Journal of Applied Ichthyology

J. Appl. Ichthyol. 27 (2011), 533–540
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ISSN 0175–8659

Received: August 8, 2010
Accepted: November 17, 2010
doi: 10.1111/j.1439-0426.2011.01684.x

Acclimating and maintaining Chinese sturgeon *Acipenser sinensis* in a large public aquarium environment

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Summary

Based on the five wild Chinese sturgeons which were captured from the Yichang section of the Yangtze River, and the 323 offsprings of the Chinese sturgeons, were studied as to their survival, development and behaviour under aquarium conditions between 2005 and 2007 in the captive environment of an aquarium. All five wild caught females survived, with weight gains ranging from 0.55% (Specimen W1#: Onset: 320.00 kg, Final: 336.00 kg; across 27 months) to 10.00% of original body weight (Specimen W32#: Onset: 125.00 kg, Final: 175.00 kg; across 4 months). In addition, the gonads of one captured fish redeveloped to stage IV by August 2007. The changes of the depth in the tank were observed before, during and after active food intake. Furthermore, the fish formed strong feeding associations with live food items, such as *Hypophthalmichthys molitrix*, *Cyprinus carpio*, and *Paralichthys lethostigma*, while rarely feeding on *Hexagrammos otakii* and *Epinephelus awoara*, occasionally on *Monopterus albus*, *Penaeus vannamei*, *Leiocassis longirostris*, and never on *Eriocheir sinensis* H. *Milne-Edwards*, *Misgurnus anguillicaudatus*, *Silurus asotus* Linnaeus, *Octopus variabilis*, *Anadara uropygimelana*. The development of food preferences in the captive environment suggest that these Chinese sturgeon successfully acclimated to the large aquarium, in addition, the survival rate of the filial generation offspring was 86%. Across the study period, for the older captive bred offspring (1997 and 2001 stocks) minimum weight increase per month was 4.28% (F1-2001: Onset: 12.24 ± 1.11 kg, Final: 25.35 ± 2.10 kg; over 25 months) and the minimum lengthwise growth rate per month was 1.39% (F1-1997: Onset: 187.32 ± 1.32 cm, Final: 260.00 cm; across 28 months). However, the youngest sturgeon (the 2005 offspring), had the highest weight gain of 29.35% per month (Onset: 16.50 ± 1.92 kg, Final: 8733.33 ± 739.80 kg; across 18 months) and lengthwise growth rate 35.70% per month (Onset: 15.53 ± 0.77 cm, Final: 115.33 ± 4.14 cm; across 18 months) respectively.

Introduction

The Chinese sturgeon *Acipenser sinensis* Gray is a typical anadromous fish that matures in the East China Sea and Yellow Sea, and spawns in the Zhu River and Yangtze River (Wei et al., 1997). However, the construction of the Gezhouba Dam in the 1980s and the Three Gorges Dam in 2000s in the Yangtze River block the migration of the sturgeons to their natural spawning grounds, contributing to the decline and changes in stock structure of this critically endangered population (Wei et al., 2005) which is further exacerbated by females only breeding three to four times during the course of a life cycle, with < 1% of offspring surviving due to high predation rates (Chen, 2007). It has been calculated that juveniles were further reduced by 80–90% between 1981 and 1991, despite already being at critical levels (Ke, 1999). In response to the anthropogenic changes to the river structure, some breeding cohorts that are still functional have formed new spawning grounds below the Gezhouba Dam (Wei et al., 2004).

Due to the loss of natural habitats which are critical for reproduction, *ex-situ* conservation studies (i.e. outside of the natural environment) of Chinese sturgeon are required to safeguard population numbers and prevent the genetic diversity from becoming extinct. One of the primary problems of *ex-situ* conservation is the construction of suitable artificial environments that replicate sufficiently the natural environmental features to foster feeding and breeding activity by wild caught fish (Li et al., 1994). Due to the large size of sturgeon (with adults reaching up to 4 m in total length), Beijing aquarium is considered to be one of the few units in China that are equipped with advanced technical skills and large enough aquaria tanks suitable to identify the conditions required for the acclimation of sturgeons while serving species protection needs (Liu et al., 2006). In the wild, adult sturgeon usually stop food intake on initiation of the upstream migration to spawning grounds. Fish will start feeding again only after returning to the sea following spawning (The Yangtze Aquatic Resources Survey Group, 1988). Since the 1970s, several captive breeding programmes have been initiated to boost population numbers. However, the reintroduction of captive bred sturgeon to the Yangtze River, following spawning, has so far resulted in extremely low survival rates (Wei et al., 2004). Therefore, to improve both *ex-situ* captive conditions and reintroduction success, it is necessary to develop an understanding of the feeding behaviour, and understand recovery needs after spawning, while also identifying the conditions required for gonad redevelopment of wild sturgeon that are housed in controlled environments. Such data are urgently needed to safeguard the critically endangered Chinese sturgeon.

Based on these requirements, the current study investigated the behaviour, growth and food preference of wild caught adult female Chinese sturgeon and their offsprings derived from three different captive stocks. The capacity of the wild caught sturgeon to acclimatize to the aquarium environment was also studied to identify parameters, which may be used to indicate performance and hence optimal conditions for welfare. Furthermore, the changes in the behaviour and morphology of one adult female were recorded during gonad re-development in captivity. We apply the findings of this study to identify parameters which can contribute to the successful acclimation of wild caught Chinese sturgeon. The implications of these findings will assist in the long-term captive breeding and re-introduction programmes.

Materials and methods

Fish stock

Between 2005 and 2006, five wild gravid female Chinese sturgeon were captured from the Yichang section of the Yangtze River, due to breed. The sturgeon were initially held at the Yangtze River Fisheries Research Institute of the Chinese Academy of Fisheries Sciences in Jingzhou city of Hubei Province, China. After 1 or 2 weeks in captivity the fish produced filial sturgeons and were held for a further 2 months at this site before transfer by ambulance to Beijing Aquarium. The origin of the wild caught fish, and accompanying basic measurement data are given in Table 1.

In addition, filial sturgeons from captive bred Chinese sturgeon stocks were assessed. These comprised two fish that were produced in 1997 (F1-1997), 23 fish that were produced in 2001 (F1-2001), and 298 fish that originated from the 2005 (F1-2005) reproduction. The F1-2005 sturgeons came from one of the experimental wild females (W29#), however, the F1-1997 and F1-2001 sturgeons did not originate from any of these females.

Housing conditions

The five wild caught adult females were accommodated in a square tank together with captive bred juveniles from the filial generation stock that were >1 m in total length (juvenile length ranged from 148 to 200 cm). The tank size was 29.0 (length) $\times$ 11.0 (width) $\times$ 4.4 m (height), with an exhibition-window on one side of the tank (20 m in length; 3.0 m height). The tank held a maximum water volume of 1200 m^3. The stocking density was 2.2 kg m^{-3}.

F1-2005 generation from the wild caught females (also <1 m) were housed in two connected circular tanks, with two observation-windows (20 $\times$ 20 cm). The diameter and height of each tank were 3.5 and 1.4 m, respectively, which when combined held 25 m^3 water volume. The stocking density was maintained below 2.2 kg m^{-3}.

All tanks were equipped with advanced life support systems, which automatically control water quality to set specifications. For example, several key water parameters are controlled continuously, including water temperature at 21–24°C, oxygen content to be between 7 and 10 mg L^{-1}, while pH values were maintained at 7.5–8.0, and ionized ammonia [NH_4^+] concentrations leveled at 0.01–0.05 mg L^{-1}, and [NO_2^-] concentrations remained low (0–0.1 mg L^{-1}). The main water quality parameters were determined daily, and tanks were cleaned at fixed times twice weekly.

Feeding information

Both natural food (i.e. fish) and artificial dry pelleted commercial sturgeon diets were used for all four fish groups. The natural food was purchased from the market, and included a range of fish species of size range 5–40 cm; *Hypophthalmichthys molitrix*, *Cyprinus carpio*, *Paralichthys lethostigma*, *Hexagrammos otakii*, *Epinephelus awoar*, *Monopterus albus*, *Leiocassis longirostris*, *Penaeus vannamei*, *Eriocheir sinensis* H. *Milne-Edwards*, *Misgurnus anguillicaudatus*, *Silurus asotus* Linnaeus, *Octopus variabilis* and *Anadara uropygimelana*. The natural food was offered in three different forms; including frozen, fresh but dead, and live.

In the first tank, containing the wild caught sturgeon and F1-1997 and F1-2001 generation fish of >1 m, the fish were individually hand-fed by a diver. Hence all food intake was documented. Generally, after 2 weeks, force feeding of wild fish that had been recently caught except for W1# was required on arrival, and continued until active feeding was initiated, which individually varied between 20 days and 10 months (Zhang et al., 2007). Fish were fed once a day at fixed location. In the second tank, containing F1-2005 stock of <1 m, prepared commercial feed and natural food were offered by hand at the same location (tank surface) once daily.

Table 1
Parameters of the wild caught adult female Chinese sturgeon that were housed at the Beijing Aquarium

Specimen identification	N	Origin of fish	Age at Arrival	Starting date (yy / mm / dd)
W1#	1	Capture in Yichang section of Yangtze River on 12th Oct, 2004, post mature, not propagated	Not determined	2005 / 4 / 3
W28#	1	Capture in Yichang section of Yangtze River on 5th Nov, 2005, post mature, not propagated	Not determined	2005 / 12 / 29
W29#	1	Capture in Yichang section of Yangtze River on 9th Nov, 2005, artificial propagation	Not determined	2006 / 1 / 13
W31#	1	Capture in Yichang section of Yangtze river on 30th Oct, 2006, artificial propagation	Not determined	2006 / 12 / 15
W32#	1	Capture in Yichang section of Yangtze river on 30th Oct, 2006, artificial propagation	Not determined	2006 / 12 / 19
F1-1997	2	Controlled propagation in 1997	7+	2005 / 4 / 16
F1-2001	23	Controlled propagation in 2001	3+	2005 / 3 / 25
F1-2005	298	Controlled propagation in 2005	0+	2005 / 12 / 29

N, number of fish.

Data collection

Growth measurements. Four different growth measurements were obtained during the course of the study: (i) body circumference, (ii) waist girth, (iii) total body length (head to the end of vertebra), and (iv) body weight. The 'body circumference' was measured at the highest point of the third dorsal bony plate. The 'waist girth' was measured at the highest point of the fifth dorsal bony plate. For the wild caught sturgeon, these two measurements were obtained monthly by a diver using a tape measure under water while swimming with the fish. The total body length was measured using a tape measure, and the body weight was recorded after the fish removed from the water. For juvenile stock of > 1 m the same procedure was followed. For juvenile stock of < 1 m the fish were removed from the water to acquire all measurements every 3 months. Each measurement was repeated three times on each occasion for each fish. The means of these three measurements were used in the results.

Measurements were taken underwater due to the large size of the fish, a validation test was run to determine the degree of error that might exist by the same individual and by different individuals measuring the same fish. A total of three people made measurements on separate occasions during the course of 1 day. We found that measurement error was on average 0.5 cm (range 0–1; 0.5 ± 0.32 cm) for repeated measurements by one person, and on average 1.5 (range 0–2.5 cm; 1.5 ± 0.41 cm) for repeated measurements by different people. Based on these findings, during the main experiment only one person conducted all measurements to keep measurement error to a minimum.

Gonad development. The oocytes of one wild caught adult Chinese sturgeon (W1#) were removed by a veterinarian by biopsy and photographed on 4 August 2007. The diameter of the most of the oocytes was measured.

Behavior observations. Opportunistic sampling of the behavior of the wild caught sturgeon and the three different juvenile age groups was conducted. Behaviour was observed and documented for three times per day between 8.30 and 17.30 (total 90 min of observation period). In addition, feeding behavior was observed and documented daily. Food preference calculations followed the methodology of Liang (1995). The wild sturgeons' feeding behaviours of 13 live baits were recorded and observed lasting for 1 month. Calculations on feeding behaviour was referred to the rate of special behaviour after Liang (1995). Each bait was given 10 days, three times per day, and 6–7 baits were given simultaneously and randomly in the 10 days, and the response of fish to the food item was recorded. The results are presented as percentage of observations.

Data processing

The selection of different food items by the wild caught sturgeon were analyzed for differences using the Kruskal–Wallis Test and Mann–Whitney Test.

Results

Survival

All five wild caught Chinese sturgeon survived the assessment period. After the study, three of the individuals (W1#, W29#, W31#) remained at Beijing Aquarium, while the other two (W28#, W32#) were released back into the wild in the Jinzhou region of the Yangtze River on 22 April 2007. The F1-1997 and F1-2001 captive bred filial generation juvenile stock survived the assessment period, and to date remain housed at Beijing Aquarium. Out of the 298 offspring in F1-2005 stock, 257 survived the assessment period, which is an 86% survival rate. Of these, 148 were released into the Jinzhou region of the Yangtze River on 22 April 2006, while the rest of the fish remained housed at Beijing Aquarium.

Growth and development

Wild Chinese sturgeon. The first wild caught female (W1#) was initially captured on 12 October 2004 and admitted to the aquarium on 3 April 2005. The fish initiated active food intake from 7 April 2005 until suddenly stopping feeding on 20 August 2006. As a result, an increase followed by a declining trend in body circumference was recorded, as shown in Fig. 1. On the removal of gonad tissue by biopsy indicated the presence of brown and elliptic oocytes, with an average diameter of 3.2 mm. The polar spot was vague on the animal pole of oocyte.

The second female (W28#) was initially captured on 5 November 2005 and admitted to the aquarium on 29 December, 2005. The body circumference parameters declined from arrival until August 2006. At this point force feeding was initiated, and after 21 days the fish began active feeding, at which point body circumference measurements showed a steady increase (Fig. 1).

The third female (W29#) was initially captured on 9 November 2005 and admitted to the aquarium on 13 January, 2006. The body circumference measurements declined after arrival. Force feeding was initiated on 29 May 2006 and began active feeding on 17 June 2006, after which the body circumference measurements steadily increased (Fig. 2).

The fourth female (W31#) was initially captured on 30 October 2006 and admitted to the aquarium on 15 December 2006. Force feeding was initiated on 18 June 2007, and at the end of the study period (October 2007) active feeding had not been initiated. The body circumference measurements are shown in Fig. 3.

The fifth female (W32#) was initially captured on 30 October 2006 and admitted to the aquarium on 19 December

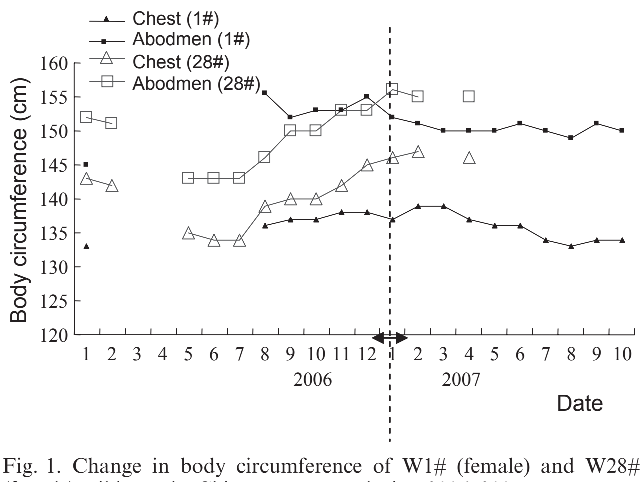

Fig. 1. Change in body circumference of W1# (female) and W28# (female) wild caught Chinese sturgeon during 2006–2007

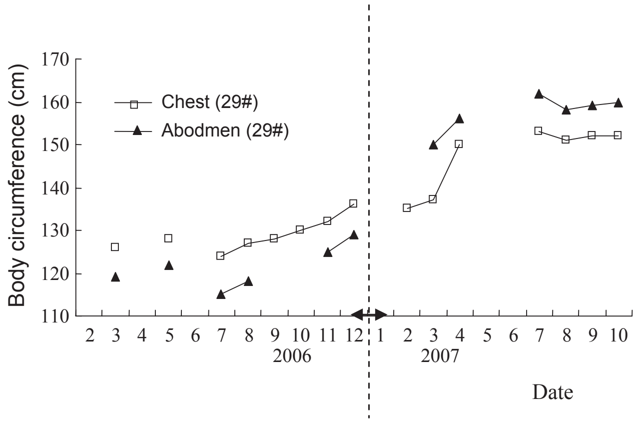

Fig. 2. Change in body circumference of W29# (female) wild caught Chinese sturgeon during 2006–2007

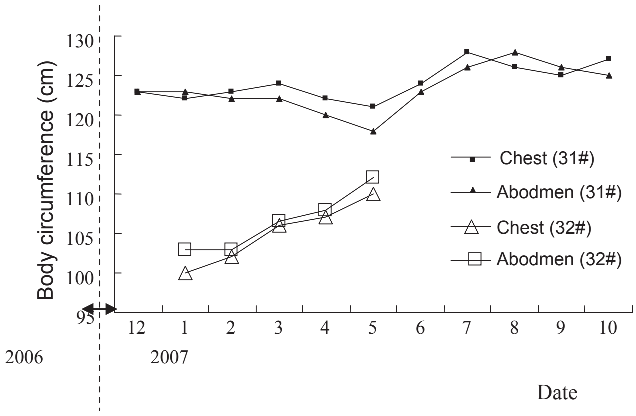

Fig. 3. Change in body circumference of W31# (female) and W32# (female) wild caught Chinese sturgeon during 2006–2007

2006. Force feeding was initiated on 9 January 2007, while active feeding commenced on 1 February 2007. Subsequently, body circumference measurements increased steadily (Fig. 3).

Figures 4 and 5 show the variation of total length and body weight respectively for the five wild captured female Chinese sturgeon.

First generation Chinese sturgeon. For the three different age groups of juvenile stock (F1-1997, F1-2001, and F1-2005), Table 2 shows the measurement data for total body weight and

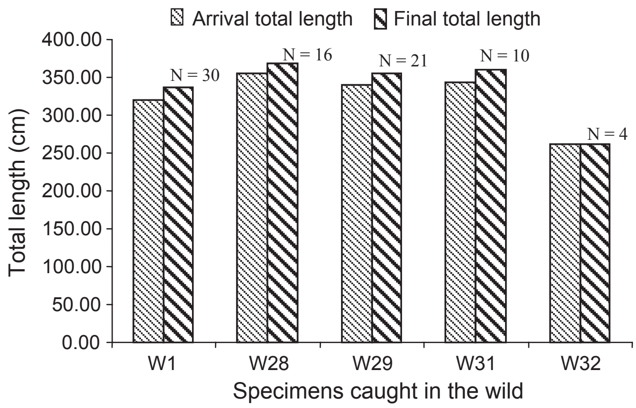

Fig. 4. Variation in total body length measurements of wild caught Chinese sturgeon (n = 5) during the study period in captivity (N = number of months in captivity)

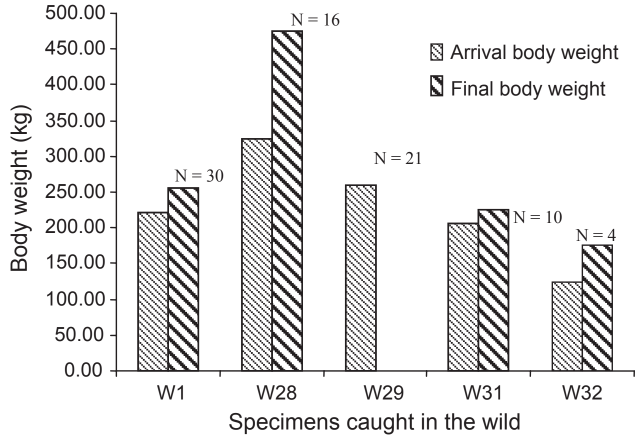

Fig. 5. Variation in body weight of wild caught Chinese sturgeon (n = 5) during the study period of captivity (N = number of months in captivity)

total body length. All age groups of juvenile sturgeon grew with respect to both body weight and body length.

For example, the F1-1997 stock exhibited a mean increase in body length and weight of 1.39% per month (n = 2; Onset: 187.32 ± 1.32 cm, Final: 260.00 cm; across 28 months;) and 6.58% per month (n = 2; Onset: 35 kg, Final: 99.5 kg; over 28 months), respectively. The F1-2001 stock exhibited a mean monthly increase in body length and weight of 1.40% per month (n = 23; Onset: 119.11 ± 2.57 cm, Final: 160.72 ± 3.41 cm; across 25 months) and 4.28% per month (n = 23; Onset: 12.24 ± 1.11 kg, Final: 25.35 ± 2.10 kg; over 25 months), respectively. The F1-2005 stock exhibited a mean monthly increase in body length and weight of 29.35% per month (n = 15; Onset: 15.53 ± 0.77 cm, Final: 115.33 ± 4.14 cm; across 18 months) and 35.70% per month (n = 15; Onset: 16.50 ± 1.92 g, Final: 8733.33 ± 739.80g; across 18 months). In other words, as the fish became older the growth rate became slower and stabilized. These observations were supported by statistical analyses, in which it was confirmed that with increasing age the coefficient of variation declined with respect to total body length and body weight, respectively.

An alternative presentation of the actual total body weight and total body length, indicated that over a 19–28 months period for Chinese sturgeon of: (i) 1 year old (F1-2005) these measurements were 80.91 cm and 3.20 kg; (ii) for those of 4 years old (F1-2001) these measurements were 138.00 cm and 25.53 kg; (iii) for those of 5 years old (F1-2001) these measurements were 154.05 cm and 21.74 kg; and (iv) for those of 8 years old (F1-1997) these measurement were 193.54 cm and 45.09 kg respectively.

Behaviour

Preferred swimming depth. A total of 45 h behavioural observations were made during the study period, comprising 90 min observations over 30 days. It was found that the five wild caught Chinese sturgeon primarily occupied the upper (i.e. 2.5–4 m depth range) and middle (i.e. 1.5–2.5 m depth range) depths of the aquarium prior to the active taking of food and did not changed their position during the period of feeding which lasted 40 min on average (range 30–60 min; 40 ± 7.1). After the completion of active food intake, the sturgeon primarily swam at medium depth for other period of time. The exception was active swimming near the bottom (i.e. 0–1 m

Table 2
Growth performance of F1-2005, F1-2001 and F1-1997 captive bred Chinese sturgeon

Indicated group	Sampling date	N	Total length (cm)		Total weight (kg)	
			Mean ± SE	CV%	Mean ± SE	CV%
F1-2005	Jan-06	15	15.53 ± 0.77	4.96	0.02 ± 0.002	11.64
	Feb-06	15	27.27 ± 1.14	4.18	0.10 ± 0.01	7.94
	Mar-06	15	40.30 ± 2.88	7.15	0.24 ± 0.03	15.74
	May-06	15	39.07 ± 2.75	7.04	0.26 ± 0.05	18.57
	Jun-06	15	53.90 ± 1.97	3.65	0.58 ± 0.06	10.00
	Jul-07	15	115.33 ± 4.14	3.59	8.73 ± 0.74	8.47
F1-2001	Apr-05	23	119.11 ± 2.57	2.16	12.24 ± 1.11	9.07
	Jul-05	20	129.20 ± 2.28	1.76	13.80 ± 0.71	5.14
	Oct-05	23	137.70 ± 1.52	1.10	–	–
	Feb-06	23	145.78 ± 2.13	1.46	–	–
	May-07	23	160.72 ± 3.41	2.12	25.35 ± 2.10	8.28
F1-1997	Apr-05	2	187.32 ± 1.32	0.70	35 ± 0	0.00
	Jun-05	2	187.32 ± 1.32	0.70	40.00	–
	Aug-07	1	260.00	–	99.50	–

N, number of fish.

Table 3
The swimming behaviour of wild caught Chinese sturgeon (n = 5) in a large public aquarium with respect to depth positioning

Indicated fish	Ordinary depth (distance from tank bottom, m)	Feeding depth (distance from tank bottom, m)
W1#	2.0–4.0	0.1–1.0, ascending to upper depth level after taking some food
W28#	2.0–2.5	0.1–0.3
W29#	3.0–4.0	0.1–0.3
W31#	1.5–2.0	0.1–0.3
W32#	2.0–2.5	0.1–0.3

depth range) of the aquarium during the period of feeding. Summary information about depth use by the individual sturgeon is presented in Table 3.

Behavioural observations of the two F1-1997 sturgeon showed a primary depth use of 1.5–2 m (85.3% of total observations), but descended to a depth of 0.5–1 m during feeding (i.e. for about 30–50 min), followed by a return to the original depth afterwards. The F1-2001 and F1-2005 stocks exhibited a similar pattern of depth use, in which the lower and bottom parts of the aquarium were primarily used.

Food intake by wild caught specimens. The acclimation to captive feeding by the five wild caught sturgeon was assessed. One fish (W1#) took food actively without the requirement of force feeding, probably due to it having been in captivity since 2004 and having already undergone the acclimation process and force feeding prior to the onset of the study. Three fish, which were captured within the timeframe of the study period, began active feeding after about 20 days of force feeding (W28# and W29# after 21 days; W32# after 19 days). However, one fish (W31#) required 10 months of force feeding before the initiation of active food intake.

During the active feeding process, the wild caught sturgeon required 1–5 min to occupy lower water depths before entering the feeding areas. The fish then reduced water depth gradually while feeding, and finally returned to normal depth use within 15 min after the feeding frenzy. When feeding, the fish remained close to the diver handing out food, and maintained a distance of about 0.5–1 m from adjacent fish, at which distance no reaction from or to the other fish was noted.

Prey preference. The wild caught sturgeon showed certain selectivity towards different food items when offered a range of 13 different species. The sturgeon preferred live fish as prey, Fig. 6 shows the differences in food preference for the 13 live species that were offered. Following acclimation, the wild caught sturgeon appeared to have strong food preferences to live food items, selecting *Hypophthalmichthys molitrix*, *Cyprinus carpio* and *Paralichthys lethostigma* on over 80% of occasions that they were offered. The following species were

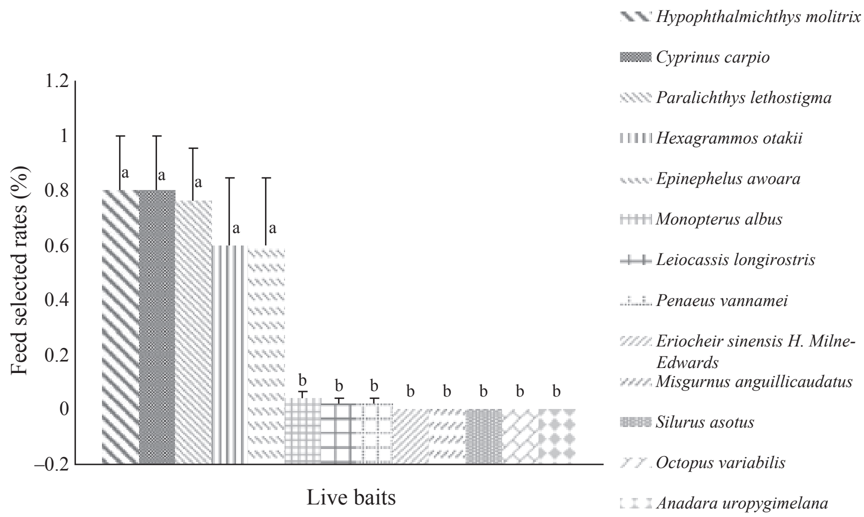

Fig. 6. The feed selected rates of the five wild caught female Chinese sturgeon (n = 5) with respect to the 13 different bait types that were offered

only selected between 15 and 60% of occasions that they were offered; *Hexagrammos otakii* and *Epinephelus awoara*, *Monopterus albus*, *Penaeus vannamei*, *Leiocassis longirostris*. The sturgeon did not take the following fish on any occasion that it was offered; *Eriocheir sinensis* H. *Milne-Edwards*, *Misgurnus anguillicaudatus*, *Silurus asotus* Linnaeus, *Octopus variabilis*, *Anadara uropygimelana*. Occasionally they preferred dead *Paralichthys lethostigma*, *Hypophthalmichthys molitrix*, *Cyprinus carpio*, *Hexagrammos otakii*, *Eriocheir sinensis* H. Milne-Edwards, *Sciaenops ocellatus*.

When the diver offered food to the wild sturgeon, the fish elongated their snout in front of the items (fresh, frozen and artificial bait), appearing to sense the item. Subsequent to this action, the following behavior patterns were observed: (i) swallow the food item directly; (ii) swallow the food item after chewing; (iii) spit out the food item after chewing; and (iv) spit out the food item immediately without chewing. The F1-1997, F1-2001 and F1-2005 juvenile stocks ate both natural food and artificial granular diets, exhibiting no food preference behaviour.

Discussion

Development and growth of Chinese sturgeon

In our study, all age groups of the first generation offspring exhibited growth measurements that were much higher than those theoretically calculated for sturgeon in the wild (Anonymous, 1988). For example, sturgeon of 1 year in age are predicted to weigh 1.55 in the wild vs 3.20 kg in our study; at 4 years this figure is 10.35 vs 25.53 kg, respectively; and at 8 years this figure is 34.75 vs 49.09 kg. However, the values obtained in this study were similar to those reported in controlled aquacultures for Chinese sturgeon of about 1 year in age in the Chengdu region (total body length 97.5 cm; total body weight 3.30 kg; Zhao et al., 1997) and slightly larger than the sizes recorded (71.77 cm and 1.96 kg, respectively) by Xiao and Li (1994). It should be noted that the body weight of the Chinese sturgeon that were caught in the wild and transferred directly to Beijing Aquarium increased significantly after the onset of active feeding. In contrast, total body length of the mature females increased slowly, which may be related to the slowing of growth with aging, as is recorded in many species. Water temperature was an important environmental parameter, particularly because fish are poikilothermic. The maintenance of optimal water temperatures in the aquarium (in contrast to replicating seasonal changes and thereby low winter water temperatures) boosted fish growth of the fish, while body weight increases were directly related to both the environment and the high nutrition levels of the food being offered (Yin, 2003).

In addition, the wild caught mature fish showed positive growth trends, for one fish (W1#) the maturation of the ovaries to stage IV (Hu et al., 2007) was recorded, which was recognized by the swelling of the belly and the cessation of food intake. However, subsequent regression of gonad status to stage II (Webb et al., 1999) and complete degeneration was recorded. Several studies have shown that reproductively viable wild sturgeon reach the bayou of Yangtze River between July and August, then migrate for 16 months. In addition, Doroshov et al. (1997) found that subsequent spawning events by *Acipenser transmontanus* occurred at almost identical times of the season. During this period the sturgeon cease all food intake (Anonymous, 1988; Wei et al., 1997). Hence, the captive female (W1#) followed a consistent seasonal pattern with respect to the onset of ovarian development (i.e. in August) and fasting behaviour. A number of factors may modify the functioning of reproductive growth hormones, in turn affecting energy storage, such as nutrition, metabolic rate and hormone actions (Lin, 1996). For example, the hypothalamus–pituitary–gonad axis adjusts the reproductive endocrine system of the sturgeon. Hence, age, body size, and seasonality may contribute towards inducing the hypothalamus to release GnRH. Subsequently, GnRH induces the pituitary release hormone GtH, which in turn boosts the development of the ovaries (Doroshov et al., 1997).

In the current study, the female (W1#) was housed in an artificial environment, in which a constant water temperature (21–24°C) was maintained, hence resulting in the growth compared to the conditions in the natural environment, in which the sturgeon would experience overall annual marine ⁄ freshwater fluctuations of between 16 and 21°C. Furthermore, the aquarium was equipped with a metal halogen lamp that provided constant light, which may also have caused the internal body rhythm of W1# to act as a trigger to induce gonad re-development. In fact, under natural conditions, the spawning cycle of sturgeon generally occurs at approximately 1–10 year intervals (Holcık, 1989), with wild female Chinese sturgeon spawning having been documented at 5–7 year intervals (Chen, 2007). In contrast, sturgeon raised under controlled conditions have been found to require 2 years to regain optimal body condition for reproduction (Williot et al., 1991; Doroshov et al., 1994, 1997), which was supported by our observations of W1# (requiring <2 years) in the current study. The difference in the time required to reach optimal body condition is probably influenced by a combination of external environmental factors, genetic inheritance and physical factors (Doroshov et al., 1997; Lin, 2004). In fact, our study clearly demonstrated that the presence of an abundant food resource and stable environmental conditions were integral towards reducing the period of time required for gonad re-development. Basically, high water temperatures accelerated the rate of the early phase of gonad development, but also accelerated the onset of regression in the later stage (Webb et al., 1999), or possibly degraded gonad quality and fertility rate. More research is required to understand how different temperatures affect gonad maturation.

Depth distribution of Chinese sturgeon

In the present study, differences were found in the depth utilization of individual sturgeon occupying the large aquarium. The Chinese sturgeon is a large fish (up to 4 m in length) that under natural conditions is adept at swimming along the river bed or seabed (Wei et al., 1998). Hence, the limited living space that is available in an artificial landscape may restrict the free space required for swimming, consequently altering the pattern of distribution of individuals that was observed in the aquarium in the current study.

Acclimation of Chinese sturgeon feeding habits

Based on the behavioural observations of this study, it was found that the captive bred Chinese sturgeon juvenile stock adjusted better to the captive environment and hand feeding regimes, than the wild caught Chinese sturgeon. The wild caught fish exhibited higher levels of food selectivity than the captive bred fish reared from hatching. In fact, a number of studies exist demonstrating that the degree of prey selectivity exhibited by fish is influenced by parameters of prey such as size (or age), morphology and activity (Coates, 1980; Magnhagen and Wiederholm, 1982; Yin, 2003). In the current study, the wild caught Chinese sturgeon were observed to 'sense' food that was present in front of the snout by possibly taste or smell, with varied results. From the existing literature, Chinese sturgeon suck food based on electric feeling, whose barbells have little taste buds, which are known to play less role in foraging (Liang, 1996). Hence, Chinese sturgeon could suck any food. However, as food was also observed to be taken into the oral cavity and accepted or rejected, the chemical sense organs in the oropharyngeal cavity may be ultimately responsible for food selection. Establishing food preferences is not easy and requires long-term observations. Hence, the identification of suitable bait that reflects the preferences of each individual fish under natural conditions is a key component in the acclimating these wild caught Chinese sturgeon to the captive environment. In the current study, offering food by divers may have increased the accessibility of the food to the fish which may have also influenced prey choice by the wild caught Chinese sturgeon. In existing studies, age (assumed to be indicated by total body length) has been considered to alter food choice composition (Yin, 2003). In our study, we found that the wild caught Chinese sturgeon almost completely avoided *Penaeus vannamei*, crayfish and mollusks, which differed from the foods selected by younger sturgeon in bayou region (Liu et al., 2006).

In the current study, the wild caught sturgeon required a short time of force feeding before the initiation of active feeding, with the exception of one fish. In general, by the fifth day of force feeding, the wild caught sturgeon occupied the bottom of the tank during forced feeding. This shift in positioning, may indicate improved appetite, however further studies with a larger sample size are required.

In addition, one mature sturgeon (W31#) appeared to exhibit an affinity to the diver, while a slow reaction to the stimulus of diver was observed. The training of individuals plays an important role in the establishment of behavioral acclimation of fish (He, 1996; Liang, 1996). Hence, in the current study, the sturgeon may have developed a positive conditional reflex to force feeding by the diver over time, or just became habituated to the force feeding procedure. On the other hand, the sturgeon exhibited a weak ability to adjust to the wide range of food that was on offer. We strongly suggest that the variability in the behaviour of individuals that are transferred from the wild to captivity requires more detailed study, particularly for application to both conservation and aquaculture.

Conclusions

The current study on the long-term welfare and acclimation of sturgeon originating from the wild and aquaculture, led to the documentation of gonad development and variability of growth parameters in the captive environment of Beijing Aquarium. The carefully regulated environment proved to be a stable and viable habitat, which facilitated the adjustment of wild caught fish to captive conditions, due to the consideration of parameters, such as fish preference, that may contribute to the transition process. In conclusion, our study provides strong support for the ability of wild caught Chinese sturgeon to be held in captivity, which may in time contribute to the repopulation of the species through reintroduction and captive breeding programs.

Acknowledgements

We extend special thanks to Mr. Weiyong Hu, the general manager of Beijing Aquarium and technical team of the aquarium, to Professor Xianliang Zhang, the president of Chinese Academy of Fishery Sciences, and to other members of Conservation of Endangered Fish, Yangtze River Fisheries Research Institute, for there sustainable supports. This study was supported by the Essential Operation Fund of Freshwater Fisheries Research Center, Chinese Academy of Fishery Sciences.

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