. 279(2):88–93. doi:10.1038/scientificamerican0898-88

Gao L. 2021. Domestication of wild animals may provide a springboard for rapid variation of coronavirus. Open Life Sci. 16(1):252–254. doi:10.1515/biol-2021-0027

Gao S. 2017. Can Chinese philosophy embrace wilderness? Environ Ethics. 39(2):147–159. doi:10.5840/enviroethics201712147

Gao X, Wang JW, Brosse S. 2009. Threatened fish of the world: *Psephurus gladius* (Martens 1862). Environ Biol Fish. 84(4):421–422. doi:10.1007/s10641-009-9443-1

Gaviria AZ, Martin RB. 2023. What do we know about the origin of COVID-19 three years later? Revista Clínica Española. in Press. doi:10.1016/j.rce.2023.02.002).

Gerken JE, Paukert CP. 2009. Threats to paddlefish habitat: implications for conservation. In: Paukert CP, Scholten GD, editors. Paddlefish Management, Propagation and Conservation in the 21st Century. American Fisheries Society Symposium 66. Bethesda (MD).

Gozlan RE. 2008. Introduction of non-native freshwater fish: is it all bad? Fish Fish. 9(1):106–115. doi:10.1111/j.1467-2979.2007.00267.x

Graham LK, Hamilton EJ, Russell TR, Hicks CE. 1986. The culture of paddlefish - a review of methods. In: Dillard JG, Graham LK, Russell TR, editors. The paddlefish: status, management and propagation. American Fisheries Society, North Central Division, Special Publication 7. Bethesda (MD). p. 78–94.

Grande L, Bemis WE. 1991. Osteology and phylogenetic relationships of fossil and recent paddlefishes (Polyodontidae) with comments on the interrelationships of Acipenseriformes. J Vertebr Paleontol. 11(sup001):1–121. doi:10.1080/02724634.1991.10011424

Grande L, Jin F, Yabumoto Y, Bemis WE. 2002. *Protopsephurus liui*, a well-preserved primitive paddlefish (Acipenseriformes: Polyodontidae) from the Lower Cretaceous of China. J Vertebr Paleontol. 22(2):209–237. doi:10.1671/0272-4634(2002)022[0209:PLAWPP2.0.CO;2]

Guenther A. 1873. Report on a collection of fishes from China. Ann Mag Nat Hist. 12(Series 4):239–250.

Hamel MJ, Koch JD, Steffensen KD, Pegg MA, Hammen JJ, Rugg ML. 2014. Using mark–recapture information to validate and assess age and growth of long-lived fish species. Can J Fish Aquat Sci. 71(4):559–566. doi:10.1139/cjfas-2013-0393

Handyside PD. 1875. On the anatomy of a new species of Polyodon, the *Polyodon gladius* of Martens, taken from the River Yangtze- Kiang, 450 miles above Woosung. Part 1, being its external characteristics and structure. Proc R Soc Edinb. 8:50–51. doi:10.1017/S0370164600029084

Hann JH. 1991. Mission to the Calusa. Gainesville: University of Florida Press.

Hao-Ren L. 1982. Polycultural system of freshwater fish in China. Can J Fish Aquat Sci. 39(1):143–150. doi:10.1139/f82-015

Hardin G. 1977. The limits of altruism: an ecologist's view of survival. Bloomington: Indiana University Press.

Havard WC.Jr. 1983. Images of TVA: a clash over values. In: Hargrove EC, Conkin PK, editors. TVA: fifty years of grass-roots bureaucracy. Urbana and Chicago (IL): University of Illinois Press. p. 297–315.

Haxton TJ, Sulak K, Hildebrand L. 2016. Status of scientific knowledge of North American sturgeon. J Appl Ichthyol. 32 (Supplement 1):5–10. doi:10.1111/jai.13235

He B, Yan F, Yu H, Su F, Lyne V, Cui Y, Kang L, Wu W. 2021. Global fisheries response to culture, policy and COVID-19 from 2017 to 2020. Remote Sensing. 13(22):4507. doi:10.3390/rs13224507

He Y. 1999. Development prospects of the American paddlefish and aquaculture techniques. China Fish. 4:25–27. (in Chinese).

Hersey J. 1956. A single pebble. New York (NY): Bantam Books.

Hodge CL. 1938. The Tennessee Valley authority: a national experiment in regionalism. Washington (DC): American University Press.

Hoffman RC. 1995. Environmental change and the culture of common carp in medieval Europe. Guelph Ichthyol Rev. 3:57–85.

Holt SJ, Talbot LM. 1978. New principles for the conservation of wild living resources. Wildlife Monogr. 59:3–33.

Hoover JJ, Bailey P, Januchowski-Hartley SR, Lyons J, Pracheil B, Zigler S. 2019. Anthropogenic obstructions to paddlefish movements and migration. In: Schooley JD, Scarnecchia DL, editors. Paddlefish: ecological, aquacultural, and regulatory challenges of managing a global resource. American Fisheries Society, Symposium 88, Bethesda (MD). p. 67–102.

Houser A, Bross MG. 1959. Observations on the growth and reproduction of the paddlefish. Trans Am Fish Soc. 88(1):50–52. doi:10.1577/1548-8659(1959)88[50:OOGARO2.0.CO;2]

Huang S, He Y. 2019. Management of China's capture fisheries: review and prospect. Aquacul Fish. 4(5):173–182. 10.1016/j.aaf.2019.05.004

Hubbard PJ. 1959. The Muscle Shoals controversy, 1920–1932. Tennessee Hist Q. 18:195–212.

Hubbard PJ. 1961. Origins of the TVA. Nashville (TN): Vanderbilt University Press.

Hubenova T, Zaikov A, Vasileva P. 2007. Management of paddlefish fry and juveniles in Bulgarian conditions. Aquacult Int. 15(3–4):249–253. doi:10.1007/s10499-007-9082-5

International Rivers. 2012. The new great walls A guide to China's overseas dam industry. Berkeley (CA).

Jackson DC, Marmulla G. 2001. The influence of dams on river fisheries. In: Marmulla G, editor. Dams, fish and fisheries. Opportunities, challenges, and conflict resolution. FAO Fisheries Technical Paper 419. Rome, Italy p. 1–44.

Jarić I, Bronzi P, Cvijanović G, Lenhardt M, Smederevac-Lalić M, Gessner J. 2019. Paddlefish (*Polyodon spathula*) in Europe: An aquaculture species and a potential invader. J Appl Ichthyol. 35(1):267–274. doi:10.1111/jai.13672

Jelkić D, Opačak A. 2013. A record of the North American paddlefish (*Polyodon spathula* Walbaum 1792) in Croatia. J Appl Ichthyol. 29(5):1152–1153. doi:10.1111/jai.12167

Ji H, Li Y. 2019. Distribution and aquaculture status of the North American paddlefish in China. In: Schooley JD, Scarnecchia DL, editors. Paddlefish: ecological, aquacultural, and regulatory challenges of managing a global resource. American Fisheries Society, Symposium 88, Bethesda (MD), p. 229–237.

Ji H, Wang C. 2009. China's limited paddlefish culture focused on meat production. Global Aquaculture Advocate July/August Issue. p. 42–43.

Jiang N, Fu L. 1998. Problems with reservoir sedimentation in China. Chin Geograph Sci. 8(2):117–125. doi:10.1007/s11769-997-0025-x

Johnson BM, Arlinghaus R, Martinez PJ. 2009. Are we doing all we can to stem the tide of illegal fish stocking? Fisheries 34(8):389–394. doi:10.1577/1548-8446-34.8.389

Jones WC, Freeman M. 2005. Three Gorges Dam: the TVA on the Yangtze River. *Twentieth Century Science &Technology Magazine*. https://21sci-tech.com/articles/Three_Gorges.html.

Jun M, Zhonglin D, Xin D, Mingyan C. 1996. Age determination and growth of Chinese paddlefish *Psephurus gladius*. Acta Hydrobiol Sin. 20:150–159. (in Chinese with English summary).

Kaczmarczyk D, Luczynski M, Brzuzan P. 2012. Genetic variation in three paddlefish (*Polyodon spathula* Walbaum) stocks based on microsatellite DNA analysis. Czech J Anim Sci. 57(8):345–352. doi:10.17221/6269-CJAS

Kaufman L. 1992. Catastrophic change in species-rich freshwater ecosystems. Bioscience.42(11):846–858. doi:10.2307/1312084

Kelton P. 2007. Epidemics & enslavement. Biological catastrophe in the native southeast 1492–1715. Lincoln: University of Nebraska Press.

Kelton P. 2015. Cherokee medicine, colonial germs. Norman: University of Oklahoma Press.

Kharin VY, Cheblukov VP. 2009. The first finding of the American paddlefish *Polyodon spathula* (Polyodontidae) in waters of the Russian Far East. Russ J Mar Biol. 35(7):611–613. doi:10.1134/S1063074009070104

Kimura S. 1934. Description of the fishes collected from the Yangtze-Kiang, China, by late Dr. K. Kishinouye and his party in 1927–1929. J Shanghai Sci Institute Section III. 1:11–18.

Kirchherr J, Matthews N. 2018. Technology transfer in the hydropower industry: an analysis of Chinese dam developers' undertakings in Europe and Latin America. Energy Policy. 113:546–558. doi:10.1016/j.enpol.2017.11.043

Kistler HD. 1906. The primitive pores of *Polyodon spathula*. J Comp Neurol Psychol. 16(4):294–298. 10.1002/cne.920160404

Kitchens C. 2013. A dam problem: TVA's fight against malaria, 1926–1951. J Econ Hist. 73(3):694–724. doi:10.1017/S0022050713000582

Krueger TA, McDonald MJ, Muldowny J. 1985. Reviewed work: TVA and the dispossessed. The resettlement of population in the Norris Dam area. Technol Cult. 26(3):651–653. doi:10.2307/3104875

LaBounty JF. 1984. Assessment of the environmental effects of constructing the Three Gorge Project on the Yangtze River. In: Energy, Resources and Environment. Papers Presented at the First U.S.-China Conference on Energy, Resources and the Environment. November 7–12, 1982. Beijing, China. p. 583–590.

Lackmann AR, AH, Andrews MG, Butler Butler ES, Bielak-Lackmann ME. Clark 2019. Bigmouth Buffalo *Ictiobus cyprinellus* sets freshwater teleost record as improved age analysis reveals centenarian longevity. Commun Biol. 2 (1):197. doi:10.1038/s42003-019-0452-0.

Lackmann AR, Bielak-Lackmann ES, Butler MG, Clark ME. 2022a. Otoliths suggest lifespans more than 30 years for free-living Bowfin Amia calva–implications for fisheries management in the bowfishing era. J Fish Biol. 101(5):1301–1311. doi:10.1111/jfb.15201

Lackmann AR, ES, Bielak-Lackmann RI, Jacobson MG, Butler and ME, Clark ME. 2022b. Otolith allometry informs age and growth of long-lived Quillback *Carpiodes cyprinus*. Environ Biol Fish. 105(8):1051–1064. doi:10.1007/s10641-022-01315-8

Larinier M. 2001. Environmental issues, dams and fish migration. In: Marmulla G, editor. Dams, fish and fisheries. Opportunities, challenges, and conflict resolution. FAO Fisheries Technical Paper 419. Rome, Italy. p. 45–90.

Lichatowich JL. 1999. Salmon without rivers. Washington (DC): Island Press.

Lilienthal DE. 1944. TVA democracy on the March. Chicago (IL): Quadrangle Books.

Lilienthal DE. 1964. The Journals of David Lilienthal Volume 1: the TVA years 1939–1945. New York (NY): Harper and Row Publishers.

Liu C, Zuo D. 1987. Environmental issues on the Three Gorges Project, China. Regul Rivers Res Manage. 1:267–273.

Liu S-L, Saif L. 2020. Emerging viruses without borders: the Wuhan Coronavirus. Viruses 12(2):130. doi:10.3990/v12020130.

Lobchenko V, Vedrasco A, Billard R. 2002. Rearing paddlefish *Polyodon spathula* to maturity in the Republic of Moldova. Internat Rev Hydrobiol. 87(5–6):553–559. doi:10.1002/1522-2632(200211)87:5/6<553::AID-IROH553>3.0.CO;2-S

Lockwood JL, McKinney ML. 2001. Biotic homogenization. New York (NY): Kluwer Academic Publishers.

MacAlpin A. 1947. Paleopsephurus wilsoni, a new polyodontid fish from the upper Cretaceous of Montana, with a discussion of allied fish, living and fossil. Ann Arbor: Contributions to the Museum of Paleontology, University of Michigan.

Main D. 2020 Jan 8. The Chinese paddlefish, one of the world's largest fish, has gone extinct. Washington, D.C: National Geographic Society. Published online. https://www.nationalgeographic.com/animals/article/chinese-paddlefish-one-of-largest-fish-extinct.

Martin C. 1976. Wildlife Diseases as a factor in the depopulation of the North American Indian. West Hist Q.7(1):47–62. doi:10.2307/967542

McCook S. 2011. The neo-Columbian exchange. Latin Am Res Rev Spec Issue.46(S):11–31. doi:10.1353/lar.2011.0038

McDonald K, Bosshard P, Brewer N. 2009. Exporting dams: China's hydropower industry goes global. J Environ Manage. 90:s294–s302. doi:10.1016/j.jenvman.2008.07.023

McDonald MJ, Muldowney J. 1982. TVA and the dispossessed: the resettlement of population in the Norris Dam area. Knoxville: University of Tennessee Press.

McNeill JR. 2010. Mosquito empires. Cambridge: Cambridge University Press.

Meffe G. 1992. Techno-arrogance and halfway technologies: salmon hatcheries on the Pacific coast of North America. Conserv Biol. 6(3):350–354. doi:10.1046/j.1523-1739.1992.06030350.x

Mei Z, Cheng P, Wang K, Wei Q, Barlow J, Wang D. 2020. A first step for the Yangtze. Science. 367(6484):1314. doi:10.1126/science.abb5537

Mestl G, Hupfeld RN, Scarnecchia DL, Sorensen J, Geik AR. 2019. Paddlefish recreational fisheries: state management of a migratory fish with a complex identity. In: Schooley JD, Scarnecchia DL, editors. Paddlefish: ecological, aquacultural, and regulatory challenges of managing a global resource. American Fisheries Society, Symposium 88, Bethesda (MD). p. 239–265.

Michaletz PH, Rabeni CF, Taylor WW, Russell TR. 1982. Feeding ecology and growth of young-of-the-year paddlefish in hatchery ponds. Trans Am Fish Soc. 111(6):700–709. 10.1577/1548-8659(1982)111<700:FEAGOY>2.0.CO;2

Midway S, R AJ, Lynch BK, Peoples M, Dance R. Caffey 2021 Aug 18. COVID-19 influences on US recreational angler behavior. PLOS-ONE. 16(8): e0254652.

Milanich JT, Milbrath S. 1989. First Encounters Spanish explorations in the Caribbean and the United States, 1492–1570. Gainesville: University of Florida Press.

Mills EL, Leach JH, Carlton JT, Secor CL. 1993. Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. J Great Lakes Res. 19(1):1–54. doi:10.1016/S0380-1330(93)71197-1

Mims S. D. 2015. Paddlefish: international status. In: Mims SD, Shelton WL, editors. Paddlefish aquaculture. Hoboken (NJ): John Wiley and Sons. p. 153–177.

Mims SD, Georgi TA, Chenhan L. 1993. The Chinese paddlefish, *Psephurus gladius*: biology, life history and potential for cultivation. World Aquacul. 24(1):46–48.

Mims SD, Onders RJ, Shelton WL. 2009. Propagation and culture of paddlefish. In: Paukert CP, Scholten GD, editors. Paddlefish Management, Propagation and Conservation in the 21st Century. American Fisheries Society Symposium 66, Bethesda (MD). American Fisheries Society Symposium. 66. p. 357–383.

Mims, S, D., and W. L. Shelton, editors. 2015. Paddlefish aquaculture. Hoboken (NJ): John Wiley and Sons.

Minahal Q, Munir S, Komal W, Fatima S, Liaqat R, Shehadi I. 2020. Global impact of COVID-19 on aquaculture and fisheries: a review. Int J Fish Aquat Stud. 8(6):42–48.

Mitchell AJ, Kelly AM. 2006. The public sector role in the establishment of Grass Carp in the United States. Fisheries 31(3):113–121. doi:10.1577/1548-8446(2006)31[113:TPSRIT2.0.CO;2]

Moen CT, Scarnecchia DL, Ramsey JS. 1992. Paddlefish movements and habitat use in Pool 13 of the Upper Mississippi River during abnormally low stages and discharges. North Am J Fish Manage. 12(4):744–751. doi:10.1577/1548-8675(1992)012<0744:PMAHUI>2.3.CO;2

Moore M, Rider S. 2022. Polyodon spathula, paddlefish. The IUCN Red List of threatened Species 2022. https://dx.doi.org/10.2305/IUCN.UK.2022-1.RLTS.T17938A81763841.en

Muir J. 1901. Our national parks. Boston (MA): Houghtin, Mifflin, and Company.

Musick JA. 1999. Ecology and conservation of long-lived marine animals. In: Musick JA, editor. Ecology and conservation of long-lived marine animals. American Fisheries Society Symposium 23. Bethesda (MD). p. 1–10.

Nachtrieb HF. 1910. The primitive pores of *Polyodon spathula* (Walbaum). J Exp Zool. 9(2):455–468. doi:10.1002/jez.1400090211

Nakajima T, Hudson MJ, Uchiyama J, Makibayashi K, Zhang J. 2019. Common Carp aquaculture in Neolithic China dates back 8,000 years. Nat Ecol Evol. 3(10):1415–1418. doi:10.1038/s41559-019-0974-3

Narvaez L, Janzen S, Sebesvari Z. 2021. Chinese paddlefish extinction. Bonn, Germany: United Nations University.

Nichols JT. 1943. The fresh-water fishes of China Natural History of Central Asia. Vol. 9. New York (NY): American Museum of Natural History.

Nunn N, Qian N. 2010. The Columbian Exchange: a history of disease, food, and ideas. J Econ Perspect. 24(2):163–188. doi:10.1257/jep.24.2.163

Nüsser M. 2003. Political ecology of large dams: a critical review. Petermanns Geographische Mitteilungen 147:20–27.

Nuwer DS. 2009. Plague among the Magnolias: the 1878 Yellow Fever epidemic in Mississippi. Tuscaloosa: The University of Alabama Press.

Onders RJ, Mims SD. 2015. Paddlefish production for meat and caviar. In: Mims SD, Shelton WL, editors. Paddlefish aquaculture. Hoboken (NJ): Wiley Blackwell. p. 129–151.

Paradis Y, Bernatchez S, LaPointe D, Cooke SJ. 2021. Can you fish in a pandemic? An overview of recreational fishing management policies in North America during the Covid-19 crisis. Fisheries 46(2):81–85. doi:10.1002/fsh.10544

Pasch RW, PA, Hackney and JA, HolbrookII. 1980. Ecology of paddlefish in Old Hickory Reservoir, Tennessee, with emphasis on first-year life history. Trans Am Fish Soc. 109(2):157–167. doi:10.1577/1548-8659(1980)109<157:EOPIOH>2.0.CO;2

Ping C. 1931. Preliminary notes on the fauna of Nanking. Contributions of the Biological Laboratory of the Science Society of China. Zool Ser. 7(4):173–201.

Raposo A, Alturki HA, Alkutbe R, Raheem D. 2023. Eating sturgeon: An endangered delicacy. Sustainability 15(4):3511. 10.3390/su15043511

Ren S, B, Zhang WJ, Wang Y, Yuan and C, Guo C. 2021. Sedimentation and its response to management strategies of the Three Gorges Reservoir, Yangtze River, China. Catena 199:105096. doi:10.1016/j.catena.2020.105096

Rider S, J DK, Riecke DL. Scarnecchia 2019. Proactive harvest management of commercial paddlefish fisheries. In: Schooley, Scarnecchia DL, editors. Paddlefish: ecological, aquacultural, and regulatory challenges of managing a global resource. American Fisheries Society, Symposium 88, Bethesda (MD). p. 267–297.

Rien TA, Beamesderfer RC. 1994. Accuracy and precision of white sturgeon age estimates from pectoral fin rays. Trans Am Fish Soc. 123(2):255–265. doi:10.1577/1548-8659(1994)123<0255:AAPOWS>2.3.CO;2

Rossiter A, Noakes DLG, Beamish EWH. 1995. Validation of age estimation for the lake sturgeon. Trans Am Fish Soc. 124(5):777–781. doi:10.1577/1548-8659(1995)124<0777:VOAEFT>2.3.CO;2

Rothlisberger JD, Lodge DM. 2013. The Laurentian Great Lakes as a beachhead and a gathering place for biological invasions. Aquat Invasions. 8(4):361–374. doi:10.3391/ai.2013.8.4.01

Roussow G. 1957. Some considerations concerning sturgeon spawning periodicity. J Fish Res Bd Can. 14(4):553–572. doi:10.1139/f57-016

Rowley WD. 2006. The Bureau of Reclamation: Origins and growth to 1945. Volume 1. Denver (CO): U.S. Government Printing office.

Russell D. 1949. The TVA idea. Irvington-on-Hudson (NY): The Foundation for Economic Education.

Russell T. R. 1986. Biology and life history of the paddlefish – a review. In: Dillard JG, Graham LK, Russell TR, editors. The paddlefish: status, Management and propagation. Bethesda (MD): North Central Division, American Fisheries Society, Special Publication Number 7. p. 2–20.

Sagoff M. 2005. Do non-native species threaten the natural environment? J Agric Environ Ethics. 18(3):215–236. doi:10.1007/s10806-005-1500-y

Scarnecchia DL, Gengerke TW, Moen CT. 1989. Rationale for a harvest slot limit for paddlefish in the Upper Mississippi River. North Am J Fish Manage. 9(4):477–487. doi:10.1577/1548-8675(1989)009<0477:RFAHSL>2.3.CO;2

Scarnecchia DL, Gordon BD, Schooley JD, Ryckman LF, Schmitz BJ, Miller SE, Lim Y. 2011. Southern and northern Great Plains (United States) paddlefish stocks within frameworks of Acipenseriform life history and the metabolic theory of ecology. Rev Fish Sci. 19(3):279–298. doi:10.1080/10641262.2011.598123

Scarnecchia DL, Lim Y, Ryckman LF, Backes KM, Miller SE, Gangl RS, Schmitz BJ. 2014. Virtual population analysis, episodic recruitment, and harvest management of paddlefish, with applications to other Acipenseriform fishes. Rev Fish Sci Aquacul. 22(1):16–35. doi:10.1080/10641262.2013.830592

Scarnecchia DL, Nagel CJ, Lim Y, Dalbey SR. 2021a. Demographics and management of the isolated upper Missouri River paddlefish stock of Fort Peck Reservoir, Montana. N American J Fish Manage. 41(6):1903–1919. doi:10.1002/nafm.10709

Scarnecchia DL, Ryckman LF, Lim Y, Miller SE, Schmitz BJ, Power GJ, Shefstad SA. 2009. Riverine and reservoir influences on year class strength and growth of upper Great Plains paddlefish. Rev Fish Sci. 17(2):241–266. doi:10.1080/10641260802621791

Scarnecchia DL, Ryckman LF, Lim Y, Power G, Schmitz B, Riggs V. 2006. A long-term approach for validation and verification of dentaries for age determination in the Yellowstone-Sakakawea paddlefish stock. Trans Am Fish Soc. 135(4):1086–1094. doi:10.1577/T05-081.1

Scarnecchia DL, Ryckman LF, Lim Y, Power G, Schmitz BJ, Firehammer JA. 2007. Life history and the costs of reproduction in northern Great Plains paddlefish (*Polyodon spathula*) as a potential framework for other Acipenseriform species. Rev Fish Sci. 15(3):211–263. doi:10.1080/10641260701486981

Scarnecchia DL, Schooley JD, Backes KM, Slominski A, Dalbey S, Lim Y. 2019a. Paddlefish life history: Advances and applications in design of harvest management regulations. In: Schooley JD, Scarnecchia DL, editors. Paddlefish: ecological, aquacultural, and regulatory challenges of managing a global resource. American Fisheries Society, Symposium 88, Bethesda (MD). p. 1–28.

Scarnecchia DL, Schooley JD, Lackmann AR, Rider SJ, Riecke DK, McMullen J, Ganus JE, Steffensen KD, Kramer NW, Shattuck ZR. 2021b. The sport fish restoration program as a funding source to manage and monitor bowfishing and monitor inland commercial fisheries. Fisheries 46(12):595–604. doi:10.1002/fsh.10679

Scarnecchia DL, Schooley JD, Slominski A, Backes KM, Brown B, Gordon BD, Lim Y. 2022. Patterns and scaling of reproductive output in paddlefish *Polyodon spathula* and its conservation implications. Trans Am Fish Soc. 151(3):347–355. doi:10.1002/tafs.10350

Scarnecchia DL, Schooley JD. 2020. Bowfishing in the United States: history, status, ecological impact, and need for management. J Kansas Acad Sci. 123:285–338.

Scarnecchia DL, Schooley JD. 2022. Trophies, technology and timescape in fisheries management as exemplified through Oklahoma's world record paddlefish *Polyodon spathula*. Fisheries 47(9):381–394. doi:10.1002/fsh.10764

Scarnecchia DL, Stewart PA, Power GJ. 1996. Age structure of the Yellowstone-Sakakawea paddlefish stock, 1963–1993, in relation to reservoir history. Trans Am Fish Soc. 125(2):291–299. doi:10.1577/1548-8659(1996)125<0291:ASOTYS>2.3.CO;2

Scarnecchia DLJD, Schooley SO, McAdam KM, Backes A, Slominski Y, Lim DD. Fryda 2019b. Factors affecting recruitment of paddlefish: hypotheses and comparisons with sturgeons. In: Schooley JD, Scarnecchia DL, editors. Paddlefish: ecological, aquacultural, and regulatory challenges of managing a global resource. American Fisheries Society, Symposium 88, Bethesda (MD). p. 103–126.

Schleiss AJ, Franca M, Juez C, De Cesare G. 2016. Reservoir sedimentation. J Hydraul Res. 54(6):595–614. doi:10.1080/00221686.2016.1225320

Scholten GD. 2009. Management of commercial paddlefish fisheries in the United States. In: Paukert CP, Scholten GB, editors. Paddlefish management, propagation and conservation in the 21^{st} century: building from 20 years of research and management. American Fisheries Society Symposium 66, Bethesda (MD). p. 291–306.

Selznick P. 1966. TVA and the grass roots. New York (NY): Harper and Row.

Semmens KJ, Shelton WL. 1986. Opportunities in paddlefish aquaculture. In: J. G. Dillard, L. K. Graham and T. R. Russell, editors. The paddlefish: status, management and propagation. Bethesda (MD): American Fisheries Society, North Central Division, Special Publication 7. p. 106–113.

Shelton WL, Mims SD, Semmens KJ, Cuevas-Uribe R. 2019. Artificial propagation of paddlefish. In: Schooley JD, Scarnecchia DL, editors. Paddlefish: ecological, aquacultural, and regulatory challenges of managing a global resource. American Fisheries Society, Symposium 88, Bethesda (MD). p. 191–210.

Shereen MA, Khan S, Kazmi A, Bashir N, Siddique R. 2020. COVID-19 infection: Emergence, transmission, and characteristics of human coronaviruses. J Adv Res. 24:91–98. doi:10.1016/j.jare.2020.03.005

Shi X, Kynard B, Liu D, Qiao Y, Chen Q. 2015. COVID-19 infection: emergence, transmissionand characteristics of human coronaviruses. J Adv Res. 24:91–98.

Simeanu C, B. Păsărin D, Simeanu A. Grădinaru 2015. *Polyodon spathula* – a review on its biodiversity, meat quality, and environmental impact in Romania. Aquacult Aquarium Conserv Legislation. 8:952–959.

Simonović P, Marić S, Nikolić V. 2006. Occurrence of paddlefish *Polyodon spathula* (Walbaum, 1792) in the Serbian part of the lower River Danube. Aquat Invasions. 1(3):183–185. doi:10.3391/ai.2006.1.3.13

Sneddon C, Fox C. 2012. Water, geopolitics and economic development in the conceptualization of a region. Eurasian Geogr Econ. 53(1):143–160. doi:10.2747/1539-7216.53.1.143

Sneddon C. 2015. Concrete revolution. Large dams, cold war politics, and the U. S. Bureau of Reclamation. Chicago, IL: University of Chicago Press.

Snow DR, Lanphear KM. 1988. European contact and Indian population in the Northeast. Ethnohistory 35(1):15–33. doi:10.2307/482431

Sparrowe RD. 1986. Threats to paddlefish habitat. In: Dillard JG, Graham LK, and Russell TR, editors. The paddlefish: status, management and propagation. Bethesda (MD): North Central Division, American Fisheries Society, Special Publication Number 7. p. 36–45.

Stegner W. 1961. The meaning of wilderness for American civilization. In: Brower D, editor. Wilderness: America's living heritage. San Francisco (CA): Sierra Club Books. p. 97–102.

Stewart BE, Manganiello CJ. 2018. Watershed democracy: rural environmentalism and the battle against the TVA in western North Carolina. Environ History. 23(4):748–773. doi:10.1093/envhis/emy004

Stokes GL, Lynch AJ, Lowe BS, Funge-Smith S, Valbo-Jørgensen J, Smidt SJ. 2020. COVID-19 pandemic impacts on global inland fisheries. Proc Natl Acad Sci USA. 117(47):29419–29421. doi:10.1073/pnas.2014016117

Sundstrom L. 1997. Smallpox used them up: references to epidemic disease in Northern Plains winter counts, 1714–1920. Ethnohistory 44(2):305–343. doi:10.2307/483371

Swain DC. 1970. The Bureau of Reclamation and the New Deal, 1933–1940. Pac Northwest Q. 61:137–146.

Teletchea F. 2016. Is Fish domestication going too fast? Nat. Resour. 07(06):399–404. doi:10.4236/nr.2016.76034

Teletchea F. 2017. Wildlife conservation: is domestication a solution? In: Lameed GSA, editor. Global exposition of wildlife management. London: InTech. p. 1–21.

Thomas DH, editor. 1989. Columbian consequences volume 1. Archaeological and historical perspectives on the Spanish borderlands west. Washington (DC): Smithsonian Institution Press.

Thomas DH, editor. 1990. Columbian consequences volume 2. Archaeological and historical perspectives on the Spanish borderlands east. Washington (DC): Smithsonian Institution Press.

Thomas DH, editor. 1991. Columbian consequences volume 3. The Spanish Borderlands in Pan-American perspective. Washington (DC): Smithsonian Institution Press.

Thoreau HD. 1851. Walking. In: The writings of Henry David Thoreau. Reprinted 1893. Boston (MA): Houghton, Mifflin, and Company.

Tian Z, Wang Z. 2001. The artificial propagation of the American paddlefish was successful in Yichang, China. Reservoir Fish. 21(3):3. (in Chinese).

Tilt B. 2015. Dam and development in China. The moral economy of water and Power. New York (NY): Columbia University Press.

Tin T, Yang R. 2016. Tracing the contours of wilderness in the Chinese mind. Int J Wilderness 22:36–40.

Unkenholz DG. 1986. Effects of dams and other habitat alterations on paddlefish sport fisheries. In: Dillard JG, Graham LK, Russell TR, editors. The paddlefish: status, management and propagation. Bethesda (MD): North Central Division, American Fisheries Society, Special Publication Number 7. p. 54–61.

Urban F, Nordensvard J. 2014. China dams the world: the environmental and social impacts of Chinese dams. *E-International Relations*. http://www.e-ir.info/2014/01/30/china-dams-the-world-theenvironmental-and-social-impacts-of-chinese-dams/.

Urban F, Siciliano GM, Nordensvard J. 2018. China's dam-builders: their role in transboundary river management in south-east Asia. Int J Water Resour Dev. 34(5):747–770. doi:10.1080/07900627.2017.1329138

Viola, HJ, Margolis C, eds. 1991. Seeds of change. Five hundred years since Columbus 1991. Washington (DC): Smithsonian Institution Press.

Wallus R. 1986. Paddlefish reproduction in the Cumberland and Tennessee River systems. Trans Am Fish Soc. 115(3):424–428. doi:10.1577/1548-8659(1986)115<424:PRITCA>2.0.CO;2

Wang M, Zheng H, Xie X, Fan D, Yang S, Zhao Q, Wang K. 2011. A 600-year flood history in the Yangtze River drainage: comparison between a subaqueous delta and historical records. Chin Sci Bull. 56(2):188–195. doi:10.1007/s11434-010-4212-2

Wei Q, He J, Yang D, Zheng W, Li J. 2004. Status of sturgeon aquaculture and sturgeon trade in China: a review based on two recent nationwide surveys. J Appl Ichthyol. 20(5):321–332. doi:10.1111/j.1439-0426.2004.00593.x

Wei Q, Ke F, Zhang J, Zhuang P, Luo J, Zhou R, Yang W. 1997. Biology, fisheries and conservation of sturgeons and paddlefish in China. Environ Biol Fishes. 48(1–4):241–255. doi:10.1023/A:1007395612241

White SL, Fox DA, Beridze T, Bolden SK, Johnson RL, Savoy TF, Scheele F, Schreier AD, Kazyak DC. 2023. Decades of global sturgeon conservation efforts are threatened by an expanding captive culture industry. Fisheries 48(2):54–61. doi:10.1002/fsh.10865

Wilkens LA, Hofmann MH, Wojtenek W. 2002. The electric sense of the paddlefish: a passive system for the detection of zooplankton prey. J Physiol Paris. 96(5–6):363–377. doi:10.1016/S0928-4257(03)00015-9

Williams AN. 1951. The water and the power. New York (NY): Duell, Sloan and Pearce.

Willkie W. 1937. Political power. *The Atlantic Monthly*, August issue. 212.

Worobey M, Levy JI, Malpica Serrano L, Crits-Christoph A, Pekar JE, Goldstein SA, Rasmussen AL, Kraemer MUG, Newman C, Koopmans MPG, et al. 2022. The Huanan Seafood Wholesale Market in Wuhan was the early epicenter of the COVID-19 pandemic. Science. 377(6609):951–959. doi:10.1126/science.abp8715

Wu HW. 1930. On some fishes collected from the Upper Yangtze Valley. Sinensia (Contributions from the Metropolitan Museum of Natural History. Acad Sin. 1(6):65–86.

Wu X-C. 2005. The loss of genetic diversity in the Chinese paddlefish (*Psephurus gladius* Martens) as revealed by DNA fingerprinting. J Genet. 84(3):323–327. doi:10.1007/BF02715804

Xie S, Li Z, Liu J, Xie S, Wang H, Murphy BR. 2007. Fisheries of the upper Yangtze River show immediate impacts of the three Gorges Dam. Fisheries 32(7):343–344.

Xing Y, Zhang C, Fan E, Zhao Y. 2016. Freshwater fishes of China: species richness, endemism, threatened species, and conservation. Divers. Distrib. 22(3):358–370. doi:10.1111/ddi.12399

Yang D, Kynard B, Wei Q, Chen X, Zheng W, Du H. 2006. Distribution and movement of Chinese sturgeon, Acipenser sinensis, on the spawning ground located below Gezhouba Dam during spawning seasons. J Appl Ichthyol. 22 (s1):145–151. doi:10.1111/j.1439-0426.2007.00943.x

Yang DG, Ma D. Sun 2018. Sturgeon culture: status and practices. In: Gui J.-F, Tang Q, Li Z, Liu J, DeSilva SS, editors. Aquaculture in China. Success stories and modern trends. Hoboken (NJ): John Wiley and Sons. p. 234–245.

Yang Z, Wang H, Saito Y, Milliman JD, Xu K, Qiao S, Shi G. 2006. Dam impacts on the Changjiang (Yangtze) river sediment discharges to the sea: the past 55 years and after Three Gorges Dam. Water Resour Res. 42(4):W04407. doi:10.1029/2005WR003970

Yi Y, Wang Z, Yang Z. 2010a. Impact of the Gezhouba and Three Gorges Dams on habitat suitability of carps in the Yangtze River. J Hydrol. 387(3–4):283–291. doi:10.1016/j.jhydrol.2010.04.018

Yi Y, Yang Z, Zhang S. 2010b. Ecological influence of dam construction and river-lake connectivity on migration fish habitat in the Yangtze River basin, China. Proc Environ Sci. 2:1942–1954. doi:10.1016/j.proenv.2010.10.207

Yin H, Li C. 2001. Human impact on floods and flood disasters on the Yangtze River. Geomorphology 41(2–3):105–109. doi:10.1016/S0169-555X(01)00108-8

Yu Z, Deng Z, Zhao Y, Huang X. 1986b. Observation on the gonad development of *Psephurus gladius* (Martens) in Yangtze River below Gezhouba Dam. Acta Hydrobiol Sin. 10(3):9–10. (in Chinese).

Yu Z, Deng Z, Zhou C, Xu Y, Zhao Y. 1985. Prognosis of the effects of the Gezhouba Hydroelectric Project on Fish resources of the River Chang Jiang (Yangtze). Trans Chin Ichthyol Soc. 4:193–208. (in Chinese).

Yu Z, Xu Y, Deng Z, Zhou C, Huang X. 1986a. Study on reproductive ecology of Zhonghua sturgeon (*Acipenser sinensis* Gray) in the downstreams of Gezhouba Hydroelectric Project. Trans Chin Ichthyol Soc. 5:1–16. (in Chinese with English Summary).

Zhang H, Balk H, Wang C, Wu J, Du H, Shen L, Liu Z, Wei Q. 2016. Search for Chinese paddlefish (*Psephurus gladius*) in the Upper Yangtze River during 2009–2013 including reevaluation of data from 2006–2008. Aquat Living Resour. 29(1):101. doi:10.1051/alr/2016008

Zhang H, Jarić I, Roberts DL, He Y, Du H, Wu J, Wang C, Wei Q. 2020. Extinction of one of the world's largest freshwater fishes: lessons for conserving the endangered Yangtze fauna. Sci Total Environ. 710 (2020):136242. doi:10.1016/j.scitotenv.2019.136242

Zhou Y, Miao Z, Urban F. 2021. China's leadership in the hydropower sector: identifying green windows of opportunity for technological catch-up. Ind Corporate Change. 29(5):1319–1343. doi:10.1093/icc/dtaa039

Ziyun F. 1986. Environmental impact assessment in the Yangtze Valley. Ambio. 15:347–349.