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Sturgeon aquaculture in China: progress, strategies and prospects assessed on the basis of nation-wide surveys (2007–2009)

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Summary

The authors examined the current status of sturgeon aquaculture in China, including its geographic distribution, an account on farmed species, overall production trends, state of controlled reproduction, seedling output and export. The study is based on a nationwide survey of 125 farms undertaken July and August 2009 together with data from previous studies. The census shows that: (i) the main provinces in increasing order of production are Sichuan (including Chongqing), Beijing, Hubei, Shandong and Hunan, (ii) *Acipenser baerii*, (and its hybrids) and *A. schrenckii* are the dominant cultured species, accounting for 95% of the total production, (iii) the production of farmed sturgeon has experienced a steady increase, from 17 424 t in 2006 to 21 000 t in 2009, (iv) the total reserves of captive stocks have continuously increased, reaching at present an estimated 1.22 million individuals, (v) the total supply of fertilized eggs or larvae from farmed broodstocks in China has gone up during the past 3 years, and can now basically meet the domestic demand for farming, while the number of seedlings obtained from the wild and imported from other countries gradually declined, and (vi) since 2006, China has started to export farmed caviar and the exports have been increasing year by year, meanwhile, the number of caviar processing factories has also increased. Moreover, other value-added products derived from farmed sturgeon (e.g. medical and health products, cosmetics, leather etc.) appeared in recent years on China markets. Corresponding to the sturgeon aquaculture development in China, some additional future aquaculture strategies are discussed: (i) make full use of the resources, (ii) strengthen management strategies and upgrade the culture techniques, (iii) develop and implement labeling systems for good quality control, (iv) foster deep-processing (value added products) in sturgeon farming to widen market options, (v) enhance extensive genetic studies and research on gynogenesis and cryopreservation of gametes for better resource management, (vi) improve the knowledge on early sex-differentiation in sturgeon, and (vii) prepare standards for management of sustainable sturgeon aquaculture. Considering the current progress of sturgeon aquaculture, the prospects of future sturgeon farming are assessed: (i) there will be a potential for considerable aquaculture to serve the caviar market, and farmed caviar may replace wild products, (ii) product diversification will increase and target for export markets, (iii) hatchery operations to produce juveniles from controlled reproduction will completely replace supply from wild and imported resources, and (iv) an industry chain will be gradually established to ensure sustainable sturgeon aquaculture production in China.

Introduction

The conflict between limited natural population abundances and the great economic interest in sturgeon products is one of the driving forces to push the development of sturgeon aquaculture in China. Sturgeon aquaculture can be used as a tool not only for economic development to meet the demand for products from these species, but also for restocking (Barannikova, 1987; Birstein, 1993; Burtzev, 1999; Rosenthal et al., 2006). Establishment of closed-cycle systems for maintaining captive broodstock may provide the quality control needed for the foundation of sustainable sturgeon farming while also serving as a tool for the preservation of the gene pool of endangered sturgeon species (Chebanov et al., 2002). Furthermore, sturgeon aquaculture is considered to be a new aquaculture sector similar to shrimp farming, or Japanese eel culture and soft-shell turtles which all experienced large market surges while natural stocks are being endangered (Wei et al., 2004).

Controlled reproduction by collecting mature broodstock from the wild at relevant spawning grounds and stimulating final maturation by injection of pituitary hormones was initially successful in China for *A. schrenckii* in 1957 (Sun et al., 2003). In the 1980s, fingerling culture was studied, meanwhile, cultured *A. sinensis* and *A. schrenckii* have been released into the rivers, and large-scale controlled culture of *A. schrenckii* was conducted. During the 1990s, sturgeon aquaculture techniques were gradually developed, and a large number of fertilized eggs and raised juveniles from sturgeons species and their hybrids were imported and introduced to farms in different provinces to develop commercial farming in the late 1990s (Wei et al., 1997; Chang and Cao, 1999; Zhuang et al., 2002; Sun et al., 2003). Due to market demands and the economic benefits, sturgeon aquaculture in China has become popular since 1998 with eleven species and hybrids presently being cultured, mainly for restocking programmes in the Yangtze and Amur rivers (Chang and Cao, 1999; Wang and Chang, 2006). So far, this form of sturgeon farming is already 12 years old in this country. The cultured sturgeons have not only been used as food for human consumption, but also developed to derive at medical products, leather and other uses. Now sturgeon farming and trade have become a fast developing industry in China, with more and more

high-level structured businesses including services for commercial farming, processing as well as support systems for domestic and international trade (Li et al., 2009). Thus, the development of sturgeon aquaculture in China is an important issue in aquatic food production, not only within China but also in relation to global developments.

Based on the fast development of the sturgeon aquaculture industry in China, further improved domestic management approaches for sturgeon farming and caviar processing are needed, and attention towards the development of a sustainable sturgeon-culture industry as well as towards solid species conservation programmes are needed (Cui et al., 2006). The status of sturgeon farming in China has been described in our previous studies (Wei et al., 2004; Li et al., 2009). Nevertheless, some recent changes in the overall development make it worthwhile to outline the progress made in recent years. Therefore, published information related to sturgeon farming is updated, new strategies are discussed, and the most likely course to be taken for a sustainable sturgeon aquaculture industry are highlighted, and the perspectives for further research and development are presented.

Materials and methods

This report is based chiefly on the results of an independent survey undertaken during July and August 2009: the sturgeon research team of the Yangtze River Fisheries Research Institute (YFI) visited 125 large (over 200 t production) and mid-size (50–200 t production) sturgeon farms as well as 52 live-fish wholesale markets in the 17 provinces of Beijing, Shandong, Liaoning, Hebei, Heilongjiang, Henan, Shanxi, Guizhou, Sichuan (including Chongqing), Yunnan, Hunan, Hubei, Jiangsu, Zhejiang, Guangdong, Guangxi, Fujian. Interviews were conducted based on the method described by Li et al. (2009). Only one leading member with a seniority of 8–10 years of continuous service was selected from each farming company to ensure that interview data were independent. Almost all informants readily participated in the study and completed the entire questionnaire. The data of the survey were analyzed by a general linear model (GLM) in R 2.7.2.

Progress of sturgeon aquaculture in China

The geographic distribution of sturgeon aquaculture

Based on our survey results, the distribution of sturgeon aquaculture depends on the water resource conditions of different provinces. Commercial fish farms were centered in the middle and southern areas of China, such as Shandong, Hubei, Sichuan (including Chongqing), Guangdong, Guangxi, Fujian, while broodstock culture and controlled reproduction were centered largely in northern regions of China, such as Beijing, Liaoning, Henongjiang. In addition, sturgeon caviar farms were mainly located in the provinces of Hunan, Hubei, Yunnan, Zhejiang and Sichuan. Sichuan, Beijing, Hubei, Shandong, Hunan and Guangdong are the areas contributing the most to sturgeon production in China. The production and its proportion in each province from 2007 to 2009 are shown in Table 1 and Fig. 1, respectively.

Table 1
Production estimates (t) for the main areas in China where sturgeons are cultured (2007–2009). Data represent means and standard deviations as reported from the various farms in each region

Province	2007	2008	2009
Sichuan & Chongqing	3810 ± 250	4050 ± 320	4220 ± 280
Beijing	3420 ± 287	3600 ± 258	3780 ± 255
Hubei	3230 ± 143	3400 ± 280	3570 ± 238
Shandong	2850 ± 169	3000 ± 148	3150 ± 225
Hunan	2310 ± 138	1800 ± 120	1890 ± 210
Guangdong	1820 ± 120	1600 ± 105	1680 ± 135
Hebei	1440 ± 153	1200 ± 105	1260 ± 160
Jiangsu	575 ± 85	650 ± 80	630 ± 50
Others	760 ± 83	802 ± 98	840 ± 90
Total	19 875 ± 165	20 152 ± 190	21 000 ± 202

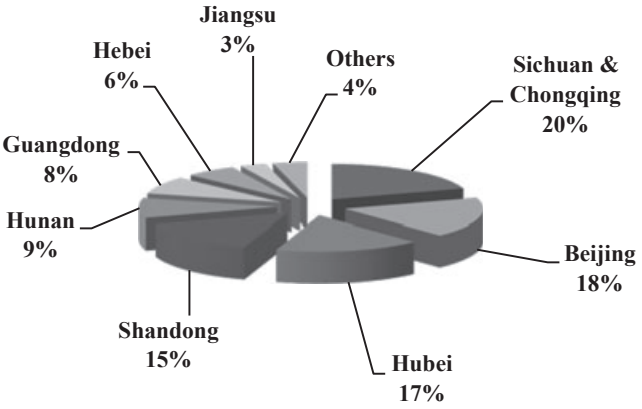

Fig. 1. Distribution of sturgeon aquaculture production (by weight) in different Provinces of China between 2007 and 2009

Farmed species

Up to the present time, our survey indicates that there are more than 13 sturgeon species or hybrids cultured in China: *Acipenser baerii*, several hybrid sturgeons (e.g. *Huso dauricus* ♀ × *A. schrenckii* ♂; *A. schrenckii* ♀ × *Huso dauricus* ♂; *A. baerii* ♀ × *A. schrenckii* ♂; *H. huso* ♀ × *A. ruthenus* ♂ and others) and *A. schrenkii* have so far been the dominant farmed species during the past 3 years, representing 95% of the annual production, while the remaining 5% of the total production originates from other species (Fig. 2). Moreover, caviar production from farmed sturgeons were also mainly from the above three species or hybrids. Their proportional contribution to the overall production is shown in Fig. 3.

Production trend

Sturgeon aquaculture in China had experienced tremendous growth rates since 1998 (Fig. 4). Overall production reached 17 424 t in 2006, accounting for nearly 80% of the world total production (21 319 t in 2006). Sturgeon farming in China continues to achieve new records, as obvious from the following statistics: 19 875 t in 2007; 20 152 t in 2008; 21 000 t in 2009.

Success in controlled reproduction from captive breeders of major species

With the development of sturgeon aquaculture and the increase of cultured broodstocks, the quantity of captive fish in the 125 farms surveyed reached about 1.22 million in the survey year (Table 2). The controlled propagation from captive breeders of eight major species has been successfully

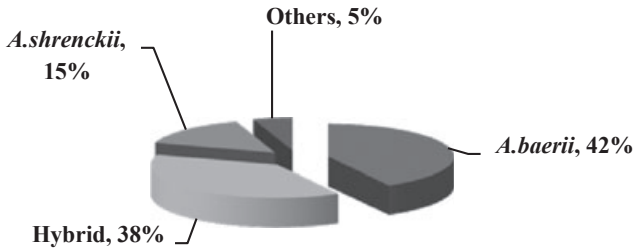

Fig. 2. Production level (percentage of total biomass) for the main sturgeon species farmed in China during the period 2007–2009. Hybrid: *A. schrenckii* ♀ × *Huso dauricus* ♂, *H. dauricus* ♀ × *A. schrenckii* ♂, *A. baerii* ♀ × *A. schrenckii* ♂ and *H. huso* ♀ × *A. ruthenus* ♂. Others: *A. gueldenstaedtii, H. dauricus, A. ruthenus, P. spathula*

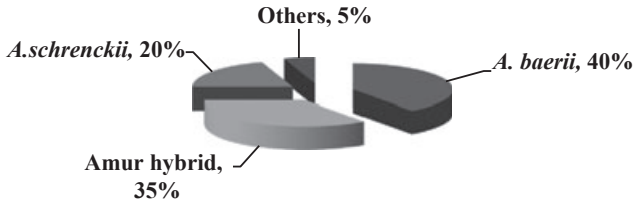

Fig. 3. Proportion of caviar production (percentage of total) for the main sturgeon species farmed in China. Data are for the years 2007–2009. Others are: *A. gueldenstaedtii, H. dauricus, A. ruthenus, P. spathula*

undertaken. Information on the first success in controlled reproduction from those species is given in Table 3.

Supply of larvae and juveniles: independence gained from wild stocks and imports

Based on the success of the controlled propagation of F1 generation from the major sturgeon species such as *Acipenser baerii*, *A. ruthenus*, *A. schrenkii*, Amur hybrid (*H. dauricus* ♀ × *A. schrenckii* ♂), *Huso dauricus*, and *Polyodon spathula*, culture techniques have been improved and the spawning season for several species has been expanded to fall, winter and early spring, depending on market demands. The total supply of fertilized eggs or larvae from farmed broodstock has now reached a level that can basically meet the domestic demand. Fertilized eggs obtained from controlled reproduction accounted for an estimated 42 million in 2007, 54 million in 2008 and 60 million in 2009, whereas the seedlings supply from wild catches have declined considerably (estimated 5, 4 and 3 millions from 2007 to 2009, respectively). The import of seedlings has also declined, and only fertilized eggs of *A. baerii* were imported in off-season. The quantity of fertilized eggs or larvae imported between 2007 and 2009 declined from 20 to 17,

Table 2
Quantity ($\times 10^3$ specimens) of captive stock maintained in the surveyed 125 sturgeon farms. Data represent means and standard deviation. Others: *A. gueldenstaedtii, H. dauricus, A. ruthenus, Polyodon spathula*

Province	Number of farms surveyed	*A. baerii*	Amur hybrids	*A. schrencki*	Others
Beijing	20	122 ± 18	28 ± 10	65 ± 2.5	8 ± 1
Sichuan & Chongqing	18	105 ± 25	32 ± 11	55 ± 13	16 ± 0.2
Hubei	15	84 ± 27	2.8 ± 1.0	47 ± 1.4	25 ± 5
Shandong	15	36 ± 15	12 ± 5	57 ± 26	7 ± 2
Hunan	9	13 ± 6	37 ± 18	41 ± 12	4 ± 1
Zhejiang	6	43 ± 13	14 ± 1.0	18 ± 12	5 ± 1
Liaoning	5	35 ± 10	3 ± 20	13 ± 9	10 ± 5
Hebei	7	31 ± 12	17 ± 5	12 ± 3	2 ± 0.5
Yunan	4	13 ± 4	16 ± 5	24 ± 12	8 ± 1
Henan	4	23 ± 8	0 ± 0	1.6 ± 3	6 ± 1
Guizhou	3	15 ± 4	4 ± 2	1.6 ± 1	1 ± 0.3
Gongdong	5	10 ± 2	4 ± 1	8 ± 2	1 ± 0.5
Fujian	4	9 ± 2	6 ± 1.4	1 ± 0.2	2 ± 0.7
Jiangsu	5	6 ± 1	2 ± 0.3	4 ± 1.3	1 ± 0.8
Heilongjiang	5	0 ± 0	3 ± 1	4 ± 1.2	1 ± 0.6
Total	125	545 ± 25	206 ± 13	380 ± 10	80 ± 6

Table 3
A listing on the first reported Chinese successes in controlled reproduction of captive breeders of major cultured species

Species	Age of female at initial reproduction (year)		The first success of reproduction from cultured breeders
	Captive	Wild	
A. baerii	5	11	2000
P. spathula	5	8	2001
A. ruthenus	4	4	2001
A. schrenkii	6	9	2002
A. guldenstaedtii	7	12	2004
Amur hybrid: *H. dauricus* ♀ × *A. schrenckii* ♂	7	–	2006
Huso dauricus	8	18	2008
A. sinensis	16 (?)	14	2009

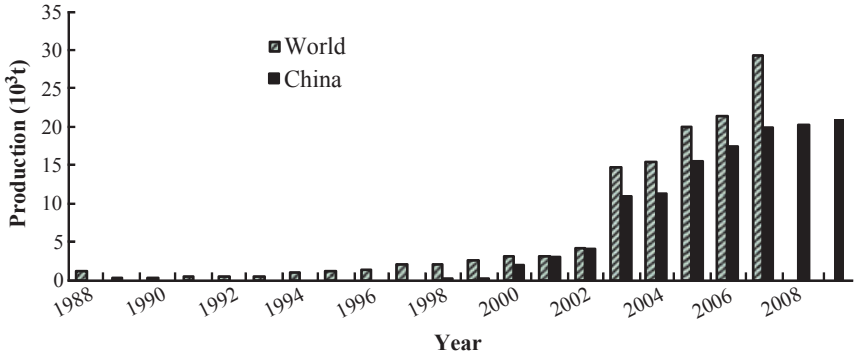

Fig. 4. Comparison of the production trends in acipenseriform aquaculture world-wide and in China between 1988 and 2009 (Sources: Data from 1988 to 2006 are from FAO Fishstat Database, 2007. Data from 2007 were collected from the surveyed 125 Chinese sturgeon farms)

and 8–10 millions, respectively. The data on the sources of Acipenseriformes seedlings acquired between 1998 and 2009 are summarized in Fig. 5.

Export of sturgeon product

Hangzhou Qiandaohu Xunlong Sci-tech Development Co., Ltd was the first company exporting cultured caviar from China in 2006. Since then, China has started to export farmed caviar and an increasing rate year by year (about 1, 2, 5, and 8 t between 2006 and 2009, respectively). Meanwhile, the number of caviar processing plants have increased from one in 2006 to three in 2009. The canned goods produced from sturgeon by the Hubei Tianxia Xunye Co., Ltd have been supplied to the market in batches since 2003. Moreover, the meat products (including Semi-finished products, finished products, smoked products), as well as medical and health products, cosmetics, industrial glue, leather and other value-added products have appeared in China in recent years.

Strategies for the development of sturgeon aquaculture in China

The problems and strategies of sturgeon aquaculture in China have been reviewed by Wei et al. (2004) and Li et al. (2009), mainly focusing on *A. sinensis*, hybridization, exotic species, disease risks, and market development. Here, we provide additional information on strategies that need to be developed and perfectionated in order to ensure a sustainable development of sturgeon aquaculture in China.

Promoting diverse production systems

One key issue will be to make a complete use of resources through product diversification in order to reduce the breeding costs. Presently, the profit generated by sturgeon aquaculture is very low because of the long culture period compared to teleost species. Therefore, efficient culture (grow-out) methods are required because of the relatively long time needed to reach market size. For example, pond aquaculture, reservoir aquaculture, culture in large water bodies as well as cage culture can reduce the production cost and should be advocated in an environmentally compatible manner. This would permit to reduce the high energy consumption for intensive facilities requiring temperature controls and oxygen supply. Especially culture in large water bodies in cages can encompass new fisheries growth, and even can intensify the sturgeon aquaculture industry if operated in an environmentally compatible manner (Sun et al., 2003). Safeguarding standards as to the carrying capacity and environmental compatibility need to be developed for this purpose.

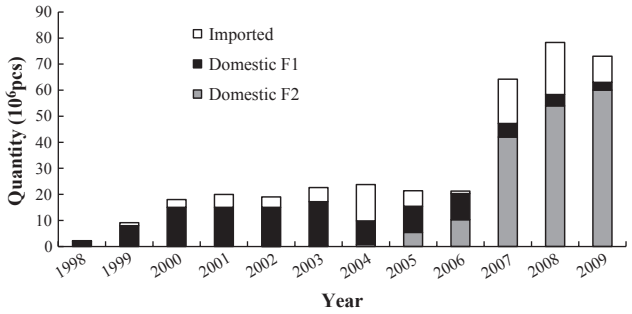

Fig. 5. Acipenseriformes hatchery output in China. Data compiled according to three different sources: wild captures, controlled reproduction and imports. Data cover the period from 1998 to 2009 (Sources: Data prior to 2006 were from the report entitled; Sturgeon Culture in China for 15 years (Sun D., unpubl. data). Data from 2007 to 2009 were collected from the surveyed 125 sturgeon farms; pcs = pieces (or number of specimens)

Strengthening / upgrading farm management and techniques

There is a need to enhance the research on adequate feeds suitable for sturgeon aquaculture. We need also pay much more attention to disease prevention and to minimize treatment (prophylaxis rather than treatment with antimicrobials). Further, guidelines need to be developed for production systems that avoid environmental pollution (for example, use the herbs and natural plant products for disease control; implement the provisions of withdrawal periods for drugs; limit licences to approved drugs only; define organic environmental loads released from sturgeon farms). While developing these strategies, one should try to achieve a win-win situation for both, food safety and environmental protection.

Developing / implementing a sturgeon aquaculture labeling system

There is a need prevent more effectively the escape of farmed sturgeon into the wild in order to effectively avoid potential threats of genetic pollution in native species (Wei and Yang, 1998; Zhu et al., 2002, 2005; Ludwig, 2006, 2008). There is also a need to meet the requirements of CITES more completely, assuring that industry complies with the international regulatory requirements in sturgeon trade thereby preparing methods in line with CITES to overcome technical barriers and opening up international markets (Rosenthal and Gessner, 1992). To also assure to track the aquatic product from farm to kitchen so it meets the requirements a tracking system for safe aquatic food products in China. At the same time, such a labeling system for sturgeon products would be beneficial towards the standardization of sturgeon aquaculture, processing and trade (Rosenthal et al., 2006; Zhu et al., 2008). Practical external or visible labels have to be urgently developed to meet the management needs of sturgeon culture and trade. Currently, the Coded Wire Tag (CWT) may be a practical tool for tracking juveniles or sub-adults farmed for fish market, while PIT tags may be the ideal ones in managing broodstocks or fish reared for caviar (Markin et al., 2010).

Promoting added-value products ('deep processing')

To develop added-value products (deep processing) of sturgeons by utilizing various parts of the entire fish for different products can not only make full use of the sturgeon resources to increase the economic values of the products for enterprises, but also enrich the connotation of aquatic products to meet the pursuits from customers. Additionally, to promote sturgeon product diversification and increase market demand will lead to further development of the sturgeon aquaculture industry. It is a good time to develop 'deep processing' strategy for products derived from sturgeons. At present, China has commenced projects in this direction, however, at a low scale that needs urgent expansion.

Enhancing studies on gynogenesis and gamete cryopreservation

At present, the gynogenesis technology to obtain monosex female populations in several acipenseriform species (Van

Eenennaam et al., 1996; Mims et al., 1997; Fopp-Bayat, 2007) is in progress and will improve the economic efficiency of caviar production as well as can be used as a valuable tool to the restoration of endangered and extinct species. Cryopreservation of gametes seems to be a highly attractive subject area in order to become more independent from the need to synchronize the catch of mature fish of both sexes, while also using cryopreservation for gene banking and broodstock management towards selective breeding, targeting for specific domestication traits (Rosenthal et al., 2006). All of these studies have highly practical relevance for farming operations and improved management of broodstocks. The cryopreservation of sturgeon sperm is now possible with limited success (30% fertilization of eggs on average with an excess of sperm) (Billard and Lecointre, 2001). It is acceptable for conservation purposes, but this is not sufficient for routine aquaculture operations. So far, no successful report on cryopreservation of sturgeon egg is available.

Promote extensive genetic studies

Sturgeon population genetic studies provide important information which can be used for management, sustainable use and conservation of the species concerned. Not only traditional methods but also molecular methods such as RAPD, mtDNA and microsatellites are widely used in genetic studies in sturgeon. However, a scientific stock assessment for the *A. schrenckii* and *A. sinenesis* based on genetic diversity and on the population structure is still lacking. Little was known about the genetic influence or risks associated with restocking/rehabitation programmes on the wild populations in China, which will impede progress in sturgeon aquaculture, control of caviar trade as well as the development of adequate strategies in conservation genetics (Zhu et al., 2008). The proposed techniques can also be used to identify different broodstocks that are being used for farming propagation. Using this technique allows appropriate broodstock management both in aquaculture and in sturgeon restocking programmes (Bronzi et al., 1999; Rosenthal et al., 2006).

Improving the knowledge base on early sex-differentiation

Sex differentiation of sturgeons at an early stage is highly important both in evolutionary and developmental biology aspects. Gonad maturation in sturgeons is often delayed for several years and it is assumed that the transition from previtellogenesis to vitellogenesis must be triggered by a mechanism that is responsible for switching on steroid-genesis. The role of the IGF-I system, a paracrine insulin-like growth factor, has been studied in *A. ruthenus* (Wuertz et al., 2007). *Sox* gene studies in *A. schrenckii* provided important data for studying the function of sex-differentiation genes in sturgeons. This subject is of central importance to understand the physiological mechanisms underlying the maturation process and subsequently to utilize this knowledge in common procedures for broodstock management and farming operations.

Setting farm management standards for sustainable sturgeon aquaculture

Sturgeon industry must be managed based upon frequent monitoring of population size, age and abundance and periodic stock assessment. Advances in modeling the response of sturgeon population to different management schemes are revealing whether sustainable sturgeon aquaculture are indeed possible and quantifying acceptable levels of mortality (Boreman, 1997; Root, 2002). Consideration might be given to set guidelines for population monitoring, stock assessment and fisheries management programmes (e.g. water quality, feed and drug etc.). Established as a textbook or manual for policy-makers, managers and scientists, this effort would set a universal basis for acceptable management standards and could guide decision-making on commercial exploitation and trade (Pikitch et al., 2005).

Prospects of sturgeon aquaculture in China

Potential market for farmed caviar

It was reported that the production of world sturgeon captures reached 15 000–30 000 t between 1960 and 1992 which indicated that there was a potential world market in the range of 1000–2000 t of caviar (FAO-Fishstat, 2007). With the declining production of caviar from wild sturgeon, but the rapid increase in the quantity of caviar from farmed sturgeons, it is believed that there will be a considerable caviar market, and farmed caviar will replace wild caviar in the future. According to statistic, there may be a potential market of 1000–2000 t caviar world-wide, so far, there is a considerable gap (> 900 t) on the traditional caviar markets such as North America, Europe and Japan. New regions in some fast developing countries such as China but also overseas (e.g. South America), should not be ignored (estimated potential market of 100 t). In the foreseeable future, there may be very little wild sturgeon products on the world market, so that aquaculture production will be the major contributor to the caviar trade. Moreover, there will be more than 300 t of caviar produced in China during the next 3 years (Table 4), and the quantity of export will continue to grow. Thus, new market segments will have to be developed and different customer target groups who are willing to pay for a medium rather than high-priced product will have to be considered.

Diversified utilization of farmed sturgeon

Formerly, there were only two main products from sturgeon on Chinese market, meat and caviar. However, with the enhancement of processing techniques for sturgeon products, leading companies include more and more services for commercial farms, processing diversified products, targeting for domestic and international trades. These activities are rapidly increasing in China. Meanwhile, different sturgeon products appear on the market, e.g. medical and health products, cosmetics, leather from skin and other deep-processed

Table 4
Forecast for captive stocks for meat and caviar production for the next 3 years in China

Year	The total weight (t) of captive broodstock (≥7 years old)	Caviar production (t)
2009	740	24
2010	1390	69
2011	1510	108
2012	1520	144
Total	5160	321

products. In this regard, it is believed that diversification of products will increase in the future, serving more than one market and contribute to the sustainability of the industry.

Seed production to become independent from wild sources and imports

Based on the rapid increase of captive broodstock and building on the success of controlled reproduction for the main cultured sturgeon species, it is projected that the total number of adult and unsexed sturgeons (over 8 years old) is at present in the order of 1.22 million specimens. It is also estimated that the annual quantity of juveniles obtained from captive breeders will be in the order of 6000–8000 millions in the near future (based on the results of the survey data). This level of output will provide sufficient supplies of juveniles so that captures from the wild are no longer needed. This is a needed step towards the sustainable development of the sturgeon aquaculture industry. Therefore, we can expect that the fertilized eggs and larvae from controlled reproduction will meet the market demands and wholly replace wild and imported ones.

Gradually establish an industry chain of sturgeon aquaculture

Currently, the most popular industrial mode of sturgeon aquaculture in China is the 'company + individual farmer link' mode, which can expand production very quickly. However, this mode is no longer appropriate for further development of the sturgeon industry (Li et al., 2009). Therefore, a so-called 'sturgeon guild', an organization that guides and manages professional co-operatives and farmers based on domestic sales and export, will be gradually established. Once this 'sturgeon guild' is established, the farmers will deal with or join such type of co-operatives instead of selling fish directly to the companies or local markets. It will help the farmers to reach better profitability while also promoting quality control in an attempt to prevent companies from purchasing fish with potential problems from any irresponsible individual farmer.

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