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RESEARCH PAPER

Hydrological Status of the spawning ground of *Acipenser sinensis* underneath the Gezhouba Dam and its relationship with the spawning runs

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Abstract: The spawning runs of Chinese Sturgeon (CS; *Acipenser sinensis*) were observed 37 times below Gezhouba Dam of Yangtze River between 1983 and 2004. Five hydrological factors (water temperature, water level, flow discharge, silt content and current velocity) were monitored on a daily basis at the spawning ground between October and November for 22 consecutive years (1983–2004). The effect of current velocity on the spawning ground at the bottom layer of the river, where CS was spawning for four years, was measured (1996–1999). The authors of this study analyzed the relationship between the five hydrological factors and the respective spawning runs. Twenty-two years of continuous observations indicated that the daily mean values of all the five hydrological factors fluctuated within a certain range when CS was spawning. It was concluded that the optimal values for the hydrological factors during the spawning runs are 18.0–20.0℃ for temperature, 14100 m^3/s for discharge volume, 42.0–45.0 m for water level above the sea level, and 0.2–0.3 kg/m^3 for silt content in the water, wherein the current velocity above the bottom layer to stimulate the fish to spawn should be between 1.0–1.7 m/s. The optimal water temperature might provide an essential precondition for other factors to trigger spawning. As water temperature reaches the optimal values and most of the other parameters are at the brink of deviation from their optimal range of values (water level, current velocity and silt content in the water), CS would begin to spawn. By 2009, when the Yangtze Three Gorges Project, which is located 45 km upstream of the Gezhouba Dam, is completed and begins to operate normally, changes in the downstream water temperature are expected to occur, which may have a negative effect on the development of gonad and the stimulation of spawning of CS; however, the anticipated decrease of the silt content in the water may be considered favorable for the performance of the spawning site.

Key Words: *Acipenser sinensis*; spawning; hydrological condition; hydroelectric dam; Yangtze River

The Chinese Sturgeon (CS), *Acipenser sinensis* Gray, is an anadromous fish. Before the construction of the Gezhouba Dam, the spawning grounds of the CS were mainly distributed in from Laojuntan of lower Jinsha River to Hejiang city of upper Yangtze River, covering about 600 km in length[1]. As a result of the construction of Gezhouba Dam in 1981, the upstream spawning migration route was blocked. However, in 1982, the natural reproduction of *A. sinensis* was observed underneath the dam. Their spawning grounds were primarily distributed in the section from the Gezhouba Dam to Gulaobei Dam, about 30 km long[2–5]. After 1995, Wei *et al*. concisely confirmed the position of the spawning grounds using ultrasonic telemetry and track technology. The spawning grounds were 7 km long and were distributed in the main channel of the Yangtze River, from 860 m downstream of the Dajiang Power Plant of Gezhouba Dam to 1.5 km upstream of the Yanzhi Islet.

The spawning runs of the fish are related to the environment of its spawning grounds, especially the hydrological status. For example, black carp (*Mylopharyndodon piceus*), grass carp (*Ctenopharyngodon idellus*), silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) in

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China spawn under certain water temperature, flow discharge and water level[9]. There were also reports about the hydrological needs during the natural spawning of the sturgeons, such as *A. oxyrhynchusu, A. brevirostrum* and *A. fulvescens*[10–12]. Before the closure of the Gezhouba Dam, researchers have analyzed the hydrological condition of the historical spawning grounds in the Jinsha River, such as Sankuanshi, Pianyanzi and Jinduizi, and reported that water temperature determined the upper limit and the lower limit of the CS spawning seasons, whereas water level, silt content and current velocity influenced the actual spawning dates[1]. However, other researchers reported that exoteric factors stimulating the CS to spawn were not the changes of hydrological condition, but the substrate type of the spawning grounds.

The authors of this study surveyed the spawning activities of the CS downstream of the dam every year to ensure that the hydrological status as well as the relationship between its fluctuation and the spawning runs when the CS spawning is essential to enhance the protection of this species and to carry out the improvement projects on spawning grounds after the closure of Gezhouba Dam. From 1983 to 2004, 37 spawning runs were investigated and the actual spawning time was recorded. After 1996, when the actual positions of the spawning sites were located, current velocity was measured in the spawning reaches where the fish has been reproducing for some years. The hydrological condition and its variations were analyzed in the spawning grounds, downstream of the dam, during the spawning seasons.

1 Methods

The surveyed sites were located in one river reach, 7 km long and downstream of the Gezhouba Dam (Fig. 1). The analyzed hydrological factors were water level, current velocity, flow discharge, silt content and water temperature.

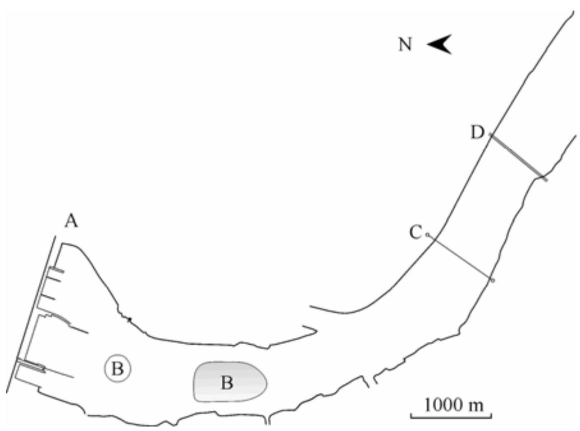

Fig. 1 Spawning grounds of Chinese sturgeon and sampling sites
A, Gezhouba Dam; B, Sampling sites for measuring current velocity at the bottom layer; C, Sampling sites for measuring daily average hydrological factors; D, Yiling Yangtze River Bridge; B–D, area of spawning ground of Chinese Sturgeons

The related hydrological data had two sources. Yichang Hydrological Monitoring Station of the Changjiang Water Resources Commission measured the daily average water level, flow discharge, current velocity, silt content and water temperature between October and November of the concerned years. The monitoring station is located in the Mojishan reach, and Yichang was close to the spawning grounds of the CS (C in Fig. 1). The current velocity at the bottom layer was real-time measured in the mating region during the spawning runs between 1996 and 1999. To monitor the spawning of the CS before the spawning of every year, sonic tags were used to tag about 10 mature fish and the fish was then released; simultaneously, the preying fish swallowing the CS eggs was anatomized by the authors of this study. When the fish was spawning, the positions of the parent fish were marked with the sonar emitter and then immediately tracked. Their positions were located, the current velocity of these positions was measured, and nets were set to capture sturgeon eggs. A 2000 type portable electric kinemometer manufactured by Marsh-McBirney Corporation was used to measure the current velocity (equipped with 30 m long underwater cable, measured range –0.15–6.0 m/s, and zero stability 0.015 m/s). When measuring the data, the electric inductive head was fixed on a 15 kg-weighted lead fish and immersed it in the water using the hydrological winch. The data were read when the electric inductive head was descended to 1 m under the water, and one reading was recorded every 2 m until it was 0.5 m from the river bottom layer. The geographic coordinate and the water depth in the measured position were also recorded. From 1996 to 1999, five real-time runs of the current velocity during spawning were measured.

The data were analyzed by SPSS 12 software.

2 Results

2.1 The hydrological status and its changes in the CS spawning grounds before and after the closure of the Gezhouba Dam

The Gezhouba hydroelectric hinge was dammed in January 4, 1981, and was sluiced in May 23. According to the hydrological data measured at the Yichang Hydrological Monitoring Station, the monthly mean water level, current velocity, silt content, flow discharge and water temperature in the CS spawning grounds were analyzed, respectively, by the authors of this study from October to November in 1977–1980 and 1981–2000 by different stages (Table 1).

The results showed that monthly mean water level, current velocity and silt content decreased after the closure of the dam compared with those before the closure; monthly mean flow discharge increased, whereas monthly water temperature did not show a remarkable change. But the results of the variance significance test showed that there are no significant differences in the individual hydrological parameters (P>0.05) except for the monthly current velocity of December to November and the monthly silt content of November every year before and after the closure of the dams (P<0.001).

2.2 The hydrological condition of downstream of the Gezhouba Dam during spawning of the CS

From 1983 to 2004, 37 spawning runs were monitored in the CS spawning grounds in Yichang by the authors of this study, intraday water level, current velocity, flow discharge and water temperature (without current velocity and silt content in six spawning runs between 2001 and 2004) were measured, and eggs were collected. In addition, the fluctuating ranges and means of the five hydrological factors were also calculated when the CS were spawning (Table 2).

2.2.1 Water temperature

Water temperature during spawning fluctuated between 16.1 ℃ and 20.6 ℃ with the difference of 4.5 ℃, the average value of 18.6 ℃ and the mode of 18.0 ℃. The fluctuation of water temperature was relatively small. About 32 spawning runs in 37 runs occurred at a temperature between 17.0 and 20.0 ℃, accounting for 86.5% of the total, while only five runs occurred beyond this temperature range (two runs at a temperature lower than 17.0 ℃ and three runs at a temperature higher than 20.0 ℃). About 26 spawning runs occurred at a temperature from 18.0℃ to 20.0℃, accounting for 70.3% of the total.

In most years, the CS spawned twice in one reproducing season; for example, in the 22 years from 1983 to 2004, there were 15 years during which two spawning runs occurred. When there were two spawning runs, the water temperature of the first run was significantly higher than that of the second one. The water temperature of the first run fluctuated between 17.2℃ and 20.6℃, with the mean of 19.3 ℃, whereas that of the second one varied from 16.1℃ to 19.6℃, with the mean of 17.9 ℃.

2.2.2 Water level

In the days between 1983 and 2002 when the CS spawning was surveyed, the water level was from 40.69 m to 47.32 m in the Yichang section, with the mean 44.01 m, the median 44.00 m, and the mode 44.24 m.

When the CS spawned for two times, the water level of the first run was significantly higher than that of the second one. According to the data of 15 years when two spawning runs occurred, the average water levels of the first and the second runs were 44.78 m and 43.17 m, respectively, with the difference value of 1.61 m. Moreover, the water levels of every run showed a remarkable fluctuation. The first run fluctuated between 42.00 m and 47.32 m, and that of the second run from 40.69 m to 45.92 m. The ranges were 5.32 m and 5.23 m, respectively.

2.2.3 Flow discharge

Flow discharges of the 37 spawning runs were recorded from 1983 to 2004; according to these data, average value, mode and variation range in the Yichang section were 13908

Table 1 Hydrological condition of spawning grounds of the CS in Yichang city before and after the closure of Gezhouba Dam in October and November

Factor	Time	October		November		n
		Range	Mean ± SD	Range	Mean ± SD	
Water level(m)	Preclosure	44.57–48.30	46.28±1.61	42.43–43.66	43.11±0.52	4
	Post	43.37–46.77	45.38±0.95	44.13–40.69	42.54±0.84	20
Flow discharge (m^3/s)	Preclosure	8060–25400	14577±7886	5130–10900	7893±2980	4
	Post closure	12816–32700	17981±4949	7153–12766	9874±1776	14
Current velocity (m/s)	Preclosure	1.69–2.11	1.89±0.18	1.37–1.52	1.45±0.07	4
	Post closure	1.34–1.78	1.51±0.13	0.83–1.31	1.05±0.13	20
Silt content (kg/m^3)	Preclosure	0.49–0.89	0.66±0.17	0.30–0.67	0.48±0.15	4
	Post closure	0.33–0.92	0.61±0.14	0.11–0.41	0.24±0.09	20
Water temperature (℃)	Preclosure	19.30–20.20	19.75±0.42	16.10–16.90	16.43±0.39	4
	Post closure	18.85–20.13	19.31±0.47	15.30–17.04	16.39±0.62	10

Table 2 Main hydrological factors of the spawning ground during the spawning of CS

Item	Water temperature(℃)	Water level(m)	Flow discharge(m^3/s)	Silt content (kg/m^3)	Current velocity (m/s)
Range	16.10–20.60	40.69–47.32	7170–26000	0.10–1.32	0.81–1.98
Mean ± SD	18.63±1.10	43.91±1.72	13908±4595	0.46±0.30	1.30±0.27
CV(%)	5.9	3.9	33.0	65.2	20.8
N	37	37	37	31	31

m^3/s, 14100 m^3/s and 7170–26000 m^3/s, respectively. Analyzing the data of these years when the CS spawned for two times, the average value, the mode and the variation range were 1650 m^3/s, 16087m^3/s and 10125–26000m^3/s with the difference value of 15875m^3/s, respectively, and those of the second spawning run were 11811m^3/s, 12300m^3/s and 7170–18100 m^3/s with the difference value of 10930 m^3/s, respectively.

2.2.4 Silt content

The average silt content when the CS was spawning was 0.46 kg/m^3, with the median, the mode and the variation range were 0.33 kg/m^3, 0.28 kg/m^3 and 0.10–1.32 kg/m^3, respectively. In the years when the CS spawned for two times, the mean silt content and the variation range of the first run were 0.63 kg/m^3 and 0.28–1.32 kg/m^3, respectively, whereas those of the second run were 0.30 kg/m^3 and 0.10–0.65 kg/m^3, respectively. According to the statistical results of the 26 spawning runs for 13 years, the fish spawned for two times, and the range of difference value during the first and the second runs of spawning was 0–1.02 kg/m^3. The results also showed in the 31 spawning runs between 1983 and 2000, and the silt contents of the 15 runs fluctuated between 0.2 kg/m^3 and 0.3 kg/m^3.

2.2.5 Current velocity

According to the current velocity measured in the Yichang Hydrological Monitoring Station during 1983 to 2000 and the velocity measured by the authors of this study for 31 spawning runs, the mean, the mode and the variation range were 1.30 m/s, 1.26 m/s and 0.81–1.98 m/s, respectively, in this section on the respective days when the fish spawned, in which the current velocity of 1.00–1.66 m/s accounted for 81% of the total.

The surface current velocity was larger than that on the bottom layer according to 48 groups of layered current velocity measured from the five spawning runs during 1996–1999. During spawning, the surface current velocity was commonly larger than that of the bottom layer. In general, current velocities on the average surface and the bottom layer were 2.00 m/s and 1.42 m/s, respectively, with the ranges of 0.66–3.20 m/s and 0.64–2.36 m/s, respectively. Analyzing the current velocity of the single spawning run, similar result was obtained, which stated that the current velocity on the surface was larger than that on the bottom layer in the respective spawning runs. At the same time, the surface current velocity showed a remarkable fluctuation, with the range of 1.37–2.98 m/s. But the bottom layer showed less fluctuation, with the range of 1.07–1.65 m/s (Table 3).

3 Discussion and conclusion

3.1 The favorable hydrological factors for the CS reproduction downstream of the Gezhouba Dam

In 1981, the Gezhouba hydroelectric hinge was dammed, and in 1982 it was found that the CS could naturally spawned downstream of the Gezhouba Dam[2]. After the year 1982 the spawning activity of the CS was monitored every year, which showed that this river reach could meet the environmental and ecological needs for the reproduction of CS, and there were certain ranges for the main hydrological factors. The range of water temperature was from 15.3℃ to 20.5℃, and the relatively suitable one was from 17.0℃ to 20.0℃, especially from 18.0℃ to 20.0℃ was the most favorable. At present the flow discharge monitored fluctuated between 7170 m^3/s and 26000 m^3/s, and the relatively suitable one was 14100 m^3/s. The water level fluctuated between 40.7 m and 47.3 m. From the variation of the water level before and after the spawning day (Table 2), it was estimated that the CS usually spawned when the water level gradually declined, which was in the ebb stage after the flooding stage. And it was most likely that the fish spawned when the water level was 42.0–45.0 m.

Although the silt content sharply varied during the spawning of the CS (0.10–1.32 kg/m^3), the silt content data in terms of the frequency of each spawning run for those years when two spawning runs occurred were analyzed, respectively, by

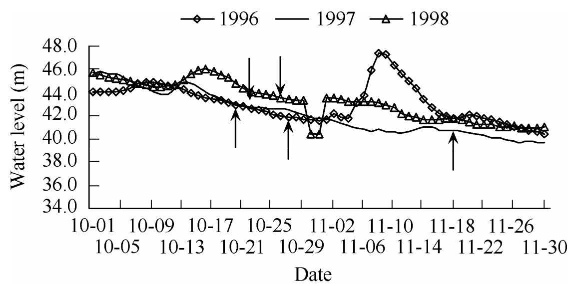

Fig. 2 The relationship between spawning of Chinese Sturgeon and water level

→: Date of Chinese Sturgeon spawning

Table 3 Flow velocity of the spawning ground of CS from 1996 to 1999

Item	Flow velocity of upper layer(m/s)		Flow velocity of bottom layer (m/s)		Water depth(m)	
	Mean	Range	Mean	Range	Mean	Range
1996 (I)	1.37	0.66–2.28	1.19	0.68–1.99	13.2	5–25
1996 (II)	2.98	2.73–3.20	1.53	1.11–2.03	11.5	5–20
1997	1.45	1.34–1.50	1.07	0.64–1.38	12.3	5–16
1998	1.93	1.64–2.84	1.65	1.16–2.25	9.5	7–16
1999	2.47	2.20–2.90	1.61	1.03–2.36	18.5	16–24

the authors of this study. The results showed that the silt content of the first run had two intensive distributions, which were about 0.25 kg/m^3 and 0.22 kg/m^3, respectively. However the second run had only one intensive distribution of 0.25 kg/m^3. The results also showed that the modes of the silt content of the first and the second spawning runs were rather approximate, which were 0.28 kg/m^3 and 0.22 kg/m^3, respectively. It could be concluded that the CS tended to spawn in the environment with low silt content, and the present calculated value was 0.2–0.3 kg/m^3.

According to the real-time measured current velocity in the mating region, the current velocity of the bottom layer fluctuated from 0.64 m/s to 2.36 m/s, and that of each spawning run was 1.07–1.65 m/s. But the current velocity was calculated from the monitored data year-to-year provided by the Yichang Hydrological Monitoring Station, the current velocity of the spawning day was 0.81–1.98 m/s, and that of 1.00–1.66 m/s accounted for 81% of the total. The result was similar to the measured one of the bottom layer, which suggested that this range was favorable for the CS to spawn.

3.2 The relationship between the hydrological factors and the spawning of the CS

The spawning activities of a lot of fish are closely related to the hydrological condition of their spawning grounds. For example, important economic fish, i.e., *Mylopharyndodon piceus*, *Ctenopharyngodon idellus*, *Hypophthalmichthys molitrix* and *Aristichthys nobilis* in China spawn under certain water temperature with increasing water level, flow discharge, current velocity, decreasing transparence and complex flow state[9]. When the water temperature is above 17℃, flooding or ebb is also the main inducing factor for Largemouth bronze gudgeon (*Coreius guichenoti* Sauvage & Dabry) and Bronze gudgeon (*Coreius heterodon*) to spawn. But there exists controversy over which hydrological factors affect the spawning of sturgeons and how these different factors influence their activity. Some researchers assume that the riverbed made of gravel or rock, and certain bottom current velocity are essential for the spawning of sturgeons[11,12]. Researchers in China also assume different opinions on the ecological condition for the natural spawning of the CS. Some researchers believe that the temperature of water decides the spawning time, and water level, silt content and current velocity are essential to the actual date[1]. However other researchers assume that the substrate type mainly affected the spawning activity①.

Water temperature, water level, flow discharge, current velocity and silt content during the spawning season of the CS, all fluctuated in certain ranges, but according to the variation coefficient of each mean of hydrological factors (Table 2), there were differences in the variation ranges of different factors. The variation coefficients of water temperature and water level were relatively small, while those of flow discharge, current velocity and silt content were relatively large.

The spawning of CS takes place under certain range of water temperature, which is the result of adapting to the natural environment and a long time evolution. Fish is a poikilotherm without the body temperature-regulated mechanism by itself, and the water temperature influences all of its physiological progress. So the spawning activity of the fish is performed under certain water temperature. As for sturgeons, for different species, distributions and spawning seasons, there are differences in spawning water temperature and its variation range. *Acipenser baeri* Brandt spawns when water temperature is 9–18℃. *A. oxyrhynchusu* spawns under water temperature of 14.5–23.4℃ in the St. Lawrence River, while 13.3–17.8℃ in the Delaware River[14]. About 18 spawning runs were recorded in this investigation on the original spawning grounds of the CS in the upper Yangtze River and the Jinsha River, in which 17 runs occurred under water temperature of 17.0–20.2℃, and the other one under water temperature of 15.2℃, but the scale was rather small[1]. The research on the downstream of the Gezhouba Dam showed that the spawning water temperature of the CS was 16.1–20.6℃, which was in accordance with that of the original spawning grounds. Thus far, it has not been found that the CS can spawn under water temperature below 15.0℃ or above 21.0℃. Compared with other sturgeons, the suitable water temperature range for the CS is relatively narrow. So favorable water temperature is the precondition for this fish to spawn.

The measured and analyzed results of the current velocity on the spawning grounds of the CS downstream of the Gezhouba Dam showed that CS requires a larger bottom current velocity than that required for other sturgeons[10,12,15–17]. Lake Sturgeon (*A. fulvescens*) spawns under current velocity of 0.35–0.73 m/s, while 0.3–1.5 m/s for *A. brevirostrum* and American paddlefish (*Polyodon spathula*). Kynard *et al*. experimentally found that *A. brevirostrum* was most likely to spawn under current velocity of 0.5–0.7 m/s② while the measured bottom current velocity for the CS fluctuated between 0.64 m/s and 2.36 m/s, which may be related to its unique reproductive biology. The diameter of the CS mature eggs is 4.0–5.0 mm and is considered to be the biggest among the eggs of other sturgeons. The CS egg is sinkable with high specific gravity and glutinosity. Eggs can only float in the water and scatter in the environment with relatively high current velocity after being spawned. This is advantageous for the union and fertilization of eggs and spermatozoa, and than fertilization rate is increasing. In the same time, high current velocity is propitious for fertilized eggs to disperse in scree

①Chang J. The characteristic and fluctuating tendency of the Chinese Sturgeon reproductive population in the Yangtze River, 1999

②Boyd K, Don P, Micah K, *et al*. Spawning of Shortnose Sturgeon in an Artificial Stream: Adult Behavior and Rearing and Dispersal of Early Life Stages; Submitted to American Fisheries Society Monograph on Connecticut River Shortnose Sturgeon, 2003 riverbed of the downstream, resulting in decreasing chance for them to adhere with each other. In addition, this will reduce the probability of the preying fish swallowing the fertilized eggs.

The relationships between the silt content and the spawning of the CS were: ① The favorable silt content showed a large range of fluctuation (0.10–1.32 kg/m^3), but a relatively little silt content (0.2–0.3 kg/m^3) was more favorable for the spawning activity; ② Before the CS spawned, the silt content significantly decreased, and the parent fish spawned after the silt content was relatively stable.

There exists some internal relationship among the water level, the current velocity, the flow discharge and the silt content of river water. Among these factors, the flow discharge of the upper river plays the major role, while the water level and the current velocity vary with the river section. In one section, the water level, the silt content and the flow velocity increase with the increasing of the flow discharge. The CS spawns when the flow discharge, the water level and the silt content gradually decrease and this reflects their inner relationship. Under suitable conditions of water temperature, when the water level, the current velocity and the silt content gradually decrease, the fluctuant trend induces spawning of the CS, i.e., gradually declines from certain large value, and in addition each hydrological factor reaches its favorable ranges, then the CS will spawn.

3.3 The effects of changing hydrological factors resulting from hydroelectric construction on spawning of the CS

Hydroelectric construction will inevitably change the hydrological condition of river and its temporal and spacious distribution pattern. After closure of the Gezhouba Dam, the hydrological condition of the spawning grounds of the CS in Yichang section did not show a remarkable change except for the silt content in November. This was related to the fact that the Gezhouba hinge belongs to a pathway-flow power station and its ability of sluice discharge is limited. Though running of the hinge influenced the flow discharge and the silt content on the spawning grounds during the spawning season of the CS to certain extent, the fish could still spawn because these factors did not change beyond their favorable ranges. This had been proved by the year-to-year monitored results after damming. After running the Three Gorges Project, the downstream hydrological condition and its temporal and spacious distribution pattern showed a remarkable change because of the tremendous modulating and sluicing function of the Three Gorges Reservoir. The decreasing silt content will be advantageous for the CS to spawn. But the effects of changing water temperature on its natural reproduction will be rather complex. The water body of the Yangtze River, being a large river, has strong fluidity and the water temperature is mainly affected by the climate variation in the drainage area and the water temperature of incoming water. When there is no external (for example, climate warms up) and humane disturbance (for example, water temperature changes because of reservoir construction), the water temperature usually shows seasonal change. After running the Three Gorges Project, the changing rule of certain river section in the downstream will alter. Water temperature in spring and summer will decrease compared with that before running of the project, while that in autumn and winter will increase. These changes will probably influence the spawning of CS in two aspects. On one hand, accumulated temperature change will influence the development of gonad in the parent fish. The development of gonad in fish usually requires a steady accumulated temperature. The key stage for the development of gonad in CS from stage III to stage IV is accomplished in one year before spawning after it enters the Yangtze River. After the closure of the Gezhouba Dam, the CS mainly inhabits in the river section from the dam to Shishou, Hubei Province in this stage, which is just in the influencing range of the water temperature. If the water temperature fluctuates rather remarkably, the overall temperature for the development of gonad will access the favorable range, and then the development will slow down, or the sex gonad cannot mature. This needs a long-term investigation. On the other hand, the water temperature in the spawning season will directly affect the spawning activity of the CS. The running of the Three Gorges Project will make it different for suitable water temperature to match with the current velocity, the water level and the development of gonad. The biological and the ecological hydraulics condition cannot meet the spawning needs of the CS, and this should be paid special attention.

Acknowledgements

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