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Search for Chinese paddlefish (*Psephurus gladius*) in the upper Yangtze River during 2009-2013 including reevaluation of data from 2006 to 2008

Hui Zhang[1], Helge Balk[2], Chengyou Wang[1], Jinming Wu[1], Hao Du[1], Li Shen[1], Zhigang Liu[1] and Qiwei Wei[1,a]

[1] Key Laboratory of Freshwater Biodiversity Conservation, Ministry of Agriculture of China, Yangtze River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Wuhan, Hubei Province 430223, P.R. China
[2] Department of Physics, University of Oslo, Oslo, Norway

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Abstract – Since two large specimens of Chinese paddlefish *Psephurus gladius* were found unexpectedly in December 2002 and January 2003, a series of measures have been undertaken to attempt to save this critical endangered species. As a part of the rescue plan, a total of eight hydroacoustic and capture surveys were conducted in the upper Yangtze River between 2006 and 2013. Preliminary results from the first four surveys (2006−2008) were reported in 2009. The later four surveys were conducted in the same area and consisted of 578 setlines, 8 anchored setlines and 2003 drift net catches. A total of 1982 fish belonging to 38 species were captured. For the hydroacoustic surveys, a BioSonics echo sounder with a vertically down looking 199 kHz split-beam transducer was applied, both for data recording, and for guiding the capture trials by drift nets and setlines. Post processing applying automatic tracking identified 7217 single targets from the eight acoustic surveys. Body size was estimated from TS values of single targets. No *P. gladius* were captured. The acoustic data, however, revealed at least a few observations that are difficult to interpret as something other than large *P. gladius*. Although not conclusive, this gives hope that this species may still exist in the river.

Keywords: *Psephurus gladius* / Yangtze River / Hydroacoustic / Endangered fish / Protected area

1 Introduction

The Chinese paddlefish *Psephurus gladius*, 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 recorded *P. gladius* was a specimen of more than 7 m in total length (Liu and Zeng 1988; Xie 2003). Due to the rarity of the species and lack of related scientific research, the life history, migration pattern and population structure is not well understood. It is known as a predatory fish and commonly considered to be an anadromous species (YARSG 1988; Mims 1993; Wei et al. 1997). Available information indicates that spawning took place between March and April in the lower Jinsha River between Shuifu and Yibin (Liu and Zeng 1988; Li et al. 1997). Since the middle of the 20th century, the population has decreased drastically because of overfishing and habitat deterioration (e.g. damming and pollution) (Wei et al. 1997), especially after 1981 when its migration route was blocked by the Gezhouba Dam, the first dam on the Yangtze.

Although the species has been listed as a top-level protected animal in China since 1989 and has also been red-listed as critically endangered by the International Union for Conservation of Nature (IUCN) since 2006, the decline of the population seems not to have reversed. There was a long period with no reported observation until two specimens were captured unexpectedly near the cities of Nanjing and Nanxi in December 2002 and January 2003, respectively. This initiated a new series of actions to attempt to save this species, including construction of a protected area (Fan et al. 2006), a fishing ban, and a rescue network aimed at saving individuals from being bycaught. In addition, funding was made available for research projects including the hydroacoustic and capture surveys (Zhang et al. 2009), a cryopreservation study of sperm (Li et al. 2008) and a gynogenesis study (Zou et al. 2011a, 2011b) on similar species (American paddlefish *Polyodon spathula*).

In this study, a total of eight capture and hydroacoustic surveys were conducted in the most probable refuge for the species in the period 2006−2013. Zhang et al. (2009) reported preliminary results from the first four surveys carried out in 2006−2008. In these surveys, a total of 4762 setlines, 111 anchored setlines and 950 drift net sets were conducted catching

[a] Corresponding author: weiqw@yfi.ac.cn

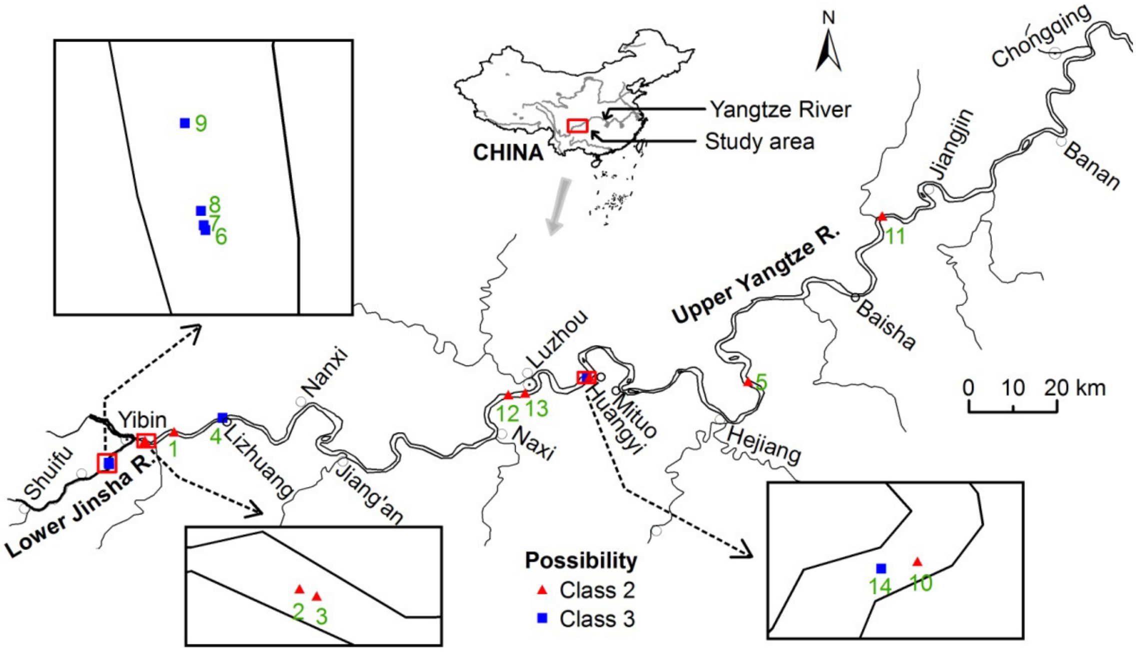

Fig. 1. Study area, upper Yangtze River system, and spatial distribution of 14 potential acoustic targets of *Psephurus gladius* observed in eight surveys carried out in 2006–2013. Number is target ID, possibility is based on the estimated length of the target (Tables 3 and 5). Size class 2 corresponds to targets with estimated length 95−152 cm, and Class 3, 152−230 cm.

472 fishes of various species but not a single *P. gladius*. Moreover, the four acoustic surveys identified nine potential targets ($TS > -26.29$ dB) of *P. gladius*, and two ($TS > -22.40$ dB) of them were very probably the species. As a continuation of this study, four more surveys were conducted in the years 2009−2013. To obtain consistent results, the data from the first period were reanalyzed. The principal aim of the rescue program was to determine if it was likely that the species still existed in the river. The second aim was to try to capture live specimens and use biological techniques (e.g. artificial gynogenesis, androgenesis) to produce new individuals for rehabilitation of the population.

2 Materials and methods

2.1 Study area

The most likely refuge for the species was considered to be the around 400 km flowing reach between Shuifu and Chongqing. Upstream from Shuifu the Xiangjiaba dam has closed the migration route since 2008. Downstream from Chongqing the river ends due to the reservoir created by the Three Gorges Dam opened in 2003. This reach has been reported as a spawning area (near Yibin, Fig. 1) (YARSG, 1988) and the last observations of live *P. gladius* were recorded there (near Nanxi, Fig. 1).

All eight surveys were conducted in the potential refuge area surveying 404 km (Fig. 1). Here the river passes through a mountainous landscape 200–500 m above sea level (Yu and Lu 2005). The river is generally 200–800 m wide, but broadens at certain points up to 1000–2000 m. Water depth is mostly >8 m with the mean of the river thalweg depth 12.51 ± 8.03 m (range 3.40−60.73 m). River morphology within the study area is uneven with many "stairs", central bars and reef structures. Water flow is usually around 1–3 m s^{-1}, depending on the river bed morphology and location in the river channel. Water quality in the study area was good. More than 90% of the reaches meet level 3 of Environmental Quality Standards for Surface Water issued by the Chinese government, which is suitable for fish and human uses (CWRC 2013).

The aquatic ecosystem has high biodiversity, including around 200 fish species. A national protected area called "National Nature Reserve for the Rare and Endemic Fishes in the Upper Reaches of the Yangtze River" was designated here. The protection was intended to preserve three internationally protected fish species, *P. gladius* (Martens 1862), Dabry's sturgeon *Acipenser dabryanus* (Duméril 1869), and the Dianchi Bullhead *Pseudobagrus medianalis* (Regan 1904), as well as 67 endemic species and their remaining habitat (Fan et al. 2006). Many of these species are severely threatened to near-extinction due to human activities like fishing and ship traffic (Fu et al. 2003).

2.2 Hydroacoustic sampling

A 199-kHz BioSonics DT-X echo sounder equipped with a 6.8° split-beam transducer was used for acoustic data collection during all surveys. A GPS receiver (JRC, Japan) was attached to the echo sounder for recording geographical positions The transducer's source level was 220.8 dB re 1 μPa@1 m and receiver sensitivity was –50.4 dB re 1 μPa. A Dell Latitude D810 laptop running Visual Acquisition 5.0.3 software (BioSonics Inc., USA) recorded the data. The system was factory calibrated on Aug 2010. The transducer was

Table 1. Sampling periods and locations (river stretch, km) of eight hydroacoustic surveys aiming to detect *Psephurus gladius* in the upper Yangtze River. Rkm is the abbreviation for river km, Rkm 0 is at the Yangtze estuary.

Year	Dates	River stretch (from-to)	Start-endpoint (Rkm)	River length covered (km)	Degree of coverage (%)	Sampling volume (%)
2006	Apr. 18−30	Pingshan-Mituo	2772.7−2542.9	229.8	25.1	0.15
2007	Jan. 11−31 and Feb. 7	Shuifu-Mituo	2741.7−2542.9	198.8	39.0	0.25
2007	Mar. 3−Apr. 11	Pingshan-Baisha	2772.7−2440.2	332.5	64.3	0.33
2008	Mar. 28−May 1	Shuifu-Chongqing	2741.7−2329.2	412.5	37.6	0.20
2008/2009	Dec. 26 −Jan. 8	Shuifu-Jiangjin	2741.7−2399.2	342.5	32.0	0.18
2011	Mar. 29−May 3	Shuifu-Chongqing	2741.7−2350.8	390.9	56.6	0.29
2012	Apr. 19−May 3	Shuifu-Chongqing	2741.7−2337.5	404.2	37.8	0.19
2013	Mar. 20−Apr. 10	Shuifu-Jiangjin	2741.7−2399.2	342.5	44.1	0.24
				Average:	42.1	0.23

mounted in the front of a 6.3 m long boat equipped with an 85 hp motor. During operation the rod was lowered so that the sound beam started 0.5 m below the surface aiming vertically down. Sampling was set to start 1.0 m below the transducer so that the river was monitored from 1.5 m down to the bottom. Inspection of echograms showed that the 1.5 m was enough to exclude surface detections in most cases. Pulse duration was 0.4 ms and pulse rate 6 pings per second. The BioSonics system can set a recording threshold to reduce file size. This threshold was set to –80 dB. This low threshold enabled us to investigate whether echoes were caused by real targets or by noise. The surveys were conducted during day time only. The survey design followed a zig-zag pattern from riverside to riverside, advancing about 100 m downstream per crossing at a speed of around 8 km·h^{-1} (~4.32 knots). On lakes it is common to carry out night surveys because fish then tend to be resolved as single targets in open water while many fish species tend to form schools during daytime (Simmonds and MacLennan 2005). Daytime schooling is, however, not a problem in the study area (FLIHHP 1976), and especially not for large Chinese paddlefish which tend to stay on their own (YARSG 1988).

Key information for the eight surveys is presented in Table 1. The degree of sampling coverage (Λ) was calculated using the method recommended by Aglen (1989):

$$\Lambda = \frac{D}{\sqrt{A}} \quad (1)$$

where D is transect length and A the size of the surveyed area.

The percent sampling volume is defined as the water volume that has actually been sampled by the echosounder divided by the actual water volume in the river. The sampling volume was assumed to be a triangular prism calculated from the beam geometry, ping number and boat speed. The actual water volume in the river was calculated by multiplying river width, length and depth (depends on water level during the survey period).

2.3 Capture trials

Six capture trials were conducted four in 2006−2008 and one in 2011 and 2013 (Table 2). The methods were the same for all trials except that the proportion of setlines and gillnets varied. Zhang et al. (2009) described the first four surveys. More gillnets and fewer setlines were deployed in the two latter surveys. Overall 578 setlines, eight anchored setlines and 2003 drift nets were deployed (Table 2).

The setlines were about 40 m long with 300−350 hooks on each line. At wide parts of the river, two or more setlines were connected to assure comparative fishing effort. A triple gillnet (a gillnet consist of three layers of net, mesh size of each layer: 40 cm, 8 cm and 2.5 cm) 50 m long and 4 m high was used. It was specially designed for catching Chinese paddlefish. Two fishing boats kept the nets straight while drifting along with the current for about 1.5 km. Each trial took 30 to 60 min. Except for periods of bad weather like thick fog or heavy rain, or for logistical reasons, fishers worked 7−7.5 h a day, setting the net 7−14 times. Fishing effort was increased for deep pools where fish were expected to aggregate. Here captures were repeated two or three times. In general 8−10 km were covered per day. In addition, anchored setlines were set during the night when conditions were suitable.

2.4 Data analysis

2.4.1 Hydroacoustic analysis

Sonar5-Pro was used for the analysis of all data (2006−2013). The surface exclusion zone was set to 1.5 m (1 m below transducer). Automatic bottom detection was applied to avoid false tracks from bottom. Single echo detection (SED) was carried out with a minimum target size of −70 dB, minimum and maximum echo length of 0.8 and 1.3 respectively, relative to transmitted pulse length, maximum gain compensation of −3 dB (one way), maximum sample angle standard deviation of 0.3° (true mechanical degrees). Multiple peak suppression was set to medium (exclude echoes with local dips greater than 1.5 dB). The tracker was set up with a minimum track length of 3 pings, a maximum ping gap of 2 ping, a gating of 0.3 m in the range domain and with a zero velocity predictor expecting successive echoes to be found at almost the same depth. Scrutinizing the tracking results showed that these tracking parameters worked well for our datasets.

For each track a set of features were registered for analysis. The features were average track target strength (TS), track length measured in number of detections, target depth, bottom

Table 2. Sampling periods and locations (river stretch, km) of two capture trial surveys aiming to capture *Psephurus gladius* in the upper Yangtze River. Rkm is the abbreviation for river km, Rkm 0 is at the Yangtze estuary.

Year[a]	Dates	River stretch (from–to)	Start-endpoint (Rkm)	River length covered (km)	Number of fishing boats
2011	Mar. 19–May 3	Shuifu-Jiangjin	2741.7–2399.2	342.5	6
2013	Mar. 20–Apr. 10	Shuifu-Jiangjin	2741.7–2399.2	342.5	6

[a] Four capture trials carried out in 2006–2008 are described in Zhang et al. (2009).

Table 3. Definition of size classes used to classify acoustic targets based on estimated length.

Size class	Total length (cm)	Target strength (dB)[e]	Possible species
1	30–95[a]	–35.86 to –26.29	Small *P. gladius*, other Yangtze fish species
2	95–152[b]	–26.29 to –22.40	Medium *P. gladius*, Larger Yangtze fish species
3	152–230[c]	–22.40 to –18.96	Large *P. gladius* before 2008, *P. gladius* or *A. sinensis* after 2008
4	230–700[d]	–18.96 to –9.73	Large *P. gladius*

[a] Size of the largest fish caught in the capture surveys, see Table 4 and Zhang et al. 2009; [b] size of the largest reported fish in this area, excluding *P. gladius* and *A. sinensis* (FLIHHP, 1976); [c] estimated length of *A. sinensis* in this area based on the age of the introduced fishes (Du et al. 2013); [d] size of the largest *P. gladius* ever recorded (Xie 2003). [e] Note that Love's equation is not applicable for very large fishes, the TS is just provided for reference (Love 1971).

depth at the target, time, date and GPS position. From the target depth and water depth, we estimated a normalized target depth (NTD) defined as:

$$\text{NTD} = (\text{bottom depth} - \text{target depth}) / \text{bottom depth} \quad (2)$$

with NTD = 0 being the bottom and NTD = 1 being the surface. Using normalized target depth made it easier to compare the vertical position of fish in the water column.

2.4.2 Classification

A regression formula was applied for the conversion between TS and body length. Many formulas have been published over the years (Simmonds and MacLennan 2005). Most of these formulas are specific for one or a few species like Lilja's salmon formulas (Lilja et al. 2000) or Foote's formulas for Norwegian Sea fish species (Foote et al. 1986). The variety of species monitored in our study required, however, a general TS/length conversion formula applicable for many species. Hence, we chose to use the inversion of Love's general regression formula for dorsal observed fish presented in equation (3) (Love 1971). This formula was derived from 16 fish families in eight different orders, ranging from under 1 inch (2.54 cm) to 1 yard (91.44 cm) in length. Some had swim bladders, while others did not.

$$TS = 19.1 \log_{10}(TL) - 0.9 \log_{10}(f) - 62.0. \quad (3)$$

Here TL is the total fish length measured in cm and f is the frequency of the transducer measured in kHz.

Species classification was then done by comparing the TS-derived length estimates to known fish lengths in this area (FLIHHP 1976; Du et al. 2013), including those of the reintroduced Chinese sturgeon *Acipenser sinensis* for surveys carried out after June 2008 when 470 juvenile *A. sinensis* with TL 43–81 cm and 28 sub-adults with TL 117–178 cm were reintroduced into the upper Yangtze and the Three Gorges Reservoir (Du et al. 2013). The tracked targets were divided into four size classes, denoted 1 to 4 (Table 3).

The limits for the size classes were chosen for the following reasons. For class 1 a minimum value of 30 cm was selected because it is the minimum target length that could be reliably identified by the hydroacoustic method in the study area due to general background noise. As the noise level was very high in some of the fast flowing and strongly turbulent reaches, we used the highest observed noise level to handle all acoustic data. The upper limit of class 1 was set to 95 cm which corresponded to the largest fish found across all six capture surveys (Table 4). This class can, thereby, include fish from different species including small *P. gladius*. We assumed that the species composition found in the catch data reflected the species composition of the hydroacoustic data assigned to this size class. Size class 2 included fish up to 152 cm. This limit was set according to the largest "ordinary" fish that had been captured and reported; we considered *P. gladius* or *A. sinensis* as non-ordinary in this context. Acoustic tracks assigned to this size class can correspond to *P. gladius*, *A. sinensis* and other species not present in our catch data. Size class 3 was defined so that it could only contain *P. gladius* until July 2008, and afterwards also *A. sinensis*. According to estimates made by Du et al. (2013), *A. sinensis* can reach up to 230 cm which was chosen as the upper limit of this class. Size class 4 corresponded to fish longer than 230 cm which could only be *P. gladius*.

Given the limits of the size classes, individuals assigned to class 3 before June 2008 and those in class 4 were the most interesting since they provided unambiguous evidence for the presence of *P. gladius*.

Table 4. Catch information for six capture trials. The four trials carried out in 2006–2008 are the same as in Zhang et al. (2009).

Year	Number of fishing days	Drift setlines	Anchored setlines	Drift nets	Number of fish caught (TL > 30 cm)	Species of largest individual caught	Length of largest specimen (TL, cm)
2006	24	585	0	131	14	Hybrid sturgeon	73
2007	30	1036	32	0	8	*Ctenopharyngodon idellus*	70
2007	40	1381	43	0	14	*Hypophthalmichthys molitrix*	83
2008	53	1760	36	819	436	*Parasilurus sp.*	95
2011	45	357	3	1077	111	Hybrid sturgeon	68
2013	21	221	5	926	26	Long snout catfish *Leiocassis longirostris*	68

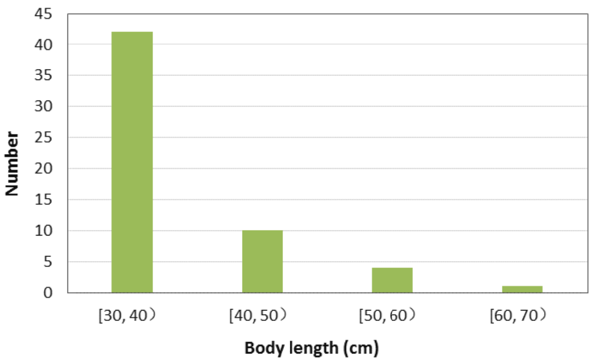

Fig. 2. Histogram of 57 captured fishes with body length >30 cm.

3 Results

3.1 Capture trials

Despite the tremendous capture effort, not a single *P. gladius* was captured. During the 2006–2008 surveys, a total of 472 fishes were caught, with the largest specimen being 95 cm (Table 4). During the 2009–2013 surveys a total of 1982 fishes were caught. The largest specimen caught in this period was 68 cm. Due to the background noise, the hydroacoustics could only recognize fish down to 30 cm (Table 3). The catch data contained 137 specimens longer than this. In Figure 2 we plot the size distribution for the 57 individuals captured during 2009–2013. Note that during the 2009–2013 surveys, the fishing method was changed to drift nets and drift nets can catch comparatively smaller fishes than either drift or anchored setlines. Therefore, the number of caught fishes cannot be compared with the numbers obtained in the 2006–2008 trials.

3.2 Hydroacoustic survey results

The tracking analysis of the eight hydroacoustic surveys resulted in a total of 7217 target observations. Converting mean TS of tracked individuals into fish lengths resulted in 80 targets falling into size class 1, 8 into size class 2, 6 into size class 3. No targets corresponding to size class 4 (surely Chinese paddlefish) were observed. The individuals for the remaining 7217 tracks were estimated to have been smaller than 30 cm.

Based on the size class analysis, there are strong indications of *P. gladius* having been observed in the upper Yangtze River in 2008. Five tracks estimated to have come from individuals falling into size class 3 were detected. This was at a time when no species other than *P. gladius* could match the estimated size. During the period 2009 to 2013, one individual of the same size class was tracked. However, due to presence of introduced *A. sinensis* of similar size, we cannot determine whether it was *P. gladius* or *A. sinensis* that was observed.

The fourteen observed targets estimated to have size class 2 and 3 were distributed unevenly across the study area (Fig. 1). Eight were observed near Yibin, four near Luzhou, and two below Hejiang. Most targets (10 individuals, 71.4%) were in water >10 m deep, and a majority of targets (12 individuals, 85.7%) were close to the river bottom with NTD less than 1/3. Among the five targets in the size class that could only contain *P. gladius*, four were observed above Yibin, and one near Lizhuang. It should be noted that the four targets in size class 3 (target ID = 6, 7, 8, and 9 in Table 5) near Yibin were found on the same day (March 30, 2008). GPS locations indicated that the closest distance between targets 6, 7 and 8 was 14 m seen with a time difference of 7 min. This means that some of the observations could have come from the same target moving around and being observed more than once or a group of fishes staying close together. This makes the interpretation of the number of observed fishes unreliable since the true number might be smaller. Nevertheless, this area seems to be interesting for capturing *P. gladius*. The subsequent four hydroacoustic surveys carried out in 2009–2013 did, however, not find any indications for the presence of large *P. gladius* in this area.

4 Discussion

4.1 Main findings

The main aim of the 2006–2013 observation program was to verify whether *P. gladius* still existed in the upper Yangtze River. For this aim, the results are positive. The hydroacoustic surveys observed five targets that most likely were *P. gladius* in addition to one target that could either have been *P. gladius* or *A. sinensis*, and eight targets that may have originated from *P. gladius* or other species. The secondary aim was to capture one

Table 5. Descriptive information for 14 potential targets of *Psephurus gladius*.

Target ID	Year	Date	Time	Number of echoes	Mean TS (dB)[a]	Target depth (m)	Normalized target depth[b]	Estimated TL (cm)[c]	Size class[d]
1	2006	28 Apr.	11:05:46	3	–22.75	17.2	0.05	145.7	2
2	2007	16 Jan.	09:39:59	6	–25.87	8.9	0.22	100.1	2
3	2007	7 Feb.	11:25:39	4	–25.22	13.2	0.21	108.1	2
4	2007	12 Mar.	14:35:56	3	–21.48	6.6	0.32	169.8	3
5	2007	5 Apr.	15:07:36	3	–25.43	20.6	0.13	105.4	2
6	2008	30 Mar.	10:36:32	9	–20.01	24.6	0.26	202.8	3
7	2008	30 Mar.	10:43:21	6	–19.29	22.9	0.04	221.1	3
8	2008	30 Mar.	10:46:07	7	–22.00	22.0	0.22	159.4	3
9	2008	30 Mar.	10:57:18	5	–21.85	12.1	0.04	162.4	3
10	2011	17 Apr.	09:14:59	4	–25.19	17.8	0.04	108.6	2
11	2012	2 May	09:35:43	4	–24.19	12.8	0.31	122.4	2
12	2013	30 Mar.	11:23:49	3	–25.91	7.9	0.44	99.5	2
13	2013	30 Mar.	13:35:55	3	–26.21	9.5	0.46	96.0	2
14	2013	1 Avr.	11:54:05	4	–19.24	24.9	0.06	222.3	3

[a] TS means target strength from off axis compensated single echo detections; [b] normalized target depth = (bottom depth − target depth)/bottom depth; [c] total length (TL) of target was estimated from the Mean TS by a generalized equation between fish TL and TS (Love 1971); [d] size class based on estimated TL, ref. Table 3.

or more *P. gladius* in order to rescue the species. This aim was not reached as not a single *P. gladius* was captured. The results from the capture surveys do not contradict the acoustic results. Around 2000 fishes were captured, but if the relative abundance of *P. gladius* is less than 1/2000, which seems likely, the chances of catching a *P. gladius* are extremely small. The acoustic surveys had a higher degree of coverage covering on average 42.1% of the studied river area. This makes it credible that the acoustics observed *P. gladius* while the capture trials did not.

4.2 Exclusion and shadow zones for acoustics

In acoustic abundance study, it is generally necessary to remove the acoustic data collected close to the boat due to avoidance and small sampling volume. Larger targets close to the transducer will fill the beam and break the point source assumption applied for estimating TS. For such studies, we would have set the surface layer to start around 4 m, and not at 1.5 as in this study. The aim of this study was, however, not to obtain a reliable abundance estimate of *P. gladius*, but to prove that it still existed in the river. Hence, we were interested in all possible observations, including observations biased by avoidance and breaking of point source assumption. If we had observed large targets in the first few meters we would have had to discuss the meaning of the recorded TS values, but since no such observations were made, this is not necessary.

Detection of targets near the bottom is also a problem due to the bottom dead zone and shadow regions caused by steps and reefs along the river bottom. Following Ona and Mitson (1996) and assuming a fish with a swim bladder of 10 cm high situated at an average river depth of 8 m, we had a dead zone of 0.4 m on the axis and 0.42 m at the side of the beam which is not enough to mask a large *P. gladius*. Another potential bias of interest comes from the many drops and reefs along the reach. They can form shadow zones where even larger fish can hide from being observed by the acoustics. The narrow beam and shallow water do, however, minimize the problem. As a general comment, unreachable zones and zones with low detection probability increase the chances that the species still existed in the river during the latter surveys when no *P. gladius* was found.

4.3 Changed post processing software

A different acoustic post-processing system was used in this study compared to Zhang et al. (2009). The re-analysis of the four acoustic surveys (2006–2008) identified more potential targets being *P. gladius* compared to the previous analysis. The reasons for the differences could be: (1) change from manual to automatic tracking. The use of automatic tracking is regarded as more objective, accurate and effective when it comes to analyzing large amounts of data (Parker-Stetter et al. 2009). (2) Some of the targets (target = 6, 7, and 8) which previously had been regarded as artificial tight wires for anchoring ships were studied more closely in the later surveys and found to be echoes from fishes.

In the capture surveys, we are still facing the problem that we cannot capture what we see on the echogram. Rough riverbed, large underwater reefs, fast flowing water and busy ship traffic make the accompanying capture surveys challenging. Alternative methods such as electrofishing mentioned as an option in Zhang et al. (2009), were not applied. Reasons for this were that it would be inefficient in such a large water body, and that it may be harmful to other endangered and endemic fish species, as there are no studies on electrofishing in the study area.

4.4 Suitability of Love's formula

The conversion from observed TS to fish length introduces more uncertainty into the results. We chose to use Love's

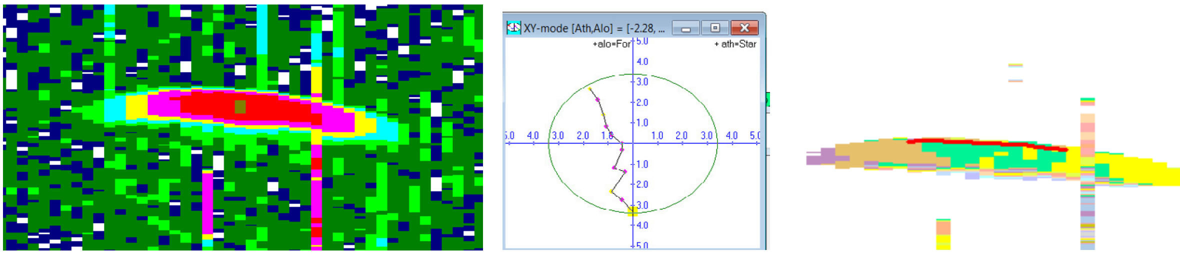

Fig. 3. Echo from Target *ID* nr 6, Table 5, believed to originate from *P. gladius*. Left: Echogram with fish trace and background noise, the *x*-axis is ping and the colors indicate a very strong echo in the center weakening to the sides. Center: Position diagram showing the boat/fish passage. Left: sample angle echogram showing the athwart ship sample angles interpreted as colors. Yellow = 1, green = −1, orange = −2 deg.

equation for the conversion, but we are unable to evaluate the suitability of it. If *P. gladius* was a stronger scatterer, then the lengths will be overestimated and vice versa. The same applies to other species. This means that the results of the size class analysis may be inaccurate, in particular observations close to the class borders. What we do know however, is that the Chinese paddlefish has one main physostome swim bladder and that it looks like the American paddlefish, meaning that the shape, size, and position are similar. Their body shapes and structures are also very similar. Hence, it is reasonable to assume that the acoustic properties of the Chinese paddlefish are similar to the properties of the American paddlefish. Since the American paddlefish is well described by Love's formula (Hale et al. 2003), it is reasonable to assume that our size classes for the Chinese paddlefish are fairly correct. According to Hale et al. (2003), *TS* measurements on a 100 cm long American paddlefish deviated by less than 2 dB relative to estimates based on Love's formula.

Another source of error is the unknown scattering properties of many other species in the river. If some of these, close to *P. gladius* in size, scattered more than assumed, they could have been misinterpreted as *P. gladius*. Hence, studies of the *TS*-length relationships for the competing species in the river are needed.

4.5 Possibility of the targets being *P. gladius*

For species classification, features like distance to bottom, date and time, bottom substrate, distance from riverside, relation to water current, and geographical position can be informative. There is, however, too little knowledge about the behavior and preferences of *P. gladius*, for using such other information. The only reliable feature is the *TS* as also concluded by Zhang et al. (2009). This makes the confirmation of the targets very difficult. The situation is further complicated by the reintroduction of *A. sinensis* in 2008 and the release of other species falling into the same size classes.

Observed targets can be fish, but they can also be something else, like drifting debris, constructions sticking up from the river bottom etc. Hence it is necessary to study this in details, especially for the larger targets falling into class 3 (Table 3). According to the classification based on size, these targets could only be *P. gladius* if found before July 2008, unless they originated from artificial targets. Figure 3 shows the trace from the target with ID 6 in Table 5. The echo trace for target ID 6 showed interference from another acoustic device crossing the fish trace at several instances. These noise bars formed very long echoes which were removed by applying the echo length criterion in the single echo detection algorithm and therefore did not influence the results. This target had a *TS* of −20.01 dB which converted to a length of 202.8 cm. The trace was seen at a depth of 24 m, 6 m above the river bottom. The figure shows a regular echo trace, shaped like an echo from a fish with stronger echoes in the center, gradually decreasing to the side. If this had been an obstacle sticking up from the bottom or an anchored floater we should have seen traces of the attachment beneath the trace. We did not see anything like this here. Moreover, if it had been a drifting target like a branch from a sunken tree, the trace would have fluctuated more in thickness, echo strength, and sample angle positions (shown to the right in the figure). The minor fluctuation seen in the position diagram is common for fish observed in mobile surveys. Another strong indication of the observed targets being fish is the movement relative to the water current. Based on GPS signals recorded during the survey, knowledge of the water current at the site and the observed echo positions we have estimated that the target ID 6 was moving upstream (Fig. 3).

In order to interpret the results and to draw conclusions about the abundance of *P. gladius* we need to discuss the chance of observing *P. gladius* in the catch data and in the hydroacoustic data. The catch effort was extensive, applying methods known to have captured *P. gladius* in earlier times. A total of 1982 fishes from 38 species were captured without any traces of *P. gladius*. This, and the fact that no one has observed *P. gladius* for more than 10 year do not prove that it is extinct, but we can conclude that it is either extinct or extremely rare. With, at the most a few specimens left, combined with the Gezhouba Dam closing its migration route to its spawning grounds and the Three Gorges Dam further changing the river habitat, we assume that *P. gladius* most likely have not reproduced after 1992 (the last year that young *P. gladius* were found). This means that eventual remaining specimens are to be found only in the largest size classes. Based on these assumptions we conclude that, like the catch data, the hydroacoustic data also did not contain any *P. gladius* in size class 1 [30, 95) cm. For size class 2 [95, 152) cm we have 8 potential hydroacoustic observations of *P. gladius*, but the reintroduced *A. sinensis* (Du et al. 2013), the released *A. dabryanus* (Zhang et al. 2011) and other larger fish species (FLIHHP 1976) make it impossible to determine whether the acoustic targets in this class were *P. gladius* or not. Hence, we can only state that there is an unknown and low, but still existing probability that one or more of these observations were *P. gladius*. The probability is higher for the first four targets observed before *A. sinensis* was reintroduced.

4.6 Recommendations for future work

The hydroacoustic results indicated that it still may be possible to find a live specimen of *P. gladius*. The conducted campaigns focused on the most probable refuge for the fish. However, due to the huge potential distribution area, it is necessary to focus the search even more, and to find ways to improve monitoring efficiency.

1. First, a more thorough background study should be carried out, attempting to learn as much as possible about the Chinese paddlefish, its behavior, preferred habitats, feeding, applied fishing methods, periods of time and year when and where it was fished etc. This will involve interviewing old fishermen and a study of historical documents. In addition, one should look at the related American paddlefish and take into account the knowledge available about the behavior of this species. To know more about the fish, one should study maps of the river and mark the most likely areas where the fish may be found.
2. Hydroacoustics should be applied to detect the fish in the selected areas and at times of day and year (including night time) identified before. The hydroacoustic method should also be optimized according to the nature of the selected sites.
   a. Some places may be best surveyed with vertical mobile transducers while other places may be better suited for horizontal beaming using split beam or multi beam echosounders.
   b. Setting up permanent stationary horizontal and/or vertical monitoring stations will dramatically increase the monitoring effort.
   c. Studying the acoustic backscattering characteristics of other Yangtze fish species will improve the ability to differentiate them from *P. gladius*.
   d. Multibeam acoustic cameras should be focused at places where the ordinary split beam systems observe tracks of potential *P. gladius*. This will improve the chances of verifying that the observations really are *P. gladius*.
3. Capture trials should be carried out only when the acoustic monitoring indicates occurrence of *P. gladius*. Capture methods and time of year and time of day should be selected according to the findings from the investigations described in step 1. In addition, trawls or purse seines can be efficient alternative capture methods.

Ten years has passed since the last observation of *P. gladius*. This species seems to be in great danger and will disappear very soon. Since the active search for this species is difficult, it is recommended to maintain the present rescue network between fishermen, the fishery administrative agency, and fish specialists. In case the fish is found, there is a greater chance of obtaining a healthy specimen. At the same time, modern biological techniques including artificial gynogenesis, androgenesis, cloning, and surrogate broodstock technologies, should be well prepared and ready to act if specimens are captured. This will enable production of new individuals and further rehabilitate the population even if only a single male/female or immature individual is captured. This seems to be the only hope we have to preserve the species.

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