

The practice and effectiveness of ecological operation experiment on spawning of the four major Chinese carps by Three Gorges Reservoir

Wei Xu, Xiaojuan Chen, Jiangping Tao, Cao Jun

^{1,2}Key Laboratory of Ecological Impacts of Hydraulic Projects and Restoration of Aquatic Ecosystem of the Ministry of Water Resources, Institute of Hydroecology, Ministry of Water Resources & Chinese Academy of Sciences,

Abstract: Eco-operation experiment by the Three Gorges Reservoir was carried out ten times to facilitate spawning of the four major Chinese carps in the lower reaches of Yangtze River, from 2011 to 2017. To get knowledge of fish spawning response to man-made flood process, and also assessing the positive effect of eco-operation on fish spawning, fish eggs were monitored daily by drift-net method, in a fixed profile in Shashi reach between mid-May to mid-July each year. Basing on the consecutive data and research for seven years, the practice and effectiveness of TGR eco-operation experiment on fish spawning were summarized and prospected. The main findings were as follows: eco-operation experiment usually operated in a suitable condition from late May to the end of June. Based on the hydrological monitoring data in Yichang station, the continuous days of rising limb varied from 3 days to 9 days, the mean diurnal increment of water level varied from 0.43 m to 1.30 m, and the water temperature varied from 20°C to 24°C, except in 2013 that only below 18°C, during eco-operation period within seven years. According to the fish eggs monitoring data in Shashi reach, annual egg abundance of the four major Chinese carps ranged from 116 to 610 million, grass carps and silver carps were two dominant species with proportion of more than 80%. Egg abundance of the four carps produced in eco-operation period accounted for about 38% averagely of total amount in the whole monitoring period, with nine floods in total of thirty-three floods. Four indicators representing fish spawning performance, the time interval from water rising to spawn happening, duration time of spawning, extent of spawning grounds, and spawning scale, were calculated in each spawning event corresponding to each flood process. All indicators gave evidence that spawning performance of the four carps were better in eco-operation period, compared with other routine operation period. It was concluded the Three Gorges Reservoir eco-operation had done its work on boosting spawning of the four major Chinese carps, but further and foremost research should be developed on the following aspects, quantifying the eco-operation effect, optimizing the eco-operation index, and extending the eco-operation target to other important life history stage of fishes.

1 Introduction

The four major Chinese carps were common name of four endemic fishes consist of grass carp, silver carp, bighead carp and black carp, as they played very important role in both cultivation and capture freshwater fishery in China [1, 2]. Yangtze River was a natural origin of the four carps, and their major habitats largely located in the middle reach, with spawning scale from Yichang to Chenglingji reach contributed to 42.7% of Yangtze mainstream historically [3, 4]. The requirements of FMCC spawning were specific and rigorous, such as typically spawned in large and turbid rivers; the lowest water temperature for spawning was 18°C, spawning peak occurred at 21 to 24°C, increase of river flow was the key triggering factors, eggs and larvae must drift in the current until they matured enough to migrate into

nursery habitats[5~7]. The resource dynamics of the four carps could represent the health state of river ecosystem because of their long term adaption to river-lake integral ecosystems in the middle and lower reaches of Yangtze River. These characteristics made them receive much attention during the construction and operation of Three Gorges Project [8].

The Three Gorges Project in China is one of the biggest hydro-power engineering projects worldwide. According to TGP operation rules, The Three Gorges Reservoir (TGR) would balance water discharge both in May and June, which caused flood process in downstream more smoothly and discharged water temperature lower than the natural condition. Therefore, two important factors for the spawning of four carps, river flow increase and water temperature changed inevitably [9, 10]. Many research verified that the degradation of the four carps spawning had a close

*Corresponding author: Wuhan, China, betty3115@126.com

association with the changes in hydrological and thermal conditions caused by the TGR [11~13].

In order to enhance the natural reproduction of the four carps, the TGR operation could adjust in several days to create a suitable flood process favored fish spawning, which was called ‘eco-operation’. Experiment of eco-operation was put into practice first time in June 2011. From then on, the eco-operation kept carrying on for one or two times every year. Although preliminary result showed the spawning of four carps and other fishes had good response to the eco-operation flood [14, 15], something must be done to sum up the experience of TGR eco-operation, such as characteristic of flood process, regular pattern of fish spawning, and further effect of eco-operation. Basing on the monitoring data in Shashi section from 2011 to 2017, this paper focused on three aspects, the implementation of TGR eco-operation, the spawning trait of the four major Chinese carps, and the effect of TGR eco-operation on fish spawning.

2 Implementation of TGR eco-operation from 2011 to 2017

From 2011 to 2017, a total of ten times of TGR

eco-operation were carried out in seven years, with one or two times each year. The eco-operation only implemented during late May to the end of June to coordinate spawning time and TGR regulation. In the original eco-operation plan, operation indexes including the starting of TGR discharge flow, diurnal increment of discharge flow, continuous days of flow increase, and terminal discharge flow, were explicit to make TGR operable. Due to discrepancy of hydrological regime in time and space among years, and considering other water needs, the implementation of TGR eco-operation were different in timing and extent. The basic information and operation indexes during each eco-operation from 2011 to 2017 were concluded in table 1. The starting discharge flow by TGR varied from 6230 to 18300 m³ s⁻¹, and mean diurnal increment of TGR discharge flow varied from 1100 to 3130 m³ s⁻¹. Yichang hydrological station was the first monitoring section located in the downstream of TGR, monitoring data showed the continued days of rising limb varied from 3 days to 9 days, the average diurnal increment of water level varied from 0.43 m to 1.30 m, and the water temperature varied from 20°C to 24°C, except in 2013 (17.5°C), in Yichang reach.

Table.1 statistics of eco-operation implementation from 2011 to 2017

year	the date during period of TGR eco-operation	the starting discharge flow of TGR	mean diurnal increment of discharge flow	continuous days of flow increase	mean diurnal increment of water level in Yichang	mean water temperature in Yidu section
2011	6.16-6.19	12000	1650	4	0.88	23.6
2012	5.25-5.31	18300	2600	4	1.02	20.5
	6.20-6.27	12600	1550	4	0.64	22.3
2013	5.7-5.14	6230	1100	9	0.51	17.5
2014	6.4-6.6	14600	1450	3	0.46	20.3
2015	6.7-6.10	6530	3130	4	1.3	21.6
	6.25-7.2	14800	1930	3	0.86	22.5
2016	6.9-6.11	14600	2100	3	0.55	21.8
2017	5.21-5.25	11200	1320	5	0.43	20.9
	6.4-6.9	11200	1370	6	0.51	23.2

3 Spawning trait of the four major Chinese carps

3.1 Spawning time and frequency

By the initial and final date that sampled eggs of the four carps, The starting time of the carps spawning usually at latter half of May, the earliest was in May 13, 2013 and the latest was in June 5, 2014. The ending time of

spawning usually was in late June and early July. The spawning period by the monitoring lasted about two months, which was a little shorter than the historical record (May to July). In figure 1, the frequency of spawning peak was about three and four times each year, mainly occurred in three period of time, the end of May, the late June and the early July. The frequency of scattered spawning was about two and three times each year, mainly occurred in the first and middle third of June.

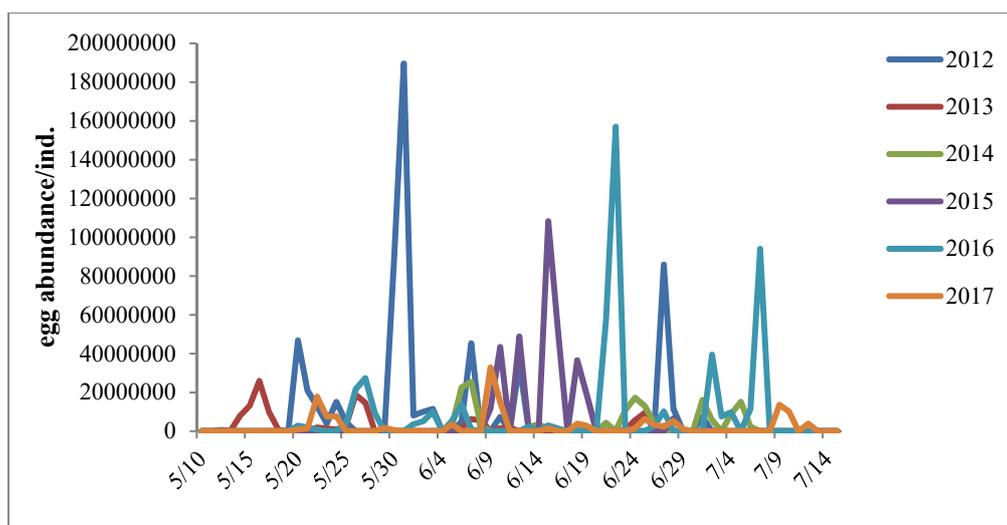


Fig. 1 the daily variation of egg abundance from 2011 to 2017

3.2 Annual abundance and composition

The annual egg abundance of four carps was 610 million, 116 million, 161 million, 326 million, 502 million and 145 million, from 2012 to 2017, indicating the population of four carps fluctuated obviously year by

year. The data in 2011 was omitted, since the monitoring period only covered one month. Figure 2 showed the species composition had some variation among years, but generally grass carps and silver carps were two dominant species with proportion of more than 80%. Black carps and bighead carps maintained a lower abundance, especially for bighead carps.

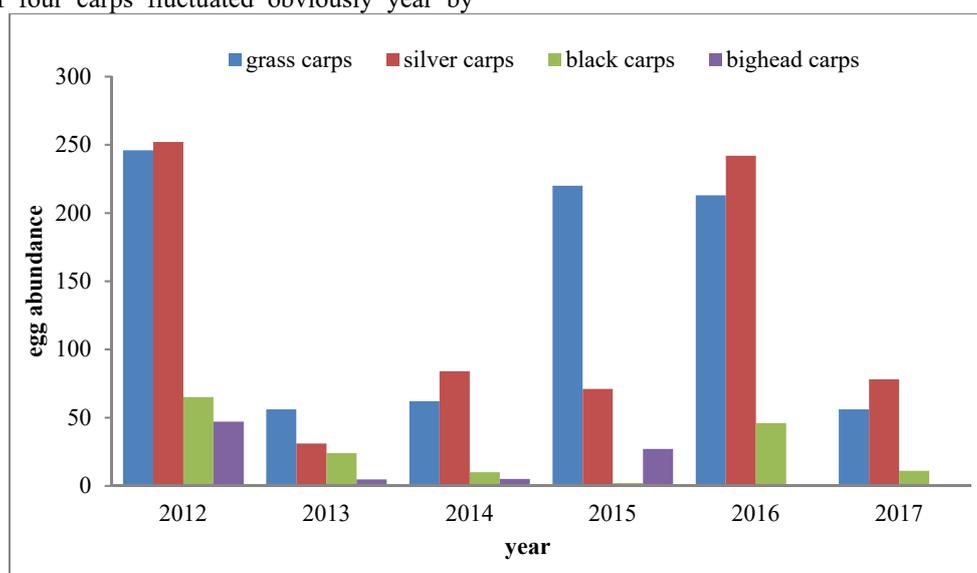


Fig. 2 composition of four carps in egg abundance from 2012 to 2017

3.3 Spawning location and scale

As for the spawning locations, Jiangkou, Dongshi, Songzi and Zhicheng were four stable spawning grounds below Yichang city. The length of spawning ground was longest in Zhicheng with average of 14.5km, next was in Dongshi with average of 7km. The proportion of

spawning scale was biggest for Dongshi with average of 20.94%, next was for Zhicheng with average of 18.98%. Songzi showed notable spawning scale only in 2015, while Jiangkou showed none spawning in the same time. There were other two spawning grounds located in Yuanshi and Shashi showed scattered spawning in few years. With tiny spawning scale, the statistical data was omitted in table 2.

Table.2 spawning scale and length in different spawning grounds from 2012 to 2017

Item	Spawning ground	Year						Average
		2012	2013	2014	2015	2016	2017	
Spawning scale	Jiangkou	1.8	12.02	18.25	0	21.36	18.08	11.92
	Dongshi	5.99	17.93	18.25	26.15	23.53	33.79	20.94

(%)	Songzi	3.59	0	9.52	33.85	3.73	0.91	8.60
	Zhicheng	13.77	35.42	16.67	17.23	8.98	21.8	18.98
Spawning length (km)	Jiangkou	7	4	3	0	10	8	5.33
	Dongshi	5	12	10	5	4	6	7.00
	Songzi	4	0	5	4	2	1	2.67
	Zhicheng	20	25	15	8	1	18	14.50

4 Effect of TGR eco-operation on fish spawning

4.1 Spawning response to hydrograph

Most times of four carps spawning happened in the rising limb of hydrograph and very few happened in the recession limb of hydrograph, while carps would never spawn in the condition of water subsiding (Figure 3, 4). It was again proved the river flow increase was indispensable to the four carps spawning. Figure 3 and 4 also showed the daily egg abundance of four carps had concurrent variation along with flood process, respectively in 2012 and 2017. The duration time of one spawning event ranged from 1 to 6 days and the total egg

abundance of one spawning event varied from 1.22 (in June 14, 2017) to 308.4 (in May 29 to June 1, 2017) million, mainly depended on the population participating in breeding, as well as the duration time of freshet.

To know how the four carps spawning to response eco-operation flood, Figure 5 showed egg abundance of the four carps produced in eco-operation period accounted for about 38% averagely (ranged from 0.48% to 66.56%) of total amount in the whole monitoring period, with flood frequency 9 times in the former and 33 times in the latter. An exception was in 2016, the four carps could hardly spawn in the eco-operation period. The reasons might be that it was high flow year in 2016, the hydrological condition for fish spawning was good enough, and before eco-operation carried out, the four carps had just spawned for about three and four times.

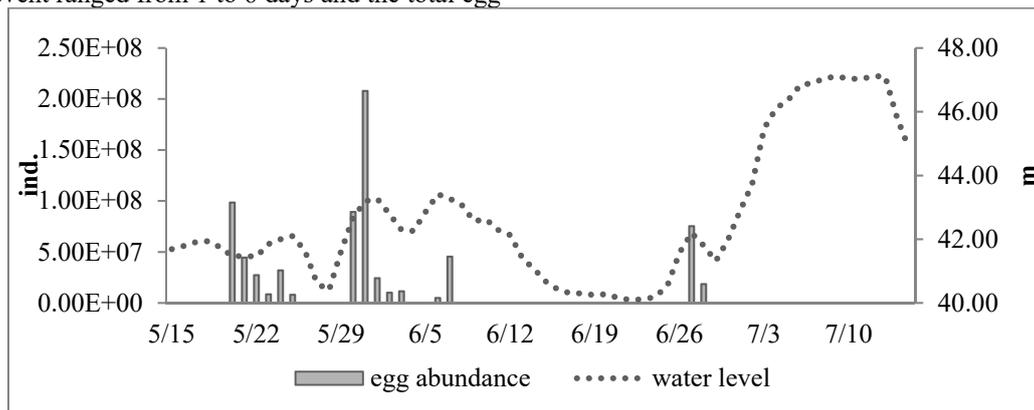


Fig. 3 relations of daily egg abundance of four carps and water level in 2012

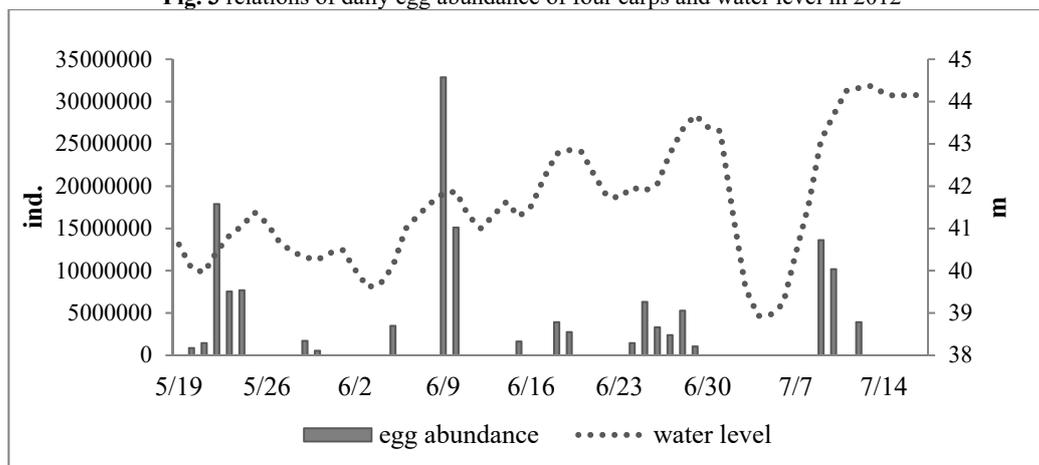


Fig. 4 relations of daily egg abundance of four carps and water level in 2017

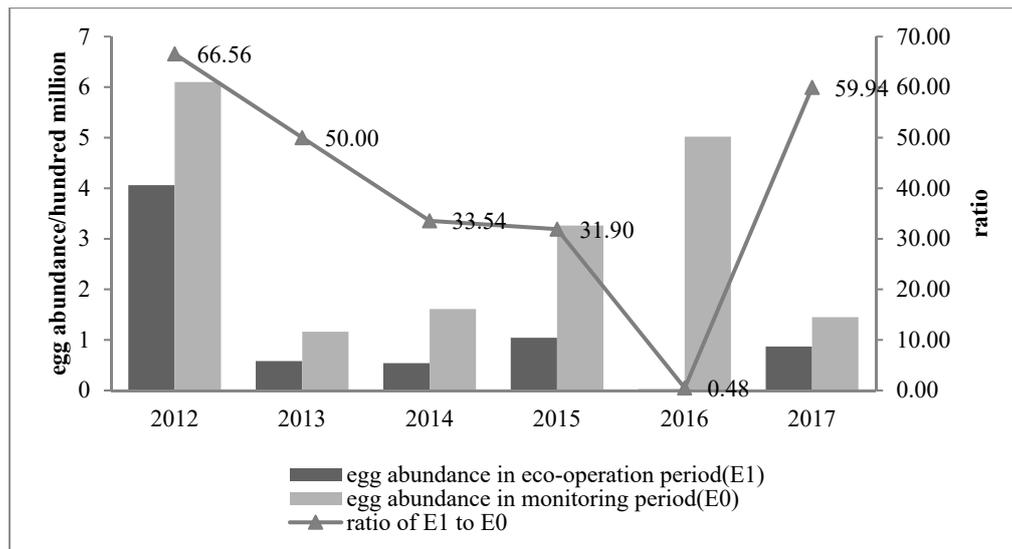


Fig. 5 egg abundance in eco-operation period and monitoring period

4.2 Comparison of spawning performance between eco-operation and routine-operation

It had proved that a suitable flood condition could produce a successful spawning event. To assess the effectiveness of TGR eco-operation, four indicators were selected to give evidence of the discrepancy in spawning performance with different flood operation mode. They were the time interval from water rising to spawn happening (SP1), duration time of spawning (SP2), extent of spawning grounds (SP3), and the spawning scale (SP4). For each spawning event with scale larger than 10 million, these indicators were calculated in each year. There were 22 data groups of calculated indicators, representing 22 times of spawning event, in which 7 times was in eco-operation mode. The variation range of each indicator was from -2 to 6 days in SP1, from 2 to 6 days in SP2, from 17 to 106 km in SP3, from 2 to 4 species in SP4, and from 13.39 to 308.4 million individuals in SP5.

Comparison of mean value for each indicator

Table.3 mean and range value of indicators of spawning performance

Flood mode	item	SP2 (days)	SP3 (km)	SP4 (million)
eco-operation	mean	4	83	92.54
	range	3~5	56~106	35.41~308.4
routine-operation	mean	3	68	61.64
	range	2~6	17~105	13.39~214.38

5 Conclusions and outlooks

This paper focused on three aspects. Firstly, to summarize spawning characteristics of the four major Chinese carps in Yichang to Shashi river reach; secondly, to ascertain spawning response of the four carps to hydrograph especially in eco-operation flood; thirdly, to identify the discrepancy of spawning performance using indicators between eco-operation and routine-operation, and assess the effectiveness of eco-operation. From eco-operation experiment and fish field data by several years, we could concluded the eco-operation practice by

between eco-operation mode and routine-operation mode was showed in table 3. As for SP2, SP3 and SP4, spawning performance in eco-operation mode was preferable to that in routine-operation mode. As for SP1, the spawning during eco-operation flood all happened in the rising limb, with SP1 no more than two days. There was one exception, just because a lower temperature (below 18°C) in 2013, the spawning occurred six days later from water rising. While spawning during routine-operation flood had two different responses, some happened one or two days earlier than water rising began (probably in the recession limb), and some happened more than two days after water rising. In other words, fragmentation of flood peak (routine-operation) made spawning of four carps scattered, and had inconsistent response with hydrograph. While eco-operation of TGR alleviated this kind of fragmentation, and four carps could spawn massively and continuously, which showed positive response to hydrograph.

TGR had done its work on boosting spawning of the four major Chinese carps, just because spawning performance during eco-operation flood mode was preferable to that during routine-operation flood mode. The practice of TGR eco-operation was first attempt aiming to help spawning of important fishes. Experience in proposal, implementation, monitoring and assessment of TGR eco-operation had achieved during these years, which could be good example for other similar hydro-power project. However, further and foremost research should be developed on the following aspects, quantifying the eco-operation effect, optimizing the eco-operation index, and extending the eco-operation target to other important life history stage of fishes.

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