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Effects of high water level on the river residence period of juvenile Chinese sturgeon *Acipenser sinensis* in the Yangtze River

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ABSTRACT

Key-words:
Acipenser sinensis, downstream migration, water level, Three Gorges Project

The migration time of newly hatched *Acipenser sinensis* from the spawning area (river km 1675) to the Yangtze estuary (rkm 0) was ascertained in the years 1996–2007 (time range 192–243 days), and its relationship to water levels surveyed at 12 typical hydrological monitoring stations in the middle and lower reaches of Yangtze River was determined. Migration time showed a positive correlation ($R = 0.621–0.738$, $P = 0.013–0.041$) with the water levels surveyed during April at eight stations (from Jianli to Anqing, rkm 1356.2 to rkm 639.4). Stepwise regression analysis indicated that when the water level at a typical station, Luoshan (rkm 1244.2), increased by 1 m, migration time deferred 11.6 days. The high water level created expanded riparian habitat and thus may have prolonged juvenile residence time. This variable residence time due to variations in water flow caused by the Three Gorges Project needs to be addressed, and more investigation is required.

RÉSUMÉ

Effets du niveau des hautes eaux sur la période de résidence en rivière des juvéniles d'esturgeon chinois *Acipenser sinensis* dans le fleuve Yangtsé

Mots-clés :
Acipenser sinensis, dévalaison, niveau de l'eau, projet des Trois Gorges

La période de migration de *Acipenser sinensis* depuis la zone de frai (km 1675) à l'estuaire du Yang Tsé Kiang (km 0) a été observée dans les années 1996–2007 (intervalle de temps : 192–243 jours juliens), et sa relation avec les niveaux d'eau étudiée dans 12 stations de surveillance hydrologique dans les cours moyen et inférieur du fleuve Yangtze. La période de migration est corrélée positivement (R = 0,621 à 0,738, P = 0,013–0,041) avec les niveaux d'eau enregistrés en avril dans huit stations (à partir de Jianli à Anqing, rkm 1356,2 au km 639,4). L'analyse de régression montre que lorsque le niveau d'eau dans une station typique, Luoshan (km 1244,2), augmente de 1 m, le temps de migration est différé de 11,6 jours. Le niveau d'eau élevé crée un habitat rivulaire plus important et permet donc un allongement du temps de séjour des juvéniles. Ce temps de séjour variable influencé par les changements de débit causés par le projet des Trois Gorges doit être étudié, et une recherche plus approfondie est nécessaire.

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INTRODUCTION

The Chinese sturgeon, *Acipenser sinensis*, a large anadromous fish, is distributed mainly in the East China Sea and the main course of the Yangtze River (YARSG, 1988; Wei *et al.*, 1997). Since the 1970s, the population has decreased dramatically due to overfishing and habitat deterioration (Wei *et al.*, 1997; Gao *et al.*, 2009), especially after 1981 when its migration route was blocked by the Gezhouba Dam, the first dam on the Yangtze main course. Since 1989, the fish has been listed as a first-class protected animal in China, and, since 2009, as a critically endangered species in the IUCN red list (Wei, 2009).

The majority of the fish's life is spent at sea (YARSG, 1988; Wei *et al.*, 1997). After about ten years (male ≥ 8 years, female ≥ 14 years), individuals reaching maturation enter the Yangtze estuary (July-August) and swim upstream about 1685 km to mate and spawn in October-November of the following year (Kynard *et al.*, 1995; Yang *et al.*, 2006; Wei *et al.*, 2009). The newly hatched yolk-sac larvae move passively downstream and become distributed along the river (Zhuang *et al.*, 2002). They feed in the river and take refuge there reaching the estuary April-August of the following year (Li *et al.*, 2011). Newly hatched individuals will therefore spend 7–9 months in the river.

Hydroacoustic surveys of the only remaining spawning area below the Gezhouba Dam have reported approximately 200 adult individuals (Qiao *et al.*, 2006), only tens of which spawn successfully (Gao *et al.*, 2006). In the Yangtze estuary, a mark-recapture method and molecular technology showed more than 90% of juveniles to be from natural reproduction, although large numbers of artificially produced juveniles have been released into the river annually (Zhu *et al.*, 2002; Yang *et al.*, 2005). Thus, a thorough knowledge of the freshwater life history of *A. sinensis* is critical to preserving and rehabilitating the wild population.

Studies of the seaward migration of juveniles have focused on the quantity and size of juveniles found in the estuary as well as the time spent there (Li *et al.*, 2011) and on the ontogenetic behavior of the fish (Zhuang *et al.*, 2002). The latter have revealed that almost all embryos cease migrating after 8 days (Zhuang *et al.*, 2002), implying that they disperse in the middle reaches of the river for refuge and feeding. However, the time at which juveniles resume their seaward migration and whether and how environmental factors influence this migration are unknown.

The objective of this study was to provide further information on the seaward migration of *A. sinensis* juveniles by analyzing the duration from hatching in the spawning area to reaching the estuary, relative to water levels of the middle and lower reaches of the Yangtze River.

MATERIALS AND METHODS

> *STUDY AREA*

With the completion of the Gezhouba Dam in 1981, the migration route of *A. sinensis* to the historic spawning areas in the upper Yangtze River and lower Jinsha River was blocked, and fish were restricted to the middle and lower reaches of the Yangtze River (~1675 km river length, river km 0 is at the estuary) (Figure 1) (Wei *et al.*, 1997). These reaches flow through foothills or plains with many lakes and tributaries with point bars and islets of varying size in the river (Yu and Lu, 2005). Most of the river channels are 1000–3000 m wide and 10–40 m deep (Chen *et al.*, 2007), with riverbed gradients of 0.579×10^{-4}–0.097×10^{-4} (Yu and Lu, 2005). The average annual water levels during 1950-2000 at Yichang and Datong stations were 43.83 m (daily mean range 38.30–55.73 m) and 8.74 m (daily mean range 3.14–16.64 m), respectively, with flow rates of 13 900 $m^3 \cdot s^{-1}$ (daily mean range 2770–70 800 $m^3 \cdot s^{-1}$) and 28 700 $m^3 \cdot s^{-1}$ (daily mean range 4620–92 600 $m^3 \cdot s^{-1}$). Silt concentration was measured at 1.14 $kg \cdot m^{-3}$ (daily mean maximum 10.5 $kg \cdot m^{-3}$) and 0.486 $kg \cdot m^{-3}$ (daily mean maximum 3.24 $kg \cdot m^{-3}$), respectively (Yu and Lu, 2005). The flow velocity at most of the reaches is 1.0–1.5 $m \cdot s^{-1}$ (Chen *et al.*, 2007). Both the river channel and river banks are heavily used by

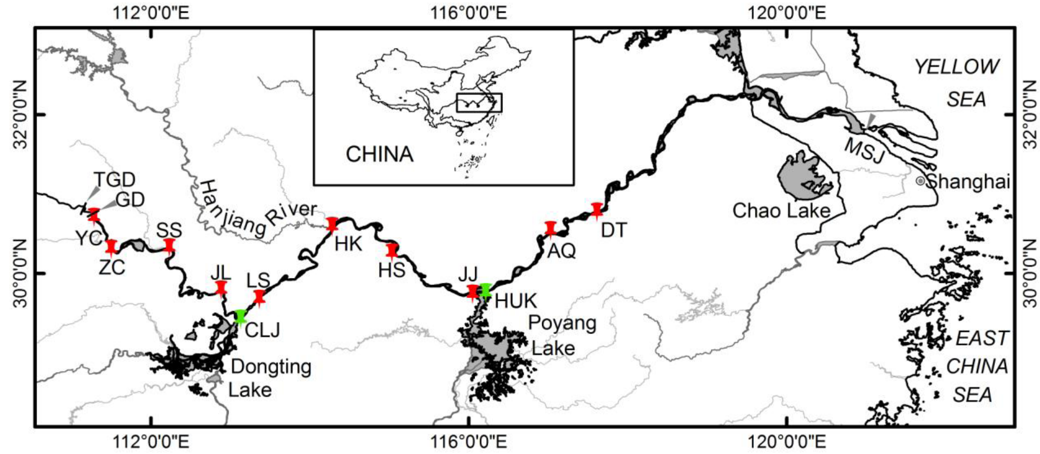

Figure 1

Locations of 12 hydrological monitoring stations in the middle and lower reaches of Yangtze River. TGD: Three Gorges Project, GD: Gezhouba Dam. Stations in the mainstream: YC: Yichang, ZC: Zhicheng, SS: Shashi, JL: Jianli, LS: Luoshan, HK: Hankou, HS: Huangshi, JJ: Jiujiang, AQ: Anqing, DT: Datong. Stations in the tributaries: CLJ: Chenglingji, HUK: Hukou. MSJ: monitoring site of juvenile Acipenser sinensis.

humans for navigation, fishing, sand extraction, and habitation. It is one of the most intensely exploited areas in China.

> *SAMPLING OF JUVENILE* A. SINENSIS *AT THE YANGTZE ESTUARY*

The sampling site at Xupu reach, Changshu City (Figure 1) is located in the Yangtze estuary and is a route that the juveniles must pass. This reach is comparatively narrow, making the density of juveniles higher than in other areas, and, before a fishing ban was enacted in 2002 in the Yangtze River, sturgeon juveniles were caught as a by catch mainly with deep water frame swing nets. Wei (2003) summarized the capture records of sturgeon juveniles at Xupu reach from 1986–2002.

From 2002 to 2007, a set net was installed at the same site to monitor juveniles from the upstream reaches (Figure 1). The net was 2377 m long, 750 m wide, and 4 m deep. The effective net height varied with water levels; however, it was usually 2.5 m. The net comprised 16 net bags of 4 cm mesh size (measured from knot to knot). The net was checked daily, except in extremely bad weather; the fish were counted, measured (total length and standard length), weighed, and released. Injured fish were transported to the rescue center for rehabilitation prior to releasing. Li *et al.* (2011) reported detailed monitoring results during 2002–2009.

The sample numbers during the two periods were different, >1000 compared to 20–718 individuals (Wei, 2003; Yang *et al.*, 2005; Li *et al.*, 2011). The decrease in numbers can be attributed chiefly to the reduction in sampling nets; however, a decline in population may have contributed (Gao *et al.*, 2009). As the number captured in 2003 was 718 (close to pre-2002 numbers), the single monitoring net of 2377 m long located in a relatively narrow reach may have been sufficient for sampling purposes. Both pre- and post-2002, the capture effort in each year was regarded as stable, thus the largest sampled number was seen as suitable to represent the peak time for juveniles reaching the estuary.

For each year from 1997 to 2007, to identify the peak time for juveniles reaching the estuary, we divided each of the months April-August into three periods: the first 10 days, the second 10 days, and final 10 or 11 days. Computing peak time over a period of ten days reduced sampling error.

> MONITORING OF WATER LEVEL

Twenty hydrological monitoring stations have been installed in the main course of the middle and lower reaches of the Yangtze River by the Yangtze Water Resources Commission (YWRC). Water levels along the Yangtze River were surveyed daily at 8:00 by the YWRC as prescribed by the Water Survey Standards (GBJ 138-90, GB/T50138-2010) issued by the Chinese government. In this study, 12 stations located above or below a tributary or lake confluence were selected for conducting the analysis. Data for the study period of 1997–2007 for 12 hydrological monitoring stations along the middle and lower reaches of Yangtze River (Figure 1) was obtained from the Data Sharing Center of China Water Resources (http://www.hydrodata.gov.cn). While erosion and deposition may cause some systematic deviation in the water levels, according to Guo *et al.* (2006) and Luan *et al.* (2009), this deviation was comparatively small and can be ignored in this study.

> DATA ANALYSIS

Currently, any relationship between the duration of migration and water level is unknown. In order to explore the relationship, a Pearson correlation was used for analysis, based on general knowledge of this species and some assumptions. For instance, as the fish spend 7–9 months (from Dec. 1 to Jun. 30 of the following year) in the river, in 1997–2007, at the 10 hydrological monitoring stations in the main course of the middle and lower reaches of Yangtze River, the mean water level in this period was first calculated to explore its relationship with migration time. As all embryos cease migrating 8 days after hatching and resume their seaward migration at a later time, we speculated that the water levels in the spring (March/April) is more important and analyzed its relationship with the migration time.

After significant correlations were found among Luoshan and the five stations downstream of it, Luoshan was regarded as a suitable station for analyzing the correlations between migration time and water level. In order to reveal further information about the relationship between migration time and water level at Luoshan during April (WLLA), five characteristic indices were tentatively proposed to describe the water level status, including the Max_{WLLA}, $\text{Mean}_{\text{WLLA}}$, Min_{WLLA}, $\text{Max-Min}_{\text{WLLA}}$ (maximum minus the minimum), and $\text{Increase}_{\text{WLLA}}$ (the water level on April 30 minus the water level on April 1, divided by 30 days). Then stepwise regression was further used to ascertain the significance of the indices.

Pearson correlation and stepwise regression methods were used to examine relationships between water level and migration time (SPSS, version 16.0). Pearson correlation (Test of significance, $P < 0.05$) was used to measure the strength of linear dependence between migration time and water level or among water levels. Stepwise regression (use probability of F, Entry: ≤ 0.05, Removal: ≥ 0.10) adds and removes indices to the regression model to identify a useful subset for predicting migration time. Lastly, ANOVA (F-test) was used to test the significant ($P < 0.05$) of the model.

RESULTS

> MIGRATION TIME TO THE YANGTZE ESTUARY

The period with the maximum number of fish captured was regarded as the peak arrival time. The spawning date of the previous year was obtained from Wei (2003), Wei *et al.* (2009) and unpublished data to calculate the duration of migration from the spawning area to the estuary (Table I). Annual peak time for juveniles reaching the estuary occurred between May 11 and June 30 (ranged from 192 to 243 Julian days), with migration speed estimated at 6.89–8.72 $\text{km}\cdot\text{day}^{-1}$. This suggested that the seaward migration behavior of the juveniles differed among the years monitored.

Table I
Seaward migration time and speed of Chinese sturgeon juveniles from the remaining spawning area (river km 1675) to the estuary (river km 0) in the Yangtze River from 1996–2007.

Year	Spawning date*	Period of maximum sampling at the estuary the following year	Migration time (days)**	Downstream migration speed (km·day^{-1})
1996	Oct. 20	Last 11 days of May	218	7.68
1997	Oct. 22	First 10 days of June	227	7.38
1998	Oct. 26	Second 10 days of May	202	8.29
1999	Oct. 27	Last 10 days of June	243	6.89
2000	Oct. 15	Last 11 days of May	223	7.51
2001	Oct. 20	First 10 days of June	229	7.31
2002	Oct. 27	Last 11 days of May	211	7.94
2003	Nov. 6	Second 10 days of May	192	8.72
2004	Nov. 12	Second 10 days of June	216	7.75
2005	Nov. 10	Second 10 days of June	218	7.68
2006	Nov. 13	Last 11 days of May	194	8.63

* First spawning date was used to calculate migration time (Wei, 2003; Wei *et al.*, 2009); ** the three periods in each month use day 5, 15, and 25 to calculate migration time, respectively.

> RIVER WATER LEVEL

From 1997 to 2006, spawning of Chinese sturgeon took place during a period from Oct. 15 to Nov. 13 (Table I). Usually, the newly fertilized eggs required about 5 days before hatching into free embryos and beginning a downstream dispersal from the spawning-egg rearing reach (Wei *et al.*, 2009). The peak time for juveniles arriving at the estuary the following year was a period from the second 10 days of May to the final 10 days of June (Table I). Thus, a period from Dec 1 to Jun 30 of the following year was considered the time range that hydrological status may influence seaward migration. From Yichang to Datong, on average, the water level decreased from 40.69 m (39.16–41.48 m) to 7.19 m (5.53–9.06 m), a decrease of about 33.5 m (Table II).

> CORRELATIONS BETWEEN DURATION OF MIGRATION AND WATER LEVEL

The correlation between annual migration time of juveniles from the only remaining spawning area to the estuary (Table I) and the water level at the 10 monitoring stations (Table II) was ascertained by Pearson correlation (Table III). All correlation coefficients were below 0.5, with the highest correlation observed at Luoshan station. In general, except for Zhicheng and Anqing stations, the coefficients of the stations from Yichang to Datong showed wider variations than Luoshan. Upstream of Luoshan, the correlation coefficients were approximately 0.2–0.3 (except for Zhicheng), and below it the coefficients were higher than 0.4 (except Anqing).

> CORRELATION OF WATER LEVELS AMONG THE 10 STATIONS

Since the correlation between migration and water level varied among the 10 stations, it was necessary to ascertain the relationship among stations. Pearson correlation shows that

Table II
Mean water level (m) during a period from Dec. 1 to Jun. 30 of the following year (n = 11) and statistical characteristics (Max., Mean ± S.D. and Min.) at 10 hydrological monitoring stations (Figure 1) along the mainstream of the middle and lower reaches of the Yangtze River, from 1997–2007.

Period	Yichang	Zhicheng	Shashi	Jianli	Luoshan	Hankou	Huangshi	Jiujiang	Anqing	Datong
Jan. 1, 1997–Jun. 30, 1997[*]	40.82	40.06	33.60	27.87	22.67	17.65	15.36	13.05	9.02	7.17
Dec. 1, 1997–Jun. 30, 1998	40.30	38.88	32.94	27.06	23.49	18.77	15.96	14.16	10.83	9.06
Dec. 1, 1998–Jun. 30, 1999	41.21	38.85	33.21	25.91	21.36	16.48	13.36	11.14	8.01	6.48
Dec. 1, 1999–Jun. 30, 2000	41.36	38.98	33.39	26.27	22.18	17.09	13.77	11.55	7.02	6.90
Dec. 1, 2000–Jun. 30, 2001	40.86	38.48	33.41	26.52	22.40	17.70	14.32	12.09	8.96	7.40
Dec. 1, 2001–Jun. 30, 2002	41.48	39.25	34.05	27.38	22.80	18.02	14.43	12.16	8.97	7.57
Dec. 1, 2002–Jun. 30, 2003	40.12	38.38	32.51	26.65	23.13	18.32	15.00	12.85	9.65	8.11
Dec. 1, 2003–Jun. 30, 2004	40.94	39.07	33.27	26.45	21.71	16.82	13.15	10.82	7.68	6.34
Dec. 1, 2004–Jun. 30, 2005	40.86	39.07	33.41	27.07	22.70	17.70	14.26	11.97	8.79	7.30
Dec. 1, 2005–Jun. 30, 2006	40.45	38.76	32.87	26.66	22.21	17.29	14.03	11.74	8.60	7.24
Dec. 1, 2006– Jun. 30, 2007[*]	39.16	37.76	31.19	24.93	20.17	15.02	11.54	9.41	6.62	5.53
Max.	41.48	40.06	34.05	27.87	23.49	18.77	15.96	14.16	10.83	9.06
Mean ±S.D.	40.69 ±0.66	38.87 ±0.57	33.08 ±0.74	26.62 ±0.78	22.26 ±0.92	17.35 ±1.01	14.11 ±1.19	11.90 ±1.25	8.56 ±1.19	7.19 ±0.93
Min.	39.16	37.76	31.19	24.93	20.17	15.02	11.54	9.41	6.62	5.53

[*] Lacking data before Jan. 1, 1997 and after Apr. 26, 2007.

Table III
Pearson correlations between migration time of juvenile Chinese sturgeon from the only remaining spawning area to the Yangtze estuary (Table I) and water level (mean from Dec. 1 to Jun. 30 of the following year) at each monitoring station along the main course of middle and lower reaches of Yangtze River (Table II), in 1998–2006 (n = 9).

Station	Yichang	Zhicheng	Shashi	Jianli	Luoshan	Hankou	Huangshi	Jiujiang	Anqing	Datong
Correlation (*P*, 2-tailed)	0.205 (0.597)	0.093 (0.812)	0.296 (0.440)	0.327 (0.390)	0.462 (0.211)	0.404 (0.281)	0.420 (0.261)	0.410 (0.273)	0.092 (0.814)	0.414 (0.268)

Luoshan was located at a boundary (Table IV). For Luoshan and the five downstream stations, the water levels showed significant correlation with other stations, although tributaries, such as the Hanjiang River, and large lakes, such as Poyang Lake, flow into the main course (Figure 1). No significant correlations were found among the four stations upstream of Luoshan, except between Yichang and Shashi, or with the six stations downstream.

> CORRELATIONS BETWEEN MIGRATION TIME AND WATER LEVEL AT THE LUOSHAN STATION DURING MARCH AND APRIL

As the water level at Luoshan had the highest relationship with the duration of migration from the spawning area to the estuary (Table III) and the correlation boundary of water levels occurred at Luoshan (Table IV). Luoshan was selected as a key and typical station. As May/June was the major time for juveniles reaching the estuary, we speculated that water levels in March/April should be important to migration. A Pearson correlation was computed between the migration time and the water level at Luoshan during March/April (Table V). This shows that the correlation ($R = 0.636$, $P = 0.035$) with the water level during March/April was more positively correlated than was the entire period from Dec. 1 to Jun. 30 ($R = 0.462$, $P = 0.2$; Table III). The water level during April seemed to have the most influence, as it showed the highest correlation coefficient ($R = 0.719$, $P = 0.013$) with migration time of juveniles from the spawning area to the estuary.

The relationship of migration time with water levels during April at 12 stations (Chenglingji and Hukou, respectively representing Dongting and Poyang Lakes were added) was studied further (Table VI). It revealed that migration time had a positive correlation ($R = 0.621$–0.738, $P = 0.013$–0.041) with the water levels surveyed at eight stations (Jianli to Anqing, rkm 1356.2 to rkm 639.4), covering a river stretch of about 716.8 km.

Figure 2 shows variation in water levels at Luoshan during March/April. The five indices (Max_{WLLA}, $\text{Mean}_{\text{WLLA}}$, Min_{WLLA}, $\text{Max-Min}_{\text{WLLA}}$, and $\text{Increase}_{\text{WLLA}}$) and their correlation between migration time were determined in Table VII. Table VII shows that the $\text{Mean}_{\text{WLLA}}$ was the only factor having a significant correlation ($R = 0.719$, $P = 0.013$) with migration time. The Max_{WLLA} ($R = 0.478$, $P = 0.137$) and Min_{WLLA} ($R = 0.501$, $P = 0.117$) had high correlation coefficients, but not significant. The variation in water level ($\text{Max-Min}_{\text{WLLA}}$ and $\text{Increase}_{\text{WLLA}}$) did not show a large influence on migration behavior ($R = 0.076$, $P = 0.825$; $R = 0.026$, $P = 0.940$). Stepwise regression also showed that the mean water level in April was a key factor in determining the migration time from the spawning area to the estuary (Table VIII).

DISCUSSION

This study showed that the migration time of sturgeon juveniles from spawning area to the estuary has a significant positive correlation with water levels surveyed at eight stations (from Jianli to Anqing, rkm 1356.2 to rkm 639.4) (Table VI). We concluded that the water level in the 639.4 km river reach between Jianli and Anqing was probably a key factor affecting migration behavior. High water levels mean that sturgeon juveniles tend to stay longer in the river. The high water levels may provide expanded riparian habitat, which has a major impact on the

Table IV

Pearson correlations of water levels (mean from Dec. 1 to Jun. 30 of the following year, Table II) among the 10 hydrological monitoring stations along the main course of middle and lower reaches of Yangtze River, from 1998–2006 (n = 9).

Station	Yichang	Zhicheng	Shashi	Jianli	Luoshan	Hankou	Huangshi	Jiujiang	Anqing	Datong
Yichang	1									
Zhicheng	0.656 (0.055)	1								
Shashi	0.873** (0.002)	0.707* (0.033)	1							
Jianli	–0.141 (0.718)	0.336 (0.376)	0.307 (0.422)	1						
Luoshan	–0.530 (0.142)	–0.170 (0.663)	–0.184 (0.635)	0.767* (0.016)	1					
Hankou	–0.544 (0.130)	–0.220 (0.570)	–0.178 (0.647)	0.756* (0.018)	**0.987**** (0.000)	1				
Huangshi	–0.605 (0.085)	–0.284 (0.460)	–0.303 (0.428)	0.616 (0.078)	**0.945**** (0.000)	0.960** (0.000)	1			
Jiujiang	–0.601 (0.087)	–0.277 (0.471)	–0.324 (0.396)	0.567 (0.112)	**0.919**** (0.000)	0.936** (0.000)	0.996** (0.000)	1		
Anqing	–0.676* (0.046)	–0.317 (0.406)	–0.334 (0.380)	0.604 (0.085)	**0.829**** (0.006)	0.886** (0.001)	0.921** (0.000)	0.914** (0.001)	1	
Datong	–0.619 (0.076)	–0.282 (0.462)	–0.319 (0.403)	0.616 (0.077)	**0.941**** (0.000)	0.958** (0.000)	0.998** (0.000)	0.995** (0.000)	0.921** (0.000)	1

* Correlation is significant at $P < 0.05$ (2-tailed).
** Correlation is significant at $P < 0.01$ (2-tailed).

Table V
Correlation between migration time of juveniles from spawning area to the estuary (Table I) and the water level of Luoshan during March–April, in 1997–2007 (n = 11).

Year	March–April	March	April
1997	22.15	20.71	23.88
1998	23.18	23.31	23.05
1999	19.50	17.99	21.05
2000	22.38	21.60	23.06
2001	21.40	20.47	22.43
2002	22.14	21.72	22.56
2003	22.49	22.18	22.80
2004	21.08	20.50	21.68
2005	21.84	21.62	22.08
2006	22.61	22.57	22.66
2007	20.97	21.32	20.56
Max.	23.18	23.31	23.88
Mean ± SD	21.80 ± 1.01	21.27 ± 1.39	22.35 ± 0.95
Min.	19.50	17.99	20.56
Correlation (*P*, 2-tailed)	**0.636*** (0.035)	0.429 (0.188)	**0.719*** (0.013)

* Correlation is significant at the 0.05 level (2-tailed).

migration speed of the fish, as reported in a study of Siberian sturgeon, *A. baerii* (Gisbert and Ruban, 2003). Juvenile Chinese sturgeon forages on benthic organisms, such as small Crustacea and small fishes (YARSG, 1988). These prey likely live in riparian habitats (Luo *et al.*, 2011), and if so, an expanded riparian habitat could provide additional foraging grounds for juveniles. Table VIII indicates that when the water level increases 1 m, the duration that juveniles remain in the river increased 11.6 days.

Stock enhancement using cultured juvenile Chinese sturgeon was done every year of the study. Each year, timing and site of stocking varied as did the mean size of fish. However, cultured fish were only <10% of the total number of juveniles and the migration behavior of cultured individuals is similar to behavior of natural individuals (Zhu *et al.*, 2002; Yang *et al.*, 2005); thus, we speculate stock enhancement had little effect on the results of the present study.

In recent years (2009–2010), many juveniles were captured as a by catch in Luoshan reaches over the course of the entire year (Wei *et al.*, 2009). The altered flow regime caused by the operation of the Three Gorges Project was the likely reason (Fu *et al.*, 2010). From January 1 to June 10, the water in the Three Gorges Reservoir was released, raising the water level in the downstream area much higher than before the dam was constructed (Fu *et al.*, 2010). The increased water levels during this period may have resulted in the fish staying longer in the river, and some fish may become disoriented and cease migration to the sea. Nothing is known about the long-term harmful effects of river discharge manipulation on river residence on juveniles, which needs much additional study.

Table VI

Water level (mean during April) at the 12 hydrological monitoring stations (Figure 1) along the middle and lower reaches of Yangtze River, and relationship to the migration time (Table I), by Pearson correlation analysis, in 1998–2006 (n = 9, 10, 11).

Station	Yichang	Zhicheng	Shashi	Jianli	Chenglingji	Luoshan	Hankou	Huangshi	Jiujiang	Hukou	Anqing	Datong
1997	40.69		33.66		25.31	23.88	18.95			12.64		8.18
1998	39.67	38.31	32.50	26.40	24.07	23.05	18.75	16.06	14.11	13.64	10.94	9.41
1999	40.36	38.17	32.15	25.07	22.10	21.05	16.20	13.12	11.27	10.68	8.32	6.80
2000	41.07	38.74	33.44	26.65	24.12	23.06	17.74	14.41	12.18	11.37		7.35
2001	40.07	38.05	32.70	26.18	23.60	22.43	17.62	14.21	12.06	11.55	8.91	7.45
2002	40.52	38.53	33.31	26.85	23.94	22.56	17.65	14.18	12.03	11.45	8.87	7.40
2003	39.75	38.05	32.19	26.21	23.83	22.80	18.10	14.82	12.86	12.06	9.65	8.20
2004	40.47	38.68	32.99	26.26	22.86	21.68	16.65	12.94	10.68	9.91	7.57	6.26
2005	40.23	38.59	32.98	26.51	23.35	22.08	17.00	13.58	11.33	10.69	8.18	6.82
2006	39.83	38.29	32.43	26.60	23.98	22.66	17.68	14.46	12.43	11.93	9.25	7.78
2007	39.76	38.18	31.96	25.44	21.86	20.56	15.44	12.10	10.11	9.51	7.33	6.14
Max.	41.07	38.74	33.66	26.85	25.31	23.88	18.95	16.06	14.11	13.64	10.94	9.41
Mean ± SD	40.22 ±0.45	38.36 ±0.26	32.76 ±0.57	26.22 ±0.56	23.55 ±0.98	22.35 ±0.95	17.44 ±1.05	13.99 ±1.11	11.91 ±1.14	11.40 ±1.19	8.78 ±1.11	7.44 ±0.95
Min.	39.67	38.05	31.96	25.07	21.86	20.56	15.44	12.10	10.11	9.51	7.33	6.14
Correlation (*P*, 2-tailed)	0.354 (0.285)	0.269 (0.452)	0.542 (0.085)	0.676* (0.032)	0.689* (0.019)	0.719* (0.013)	0.665* (0.025)	0.706* (0.022)	0.656* (0.039)	0.621* (0.041)	0.738* (0.023)	0.570 (0.067)

* Correlation is significant at $P < 0.05$ (2-tailed).

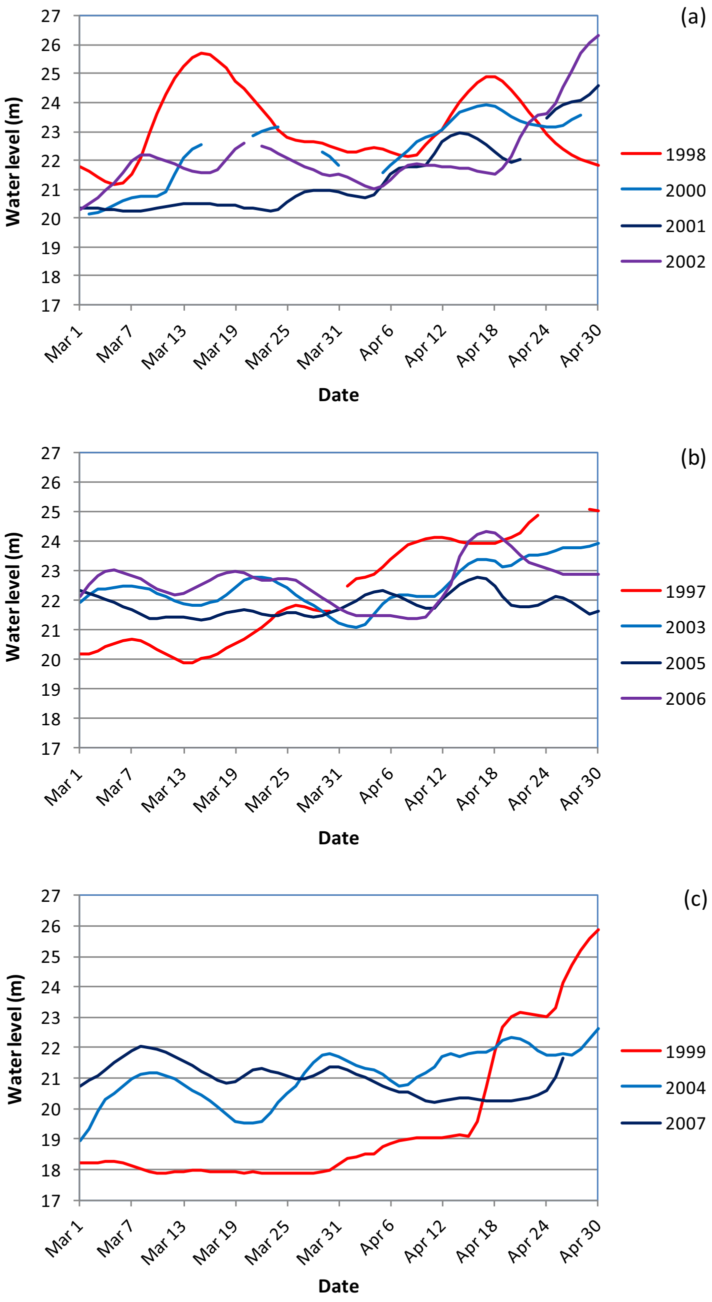

Figure 2
Water level at Luoshan station during March/April of 1997–2007, three subfigures are indicated respectively based on the duration of migration of juveniles from spawning area to the estuary (Table I), (a) 223–243 days, (b) 211–218 days, (c) 192–202 days.

It has been documented that the migration behavior of sturgeon species can be affected by many environmental variables, including water temperature (Rochard *et al.*, 2001; Caroffino *et al.*, 2009) and flow rate (van der Leeuw *et al.*, 2006). In our study, we did not have a complete data set for these environmental variables; thus, water level (which is related to river discharge) was the factor selected to address relationship between migration behavior and hydrological status. Although flow rate and velocity can be directly impacted by water level, they do not show a strict correlation, especially in such a huge and complicated lake-river system as the Yangtze River (Guo *et al.*, 2006; Luan *et al.*, 2009). Hence this study did not

Table VII
Pearson correlation among five characteristic indices of water level at Luoshan during April (WLLA) and the migration time of juveniles from spawning area to the estuary (Table I), in 1997–2007 (n = 11). Max-Min$_{WLLA}$ indicates maximum minus the minimum. Increase$_{WLLA}$ indicates the water level on April 30 minus the water level on April 1, divided by 30 days.

Index	Max$_{WLLA}$ (m)	Mean$_{WLLA}$ (m)	Min$_{WLLA}$ (m)	Max-Min$_{WLLA}$ (m)	Increase$_{WLLA}$ (m)
1997	25.07	23.88	22.46	2.61	0.09
1998	24.91	23.05	21.82	3.09	–0.02
1999	25.88	21.05	18.34	7.54	0.25
2000	23.93	23.06	21.39	2.54	0.08
2001	24.57	22.43	20.69	3.88	0.12
2002	26.30	22.56	21.03	5.27	0.16
2003	23.95	22.80	21.07	2.88	0.09
2004	22.65	21.68	20.76	1.89	0.04
2005	22.76	22.08	21.55	1.21	–0.01
2006	24.35	22.66	21.38	2.97	0.04
2007	21.68	20.56	20.20	1.48	0.02
Max.	26.30	23.88	22.46	7.54	0.25
Mean ± S.D.	24.19 ± 1.40	22.35 ± 0.95	20.97 ± 1.06	3.21 ± 1.82	0.08 ± 0.08
Min.	21.68	20.56	18.34	1.21	–0.02
Correlation (*P*, 2-tailed)	0.478 (0.137)	**0.719**[*] (0.013)	0.501 (0.117)	0.076 (0.825)	0.026 (0.940)

[*] Correlation is significant at $P < 0.05$ (2-tailed).

Table VIII
Stepwise regressions between five characteristic indexes (Max$_{WLLA}$, Mean$_{WLLA}$, Min$_{WLLA}$, Max-Min$_{WLLA}$, and Increase$_{WLLA}$, described in Table VII) of water level at Luoshan during April and the time expense of juveniles from spawning area to the estuary (Table I), in 1997–2007.

Model [*]	Variables entered	Variables removed	Excluded variables	Regression equation	*R*	*P*
Step 1	Mean$_{WLLA}$		Max$_{WLLA}$, Min$_{WLLA}$, Max-Min$_{WLLA}$, Increase$_{WLLA}$	= –42.857 + 11.571 × Mean$_{WLLA}$	0.719	0.013

[*] Criteria: Probability-of-*F*-to-enter ≤0.050, Probability-of-*F*-to-remove ≥0.100.

clearly reveal how flow rate and velocity affect the sea-ward migration of the fish. Moreover, other environmental variables, such as water temperature and turbidity, were not considered. So this study just revealed that the water level was one of the factors affecting the seaward migration of the Chinese sturgeon.

The operation of the Three Gorges Project has greatly altered the downstream abiotic environment with respect to hydrograph components, thermal regime, turbidity, riparian quality, and relationships among river system areas (Fu *et al.*, 2010) and will continue to do so.

The study revealed that water level was one factor affecting seaward migration. However, the multifaceted and cumulative effects of the environmental alterations on the migration of sturgeon are still unknown. Further study should focus on the freshwater history of the fish, in addition to natural reproduction activity in the spawning area (Yang *et al.*, 2006, 2007; Wei *et al.*, 2009; Zhang *et al.*, 2009, 2011) and seaward migration along the 1675 km river reach are also critical. Moreover, behavior cues and other biological variations which are potentially altered by the operation of the Three Gorges Project should be addressed.

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