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Present status and risk for extinction of the Dabry's sturgeon (*Acipenser dabryanus*) in the Yangtze River watershed: a concern for intensified rehabilitation needs

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Summary

Based on the restoration efforts related to *Acipenser dabryanus*, a fairly comprehensive knowledge has been gathered on the environmental variations within the upper Yangtze River ecosystem. This study aims to assess the potential options to rehabilitate the *A. dabryanus* population in its native river. This paper reviews the restoration efforts for *A. dabryanus* (from the start of the fishing ban, to the construction of nature reserve and programmes for controlled release of cultured fish) since the year of 2000. Based on the results some pathways were tentatively proposed linking human activities to the species conservation needs (including considerations on food supply/rearing habitat, migration, reproduction/spawning habitat and survival/recruitment). The analysis on variations of its native river ecosystem (including abiotic and biotic factors as well as direct effects of human activities) indicated that the major adverse factors threatening survival of this species involves river fragmentation (e.g. dam construction, waterway regulation) as well as sand/gravel extraction, intensive fishing and water pollution. To conserve or further to rehabilitate wild population of this species, damming in the upper Yangtze River and its tributaries and potential counter actions or adequate compensation measures need to be seriously considered at first.

Introduction

The Dabry's sturgeon (*Acipenser dabryanus* Dumeril, 1868), is mainly distributed in the mainstem of the upper Yangtze River and its tributaries (YARSG, 1988; Zhuang et al., 1997) (Fig. 1). The reach above Shashi in the middle Yangtze River also had some capture records. In the late 20th century, the population of *A. dabryanus* declined drastically because of overfishing and habitat degradation (Zhuang et al., 1997). It forced the population from an economic species to an endangered species. Since 1982, only tens of specimens can be captured incidentally in the Yangtze River, and there was no capture record below the Gezhouba Dam since 1995 (Chen, 2007; Table 1). The species was listed as a First Class Protected Animal by the China Government in 1989 (Wei et al., 1997). It was also listed as a Critical Endangered species in the IUCN Red List (IUCN, 2010), and protected animal in the Appendix II of CITES.

The upper Yangtze River is one of the river ecosystems with the highest biodiversity in the freshwater world (Fu et al., 2003; Fan et al., 2006). In recent years, along with the construction of the Three Gorges Dam and upsurge of river cascade development in the upper Yangtze River, the problems associated with conservation of environments and ecosystems are gaining increasingly recognition (Fan et al., 2006; Yang et al., 2007, 2009). As one of typical endemic species in the upper Yangtze River, the *A. dabryanus* was listed as one of key species in need to undertake rehabilitation measures. In 2000, a national nature reserve was established in the native area of *A. dabryanus*. Since 2007, controlled reproduction and release of cultured juveniles has been conducted every year in an attempt to rehabilitate the wild population of this species. Up to now, more than 5000 individuals have been released into the upper Yangtze River. However, as the drastic influence of hydroelectric projects on aquatic ecosystem continue to grow, and effects of other human activities expand simultaneously, the possibility to rehabilitate the wild population of *A. dabryanus* is still a serious problem that needs to be vigorously addressed.

Based on the restoration efforts related to *A. dabryanus* (including fishing ban, construction of nature reserve and releasing of propagated fish), a fairly comprehensive knowledge on the variable environmental conditions in the upper Yangtze ecosystem has been accomplished in recent years. This study aims to evaluate the possibility to rehabilitate the *A. dabryanus* population in its native river. The influence pathways linking human activities to *A. dabryanus* was tentatively proposed and the major factors influencing the surviving of the species were determined.

The knowledge on the aquatic ecosystem of the study area was compiled from many research projects which were conducted in the upper Yangtze River by our research group, such as regulation of nature reserve (Fan et al., 2006), background investigations on the nature reserve, investigations on the Chinese paddlefish *Psephurus gladius* (Zhang et al., 2009), and several environmental impact assessment projects associated with the nature reserve (such as about damming, waterway regulation and port/bridge construction) (Chen, 2009). In addition, to the best of our abilities we collected other informations referred to the fish and the upper Yangtze ecosystem functions.

Restoration efforts

Construction of nature reserve

To offset the detrimental effects of environmental degradation on rare and endemic fish species, at first a national nature reserve was created in the year of 2000 in the mainstem of upper Yangtze from Hejiang to Leibo. Furtheron in 2005, in

order to mitigate the conflict between hydroelectric projects in the Jinsha River and the maintenance of the functionality of the reserve, the range and extension of the original reserve was adjusted and enlarged (Fan et al., 2006). The area of the new reserve now is the largest aquatic reserve in China. The total length of the new reserve increased to 1 162.6 km in which the length of the mainstem is 436.5 km, and the total area to 331.7 km^2, including (i) the mainstem of the Xiangjiaba Dam, Sichuan Province, up to Masangxi, Chongqing City, (ii) the mainstem of the Chishui River and some of its tributaries, (iii) the lower Min River and its tributary Yuexi River, and (iv) the estuaries of the Nanguang River, Changning River, Tuo River and Yongning River (Fig. 1). Both the original and new reserves listed the *A. dabryanus* as a major protected species. Fishing industry transferring and enhanced management of fishery administration in the reserve also should be benefit to the fish.

Start of fishing ban

Since 2003, the fishing ban was executed in the Yangtze Basin. From Deqin County, Yunnan Province to Gezhouba Dam (GZB, Fig. 1), fishing is now forbidden from 12 o'clock of February 1 to 12 o'clock of April 30 every year. This reach covers all potential spawning areas of *A. dabryanus*, and this period covers also one of the spawning seasons of the species (YARSG, 1988; Zhuang et al., 1997).

Releasing propagated fish

Since 2007, more than 5000 individuals of *A. dabryanus* have been released into the upper Yangtze River for stock rehabilitation. The cultured *A. dabryanus* were sampled to tag and measure before release. Table 2 shows the number and sizes of fish released each year. Among them, the fish of four releases organized by Yibin city were form Yibin Institute of Rare Aquatic and Terricolous Animals. This institute is private. It holds the largest cultured population of *A. dabryanus* and it is the only hatchery can produce the juvenile the species at present. The Hatchery of Rare and Endemic Fishes of Xiluodu and Xiangjiaba Hydroelectric Power Station in Jinsha River (HREF) belongs to the China Three Gorges Project Corporation. It was aimed to offset the environment degradation caused by damming and was built in 2008. And three releases were conducted in the year of 2008–2009. In addition, five specimens equipped with ultrasonic tags were released by the Yangtze River Fisheries Research Institute to monitor the movements and discover the habitat usage (Q. W. Wei, H. Zhang and H. Du, unpubl. data). As the controlled release continued, the number of incidental capture records of the species increased a little since the year of 2007 (Table 1). Two tagged individuals were recaptured (Table 3). However, the capture in the Yibin reach of the river during the year of 2007–2008 did not find any juvenile *A. dabryanus* with body length <47.0 cm ($n = 20$). It is suggested that there has probably not been any natural reproduction during these 2 years.

Threats from human activities

Various human activities were the main reasons for the decline of the *A. dabryanus* population. Although some remediation measures were conducted, the adverse effects of human activities to the upper Yangtze ecosystem were dramatic and are still huge. The influence on the *A. dabryanus* can be divided into two facets (Hatfield et al., 2004): direct effects and indirect effects. The indirect effects include human activities causing variations to abiotic and biotic factors. For instance, the changes to habitat and food organisms induce the variations of *A. dabryanus* population indirectly. The direct effects mainly include the effects of fishing to *A. dabryanus* behavior and population, such as high mortality caused by fishing activities.

Man-made mediated variations in abiotic factors

The distribution of *A. dabryanus* has generally been reported in the area shows in Fig. 1 (YARSG, 1988; Zhuang et al., 1997). Both the mainstem and tributaries are mountainous rivers with their riversides surrounded by mountains with 1500–2000 m in elevation (Yu and Lu, 2005). The river width in the mainstem (from Yibin to Yichang) is usually 200–300 m (inside Gorges) or 600–800 m (outside Gorges), while the average riverbed gradient is 2‰. The annual mean water

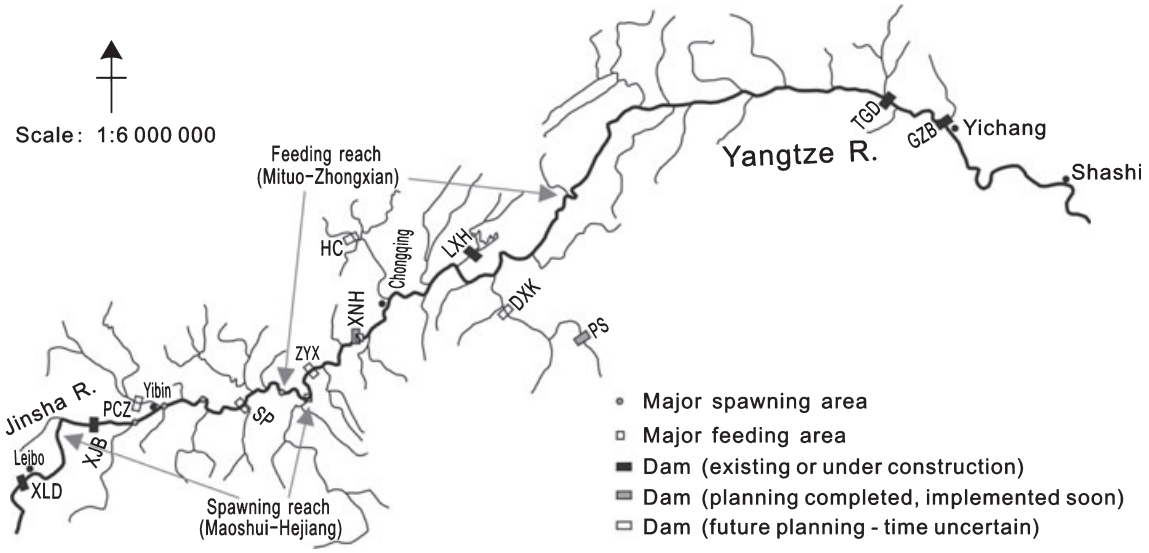

Fig. 1. The upper Yangtze River system, life history information (such as distribution area, spawning reach and feeding reach) on *Acipenser dabryanus* were from YARSG (1988) and Zhuang et al. (1997). XLD, Xiluodu; XJB, Xiajiaba; PCZ, Pianchuangzi; SP, Shipeng; ZYX, Zhuyangxi; XNH, Xiaonanhai; HC, Hechuan; LXH, Longxihe; PS, Pengshui; DXK, Daxikou; TGD, Three Gorges Dam; GZB, Gezhouba Dam

Table 1
Records of *Acipenser dabryanus* (captured incidentally) in the Yangtze River during 1982–2008 (most from Chen, 2007). The data of fish captured incidentally were form the local fishery administration

Year	Yibin reach (rkm 2741.7–2622.2)	Luzhou reach (rkm 2622.2–2511.2)	Chongqing reach (rkm 2511.2–1813.2)	Below Gezhouba Dam (rkm 1678.0–0)
1982	ND	ND	ND	11
1983	ND	ND	ND	8
1984	11[a]	ND	ND	25
1985	18[a]	ND	ND	32
1986	23[a]	ND	ND	15
1987	15[a]	ND	ND	13
1988	7[a]	ND	ND	6
1989	6[a]	ND	ND	6
1990	4[a]	ND	ND	10
1991	3[a]	ND	ND	6
1992	2[a]	ND	0	4
1993	27	ND	3	3
1994	21	ND	0	1
1995	18	ND	0	0
1996	19	11	0	0
1997	23	30	3	0
1998	27	13	1	0
1999	20	ND	0	0
2000	53	ND	0	0
2001	ND	ND	ND	ND
2002	ND	ND	ND	ND
2003	ND	ND	ND	ND
2004	8	ND	ND	ND
2005	6	8	ND	ND
2006	5	9	ND	ND
2007	8	9	ND	ND
2008	12	6[b]	ND	ND

[a]Only include the reach in Pingshan and Yibin county.
[b]Not the whole year.
ND, no data, '0', no catch despite monitoring.

Table 2
Release programme of cultured *Acipenser dabryanus* at Yibin 2007–2009

Date	Released number	Sample for measuring and tagging	Total length (Mean ± SD; cm)	Standard length (Mean ± SD; cm)	Body weight (Mean ± SD; g)	Tagging	Agency
Apr. 22, 2007	2000	500	71.0 ± 6.2	56.6 ± 5.4	1653.7 ± 514.5	PIT, DT	Yibin city
Apr. 22, 2008[a]	1000	–	75	–	2700	–	Yibin city
Jun. 11, 2008	2	1	80	64	3100	PIT, DT and UT	YRFRI
Jun. 15, 2008	3	3	75.0 ± 1.6	62.3 ± 3.9	2566.7 ± 379.3	PIT, DT and UT	YRFRI
Sep. 18, 2008[a]	ND	ND	ND	ND	ND	ND	HREF
Sep. 25, 2008	1000	20	20.6 ± 1.9	–	26.0	CWT(n = 60), DT(n = 50)	Yibin city
Dec. 7, 2008	300	20	37.3 ± 5.1	29.9 ± 4.7	231.0 ± 95.1	ND	HREF
May 8, 2009	1000	300	45.5 ± 4.9	36.0 ± 3.7	415.7 ± 107.8	DT	Yibin city
Sep. 29, 2009[a]	300	ND	ND	ND	ND	PIT	HREF

[a]As most time the agency only paid attention to the release number, few data on the tagged number and fish size.
PIT, passive integrated transponder tag; DT, dart tag; UT, ultrasonic tag; YRFRI, Yangtze River Fisheries Research Institute; HREF, Hatchery of Rare and Endemic Fishes of Xiluodu and Xiangjiaba Hydroelectric Power Station in the Jinsha River; ND means no data.

Table 3
Recapture information of two tagged *Acipenser dabryanus*

No.	Released date	Released site	Recaptured date	Recaptured site	Date interval (d)	Space interval (km)
1	Apr. 22, 2007	Yibin	Jul. 5, 2007	Pingshan	74	62.1
2	Apr. 22, 2008	Yibin	Jun. 23, 2008	Luxian	62	154.8

discharge (in the year 1950–2000) in Pingshan and Cuntan (located in Chongqing) were 4540 and 11 000 $m^3 s^{-1}$, respectively. These rivers are sufficiently used and changed by human activities, such as damming and navigation.

Along with the river cascade development in the mainstem of the upper Yangtze River and its tributaries, the living space for *A. dabryanus* has become and will become smaller and smaller (Fig. 1). At present, the Xiangjiaba Dam, which is the most downstream hydroelectric power station located at the Jinsha River, was completed in 2008. The Pianchuangzi hydroelectric power station, which will be built at the most downstream reach of the Min River, is also in planning. The Jialing River and Wu River dams also are respectively in the planning process as well as the Hechuan and Daxikou hydroelectric power stations in their estuaries. The Longxihe hydroelectric power station was completed in the year of 1959.

Along with the mainstem of the upper Yangtze River to Yichang, there is the Three Gorges Dam. Compared to the years before these dams were constructed, the unfragmented river stretch available as living space for *A. dabrynaus* has decreased greatly. Since the construction of Shipeng, Zhuyangxi and Xiaonanhai hydroelectric power stations in the reach between Yibin and Chongqing will be undertaken, the living space for *A. dabryanus* will be further limited in the reach between Xiangjiaba, Pianchuangzi and Shipeng Dams. The living space will then be restricted to only about 264 km river length.

The spawning areas of *A. dabryanus* were distributed in the reaches ranging from Maoshui, the lower Jinsha River, to Hejiang, the upper Yangtze River (YARSG, 1988) (Fig. 1). The four major spawning areas were Nanguang and Anbian near Yibin, Majia Heshibao in Nanxi County, Guanyintuo in Lu County. If there will be no construction of hydroelectric power stations between Yibin and Chongqing, most spawning areas will be retained. In order to ensure the ship navigation, the flow discharge during the spawning seasons should have arranged to satisfy the spawning of *A. dabryanus*. The largest threat to the spawning habitats will be the large-scale waterway regulation projects which are planned in the lower Jinsha River (Shuifu–Yibin) and the upper Yangtze River (Yibin–Chongqing). In addition, the gas supersaturation caused by dam operation might be another important factor that will influence the survival of *A. dabryanus* embryos and larvae.

The juveniles of *A. dabryanus* feed and move downstream with the water flow, towards the area of Chongqing (Fig. 1). Historically, many juveniles were found in the reach of Hejiang in May, especially in the backwater pools with lower velocity and rich mud / sand substrate (Kynard et al., 2003). It is suggested that the Hejiang reach was a good raring habitat for *A. dabryanus*. If the hydroelectric power station becomes a reality between Yibin and Chongqing, the feeding area will be separated from the spawning area (Rkm 2833.2–2511.5, River km 0 is at the estuary) and rearing area (Rkm 2542.9–2090.2). Although *A. dabryanus* at the early life stages may move downstream through the dam, the adults can not return upstream through the dam to the spawning areas except that a fishway will be specially designed to accommodate the migratory capabilities of the species.

Besides the fragmentation caused by damming, the variations of hydrograph components, thermal regime, velocity field, silt content and riparian habitat also have large influence on the *A. dabryanus*. The construction of Zhuyangxi hydroelectric power station will make directly many nursery areas of *A. dabryanus* disappear (Fig. 1).

Waterway regulation and sand / gravel extraction are two very important reasons for the loss of spawning and feeding habitats. During the years 2005–2009, more than 0.3 billion RMB (44 million US dollars) were invested to improve the navigation route between Yibin and Chongqing (370 km, Fig. 1). A total of 22 riffles were greatly modified for navigation, and the depth of navigation channel was deepened from 1.8 to 2.7 m. As a result, the habitat diversity was greatly lost affecting greatly the biota composition as well.

Some industrial pollutants also tend today to influence the growth and survival of the sturgeon species. For instance, maternal transfer of triphenyltin has resulted in concentrations of 25.5 ± 13.0 ng g^{-1} wet weigh in eggs of wild *A. sinensis*, which poses a significant risk to the eggs naturally fertilized or hatched in the Yangtze River (Hu et al., 2009). In order to improve the water quality it will also be very important if the rehabilitation project systematically and simultaneously addresses both habitat rehabilitation and pollution control.

Variation of biotic factors

The variations of biotic factors by the reason of environment changing also have large influence on the *A. dabryanus*, such as variation of food organisms. It was reported that after the construction of the Three Gorges Dam, the average density of benthons would be very low (Shao et al., 2008). If the Shipeng, Zhuyangxi and Xiaonanhai hydroelectric power stations construct, more benthons will disappear in the erosion and deposition processes (Fig. 1). In addition, introduced sturgeon species escaped into the river also is a large potential threat to the *A. dabryanus* (Yang et al., 2007, 2009).

Direct effects

Table 1 indicates the number of *A. dabryanus* bycatch in the fishing activities during the recent 17-year period. The mean body length of *A. dabryanus* captured in Yibin reach during the year of 2004–2008 was 58.3 cm, and the minimum length was 30.0 cm. The high bycatch number of *A. dabryanus* since 2007 not only indicated that the artificial releasing had good effects, but also showed that the fishing intensity in the Yangtze River might be too high. It is supposed that the fishing not only may cause high mortality to *A. dabryanus*, but also may impose behavioral cues on the fish.

Conclusion and perspectives

Due to the drastic decline in sturgeon populations worldwide, sturgeons are threatened or have been eliminated from most river drainage systems (Rosenthal et al., 2006; Williot et al., 2009). China is a developing country with large requirement for energy. Besides the electricity power produced, the flood control and river navigation needs also impose the possibility of further hydro project constructions. In addition, compared to other energy sources, hydroelectricity is still considered to be a better way than other energy production systems based on non-renewable resources and the future direction for energy sources in China will press for tapping more river systems.

Rehabilitation as a way of conserving wild populations has been accepted by the sturgeon scientific community for years. It must be seen as a complex and long-term process (Williot et al., 2009) as also clearly outlined in the Ramsar Declaration on Global Sturgeon Conservation (Rosenthal et al., 2006). Compared to other sturgeon species, the rehabilitation on *A. dabryanus* lacks a systematic organizational approach for conservation and adequate scientific research is urgently needed to help to develop the necessary protection strategies. At present, the key problems on rehabilitation of *A. dabryanus* population must include the following measures: (i) intensively monitoring of the effects of release of hatchery produced fish, (ii) increasing the efforts to enlarge the number of released fish to be more effective in supporting the dwindling population, (iii) encourage habitat and bait organisms investigation in order to develop scientific criteria for environmental management in nursery and growing sites, and (iv) study the genetic diversity of the population to assure that breeding programmes cover the inherent genetic variability in order to avoid outbreeding depression.

Apart from the geographical aspects, the primary key condition for successful introduction is that habitat require-

ments of the species are satisfied (IUCN, 1998). To conserve or further to rehabilitate wild populations of this species, damming in the upper Yangtze River and its tributaries need to be seriously considered at first, including potential mitigation measures that are cost-effective and which are included in the planning of all human activities. Re-adjustments after the damage is done, are much more expensive. It is for these reasons mentioned above that we presented the potential options for major pathways in linking human activities and sturgeon conservation measures.

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