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Chinese Sturgeon (*Acipenser sinensis*) in the Yangtze River: a hydroacoustic assessment of fish location and abundance on the last spawning ground

Y. Qiao[1, 3], X. Tang[1], S. Brosse[2], and J. Chang[1, 3]

[1]State key laboratory of freshwater ecology and biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, 430072 Wuhan, P. R. China; [2]LADBIO, CNRS-University Paul Sabatier, 118 Route de Narbonne, 31062 Toulouse cedex, France; [3]Graduate Student College, Chinese Academy of Sciences, 100039 Beijing, China

Summary

Chinese sturgeon (*Acipenser sinensis*), was once widely dispersed in almost all watersheds draining towards the western coasts of the Pacific Ocean. Today, the species is one of the highly endangered fish species in China and can be found only in the Yangtze and Pearl rivers and their adjacent coastal and marine areas. Due to the construction of the Gezhouba Dam, spawning grounds for the fish were drastically restricted but fortunately remained in the Yangtze River at a small-scale site located just downstream along a short reach of the river closely to the dam. Since 1998 we have undertaken annual investigations in this area using hydroacoustic methods, in order to estimate the size of spawning cohort and the selection of habitats. Based on strength and sizes of echo signals, the mature individuals of Chinese sturgeon were discriminated from the other fish species and then numerated. Most of the fish were detected close to the bottom and preferred to distribute themselves in the areas with water depths less than 15 meters. Because of different bottom structures with homogeneous granular material, the distribution of the fish was mainly influenced by water depths and perhaps current patterns. Total amount of sturgeons in the entire reach were estimated by simply summing up the numbers according to the identified densities in areas of different depths. Usually, there were about two separate spawning activities of Chinese sturgeon which took place annually during the observation period, with the scale of spawning activity being much larger at the first time than during the following spawning events. Estimations on the sizes of spawning cohorts on the restricted spawning ground before the first wave of upstream migrants appeared, were about 400 and 200 individuals during the periods of 1998-1999 and 2002, respectively. It was demonstrated that: a) the space of the current spawning site is not sufficient to accommodate all mature individuals simultaneously, and b) a serious decline in spawning stocks size of Chinese sturgeon during the investigational period seems to be indicated when comparing the counts between 1998 and 2002. The decline is about 50% which is a highly alarming figure.

Introduction

The Chinese sturgeon (*Acipenser sinensis*) is a large anadromous species distributed once in both countries, China and Korea. Its sub-adults and adults live along the western coast of the Pacific Ocean (historically recorded from the northern part of the South China Sea to the Yellow China Sea). Mature individuals have to spawn in freshwater after a long distance migration to the adjacent rivers. However, since the past hundred years, the spawning stocks have been declining and were found in China only in the Yangtze and the Pearl rivers. Because natural propagation of the stocks occur in different seasons in the two rivers (in autumn in the Yangtze River; in spring in the Pearl River), this species could be divided into two ecological groups (some researchers even considered them two different species, Zhou *et al*., 1993). Due to multi-environmental stressors, e.g. river flow obstructions, overfishing, habitat fragmentation, water pollution, and navigation, the stock in the Pearl River was considered to be or nearly to be extinct since no more catch has been reported over a long time period (Zheng, 1984). In the Yangtze River, though the same stressors exist, the stock still maintains itself at a moderate size. However, additionally to having been heavily fished over decades, migration of the fish to the upper reaches of the Yangtze River has been blocked by the construction of the Gezhouba Dam since 1981. Though a narrow reach of the river bed downstream and close to the dam is available for natural propagation, the fish cannot spawn at its former scale due to the limited space of the new spawning site (only 3.7 kilometers in length and 600 to 800 meter in width). Although commercial fishing has been prohibited since 1983 and restocking of artificially propagated larvae and juveniles has been undertaken since 1984 (Fu *et al.*, 1985, Chang and Cao, 1999), the sustainability of the sturgeon population in the Yangtze is still uncertain because the remaining spawning site the fish has chosen as an emergency alternative is limited if not marginal in its capacity. Therefore, to vigorously protect the natural propagation in the Yangtze River is an urgent mission with no sound alternative in order to maintain this endangered species (Chang, 1999). The behaviour of the mature fish on the spawning ground is not yet well understood and somewhat uncertain. One reason is that investigating rare species in large rivers is always a difficult task. Therefore, such studies must be increased to derive at sound managerial decisions supporting the species. Hence, since 1998, we have undertaken hydroacoustic surveys to follow the behavior of the mature fish when they aggregate each year beneath the dam during the spawning period between October and November. The aim of this work was first to provide information on the precise location of sturgeons during the spawning season. Then, hydro-acoustic data were collected between 1998 and 2002 and used to estimate the utility of the spawning ground, and hence to estimate the annual amount of Chinese sturgeon which occurs on the spawning ground, building the data base for eventually calculating the effectiveness of the spawning on this specific site.

Material and methods

Life cycle and Biology of Chinese sturgeon

Chinese sturgeon reaches sexual maturity at ages between 8 and 18 years in males and 13 to 26 years in females. Adults begin their freshwater migration in spring with immature gonads (in early stage III, Zhao *et al.*, 1986). After staying in freshwater of the Yangtze River nearly over a year without feeding, their gonads reach maturity and would join spawning groups during October and November. The spawning activity of Chinese sturgeon population occurs at least once a year, but there are generally two spawning occasions (occasionally three). The first spawning period occurs between 13th of October and 7th of November and second (or occasionally the third) spawning always starts beforer 18th November (Chang, 1999). The spawning areas naturally distributed in the upper Yangtze River from the Xingshi Section of the lower Jinsha River downstream to the Fuling Section, covering a river stretch of about 800 km. In this reach, at least 16 spawning sites were historically known (Zhou *et al.*, 1988). However, since the construction of Gezhouba Dam in 1981, all these spawning grounds were no longer available because of the barrier. Though fortunately an alternative spawning ground below the dam was found by the sturgeon, this site seems not at all to be sufficient due to its narrow size (about 3.7 km long) which appears to represent only 0.5% of the known spawning areas (Fig. 1).

Study site and sampling

The recent spawning area is located just downstream the Gezhouba Dam (Deng *et al.*, 1991, Wei *et al.*, 1997). Hydroacoustics were used to determine the precise location of fish and to precisely locate the spawning area. Spawning activities were confirmed by searching sturgeon eggs in the stomach content of the predators (mainly *Coreius guichenoti* and *Pelteobagrus vachelli*). The hydroacoustic surveys were carried out each year from 1998 to 2002 to estimate fish distribution and abundance. Hydroacoustic sampling has been performed two times each year: before the first spawning and between first and second spawning. However, due to equipment failure, hydroacoustic samples have not been performed before the first spawning in 2000 and 2001. Due to commercial ship traffic and underwater topography, it was not possible to set repeated hydroacoustic transects using the same route, but we adopted mostly our surveys according to a zigzagged route. For each sampling occasion, the length of the hydroacoustic record was c.a. 20km (16.8 6.2 km), covering the entire spawning area.

Hydroacoustic transducer was mounted on 20 m long vessel which cruised at a speed of 10 km/h. Acoustic data were collected with a FUSO-405 (FUSO ELECTRONICS, INC. JAPAN) operating frequency 118 kHz echosounder, equipped with a vertical single beam transducer towed at 0.3 m below the surface and aimed straight downward. Total beam angle was 17measured at the -3 dB level. All pulse were transmitted to the 17-transducer element and pulse duration was 0.2 ms. Information provided by the echosounder was recorded on a portable computer using self-developed software (Zeng *et al.*, 1999) which act as a chart recorder that can store and replay the records continuously. Time Varied Gain (TVG) was set at 40 $\log_{10}(R)$ to get a clear and stable contour of the bottom. Ship position (10 m) was recorded continuously using a Global Positioning System (GPS).

Target identification and counting

Fish count was performed using the hydroacoustic equipment. To distinguish the target species from the other fish assembling in the area, echo strength of different species was determined *in situ* including *Cyprinus capioI*, *Ctenopharyngodon idellus*, *Elopichthys bambusa*, *Aristichthys nobilis*, *Silurus meridionalis*, which are correspondingly large and common in the summer fisheries catches. The echo strength from an artificial air-bladder was also measured to determine the relationship between the water depth and echo strength. The measurements of echo strength from Chinese sturgeon were also conducted at the beginning of the survey. According to the results from the experiments described above, we established the identification standards. Trace counts of each sample were obtained from the digital echogram by visually counting the characteristic single sturgeon echoes.

All detected sturgeons contribute to the distribution analysis. The information includes the horizontal position of each sturgeon in the river that express in longitude and latitude, and vertical position express by the depth beneath the water surface (Brosse *et al.*, 1999).

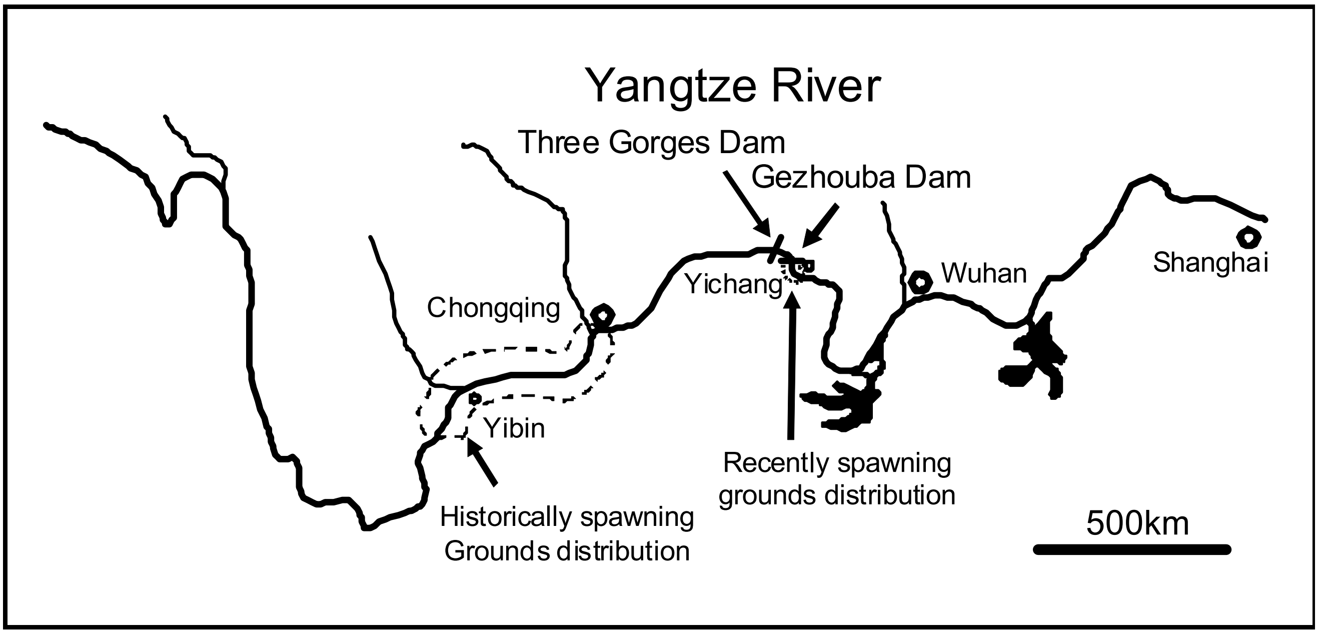

Fig.1 The historically known and recently active spawning grounds of the Chinese sturgeon (*A. sinensis*) in the Yangtze River system

Estimation of the sturgeon spawning cohort size

Chinese sturgeon is a benthic fish and hence stays close to the bottom. As only the lower part of the water column was inhabited by sturgeon, density of sturgeons was expressed by the number of sturgeons counted and divided by the area of bottom surface sampled (ind/m^2) instead of water volume (Misund, 1997).

The simple formula was used to estimate the size of the spawning cohort on the spawning ground:

$$= n/S,$$

where n is the number of sturgeons detected along the sampling route by trace counts, and S is the sampling area given by

$$S=d*L=2*\tan(?/2)*D*L,$$

where L is the sampling transect length, and D is the depth beneath the transducer along the route. As a first simplified approach, we took it for granted that the density of the "sonified" sturgeons was representative for the survey area. Therefore, total number in the entire area is presented as:

$$N=*S_{total}$$

Water depth, slope of the bottom and distance from the dam were also analyzed in determining sturgeon habitat utilization, but no significant differences were found except for water depth. Therefore, the entire area was divided into small area grids (0.1 min×0.1 min, equal to 160 m 160 m) representing characteristic depth contours. The sampling transect were subsequently divided into small sections by the boundaries of the grids. The length of each section which has the same depth characteristic as well as the fish numbers detected were added up. Then the density at certain depth was extrapolated to those grids with the same depth characteristic and summarized by depth area:

$$N=S_i*S_i$$

Results

Echo strength and identification standard for Chinese sturgeon

The results from experiments with different species show that the value of echo strength from different species is quite different (Fig. 2). The main factor of echo strength seems to be the body length of the target (with echosounders it is usually the swimbladder and certainly swimbladder size is related to body length and both factors can be considered to grow proportionally and therefore, indirectly, echo strength reflect also body length). According to the analysis of the body length distribution of fisheries catches (Deng *et al.*, 1991),the threshold of echo strength from Chinese sturgeon were set to be at a minimum of 3500.

Not only the echo strength, the length of echo trace of Chinese sturgeon was also longer than those determined for other species. Usually, the adult Chinese sturgeon was visualized at a trace length between 7-13 pixels on the screen while the other fish species showed substantial lower values ranging between 1-4 pixels length of the echotrace.

In brief, the characteristics of a single sturgeon echo signal can be recognized by a) echo strength > 3500; b) echo trace length > 7 pixel and c) no second echo on the screen. These criteria have been used in our study.

Spatial distribution of the Chinese sturgeon

A total of 38 individuals had been detected in the spawning ground among 1998-2002 (Fig. 3). There was no obvious aggregating behavior observed. No significant differences in annual distributions of Chinese sturgeon were observed as well. The most frequently detected area is in the main channel from Neihekou to Lijiahe with a depth less than 15 m. This behavior is similar with that observed in other sturgeon species (Buckley and Kynard, 1985). The area more close to the dam had lesser sturgeon encounters however this may be caused by some uncertain hydraulic factors affecting the observations and less sampling effort. We try to illustrate the relationship between the distribution and topographical factors (e.g. water depth, slope of river bed, distance from the dam, etc) but failed to do so mainly because of the low number of fish detected in total. More accurate results will be derived from the further analysis associated with the bottom depth in the whole area.

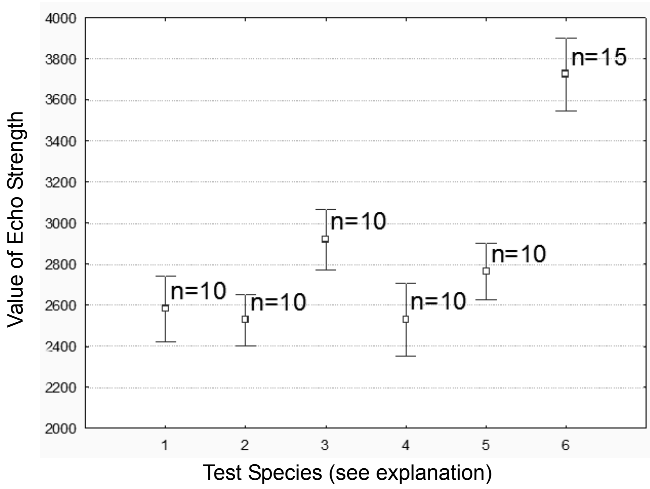

Fig. 2. The value of echo strength from different fish species as established from tank experiments in order to derive at comparative standard values for field observations. Data points represent mean values and bars the standard deviation; n=number of determinations are given in brackets directly at the data points

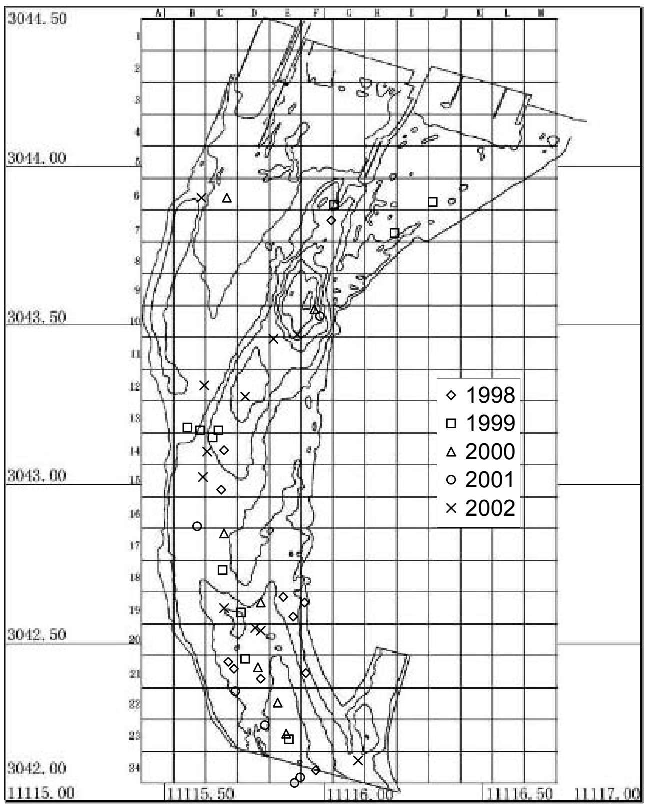

Fig.3 Active sturgeon spawning ground in the Yangtze River just below the Gezhouba Dam. Horizontal distribution of fish detected each year 1998-2002 during the hydroacoustic surveys

Estimation of the numbers of spawners (1998-2002)

The remaining spawning ground below the Gezhouba Dam reaching from the digesting apron to Miaozui, covers a total area 3.4 km^2. The numbers of adult sturgeons arriving prior to and remaining after the spawning activity on this identified spawning ground were estimated to be about 416 and 248 individuals in 1998, and about 441 and 159 individuals in 1999 (Fig 4a), respectively. The size of the spawner group after the spawning activity in 2000 and 2001 were much less, reaching about 58 and 66 individuals, respectively. The cohort of spawners prior to and after the first spawning activity in 2002 was estimated to be about 222 and 61 individuals, respectively (Fig 4b). Overall there is an alarming decline of numbers of fish arriving and staying at the spawning site.

Discussion

Validity of the data and algorithm

Species identification is quite difficult when using hydroacoustic methods. Many researchers devote lots of efforts on this subject (Kieser and Mulligan, 1984; Misund, 1997; Mitson and Knudsen, 2003)). But in our case, it is not so difficult because of the large body of the Chinese sturgeon. The observation from the scientific research during 1998-2002 (Chang, 1999) shows that the mean length of Chinese sturgeon is 321 cm with a range from 247 to 372 cm, while the other fishes is below 46 cm at the proportion of 97.5%. The large bodily form not only produces a high echo strength (over 3500) but also generates a correspondingly longer trace length (over 7 pixels on screen). Threshold echo strength below 3500 was not counted as sturgeon and therefore did eliminate the echoes from other fish species. The large body and the behavior of sturgeons to stay close to benthic habitat also reduced the effects caused by other factors, such as avoidance of vessels and surface noise.

Another problem is the identification of individuals when using the trace counting method (Misund, 1997). No overlap signals were observed in our sampling courses. This is probably because of the fact that the Chinese sturgeon distributes with substantial space between them and individual appearance at quite low density in the area was typical. This is another pre-requisite for the echo counting method and luckily was matched in our sampling efforts. So, it is reasonable to estimate the abundance of the sturgeon using our hydroacoustic datasets.

The algorithm is simply following MacLennan and Simmonds (1992) with a little revision. The extrapolation based on the depth was established on the vertical preference of the sturgeon, thereby overcoming the shortcoming of treating the distribution of Chinese sturgeons as uniform which is obviously not true. However, the present data analysis is not satisfactory because the grid units are large and cannot resolve to model realistically the habitat usage of the Chinese sturgeon. More accurate results will be achieved when the using geostatic methods to combine the results with those from other disciplines such as hydrology, underwater topography, and others.

Although the deficiency of our survey method is obvious and the detected number of fish is limited, the error is systematic over time and permits a relative comparison between years. A model to cope with the problem identified should be established. Other means to resolve the problem may be to adopt autonomous underwater vehicles as the platforms for fisheries acoustics to comprehensively cover the entire area (Fernandes *et al*., 2003).

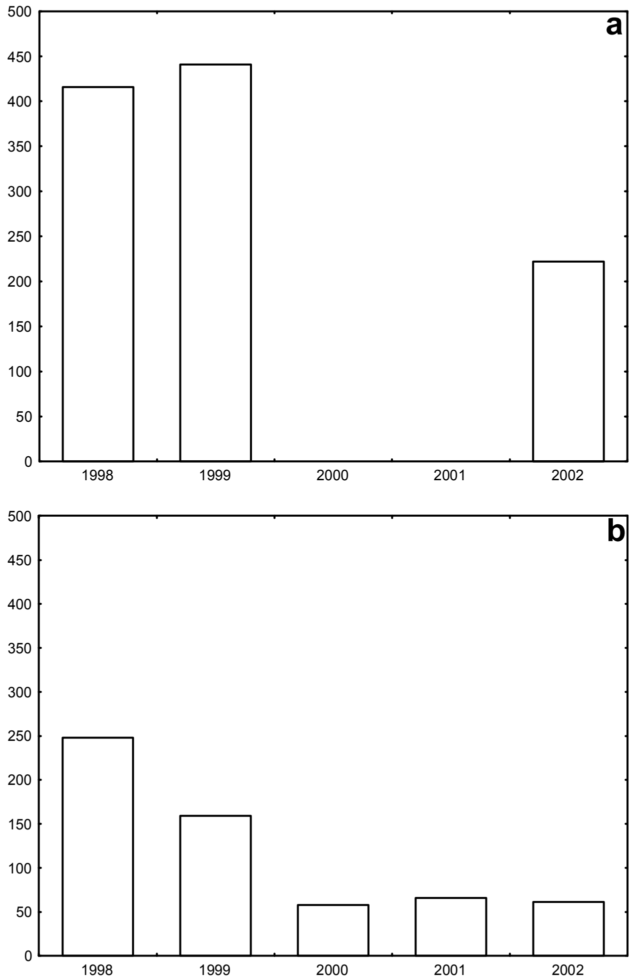

Fig. 4. Spawning stock cohort size of the Chinese sturgeon appearing on the spawning ground below the Gezhouba Dam during the survey years 1998-2002. (a) = Estimated standing stock before the first spawning, (b) = Estimated standing Estimation of the numbers of spawners (1998-2002,) stock after the first spawning

Behavior of pre-spawning and post-spawning and population dynamic

The specimens encountered in this study area consisted of two cohorts (Zhao *et al*., 1986; Chang, 1999). This was also confirmed by the facts that still some sturgeons were detected after the last spawning activity while remaining at the survey grounds. The decline between pre- and post-spawning reveals the fact that the spent sturgeons depart from the spawning ground immediately after spawning. Therefore, the habitats used by the second cohort, which will mature in the next year, distribute themselves over a broader area and do not only reside near the current study spot.

The differences between pre- and post-spawning numbers in 1998, 1999, and 2002 were 168, 182, and 161, respectively. This observation may imply that the maximum capacity of the current spawning ground is below 200 individuals although more sturgeons can aggregate in the area. However, this is strictly speculative.

Estimates over the years show that there was a decline of number of spawners, both from the estimation before and after the first spawning (although two years data are missing). Whether this represents a normal fluctuation requires further studies. However, when comparing the observations with the predicted theoretical size of spawning numbers, which were 1551 in 1998, 1446 in 1999, 1263 in 2000, 1125 in 2001, 993 in 2002, respectively (Chang, 1999), the actual numbers are much too small. It seems that the recent spawning ground is not sufficient to accomodate all spawners at the same time. It can be explained also by the fact that the second cohort distributed itself over an enlarged area which is outside the range of our survey area. Current conditions for the maintenance of the reproductive stock of sturgeon in Yangtze River remains highly critical.

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Author's address: Jianbo Chang
Institute of Hydroecology
Ministry of Water Resources and
Chinese Academy of Sciences
578 Xiongchu Avenue
Wuhan, Hubei 430079
China
E-mail: jbchang@mail.ihe.ac.cn