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EFFECT OF THE DISTANCE FROM THE DAM ON RIVER FISH COMMUNITY STRUCTURE AND COMPOSITIONAL TRENDS, WITH REFERENCE TO THE THREE GORGES DAM, YANGTZE RIVER, CHINA

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Abstract: The Three Gorges Reservoir on the Yangtze River of China is the largest hydropower project in the world. Three reaches from the upper Yangtze River were selected for the study on the effect of distance from the dam on river fish community structure and fish composition trends. A total of 8680 fish representing 58 species of 11 families were collected during the study period from November 2010 to October 2011. The results indicated that the fish assemblage in the reservoir was dominated by Cyprinids. Fish abundance in the summer was significantly higher than that in other seasons (P<0.05). Fish species richness and abundance close to the dam (Zigui reach) were less, comparatively higher at the middle reach (Wanzhou reach) and intermediate at far from the dam (Fuling reach). Fish fauna shifted from lotic species to lentic species associated with reservoir construction. Therefore, it is evident that impoundment of the Three Gorges Reservoir has altered the fish assemblage structure, and fish species compositions have shifted in their relative abundance over time.

Key words: Fish fauna shift; Impoundment; Species richness; The Three Gorges Reservoir; The Yangtze River
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The Three Gorges Reservoir (hereafter TGR) was impounded with three water filling stages in 2003, 2006 and 2009, respectively. Subsequently the water level was lifted to 135 m, 156 m and 175 m above the sea level. It is the largest typical river type reservoir with a 600 km length and a 39.3 km^3 storage capacity [1—4]. The most important point of the Three Gorges Dam construction was flood control, while supplying water, providing electricity, and expanding navigation facilities were other uses [2].

Effects of dams on riverine fish have been of great concern and extensively studied worldwide [5—8]. Dams are considered as one of the most negative anthropogenic activities on ecosystem, by altering the natural environment, blocking migration routes and destroying spawning grounds of fishes, leading to changes in fish assemblage structure and diversity [2, 7, 9]. Therefore changes in fish species richness give us clear evidence on impact of dams on aquatic environment. Distribution and colonization of fish species may be influenced by various factors such as thermal, chemical stratification of the water column, fluctuation of water level, shape and area of the reservoir, operating system of the dam, reservoir depth and other morphologic characteristics [5, 9—12]. The colonization and distribution of fish species are not random processes but depend on the longitudinal hydrological differences from the dam site to the riverine zone formed [9—13].

Some researchers have shown that the change in fish species richness within a newly impounded reservoir increases initially and decreases with the reservoir age [14—16]. Elimination of some species has also been recorded [9, 17, 18]. The other expected impact of damming is introduction of invasive species. They may colonize successfully and compete with native fish communities within the newly impounded reservoir [9, 17, 19, 20]. The occurrence of fish kills is another phenomenon associated with the reservoir filling [9].

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The changes in fish community structure in rivers are inevitable due to massive hydropower development in China [21]. There is a paucity of studies carried out in recently impounded TGR on fish assemblage structure [20, 22, 26]. The aims of this study were to investigate how the impoundment has affected species composition and abundance of fishes in three fish landing places and how fish fauna has shifted to adapt to the environment after impoundment of the TGR. Therefore, the present study may provide some baseline information for long term monitoring of the fish communities in the TGR.

1 Materials and Methods

Fish sampling was monthly carried out in three areas of the TGR in the main stream of the upper Yangtze River from November 2010 to October 2011, Zigui reach (about 1.9 km from the dam) (30°51′ N, 111°00′ E), Wanzhou reach (middle reservoir, about 300 km from the dam) (30°49′ N, 108°23′ E) and Fuling reach (upper-reservoir, about 500 km from the dam) (29°42′ N, 107°23′ E) (Fig. 1). Each sampling was done for 8—10 days. Fish were collected from the local fishing boats using 1.5 cm nylon mesh trap nets or 4—6 cm nylon mesh gill nets (100—120 m long × 1.4—1.5 m high). 5—8 fishing boats were investigated at each site. The specimens were sorted and identified. Total length of each fish was measured from the tip of the snout to the longest caudal fin ray to the nearest 0.1 mm. Weight (g) of the fish was recorded on an electronic balance sensitive to 0.001 g, after blot-drying excess water from the body.

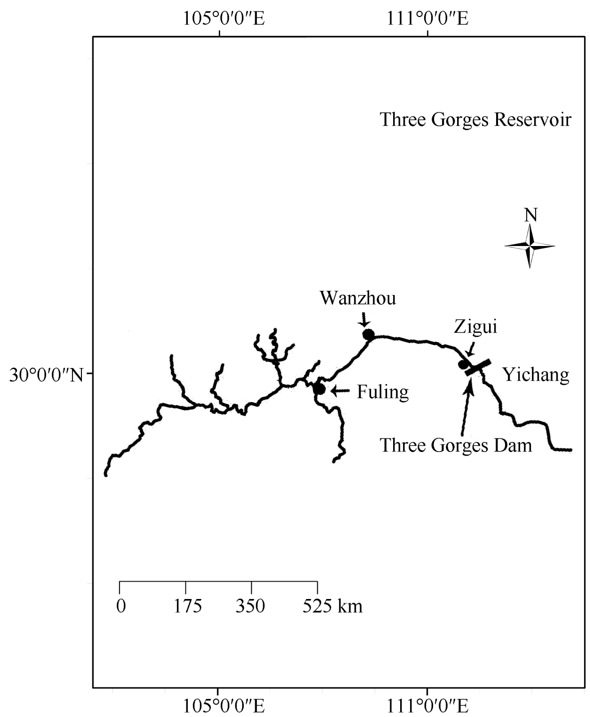

Fig. 1　Sampling sites of the three general areas along the longitudinal profile of the Three Gorges Reservoir

Data analysis was performed using SPSS 16.0. Data are presented as mean ± standard error of the mean. Sampling location differences and seasonal differences of species richness and abundance were statistically tested by one-way ANOVA followed by Turkey's test. All the statistical analyses were considered as significance level at $P < 0.05$. For the data of each sampling site, Shannon-Wiener diversity index was calculated. The data obtained were standardized and subjected to principal components analysis (PCA). PCA was carried out in the R software using the "ade4" package [23].

2 Results

A total of 8680 fish representing 58 species of 11 families were collected at three landing sites during the study period. In Zigui, a total of 2728 fish representing 34 species of 8 families were collected. Among them, 22 species (64%) were in Cyprinidae, 4 species (12%) in Bagridae, 2 species (6%) in Siluridae and in Salangidae respectively and 1 species (3%) in Cobitidae, Percicithyidae, Gobiidae and Synbranchidae respectively (Tab. 1). *Hemiculter bleekeri* and *H. leusisculus* were the dominant species. In Wanzhou, a total of 3007 fishes representing 48 species of 8 families were collected. Among them, 34 species (71%) were in Cyprinidae, 5 species (11%) in Bagridae, 3 species (6%) in Cobitidae, 2 species (4%) in Siluridae, 1 species (2%) in Catostomidae, Percicithyidae, Gobiidae and Centrachidae respectively (Tab. 1). *Hemiculter bleekeri* and *H. leusisculus* were also the dominant species in this reach. The exotic largemouth bass *Micropterus salmoides* was found in Wanzhou reach in several occasions (0.13%). A total of 2945 fishes representing 40 species of 8 families were collected in Fuling reach. Among them, 23 species (58%) were in Cyprinidae, 6 species (15%) Cobitidae, 5 species (12%) Bagridae, 2 species (5%) Siluridae, and 1 species (2.5%) in Catostomidae, Ophiocephalidae, Percicithyidae, Gobiidae respectively (Tab. 1). *Coreius guichenoti* and *C. heterodon* were the dominant species. Monthly changes in fish abundance and percentage variation of the taxonomic groups in each site are shown in Fig. 2 and 3 respectively. The abundance of fish species was peaked in Zigui in May and lowest in February. In Wanzhou, it was peaked in May and lowest in October. In Fuling it was peaked in June and lowest in October.

Comparison among fish distribution in three fishing landings along the TGR is shown in Fig. 4. PCA results indicated that there were obvious differences in fish species distributions among three sampling sites. Wanzhou represents the middle part of the TGR. More species were collected from this area with respective to the other two sites. Zigui represents the near dam area and less number of species was associated there. Moreover, fish species such as *Coreius guichenoti*, *C. heterodon*, and

Tab. 1 Structure of the fish communities in the Zigui, Wanzhou and Fuling reaches of TGR

Species	Zigui		Wanzhou		Fuling	
	Abundance	% abundance	Abundance	% abundance	Abundance	% abundance
1. *Opsariichthys uncirostris* (OU)	4	0.15	11	0.37	0	0.00
2. *Zacco platypus* (ZP)	0	0.00	16* **	0.53	0	0.00
3. *Rhodeus ocellatus* (RO)	21	0.77	16 **	0.53	11	0.37
4. *Pseudorasbora parva* (PP)	23	0.84	47* **	1.56	0	0.00
5. *Sarcocheilichthys sinensis* (SS)	0	0.00	62 **	2.06	0	0.00
6. *Coreius heterodon* (CH)	26	0.95	28* **	0.93	339 **	11.51
7. *Coreius guichenoti* (CG)	1	0.04	88*	2.93	724 **	24.58
8. *Rhinogobio typus* (RT)	201	7.37	155	5.15	73 **	2.48
9. *Rhinogobio cylindricus* (RC)	64	2.35	31	1.03	51	1.73
10. *Rhinogobio ventralis* (RV)	0	0.00	0	0.00	178 **	6.04
11. *Saurogobio dabryi* (SD)	278	10.19	140* **	4.66	183 **	6.21
12. *Saurogobio gymnocheilus* (SG)	260	9.53	150 **	4.99	100 **	3.40
13. *Gobiobotia abbreviata* (GA)	0	0.00	0	0.00	14	0.48
14. *Ctenopharyngodon idellus* (CI)	37	1.36	40	1.33	36	1.22
15. *Elopichthys bambusa* (EB)	31	1.14	17 **	0.57	0	0.00
16. *Squaliobarbus curriculus* (SCU)	0	0.00	39 **	1.30	0	0.00
17. *Hemiculter leucisculus* (HL)	375	13.75	326* **	10.84	119	4.04
18. *Hemiculter bleekeri* (HB)	621	22.76	509* **	16.93	137	4.65
19. *Parabramis pekinensis* (PPE)	0	0.00	17 **	0.57	0	0.00
20. *Culter erythropterus* (CE)	10	0.37	11	0.37	10	0.34
21. *Pseudolaubuca engraulis* (PE)	0	0.00	13	0.43	0	0.00
22. *Megalobrama amblycephala* (MA)	21	0.77	8 **	0.27	10	0.34
23. *Culter mongolicus* (EM)	0	0.00	9* **	0.30	0	0.00
24. *Culter dabryi* (ED)	56	2.05	7	0.23	10	0.34
25. *Hemiculter sauvagei* (HS)	0	0.00	15	0.50	0	0.00
26. *Xenocypris davidi* (XD)	26	0.95	9 **	0.30	0	0.00
27. *Xenocypris argentea* (XA)	0	0.00	10	0.33	0	0.00
28. *Hypophthalmichthys molitrix* (HM)	41	1.50	44* **	1.46	30	1.02
29. *Aristichthys nobilis* (AN)	43	1.58	46* **	1.53	45	1.53
30. *Cyprinus carpio* (CC)	44	1.61	70* **	2.33	81	2.75
31. *Procypris rabaudi* (PR)	0	0.00	10* **	0.33	7	0.24
32. *Carassius auratus auratus* (CA)	76	2.79	218* **	7.25	90	3.06
33. *Carassius auratus gibelio* (CGI)	0	0.00	21	0.70	11	0.37
34. *Mylopharyngodon piceus* (MP)	9	0.33	0	0.00	0	0.00
35. *Squalidus atromaculatus* (SAT)	0	0.00	87* **	2.89	22	0.75
36. *Folifer brevifilis* (FB)	0	0.00	13	0.43	9	0.31
37. *Pseudobrama simoni* (PS)	0	0.00	13* **	0.43	0	0.00
38. *Myxocyprinus asiaticus* (MAS)	0	0.00	14	0.47	10 **	0.34
39. *Botia superciliaris* (BS)	0	0.00	0	0.00	2	0.07
40. *Parabotia fasciata* (PFA)	0	0.00	9	0.30	7 **	0.24
41. *Parabotia banarescui* (PB)	0	0.00	12	0.40	6	0.20
42. *Leptobotia rubrilaris* (LR)	0	0.00	0	0.00	4	0.14
43. *Leptobotia pellegrini* (LP)	0	0.00	0	0.00	3	0.10
44. *Misgurnus anguillicaudatus* (MAN)	10	0.37	35	1.16	6 **	0.20

Continued

Species	Zigui		Wanzhou		Fuling	
	Abundance	% abundance	Abundance	% abundance	Abundance	% abundance
45. *Hemibagrus macropterus* (HMA)	0	0.00	14	0.47	9	0.31
46. *Pseudobagrus fluvidraco* (PF)	93	3.41	117	3.89	129	4.38
47. *Pseudobagrus vachelli* (PV)	90	3.30	187* **	6.22	175 **	5.94
48. *Pseudobagrus nitidus* (PN)	79	2.90	198* **	6.58	135 **	4.58
49. *Leiocassis longirostris* (LL)	24	0.88	57 **	1.90	125 **	4.24
50. *Silurus asotus* (SA)	16	0.59	11* **	0.37	9	0.31
51. *Silurus soldatovi meridionalis* (SSM)	25	0.92	15* **	0.50	12 **	0.41
52. *Channa argus* (OA)	0	0.00	0	0.00	4	0.14
53. *Siniperca chuatsi* (SCH)	35	1.28	12*	0.40	7	0.24
54. *Ctenogobius giurinus* (CGU)	49	1.80	26*	0.86	12	0.41
55. *Monopterus albus* (MA)	8	0.29	0	0.00	0	0.00
56. *Micropterus salmoides* (MS)	0	0.00	4*	0.13	0	0.00
57. *Protosalanx hyalocranius* (PH)	13	0.48	0	0.00	0	0.00
58. *Neosalanx taihuensis* (NT)	18	0.66	0	0.00	0	0.00
59. *Spinibarbus sinensis*			* **			
60. *Ancherythroculter kurematsui*			*			
61. *Acrossochelius monticola*			* **			
62. *Onychostoma sima*						
63. *Ancherythroculter nigrocauda*			**			
64. *Megalobrama pellegrini*			**			
65. *Opsariichthys bidens*			**			
66. *Acheilognathus omeiensis*			**			
67. *Ameiurus melas*			* **			
68. *Rhodeus sinensis*			*			
69. *Hemiculter tchangi*			* **			
70. *Abbottina obtusirostris*			*			
71. *Tinca tinca*			* **			
72. *Abbottina rivularis*			**			
73. *Paramisgurnus dabryanus*			**			
74. *Acheilognathus macropterus*			**			
75. *Culter alburnus*			* **			
76. *Pseudolaubuca sinensis*			* **			
77. *Ictalurus punctatus*			**			
78. *Leiocassis crassilabris*			**			
79. *Tilapia* sp.			**			
80. *Leptobotia elongata*					**	
81. *Jinshaia sinensis*					**	
82. *Leptobotia taeniops*					**	
83. *Lepturichthys fimbriata*					**	
84. *Gobiobotia filifer*					**	
85. *Xenophysogobio boulengeri*					**	
86. *Abbottina obtusirostris*					**	
87. *Hemibarbus labeo*					**	
88. *Hemibarbus maculatus*					**	

*recorded by Gao, *et al*. (2010) in 2005; ** recorded in 2006

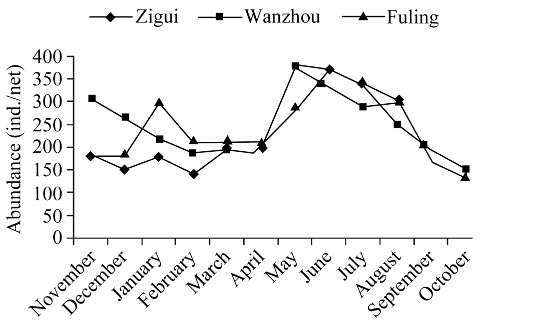

Fig. 2 Monthly abundance of total fish species (total number of individuals) from three different reaches in Three Gorges Reservoir

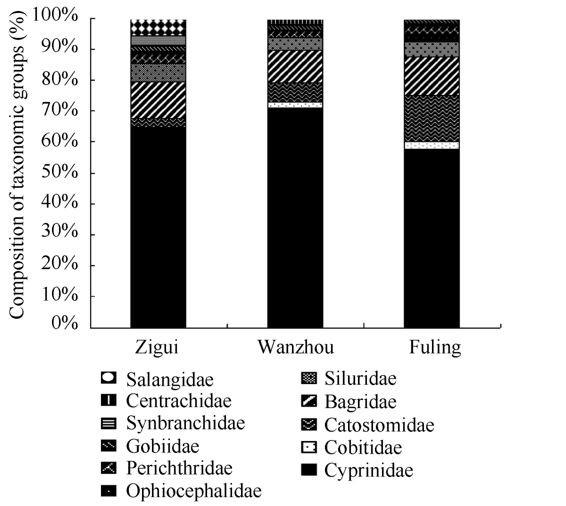

Fig. 3 Composition of taxonomic groups in three reaches along the Three Gorges Reservoir

Rhinogobio ventralis were more dominated in Fuling reach from the more riverine site sampled. We observed less abundance and richness close to the dam (Zigui) while middle (Wanzhou) of the reservoir had the highest richness and intermediate species richness was observed far from the dam (Fuling reach).

The seasonal changes in fish abundance analyzed using Shannon-Wiener diversity index are shown in Fig. 5. The calculated values for the Shannon-Wiener diversity indices in Zigui, Wanzhou and Fuling were 2.755, 3.1488 and 2.8123 in Zigui, Wanzhou and Fuling respectively. The species richness was significantly higher in summer (P< 0.05) than those in winter and autumn (Fig. 5a). The species richness among four seasons was analyzed using PCA (Fig. 5b). Fish abundance and species richness between autumn and winter and between summer and spring were found to be close, and both were higher in summer and spring than those in autumn and winter.

3 Discussion

The construction of large scale hydroelectric dams affects biodiversity at all scales by changing community, species and even genetic level [17]. Therefore changes in fish composition and community structure are unavoidable during the reservoir filling. It may be due to alteration of the hydrodynamic nature of the water body associated with the other factors that influences the species distribution. Clear changes in lotic and lentic species, elimination of some fish species and reduction

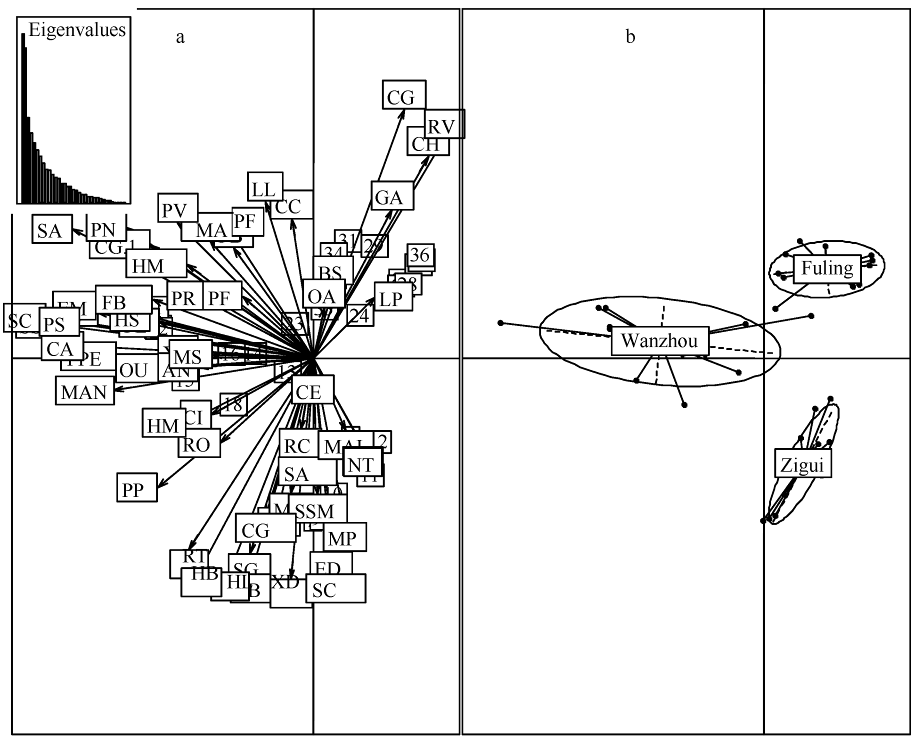

Fig. 4 Results of principal component analysis (PCA) for fish distribution comparison in the Three Gorges Reservoir. a- distribution of fish species from the three different reaches. b- each site is presented as ellipsoid

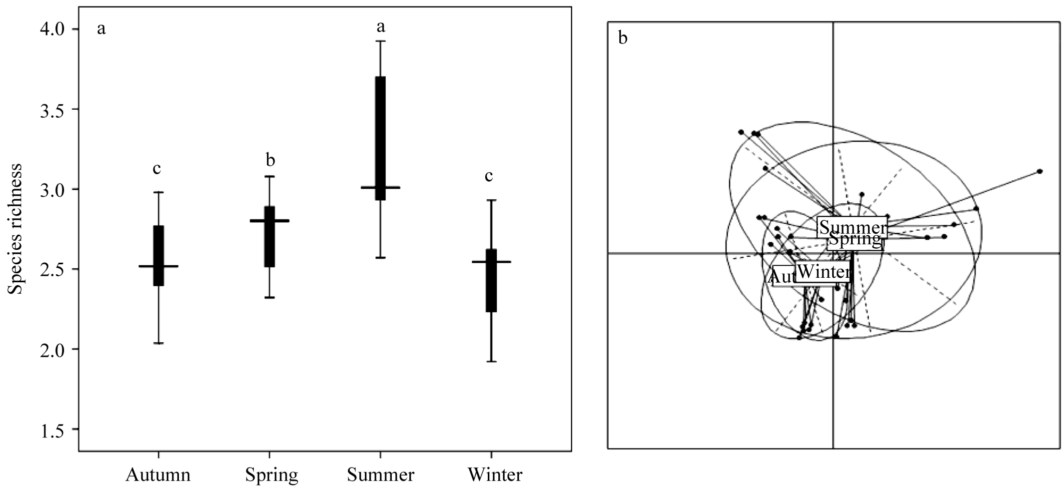

Fig. 5 Seasonal changes in fish community structure in the Three Gorges Reservoir. a- Species richness comparison among four seasons (Shannon-Wiener diversity index), b- PCA analysis among four seasons (refer Tab. 1 for abbreviations)

of the fishery productivity have been observed by many authors [9, 17, 20]. Due to the construction of Fuchunjiang and Hunanzhen dams in China, the replacements of lotic fish species by lentic species, and reduction and elimination of *Macrura reevesii* from the Qiantang River, were recorded [21]. Fish community changes with reduction from 107 to 83 species were reported due to the Xianjiang Reservoir construction in China [21].

Changes in fish community structure in the TGR were observed by some other authors [20-22]. We observed differences of fish composition and abundance from fish collected from the three reaches of the reservoir. During autumn and winter, we found comparatively less abundance and richness as the water level rose to 175 m during the period of October to April. And the catches were observed to be far less. We observed comparatively higher abundance and richness during the spring and summer with the flood season (from May to September) when fishes spawned. No other seasonal observations of changes in fish community structure were found in three reaches (Zigui, Wanzhou and Fuling) from the TGR previously. However, the higher Shannon-Wiener diversity index in summer was observed in fish collected from Mudong section of the Three Gorges Reservoir [22]. The TGD has set the 145 m (the flood control level) and 175 m (the normal pool level) and therefore this large scale fluctuation of the water level may be the main reason to influence the distribution, composition and abundance changes. The water level is raised to 175 m level during the period of October to April and less fish were caught. We could observe comparatively higher abundance and richness during spring and summer with the flood season (from May to September) which was the spawning period of most species. We observed higher number of species and abundance from the middle reach (Wanzhou) of the reservoir. Since the water level fluctuation occurs every year, there might be unique fish assemblage structure in each zone (lacustrine, transitional and riverine)[20]. Moreover, fluctuation of the water level causes the greater influence on fish distribution and reproduction [24]. Furthermore, fish species have both greater reproductive plasticity and require simpler biological demand may colonize well in newly impounded reservoirs [9]. Present study found a lower species richness and abundance close to the dam. Therefore our findings also agree with the decreasing fish abundance towards the dam [9]. More lentic species appeared as the most dominated species such as *Hemiculter* species before the impoundment. Percentage abundance of the *H. leucisculus* (before the second filling in 2005) was 61%. However, it has been reduced to 39.7% during the second filling in 2006 in Wanzhou region. The percentage abundance of the *H. bleekeri* was 3% (before the second filling in 2005). It has been increased to 39% during the second filling in 2006 in Wanzhou region [20]. However, present study recorded that reduction of percentage abundance of both dominant species of *H. bleekeri* (17%), *H. leucisculus* (11%), though the percentage abundance decreased further, *Hemiculter* species was the dominant in Wanzhou region. This agrees with the observations of [20]. We found significant contribution of *Hypophthalmichthys molitrix*, *Aristichthys nobilis*, *Cyprinus carpio* and *Carassius auratus* to fish catch in Zigui where the lacustrine zone formed near the dam with respect to the other two sites.

However, after second filling in 2006 the abundance proportion of the dominant species were decreased Gao X, *et al.* [20]. Fish community structure in Fuling reach, was still dominated by *Coreius guichenoti* (25%) and *C. heterodon* (12%) (Tab. 1). Therefore, Fuling from the TGR is still dominated by the *Coreius* species. Before the impoundment, fish composition in both Mudong and

Wanzhou reaches were similar. But after the impoundment Wanzhou reach was dominated by lentic fish species while in Mudong reach was dominated by lotic species[26]. The present study found out that in Fuling reach which is about 500 km upstream from the TGD was still dominated by lotic species. It may be due to that fish species which are not adapted to slow flowing water may move to more riverine portion. Endemic fish species such as *C. guichenoti*, *Rhinogobio ventralis* and *R. cylindricus* have given significant contribution to fish catch in upper reservoir area. Possible reason may be due to the flow regulation between transitional zone and lacustrine zone which leads to more upstream portion of the reservoir. Some other authors mentioned that upstream movement (riverine) of the endemic fishes due to flow regulation in between transitional zone and lacustrine zones [20], therefore, present study also agrees with the previous findings with more upstream movement of some fish species. The Shannon-Wiener diversity index in Fuling reach was 1.81 (after filling), in Wanzhou reach it was 1.57 (during filling) [20]. The observed Shannon-Wiener diversity indices during the survey were, in Fuling reach 2.81 and in Wanzhou reach 3.14. Therefore, changes in fish community structure in different areas in TGR may due to different environmental conditions formed during different inundation periods. Therefore, above mentioned evidence indicates that impoundment of the TGD has altered the fish assemblage structure and fish species compositions have shifted in their relative abundance over time.

Other significant incidence that we observed was the introduction of exotic piscivorous species such as largemouth bass (*Micropterus salmoides*) in Wanzhou reach at several times. In the TGR, some exotic species like *Tinca tinca*, *Ameiurus melas*, and *Ictalurus punctatus* were found to occur[20]. Introduction of exotic species into the newly impounded reservoir may pose threat to the native fish fauna. Some authors have mentioned that lacustrine zone formed during reservoir filling was more favorable to the invasive species [19, 20, 25]. More attention should be paid to situation in the future.

4 Conclusion

Present study revealed that the fish assemblage structure in TGR was totally dominated by Cyprinids exceeding more than 55% of the species composition. Past and present studies revealed that impoundment of the Three Gorges Dam had altered the fish assemblage structure and fish species have shifted in their relative abundance overt time. Therefore, species richness, abundance varied with the time. During the present investigation largemouth bass (*Micropterus salmoides*) was found in Wanzhou reach in several occasions (0.13%). As they can remarkably influence the fish community structures, impact of introduction of such species and possible routes (aquaculture, ballast water or any other) must be carefully investigated. To become an important fresh water fish production area in China, authorized government body should thoroughly examine the fishing activities in the fishing area of the reservoir; closed area, breeding area of the fishes should be declared well with the help of the other institutional collaborations.

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三峡水库不同区域对鱼类群落结构和鱼类组成动态的影响

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摘要：研究选取三峡水库三个不同的区域来研究离坝距离对鱼类群落结构和鱼类组成动态的影响。2010 年 11 月到 2011 年 10 月期间共采集了 8680 尾鱼类样本，隶属于 11 科 58 种，其中鲤科鱼类占据了三峡水库鱼类的主体。夏季时的鱼类丰度显著高于其他季节的($P<0.05$)。鱼类物种多样性与丰度在靠近大坝的江段(秭归)最低，中游江段(万州)相对较高，远离大坝的江段(涪陵)居中。随着三峡大坝的建成，鱼类区系也由适应流水生存的种类转变为适应静水生存的种类。因此，三峡水库蓄水已经明显地改变了其原有的鱼类群落结构，鱼类组成的相对丰度也随着时间发生了改变。

关键词：鱼类区系转变；蓄水；物种多样性；三峡水库；长江