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Ecological influence of dam construction and river-lake connectivity on migration fish habitat in the Yangtze River basin, China

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Abstract

Habitat fragment owning to obstruct of dams and barriers badly affect the aquatic faunas. Many spawning sites of migration fishes are lost, and their growth and reproduction are affected. The Yangtze River with connected lakes is the most important fresh water fishery area in China. The Yangtze's four major carp species (YFMCS) are the most typical migration fish lived in this area. They reproduce in river and grow in lake. Distributaries lies between the Yangtze River and Dongting Lake are the passages for these migration fishes. Due to the construction of dams and barriers, some original passages were out of use. Up to now, only four channels exist between the river and lake, there are Songcikou, Taipingkou and Ouchikou normally called "three outlets", and Chenglingji inlet. Diverted Water Volume (DWV) and the Percentage of Diverted Water (PDW) through the three outlets reflect the relationship between the Yangtze River and the Dongting Lake.

The variation of river-lake relation caused by dam construction, and the effect on migration fishes are discussed in this paper. The relationship of DWV and fry output in middle reach of the Yangtze river and the Dongting Lake, PDW and the percentage of the YFMCS in a total catch of fish, DWV and flux of carp fry at the Jianli station, DWV and yield of the YFMCS were analyzed. The results show that dams and barriers constructed on the Yangtze River threaten some fish species in this area, especially the migration fishes. The connectivity degree of river and lake decide the growth and reproduction of emigration fishes, the yield of the YFMCS increase by the DWV increase, and hydraulic project have important influence on reproduction of fishes. In order to reduce the ecological influence of hydropower projects, reservoir management especially in spawning season should integrate ecological demand.

Keywords: River-lake relation; habitat fragment; migration fish; Yangtze River; the Yangtze's four major carp species.

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1. Introduction

As economic development and increasing demand of energy, hydropower stations have been built as a part of large dam projects on rivers to generate hydroelectric power, which seen as an environmentally sound means of providing energy [1]. Therefore, a large number of dams are built in developed countries and have been building in developing countries. Although future dam construction may be limited by social, economic and environmental concerns [2] increasing demand for electricity, water and flood control is leading to continued dam construction [3-6]. Dams can affect fishes through imposing barriers to movements that fragment fish populations [1,7-9], changes in connectivity with the floodplain [10-12], and alteration of flow patterns [13, 14].

Amount of research on ecological effects [15-17] reflects scientific and public concern about the problems caused by this high level of fragmentation. Declining populations of migratory species (i.e. diadromous fauna which require a migration between fresh and salt water, and potomadromous fauna which migrate over long distances within fresh water) represent an important ecological impact of dams [18]. Migratory species are well studied in streams and rivers where they are predominantly represented by anadromous fish (i.e. fish breeding in fresh water but feeding and growth in ocean [19, 20]. Dams affect anadromous fish through a variety of mechanisms, but the most conspicuous is the physical barrier to migration with consequent decline of anadromous species in upstream areas [21]. About potomadromous fish, most researchers focus on the barrier influence on fish migration. Indeed, we are only beginning to understand the importance of the main-channel habitat of large rivers for potomadromous fishes. This paper focuses on the changes of connectivity between river and floodplain, alteration of flow regime, and management of stream barriers.

2. Study area

From last century, hydroenergy production has been highly regarded, and many dams have been constructed in China, especially in the Yangtze River basin. The 6300-km long Yangtze River is the largest and longest river in China and the third in world in length. It flows from west to east and pours into the East China Sea at Shanghai. The Yangtze River has a watershed area of 1.80 million km^2. In China, the river is called the Changjiang, with special names for different stretches (Fig. 1). From the source to Yichang is the upper reach, from Yichang to Hukou is the middle reach, from Hukou to Datong is the lower reach and below Datong is the estuary.

The middle reach of the Yangtze River is 898 km long, has a drainage area of about 680,000 km^2, and is the main reproduction area of migration fishes. The most typical migration fish lived in this area is the Yangtze's four major carp species (YFMCS). They are the black carp (Mylopharyngodon piceus), the grass carp (Ctenopharyngodon idellus), the silver carp (Hypophthalmichthys molitrix) and the big-head carp (Aristichyths nobilis), which have the most importance to the fresh water fishery in China. Fish eggs hatch in river and migrate to the Dongting Lake three months later to look for food. In the early summer and spawn during May to June, adults swim into the Yangtze River, where have suitable environment to excite their spawning.

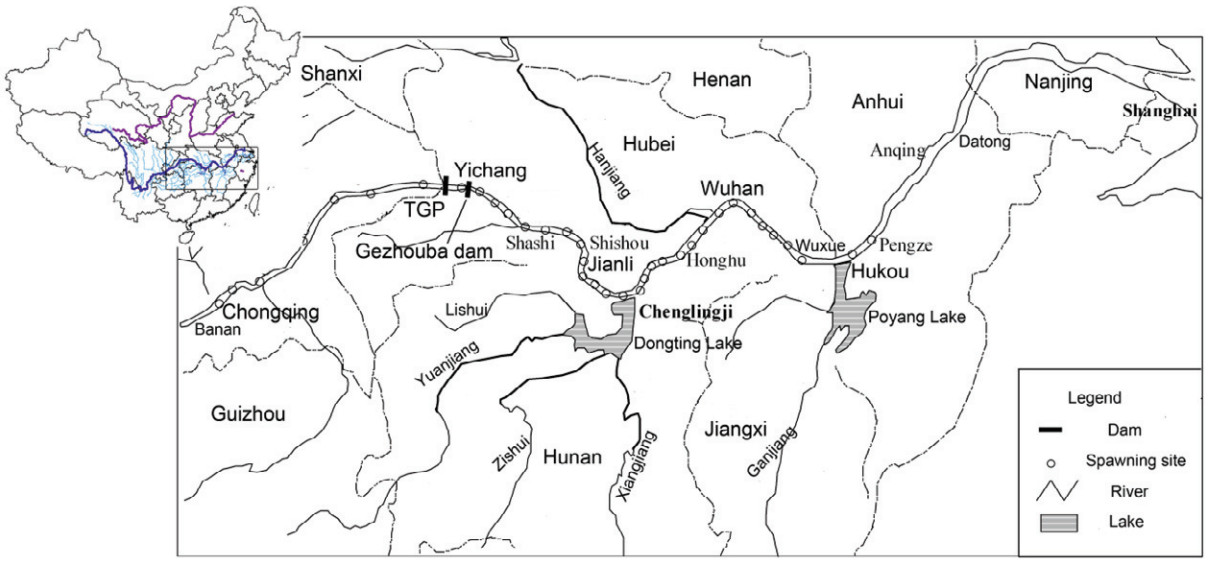

Fig. 1 Large dams and spawning area of the YFMCS before 1981 in the Yangtze River basin

The YFMCS spawning area is wide spread in the mainstream and tributaries of the Yangtze River basin. Before the construction of Gezhouba Dam, spawning areas for the YFMCS in mainstream of the Yangtze River ranged from Banan of Chongqing to Pengze of Jiangxi province, with almost 1700 km in total length. A 393 km long reach from the Yichang to the Chenglingji is one of the most important habitats for the YFMCS. There are 12 spawning sites for the carp species in this reach, with 43% of the total egg production in the Yangtze River basin. Because of the construction of hydroelectric dams on the river and flood gates between mainstream and tributaries in past decade years, 600 km spawning ground upstream of Gezhouba Dam were obstructed or inundated, and the quality of 400 km downstream of Gezhouba Dam declined [22]. Especially during 1997-2003, eight spawning sites in the Three Gorges Reservoir (TGR) were cleared for impoundment, remainder reproduce areas in mainstream for YFMCS are strictly restricted and with poor quality.

Lakes connected with river not only play an important role on flood management, but also have significant benefits on water quality and ecology. Construction of hydraulic projects on river or between mainstream and lakes are seriously affected the ecology function of lakes [23, 24]. Up to now, Dongting Lake and Poyang Lake is the only two lakes directly connected with the Yangtze River. The Yangtze River's water flows into Dongting Lake via “three outlets”, which are Sungzikou, Taipingkou and Ouchikou. Dongting Lake's water pour into the Yangtze River through the Chenglingji inlet (Fig. 2). Silt, nutrients, and fishes go freely between the Dongting Lake and the Yangtze River through these four passages. In order to find the influence of connectivity between river and lake on migration fishes, the relationship between Diverted Water Volume (DWV, Water diverted from the Yangtze River to Dongting Lake through three outlets in a year) and the weight proportion of the YFMCS in whole catches was analyzed.

After the impoundment of the TGR, the hydrological regime of river was changed, the spawning time of fishes in downstream was delayed, as a result, the fish eggs and fries at each site were decreasing. Some spawning sites even no longer satisfy the carps for spawning. The YFMCS populations have gradually declined from 1950’s. Habitats protection and restoration would be the main route to enhance the YFMCS population, and this may mainly relay on the adjustment of existing hydrosystem operations.

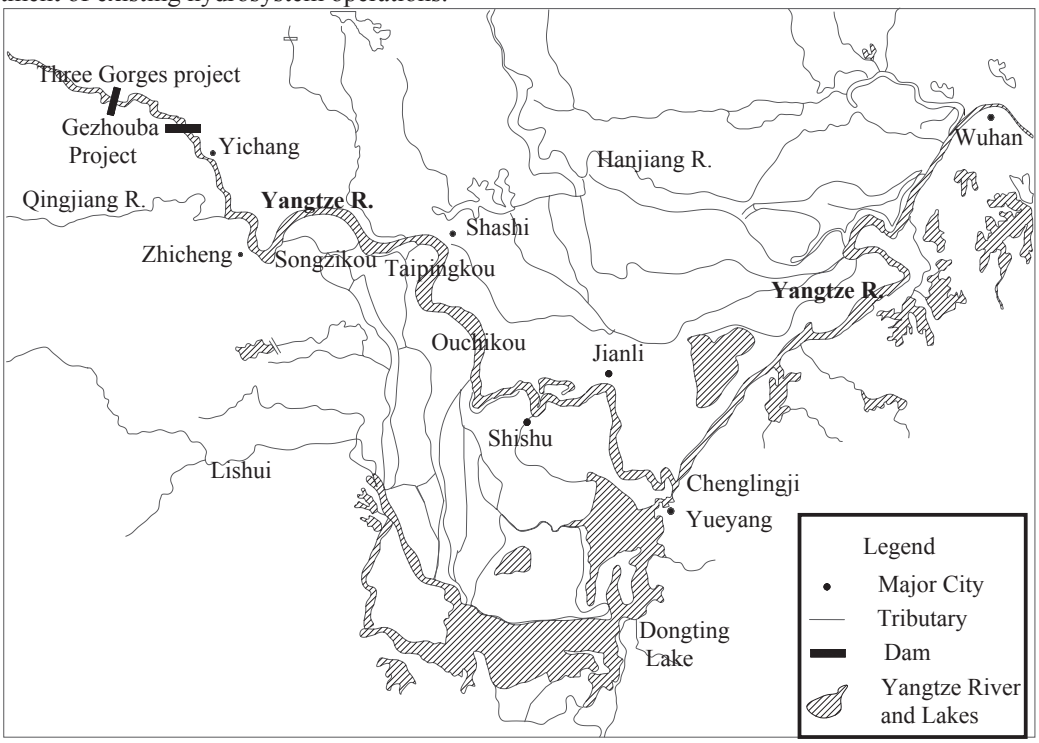

Fig. 2 Location of three outlets, one inlet, and Dongting Lake in the Yangtze River basin

3. Influence of Habitat fragment on spawning sites and fish resources

Habitat fragment is the most direct and serious factor caused by damming. Before 1981, middle and upper reaches of the Yangtze River were the biggest spawning area for YFMCS. After construction and operation of the Gezhouba Dam, the quantity and quality of spawning ground for YFMCS were reduced, and the reproduction of this species have been affected. According to field surveys, the annual egg-production was 115 billion in 1960's, and was 17.3 billion in 1981 only 15% of 1960's [25]. Subsequent impoundment of TGR in 2003 inundated eight spawning sites in the reservoir, and the quality of 400 km spawning sites downstream of the Three Gorges Dam was deteriorate sharply.

Table 1 shows the catching variation in downstream of the Gezhouba Dam. Before the construction of Gezhouba Dam, the main fish species of the Yichang reach was more than twenty, such as *Parabramis pekinensis, Coreius guichenoti, Coreius heterodon, Ctenopharyngodon idellus, Hypophthalmichthys, Aristichthys nobilis, Mylopharyngodon Piceus, Leiocassis longirostris Gvnther, Cyprinus carpio Linnaeus, Pelteobagrus rachelli, Silurus meridionalis, Squaliobarbus curriculus, Elopichthys bambusa, Siniperca chuatsi and Culter alburnus Basilewsky,* etc. [26, 27]. Among catches, the dominant species were dispersedly, the weight percentage of main species were uniform. On the period after Gezhouba Dam constructed and before impoundment of TGR, the proportion of demersal fish such as *Coreius guichenoti, Coreius heterodon, Pelteobagrus rachelli, Rhinogobio ventralis, Rhinogobio, Leiocassis longirostris* and *Silurus asotus* etc., *Ctenopharyngodon idellus* and *Hypophthalmichthys* were raised markedly, and fish such as *Parabramis pekinensis, Mylopharyngodon Piceus, Elopichthys* and *Culter* were declined, dominant species are concentrative. After impoundment of TGR, the proportion of *Cyprinus carpio Linnaeus* rise and which of YFMCS descend. Fishes such as *Luciobrama macrocephalus, Ochetobius elongatus, Siniperca chuatsi* and *Culter* were prevalent on early 1980's, but rarely on later 1980's. Fishes such as *Ochetobius elongatus, Culter mongolicus mongolicus* and *Culterdabryi dabryi* were caught only one during 1981 to 1987. Species such as *Macrura reevesii, Sinilabeo rendahli, Acrossocheilus monticola, Schizothorax prenanti, Platysmacheilus nudiventris, Saurogobio gracilicaudatus, Pseudobagrus emarginatus, Pseudobagrus ussuriensis, Fugu obscurus,* etc., were recorded before 1970's and disappeared after the later 1970's [26, 28, 29].

Table 1. Variation of catch composition in downstream of Gezhouba Dam

Fish species	Before 1981[I]		1981-1987[II]		1997-1999[III]		2000-2003[IV]	
	Weight(kg)	%	Weight(kg)	%	Weight(kg)	%	Weight(t)	%
Coreius	187.63	12.04	473.26	12.37	1017.34	32.70	1733.3	45.61
Mylopharyngodon Peters (Richardson)	163.11	10.46	406	10.61	41.5	1.33	95.00	2.50
Ctenopharyngodon idellus (Cuvier et Valenciennes)	117.25	7.52	517.01	13.51	432.96	13.92	219.3	5.77
Hypophthalmichthys Bleeker	84.22	5.4	63.3	1.65	508.1	16.33	122.3	3.22
Aristichthys nobilis (Richardson)	90.06	5.78	95.8	2.5	130.35	4.19	59.00	1.55
Cyprinus carpio Linnaeus	104.27	6.69	314.09	8.21	14.5	0.47	413.67	10.89
Silurus asotus	31.89	2.05	397.41	10.38	391.62	12.59	369.3	9.72
Pseudobagrus fulvidraco	20.09	1.29			90.32	2.90	201.00	5.29
Parabramis pekinensis (Basilewsky)	224.21	14.38	25.94	0.68	12.86	0.41		
Leiocassis longirostris Gvnther	142.25	9.13	679.62	17.76	346.53	11.14		
Elopichthys bambusa (Richardson)	76.96	4.94	130.18	3.4	13.3	0.43		
Siniperca chuatsi (Basilewsky)	66.27	4.25	21.6	0.56		0.00		
Squaliobarbus curriculus	45.27	2.9	6.06	0.16	0.99	0.03		

(Richardson)								
Culterinae	31.37	2.01	12.25	0.32	1.23	0.04		
Myxocyprinus asiaticus			184.7	4.93		0.00		
Rhinogobio			18.55	0.48	62.46	2.01		
Xenocypris Argentea Gunther			2.32	0.06	0.27	0.01		
Other fishes	22.9	1.47	10.05	0.26	24.28	0.78	654.00	17.21
Trash fish	151.08	9.69	469.18	12.26	22.85	0.73		
Total	1558.83	100	3827.32	100	3111.46	100	3800.00	101.76

Note: [I] The data before the 1981 is investigation result of 1950s and 1970s; [II] the data from 1981 to 1987 comes from [26]; [III] the data of 1997-1999 is obtained from [30]; [IV] the data of 2000-2003 comes from the Eco-environmental Monitoring Bulletin of the Three Gorges Project in the Yangtze River [27, 31-33].

The reasons which caused the change of fish species composition in the Yichang reach (downstream of Gezhouba dam) during last decades might as follows: First, migration routes were cut off. Migration fishes like *Coreius guichenoti* and *Coreius heterodon* were blocked at downstream of the Gezhouba Dam, high population density of fish appeared in this area, as a consequence, lead to high catch proportion; Secondly, overfishing of some economic fishes lead to the decline of proportion of economic fishes [30]; Thirdly, impoundment and power generation of the TGR changed the hydrologic regime of this area, the quality of spawning grounds declined, caused less reproduce of fish eggs.

4. Fishery influence of connectivity between river and lake

The passages connect main stream and the Dongting Lake are three outlets (Songcikou, Taipingkou, and Ouchikou) and one inlet (Chenglingji). Migration fishes in the Dongting Lake enter the Yangtze River through outlets and inlet to spend the winter and finish reproduction in spawning season. After reproduction, juvenile fish and parent fish in the Yangtze River swim into lake through the passages for fatten. If DWV was too small, juvenile fishes would be detained in the Yangtze River and fishes cannot grow well because of high flow velocity, low water temperature, and shortage of food in the river. Parents fish were detained in the lake cannot propagate due to lack of suitable water velocity, runoff and others hydrological condition to stimulate fish for spawning [34]. The change of relationship between the Yangtze River and the connected lakes directly affects the growth, reproduction and survival of migration fishes in this area.

4.1. Fishery resources

The DWV and fry output of middle reach of the Yangtze River and the Dongting Lake during 1963-1983 are show in Fig. 3. The developing trend of DWV and fry output are similar. Very significant correlations between DWV and fry output of middle reach of the Yangtze River and the Dongting Lake were found ($r=0.77$, $p<0.01$). Especially from 1974 to 1983, the fry output increased with DWV, its relevance $r=0.97$ ($p<0.01$). This suggests that the connectivity degree between river and lake has remarkable influence on fishery resources.

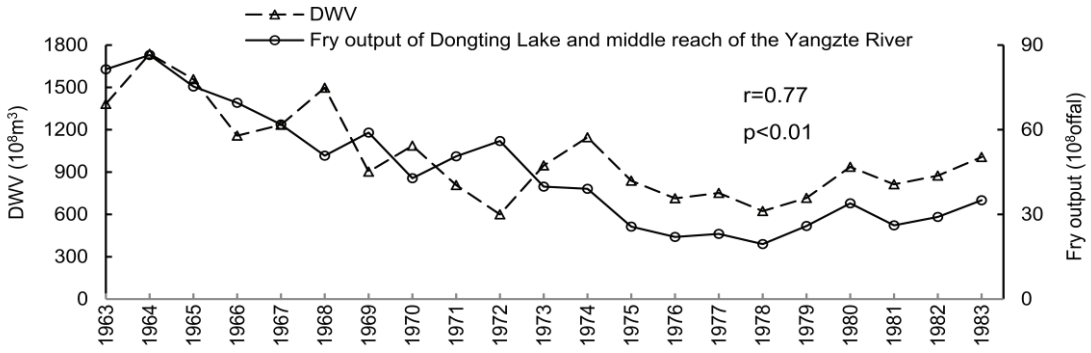

Fig. 3 DWV and fry output in middle reach of the Yangtze River and the Dongting Lake from 1963 to 1983

4.2. Migration fish

Fishery resources are influenced by river and lake connectivity, while migration fish are the most sensitive one. The YFMCS are the typical migration fish in the Yangtze River basin. In order to find the influence of river and lake connectivity on migration fish, the relation between the Percentage of Diverted Water (PDW, the percentage of annual DWV in annual discharge of the Yangtze River) and the percentage of the YFMCS in a total catch of fish in the reach below the Gezhouba Dam were analyzed (Fig. 4). From 1950 to 1989, only statistical data of decade can be collected. Very significant correlation between PDW and ratio of YFMCS was found, the relevance $r=0.92$ ($p<0.01$), is highly connected.

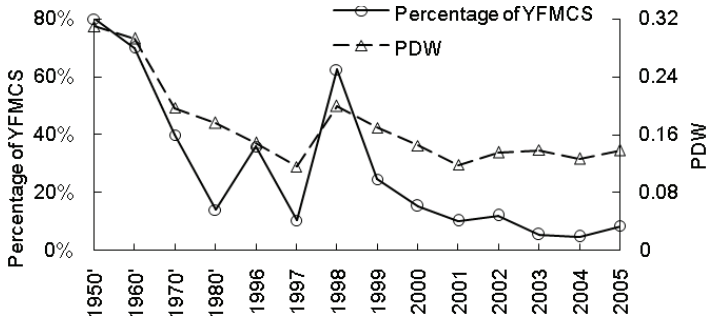

Fig. 4 PDW and the percentage of the YFMCS in a total catch of fish in the reach below the Gezhouba Dam

The percentage of the YFMCS in a total catch of fish has dropped from 80% in 1950's to less than 10% at present. Reduction amplitude of YFMCS percentage is obviously bigger than PDW. The reason would be that the proportion of migration fish is affected by both connectivity between river and lake and the species resources. The decline of YFMCS parent fishes in mainstream of the Yangtze River lead to the shrink of output of fish eggs. Based on field survey, eggs and fries of the YFMCS in mainstream of the Yangtze River (the reach from Chongqing to Wuxue) about 17.3 billion in 1981, is only 15% of 1960's. Compared with 1960's, the YFMCS eggs and fries in the reach from Chongqing to Yichang were only 12.2%, 5%, 4.5%, and 9.9% in 1981, 1982, 1983, and 1984 respectively [25].

Flux of YFMCS fry at Jianli station in spawning season is an index reflecting the fish fry output. The flux of carps fry at Jianli (Fig. 5) reduced rapidly year by year. YFMCS fry resources declined notably in 1990's compared with 1980's. After 1998, the flux of YFMCS fry correspond to a specific DWV shrank obviously. Especially after the TGR impoundment in 2003, flux of carps fry reduced remarkably compare to before impoundment at similar DWV. In 1996, 2002, 2003, and 2005, DWV was 62.8 billion m^3, 53.3 billion m^3, 56.9 billion m^3, 63.5 billion m^3 respectively, and the flux of fry at Jianli during May-June was 5.9 billion, 1.9 billion, 406 million, and 105 million respectively. The DWV of 2002 and 2003 was similar, but flux of carp fry of 2003 was less than 21.3% of 2002. The DWV in 1996 and 2005 was almost the same, but flux of carp fry of 2005 less than 2% of 1996.

The reasons would be: Firstly, the population of parent fish reduced year by year. Statistics indicate that the percentage of the YFMCS in a total catch of fish only 10.45% in Yichang to Hukou reach and 11.84% in Dongting Lake in 1997. Following the reduction of species resources, the YFMCS fry resources has declined continuously; Secondly, DWV reduction caused the reduction of parents fish migrating to the Yangtze River, consequently, the YFMCS fry reduction; Thirdly, The integrated goals of water storage, navigation and power generation of the Three Gorges Project (TGP) bring adverse influence on reproduction habitat of the YFMCS. Reservoir operation altered the original hydrologic regime, changed the original water level fluctuation process, smoothen the peak of swelling from May to June. As a result, some parent fish could not receive the stimulation of flow, and the amount of spawning eggs was restrained. The temperature of water discharged from TGR was colder than natural in reproduction season, then delayed the time which water temperature downstream of dam achieved 18 ℃, seriously influenced the reproduction of the YFMCS.

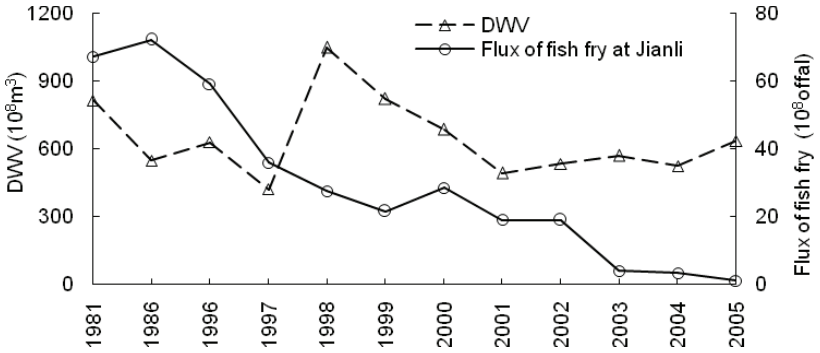

Fig. 5 Flux of YFMCS fry at Jianli station and DWV

DWV and the YFMCS yield in the reach below the Gezhouba Dam from 1996 to 2005 (Fig. 6) indicate that higher DWV corresponding to higher YFMCS yield. The correlation between them reaches 0.877. The YFMCS output decreased continuously after 1998, and obviously less than before 1998 at the same DWV. This suggested that connectivity between river and lake have intimate relation with the growth and reproduction of the YFMCS. Reduced connectivity degree restricted the juvenile fish in middle and lower reaches of the Yangtze River to enter lake for fatten. As a consequence, high velocity, low water temperature, and lack of food in river were unable to satisfy the growth and survival of juvenile fish.

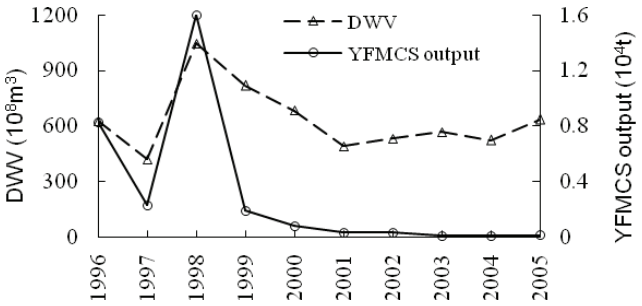

Fig. 6 DWV and the YFMCS output in downstream of the Gezhouba Dam from1996 to 2005

Another important change caused by damming is flow regime alteration. Daily water level fluctuation, which as a result of power-peaking of hydroelectric dams would disturb the spawning action of parent carps. DWV change little in 2000 - 2005, but the YFMCS output decrease obviously (Fig. 7). DWV almost the same in 2002 -2003, but the YFMCS output reduces from 336 tons in 2002 to 135 tons in 2003, the YFMCS output of 2003 only 40.18% of 2002.

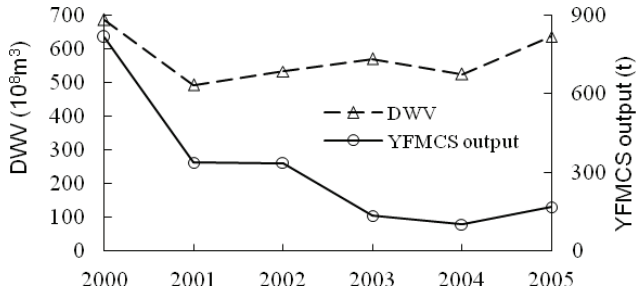

Fig. 7 DWV and the YFMCS output in downstream of the Gezhouba Dam from 2000 to 2005

5. Conclusion

Fishes in the Yangtze River basin were seriously affected by dams and barries. Dams cut off migration passage, fragment habitat, alter flow patterns, and change the connectivity between river and lake. As a result, some fish species are threatened, some are disappeared indeed, the proposition of migration fish decrease, while common carp and catfish were noticeable increased. The distribution and abundance of the YFMCS populations that spawned throughout the mainstream of the Yangtze River has changed dramatically from last century. Both the YFMCS fry and the YFMCS output are gradually decreasing. As passages between river and lake were affected by construction and operation of gates and dams, YFMCS populations of the Yangtze River basin shrank gradually. Spawning sites also become worse and worse due to the hydroelectric dam changed the water temperature and water level fluctuation, and incompatible with their life history requirements.

DWV have good correlation with the YFMCS output, the percentage of the YFMCS in a total catch of fish was changed with the connectivity between river and lake. The flux of YFMCS fry at Jianli station was affected by discharge and water level fluctuation on spawning season. After impoundment of the TGR, fry resources of YFMCS reduced more than 90%, adult resources also descended more than 50%. Engineering construction had direct influence on carp fry, consequently, influence on the YFMCS population appeared. Along with the storage of the Three Gorges dam and scouring of downstream river channel, DWV will continue to reduce, as a result the YFMCS output will decline incessantly. Existing management of TGR in spawning season influenced the reproduction of YFMCS and other fishes, so adjust reservoir action in the spawning season, scientific arrangement man-made flood peak, urge the YFMCS spawning in the reach from Yichang to Chenglingji, thereby reducing the influence of reservoir management on fishery.

Acknowledgrments

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