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Is there evidence that the Chinese paddlefish (*Psephurus gladius*) still survives in the upper Yangtze River? Concerns inferred from hydroacoustic and capture surveys, 2006–2008

By H. Zhang[1,2], Q. W. Wei[1,2,3], H. Du[2,3], L. Shen[2,3], Y. H. Li[1,2] and Y. Zhao[1,2]

[1]*College of Fishery, Huazhong Agricultural University, Wuhan, Hubei Province, China;* [2]*Key Laboratory of Freshwater Biodiversity Conservation and Utilization, Ministry of Agriculture of China, Yangtze River Fisheries Research Institute, Chinese Academy of Fisheries Science, Jingzhou, Hubei Province, China;* [3]*Freshwater Fisheries Research Center, Chinese Academy of Fisheries Science, Wuxi, Jiangsu Province, China*

Summary

Due to the rarity of Chinese paddlefish (*Psephurus gladius*), very little information is available on this species. In order to save this critically endangered giant species, four large-range hydroacoustic surveys (using an echo sounder with a 199 kHz, 6.8° split-beam transducer) and capture surveys (by drift nets and setlines) were conducted in the upper Yangtze River during 2006–2008. According to the target strength (TS) study on *Polyodon spathula* (Hale et al., 2003) and Love's formula about TS-fish length relationships (Love, 1971), the four acoustic surveys identified nine potential targets (TS > −26.29 dB) of *P. gladius*, two (TS > −22.40 dB) of them very probably the fish species sought. A total of 4762 setlines, 111 anchored setlines and 950 drift net catches were conducted in which 472 large fish specimens of various species were caught. However, no single *P. gladius* was caught directly. The gear used did not allow quantitative capture over rough ground with deep holes, perhaps allowing some large fish to effectively hide or escape; the hydroacoustic signals indicated this as likely. In any case, it is strongly suggested that *P. gladius* is on the verge of extinction and further rigid measures are proposed to save the very few remaining specimens.

Introduction

The Chinese paddlefish (*Psephurus gladius* Martens, 1862), one of the largest freshwater fishes in the world, is endemic to the Yangtze River system and the inshore areas of China (YARSG, 1988; Wei et al., 1997). The largest record for *P. gladius* was a specimen of over 7 m in total length (Liu and Zeng, 1988; Xie, 2003). Due to the rarity of the species and the lack of related scientific research, the life history, migration pattern and population structure are not well understood. It is commonly considered to be an anadromous species (YARSG, 1988; Mims et al., 1993; Wei et al., 1997). Available information indicates that spawning took place between March to April in the lower Jinsha River between Shuifu and Yibin (Liu and Zeng, 1988; Li et al., 1997). From the mid last century, the *P. gladius* population decreased dramatically because of overfishing and habitat degradation (e.g. damming and pollution) (Wei et al., 1997). The species has been listed as a first-level protected animal in China since 1989 and has also been on the Critically Endangered Species IUCN red list since 2006.

Since the construction of the Three Gorges Dam (TGD) in the Yangtze River, a series of measures have been undertaken to save rare and endemic fish species (Fu et al., 2003). *P. gladius* has been considered as one of the most important 'flagship' species in conservation, with an integrated rescue programme initiated in 2005. This extensive programme includes studies on forage fishes and habitat investigations, captive breeding programmes and propagation for release, preservation of genetic resources, and even cloning. However, any potential for successful rescue depends on two most important issues: (i) are any adults still alive, and (ii) if yes, how to find them and where is a likely chance to capture those few remaining specimens in such a large river system? Given this situation, the only way to assess the potential was to conduct a large-scale survey to search for the remaining specimens of this rapidly dwindling species. Broad-range hydroacoustic and capture surveys were therefore proposed and conducted four times in the lower Jinsha and the upper Yangtze rivers (including the historically-known spawning sites). The studies were conducted during spawning seasons between 2006 and 2008. This study reports on the results of identifying areas in which these large fish specimens can be sought out and captured.

Materials and methods

Study area

The investigation was conducted in the upper Yangtze River between Xinshi, Sichuan Province (rkm 2817.7; river km-0 is at the river estuary) to Chongqing (rkm 2329.2) (Fig. 1), covering a stretch of about 488.5 km river length. This river stretch passes through a mountainous area with an elevation of about 200–500 m above river level (Yu and Lu, 2005). At the lower Jinsha section (Xinshi–Yibin), the river is usually 150–200 m wide. However, it becomes even wider downstream of Yibin, usually varying between 200–300 and 600–800 m, respectively. The maximum river width broadens at certain points to 1000–2000 m. In the lower Jinsha River, water depth is mostly between 4 and 8 m, but downstream of Yibin, the depth is mainly more than 8 m. The river morphology within the study area is uneven and has many point elevations, central bars and reef structures shaping the river bed. Current speed usually is about 1–3 m s^{-1}, depending on the river bed morphology and location in the river channel. This aquatic ecosystem exhibits a high biodiversity, however many species are severely threatened to near-extinction due to human activities (Fu et al., 2003). In 2004 the river reach from Shuifu to Chongqing

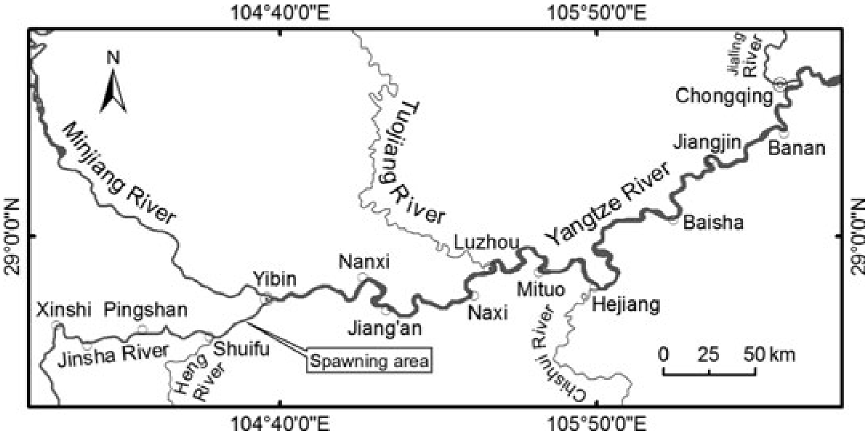

Fig. 1. Study area (Xinshi–Chongqing), upper Yangtze River system

(412.5 km river stretch, 84.4% of the length of the study area) was included in the Upper Yangtze National Nature Reserve (Fan et al., 2006).

Hydroacoustic sampling

A 199-kHz BioSonics DT-X echo sounder equipped with a 6.8° split-beam transducer with a source level of 221.0 dB / / μPa and a receiver sensitivity of −51.3 dB / / μPa was used to collect the acoustic data during the surveys. The system was calibrated following the procedures recommended by the producer (BioSonics, Inc.). A GPS receiver (JRC, Japan) was attached to the echo sounder which produced a geographical estimate of the position for each of the acoustic data points received. A Dell Latitude D800 laptop was used to receive and record the acoustic data by Visual Acquisition 5.0.3 software (BioSonics, Inc.).

The transducer was mounted on the fore-broadside of a 6.3 m long fiberglass-reinforced plastic boat equipped with an 85 hp motor. The transducer was aimed downward to sample the entire water column from 1.5 m below the surface to approximately the river bottom, with the transducer mounted 0.5 m below the water surface and the start range set at 1.0 m. Sample pulse duration was set at 0.4 ms, the pulse rate was set at 6 pings per second, and a threshold of −80 dB (−60 dB during 2006) was used to filter background noise signals. The surveys were conducted during the day in zigzag transects (~200 m interval) at a speed of 8 km / h. Four acoustic surveys were conducted during 2006–2008 (Table 1).

Data analysis

To analyze acoustic data, Visual Analyzer 4.1 software (BioSonics, Inc.) was used. Large targets were easily identifiable by large tracks for multiple consecutive pings. The individual tracks of fish were selected and echo results were used to provide estimated Target Strength (TS), location, depth and other specific information.

According to the TS study on *Polyodon spathula* by Hale et al. (2003), the other of the two extant species of Polyodontidae that have similar adult body morphology and total length (TL), targets with TS greater than −29.46 dB were defined as potentially being adult *P. gladius* as the first step. Love (1971) developed a generalized equation between fish TL and TS when measured from the dorsal aspect: $TS = 19.1 \times \log(TL) - 0.9 \times \log(\text{Frequency}) - 62.0$. This equation is widely applied and can also be used to estimate fish TS when information on accurate TS is lacking. According to the fish biology study in the upper Yangtze River (FLIHHP, 1976), a large fish (TL > 65 cm with TS > −29.46 dB according to the equation) such as *P. gladius* might be confused in the acoustic surveys with any of the following species: the long spiky-head carp *Luciobrama macrocephalus*, sheltostshek *Elopichthys bambusa*, black carp *Mylopharyngodon piceus*, river sturgeon *Acipenser dabryanus*, Chinese sucker *Myxocyprinus asiaticus*, mudfish *Parasilurus* sp., grass carp *Ctenopharyngodon idellus*, silver carp *Hypophthalmichthys molitrix*, common carp *Cyprinus carpio*, or Chinese longsnout catfish *Leiocassis longirostris*. The capture of the largest specimen of these fish species was *L. macrocephalus* with 152 cm in standard length (SL). In our study, this SL value (152 cm) was used as TL because we could not estimate the exact TL of a fish. During the 3-year study period, the largest fish in our four capture trials was 95 cm TL (Table 2). According to the data from the local Administration of Fishery Supervision, the largest fish in the 3 years of fishing was *M. asiaticus*, with 130 cm TL (Q. W. Wei, unpubl. data). In order to exclude non-target species from the acoustic records, different TS thresholds (−22.40, −23.69 and −26.29 dB) were estimated from Love's equation by TL (152, 130 and 95 cm) and used to filter out other large, non-target species.

Moreover, a TS-length formula ($TS = 20.52 \times \log(SL) - 90.08$) was developed from the TS study on *P. spathula* (juvenile 379.5 mm, TS = −37.14 dB; adult 1151 mm, TS = −27.25 dB) (Hale et al., 2003) to estimate the SL of the potential targets.

Survey dates	River stretch (from–to)	Start–endpoint identification (rkm)	River length covered (km)
28 March–1 May, 2008	Shuifu–Chongqing	2741.7–2329.2	412.5
3 March–11 April, 2007	Pingshan–Baisha	2772.7–2440.2	332.5
11–31 January, 2007	Shuifu–Mituo	2741.7–2542.9	198.8
18–30 April, 2006	Pingshan–Mituo	2772.7–2542.9	229.8

Table 1
Time (date and year) and range (river stretch, km) of four hydroacoustic sampling surveys aiming to detect *Psephurus gladius*, upper Yangtze River

Table 2
Catch from the four capture trials

Date	Number of fishing days	Drift setlines	Anchored setlines	Drift nets	Number of fish caught	Species of largest individual caught	Length of largest specimen (TL, cm)
18 April –11 May, 2006	24	585	0	131	14	Hybrid sturgeon	73
10 January–8 February, 2007	30	1036	32	0	8	*Ctenopharyngodon idellus*	70
3 March–11 April, 2007	40	1381	43	0	14	*Hypophthalmichthys molitrix*	83
14 March–5 May, 2008	53	1760	36	819	436	*Parasilurus* sp.	95

Capture trials

The acoustic surveys were accompanied by fishing trials conducted by six or eight fishing boats using setlines and gillnets. The setlines were ~40 m long with 300–350 hooks on each line. When the river width was broad, two or more setlines were connected to assure comparative fishing efficiency. A gillnet (50 m long) was used with the upper panel (up to 2 m depth) being operated as a dual net (40 cm mesh size) and the lower single panel operated with 8 cm mesh size (max. depth 4 m); this gear was applied in 2006. A third layer (down to 4 m deep with 2.5 cm mesh size) was then attached to it in 2008. The operational mode for both set nets and gill nets was that two fishing boats dragged the setlines or gillnets along the water current. The fishermen usually fished by drifting for about ~1.5 km with the net, needing ~30–60 min each time. Except under bad weather conditions (e.g. thick fog or heavy rain) or for other logistical reasons, fishers worked 7–7.5 h a day, setting the net 7–14 times. Captures were repeated two or three times in some pool reaches in which the fish potentially aggregated or remained longer. In general, the fishermen were able to cover 8–10 km per day. In addition, anchored setlines were set during the night, provided that the physical conditions were suitable. A total of four surveys covering the same sampling intensity described above were conducted during the 3-year study period (Table 3).

Results

Catch

The total fishing effort of these 3-year surveys accounted for a total of 4762 setlines, 111 anchored setlines and 950 drift nets (Table 2). Despite this tremendous effort, not a single *P. gladius* was captured. However, a total of 472 non-target fishes were caught, with the largest fish in each survey measuring over 65 cm since many of the signals might have been confused with *P. gladius* in the acoustic surveys.

Target signals

A total of 108 individual tracks of which 49 targets had TS > −29.46 dB were analyzed; 24 had TS values > −26.29 dB (an estimated TL > 95 cm according to Love's equation). However, 15 of the 24 potential *P. gladius* targets were regarded as being caused by tightwires or ropes for anchoring boats. These 15 potential targets were seen at three sites: 7.8 km above Yibin (rkm 2721.0), 9.5 km below Yibin (rkm 2703.7) and the mouth of Jialing River (rkm 2329.2). At the site above Yibin (30 March 2008), we found five highly potential targets for very large fish. However, capture trials (22 drift nets, 24 setlines) conducted synchronously did not catch any of the anticipated *P. gladius*. At the site below Yibin (28 April 2006), we found eight potential targets, but again the synchronous capture trials (14 drift nets, 28 setlines) did not yield any catch. On-site observations (ships near the site) and TS estimations of tightwires and ropes (Q. W. Wei, unpubl. data) indicated that the 13 signals at the two sites were probably the above-mentioned tightwires or ropes for anchoring ships. The two potential targets at the mouth of Jialing River revealed a similar situation.

Therefore, only nine of the potential targets signals for *P. gladius* were identified as having a high likelihood to reflect very large fish. Table 4 indicates the related information of these nine potential targets. Except for target 8, other potential targets were located in sites with water depths of more than 10 m; the strongest target value was at 35.4 m. Figure 2 shows the echograms of the two most potential targets (Nos. 2 and 7). GPS locations indicated that target 2 was located in the reach ~4.8 km below Pingshan (rkm 2767.9), and target 7 at ~6.6 km below Shuifu (rkm 2735.1). Target 7 was located directly at the known spawning area of the species.

Discussion

Due to the rarity of the species, no *P. gladius* were captured during the surveys, although the acoustic signals revealed some highly potential targets. Different from ocean acoustic and trawl surveys (McClatchie et al., 2000), the complex physical environment in the upper Yangtze River made our acoustic surveys and capture trials extremely difficult to synchronize. This may be one of the major reasons why fishermen did not manage to capture a located object (either a potential *P. gladius* or other large fish). In addition, noise echo signals produced by the turbulent flow environment (e.g. rapids and riffles) imposed some further restrictions on the acoustic samples. However, the hydroacoustic survey is still considered as one of the best methods to search for large and rare freshwater species (Hale et al., 2003).

Table 3
Time (date and year) and range (river stretch, km) of four capture trial surveys aiming to capture *Psephurus gladius*, upper Yangtze River

Survey dates	River stretch (from–to)	Start–endpoint identification (rkm)	River length covered (km)	Number of fishing boats
18 April–11 May, 2006	Pingshan–Luzhou	2772.7–2582.2	190.5	6
10 January–8 February, 2007	Shuifu–Luzhou	2741.7–2582.2	159.5	8
3 March–11 April, 2007	Pingshan–Baisha	2772.7–2440.2	332.5	8
14 March–5 May, 2008	Xinshi–Jiangjin	2817.7–2399.2	418.5	6

Table 4
Descriptive information of nine potential targets of *Psephurus gladius*

No. of target	Date	Time	Latitude (N)	Longitude (E)	TS (dB)	Correlation value	Target pulse width (m)	Target depth (m)	Bottom depth (m)	Estimated SL (cm)	Possibility
1	19 April 2006	08:23:59	28°38.6756′	104°10.3383′	−25.48	0.994	0.39	11.32	12.63	140.4	+
2	19 April 2006	15:55:13	28°38.4845′	104°12.4882′	−21.31	0.993	0.54	17.09	19.21	224.1	+ +
3	29 April 2006	13:50:54	28°46.8044′	105°10.8189′	−25.05	0.970	0.58	33.02	35.36	147.3	+
4	15 January 2007	09:34:49	28°46.4086′	104°38.3479′	−25.22	0.984	0.49	12.00	14.44	144.5	+
5	7 February 2007	11:25:40	28°46.0675′	104°39.2618′	−25.63	0.995	0.40	13.18	13.87	138.0	+
6	4 March 2007	16:06:27	28°38.3134′	104°24.6963′	−23.76	0.958	0.57	14.62	19.72	170.4	+
7	7 March 2007	12:30:20	28°38.4577′	104°28.4014′	−21.98	0.965	0.54	11.93	14.88	207.9	+ +
8	15 March 2007	11:01:27	28°49.0319′	104°57.8972′	−26.24	0.994	0.39	6.12	9.23	129.0	+
9	31 March 2007	14:05:15	28°55.9661′	105°36.7843′	−26.17	0.977	0.50	20.92	29.28	129.9	+

Possibility '+ +' means TS > −22.40 dB, it probably is *P. gladius* and could not be other large fishes (no fishes with TL > 152 cm in the study area), possibility '+' means −26.29 dB < TS < −22.40 dB, it possibly is *P. gladius* but also might be other large fishes with 95 cm < TL < 152 cm.

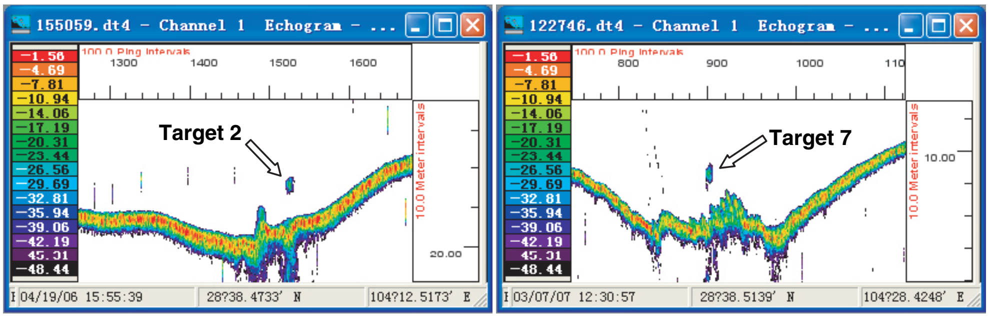

Fig. 2. Echograms of two most potential targets of *Psephurus gladius*. Arrow = echo signals of targets

Although the capture methods used in this study were previously successful in capturing *P. gladius* (YARSG, 1988), there is a need for further improvement because of restrictions regarding the bottom structure of the riverbed. Particularly at some rapid riffles, difficulties in capture may allow the fish to escape. However, available information indicates that deep pools with reef structures are very likely the preferred habitat for the species (YARSG, 1988). More effective capture methods are needed in the future to guarantee quantitative sampling, perhaps by taking electro-fishing into consideration.

Table 5 indicates occurrences of *P. gladius* after the completion of Gezhouba Dam, where it can be concluded that the population decreased rapidly and drastically thereafter. Furthermore, only three *P. gladius* have been found in the past 10 years. Two specimens (1.2 kg, 47 cm TL; 1.3 kg, 50 cm TL) were found in the Chongqing reach in 1992, these being the last recorded juveniles (Chen, 2007). Since this time, all detected individuals have been adults and >30 kg. The common assumption is that the last natural reproduction of *P. gladius* was in 1991 above the Gezhouba Dam. In the upper Yangtze River, the last two fishes were found in the years 2000 (30 kg) and 2003 (female, 363 cm TL, ~200 kg) (Q. W. Wei, unpubl. data). As the two young specimens mentioned above were released back into the river and the fishery is highly and tightly controlled, we assume that these two fishes are still alive in the upper Yangtze. Below the Gezhouba Dam (Nanjing reach), a seriously injured female (330 cm TL, 117 kg weight) was captured and transferred to the culture facility in 2002. Unfortunately, the specimen died after 30 d artificial culture (Q. W. Wei, unpubl. data). It can be concluded that the upper Yangtze is most probably the only site for capturing specimens for *ex-situ* conservation measures. As the fish is strongly

Table 5
Occurrences of *Psephurus gladius* (by incidental capture), Yangtze River, 1982–2008 (Chen, 2007; Wei et al., 1997)

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

[a]Only includes the reach in Yibin county (rkm 2741.7–2693.7); [b]Until September 2008.

influenced by environmental conditions, we speculate that the reach above Xinshi (the upper limit of navigation) is most likely the last habitat area in which remaining specimens may survive. An *ex-situ* conservation programme should focus primarily and immediately on extensive surveys with adequate equipment to capture these remaining individuals.

In the present situation, other methods should be prepared to save the species in case the fish is emergent. Even if there are only a few specimens obtainable, modern methods should include preservation of genetic materials, artificial gynogenesis, cloning, and surrogate broodstock technologies (Okutsu et al., 2007). Otherwise we face a situation that will quickly lead this valuable resource to extinction.

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Author's address: Qiwei Wei, Yangtze River Fisheries Research Institute, Chinese Academy of Fisheries Science, No. 41 Jianghan Road, Shashi District, Jingzhou City, Hubei Province 434000, P. R. China.
E-mail: weiqw@yfi.ac.cn