Effects of reservoir impoundment on fish assemblages in the Wujiang River of China

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Abstract. Fishery catches were investigated during the spring and autumn in the period 2006-2010. The fish assemblages’ composition and dynamics were analysed and compared under the pressure of the Pengshui Reservoir impoundment. A total of 101 species were sampled in the lower Wujiang River. 78 species and 83 species were found in the upper and the lower reaches, respectively. After impoundment there were five species in the Yanhe branch and nine species in the Pengshui branch. The abundance of species was higher in the Pengshui than in the Yanhe. Fish abundance did not change in the first year of impoundment (2008) in the Lujiao-Gongtan reach, but it dramatically declined by 45.95% in 2009. The fish were subdivided into three groups and two ecotypes according to their time-series appearance in fish catches and their habitat preference. Species composition changed significantly with decreases in numbers of lotic species. Fish assemblages responded more rapidly and dramatically to impoundment in the reservoir section than the section below the Pengshui Dam.

1. Introduction

Damming can cause dramatic changes in river ecosystems and is a major factor in the decline of biodiversity and variation in aquatic animal community structures [1][2]. There has been an increase in research exploring ecological response patterns that result from damming, with particular focus on the adverse and negative impacts of damming on aquatic organisms and hydro-ecosystems [3][4][5][6]. Fish live in distinct habitats [7], and the spatial distribution of fish is affected by depth, distance from the dam, and habitat choice [8]. Further, fish are sensitive to flow regimes and hydrological conditions, which can be dramatically changed by a dam [9]. This study was conducted to identify the impact of hydropower development on fish assemblages and to understand the impact pattern in sensitive ecological areas.

2. Materials and methods

2.1. Study area

The Wujiang River is a 1037 km long canyon-shaped tributary of the Yangtze River. It contains eleven cascades that produce hydropower, and these were created as a response to the increasing electric power demand in China. The Pengshui (PS) Dam is the 10th cascade, is located in the lower Wujiang River and is 147 km from an estuary. PS Reservoir is regulated seasonally, controlling a
69000 km² catchment area and covering around 78.5% of the total drainage area of the Wujiang River. Its normal and dead storage levels are 293m and 278m, respectively, and its regulated storage capacity is 0.518 billion m³. This project began in September 2005, and impoundment began in January 2008.

The Yanhe (YH), Lujiao-Gongtan (LG) and Pengshui (PS) reaches of the Wujian were selected for investigation (Figure 1). In each reach, investigations were conducted from upstream to downstream on the backwater, reservoir, and downstream sections.

Figure 1. Distribution of three sampling reaches in the lower Wujiang River.
2.2. Data collection and transformation
Commercial fishery catches of settled gillnets and hooks were investigated in the spring and autumn seasons from 2006 to 2010. The investigation was conducted each day until no new species appeared for seven consecutive days. All the specimens collected were identified, counted, and measured.

To reduce error, transformations were made to the primary data. If a species was investigated both before and after a specific year (x), but in the year (x) the species was not collected, the mean values of the number and weight of individuals in the two years it was present are used for the species data in year (x).

2.3. Statistical methods and software
The statistical methods used to present the data included:

(1) Community dominant species
Index of relative importance \( IRI = (P_i + P_m) F \times 10^4 \)

Above, \( P_i \) and \( P_m \) are the proportion of number and weight, and \( F \) is the species’ frequency of occurrence. If the \( IRI > 1000 \), this species is considered to be a dominant species [10].

(2) Fish diversity
Four indices have been used in the literature for estimating fish diversity, and are described below [11][12][13][14]:

- Margalef Index of community diversity \( P = (S - 1)(\ln N)^{-1} \)
- Shannon Wiener Index \( H' = -\sum P_i \ln P_i \)
- Pielou evenness index \( E = H'/(\ln S)^{-1} \)
- Simpson dominance index \( D = \sum (P_i)^2 \)

Above, \( N_i \) is the number of individuals of \( i \) species, \( N \) is the total number of individuals, and \( P_i \) accounted for the proportion of \( N_i \) in \( N \), that is, \( P_i = N_i / N \), \( i = 1, 2, 3...N \)

(3) Community structure similarity
Fish abundance was taken as a variation of the original matrix, and the investigational years were taken as samples of the original matrix. Similarity, in the community, structure was analyzed using the Bray-Curtis similarity coefficient[15] and Cluster analysis (the unweighted pair group method with arithmetic means (UPGMA)). First, similarity matrices between the samples were developed, and then the characteristics of fish assemblages’ structure were analyzed by establishing a cluster analysis diagram.

All of the data were analyzed using PRIMER 5.0 software packages (Plymouth Marine Laboratory, UK), EXCEL 2010, and SPSS 13.0.

3. Materials and methods

3.1. Study area
From 2006 to 2010, a total of 101 species were sampled; there were 78 species in the upper reaches (LG, YH) and 83 species in the lower reach (PS). 24 endemic species of the Upper Yangtze River and three vulnerable species, *Leptobotia elongate*, *Procypris rabaudi* (which appear on the “China red data book of endangered animals species”) and *Percocypris pingi* (which appear on the “China species red list”), were found.

After impoundment, fish abundance varied between five species in the YH reach and nine species in the PS reach. Fish abundance in the PS reach was higher than in the YH and LG reaches; fish abundance in the LG reach showed no difference in the first impoundment year (2008), but declined 45.95% in 2009 (Figure 2).
Figure 2. Dynamics in species abundance of the YH, LG and PS reaches.

In this study, fish representing more than 1% of all the species sampled in both weight and number were considered as main species, while the others were considered to be rare species. There were 20 main species in the YH reach with proportions of weight and number of 88.72% and 79.85%, respectively; there were 16 main species in the LG reach with proportions of weight and number of 89.92% and 88.99%, respectively; there were 16 main species in the PS reach with proportions of weight and number of 82.20% and 71.19%, respectively.

The fish species were classified into three groups: A) species that appeared both before and after the impoundment, B) species that appeared only before the impoundment, and C) species that appeared only after the impoundment.

The results showed that the main fish species of the YH and PS reaches did not have obvious changes in the "before and after impoundment” group; differences in species composition resulted from rare species. Fish species that appeared only after impoundment in the LG reach accounted for 34.55% of the total number of species, but in the PS and YH reaches, fish species that only appeared after impoundment accounted for smaller proportions: 19.18% and 18.07% of the total number of species, respectively (Table 1).

Table 1. Three groups of fish species based on their appearance in catches by time-series.

| Reaches | YH | LG | PS |
|---------|----|----|----|
| Groups  | S<sup>d</sup> | PS<sup>e</sup> | I<sup>f</sup> | PI<sup>g</sup> | S<sup>d</sup> | PS<sup>e</sup> | I<sup>f</sup> | PI<sup>g</sup> |
| Group A<sup>a</sup> | 50 | 68.49 | 10881 | 98.53 | 29 | 52.73 | 2576 | 87.65 | 61 | 73.49 | 8644 | 98.81 |
| Group B<sup>b</sup> | 9 | 12.33 | 40 | 0.36 | 7 | 12.73 | 56 | 1.91 | 7 | 8.43 | 32 | 0.37 |
| Group C<sup>c</sup> | 14 | 19.18 | 122 | 1.10 | 19 | 34.55 | 307 | 10.45 | 15 | 18.07 | 72 | 0.82 |

<sup>a</sup> Species appeared only before the impoundment
<sup>b</sup> Species appeared before and after the impoundment
<sup>c</sup> Species appeared only after the impoundment;
<sup>d</sup> Species
<sup>e</sup> Individuals
<sup>f</sup> Proportion of the number of species
<sup>g</sup> Proportion of the number of individuals

3.2. Ecological types and dominant species

3.2.1. Ecological types. The main species were classified by their habitat preference into two ecotypes: lotic and lentic species. Eleven lotic and nine lentic species were distributed in the YH reach, nine
Lotic and eight lentic species were distributed in the LG reach, and eight lotic and eight lentic species were distributed in the PS reach (Table 2).

Table 2. Ecotypes of main species distributed in each reach.

| Lotic species                     | Lentic species                     | YH | LG | Lentic | PS | Lotic | Lentic |
|----------------------------------|------------------------------------|----|----|--------|----|-------|--------|
| Leiocassis crassilabris Günther  | Cyprinus (Cyprinus) carpio Linnaeus|    |    |        |    |       |        |
| Mystus macropterus (Bleeker)     | Carassius auratus (Linnaeus)       |    |    |        |    |       |        |
| Semilabeo prochilus (Sauvage et Dabry) | Hemibarbus maculatus Bleeker |    |    |        |    |       |        |
| Tor (Folifer) brevifilis brevifilis (Peters) | Zacco platypus (Temminck et Schlegel) |    |    |        |    |       |        |
| Spinibarbus sinensis (Bleeker)   | Saurogobio dabryi Bleeker          |    |    |        |    |       |        |
| Opsariichthys bidens Günther     | Hemiculter leucisculus (Basilewsky) |    |    |        |    |       |        |
| Garra pingi pingi (Tchang)       | Siniperca kneri Garman             |    |    |        |    |       |        |
| Onychostoma sima (Sauvage et Dabry) | Silurus meridionalis Chen          |    |    |        |    |       |        |
| Leptobotia rubrilabris (Dabry)   | Pelteobagrus vachelli (Richardson) |    |    |        |    |       |        |
| Pseudobagrus truncatus (Regan)   | Procypris rabaudi (Tchang)         |    |    |        |    |       |        |
| Rhinogobio typus Bleeker         | Pseudobagrus ussuriensis (Dybowsky) |    |    |        |    |       |        |
| Coreius guichenoti (Sauvage et Dabry) | Silurus asotus Linnaeus           |    |    |        |    |       |        |
| Coreius heterodon (Bleeker)      | Pseudolaubuca sinensis Bleeker     |    |    |        |    |       |        |
| Rhinogobio cylindricus Günther   | Hemiculter tchangi Fang            |    |    |        |    |       |        |
| Rhinogobio ventralis (Sauvage et Dabry) | Hypophysalmichthys molitrix (Cuvier et Valenciennes) |    |    |        |    |       |        |
| Leiocassis longirostris Günther  |                                    |    |    |        |    |       |        |
| Total number of species          |                                    | 11 | 9  | 9      | 8  | 8     | 8      |

There was fluctuation in fish abundance of both ecotypes in each reach during the period of 2006 to 2010 (Figure 3). In the YH reach, lotic species declined annually in terms of both number and weight, but the lentic species increased in terms of both number and weight. In the LG reach, lotic species declined annually during the first three years of impoundment and increased in the next two years, but
the lentic species displayed a reverse trend. This indicates that the fish assemblages responded quickly to dam construction and were in an unsteady state in the first five years after dam construction. Below the dam, lotic species decreased annually in number, and in spite of an increase in weight after 2008, the lotic species weight was still lower than it had been in 2006.

Figure 3. Lotic and lentic species in the YH, LG, and PS reaches.
3.2.2. **Dominant species.** Dominant species were those species for which IRI>1000 in at least one year. There were 9 dominant species in the YH reach, 12 dominant species in the LG reach and 8 dominant species in the PS reach (Figure 4).
(b) LG reach
In the YH reach, four dominant lotic species’ IRI declined obviously after the 2008 impoundment, but three lentic species’ IRI increased rapidly, and they became dominant species. The IRI of the lotic species *Semilabeo prochilus* (Sauvage et Dabry) increased after impoundment, but decreased in 2010; lentic species *Zacco platypus* (Temminck et Schlegel) was dominant during 2007 and 2009.

In the LG reach, four dominant species were reduced to rare species after impoundment. The lotic species *Leiocassis crassilabris* Günther noticeably decreased, but it became a dominant species again in 2008 and 2009. The IRI of *Carassius auratus* and *Hemiculter leucisculus* increased continuously from 2007 to 2010.

In the PS reach, the IRI of the lotic species *Rhinogobio typus* and *Hemiculter leucisculus* increased rapidly after impoundment, but the IRI of *Carassius auratus* remained relatively stable. The IRI of the lentic species *Pelteobagrus vachelli* and *Rhinogobio cylindricus* increased from 2006 to 2008, but decreased slightly in 2009.

**Figure 4.** IRI dynamics of dominant species in the YH, LG, and PS reaches.

In the YH reach, four dominant lotic species’ IRI declined obviously after the 2008 impoundment, but three lentic species’ IRI increased rapidly, and they became dominant species. The IRI of the lotic species *Semilabeo prochilus* (Sauvage et Dabry) increased after impoundment, but decreased in 2010; lentic species *Zacco platypus* (Temminck et Schlegel) was dominant during 2007 and 2009.

In the LG reach, four dominant species were reduced to rare species after impoundment. The lotic species *Leiocassis crassilabris* Günther noticeably decreased, but it became a dominant species again.
in 2010, and Hemiculter leucisculus (Basilewsky), Semilabeo prochilus (Sauvage et Dabry), and Carassius auratus (Linnaeus) became dominant species after impoundment. The other species fluctuated, and most became dominant for only one year.

In the PS reach, Mystus macropterus declined after impoundment. Spinibarbus sinensis Bleeker and Leiocassis crassilabris decreased after 2007, but increased and became dominant again in 2010. Rhinogobio typus Bleeker, Carassius auratus (Linnaeus), and Hemiculter leucisculus (Basilewsky) became newly dominant species. The lentic species Pelteobagrus vachelli Richardson continuously remained a dominant species, and increased during the period of 2006-2009, but decreased in 2010.

3.3. Fish diversity

The following indices were calculated: Margalef Index of community diversity (R), Shannon Wiener diversity Index ($H'$), Pielou evenness index (E) and Simpson dominance index (D) (Figure 5).
Figure 5. Biodiversity attributes of the YH, LG and PS reaches.

In the YH reach, the averages of the four indices were: Margalef Index (R)=5.3331, Shannon Wiener Index (H)=2.6636, Pielou evenness index (E) =0.7201, and Simpson Index (D)=0.1052. It appeared as though there were no obvious differences before and after impoundment. In the LG reach, the averages of the four indices were: R=4.4045, H=2.3465, D=0.1515, and E=0.7096. During the period of 2006-2010, the R and H indices declined, but the E and D indices increased. In the PS reach, the averages of the four indices were: R=6.9165, H=2.8416, D=0.8992, and E=0.7172. There was no obvious difference before and after the PS Reservoir impoundment.

3.4. Community structure similarity

The Principal Component Analysis (PCA) results of the different years of the study period were analyzed using the Bray Curtis similarity coefficient (Figure 6).

Figure 6. CA plots of fish assemblages in the YH, LG, and PS reaches.

In the YH reach, the five investigated years were divided into two groups with a coefficient value of 49.42%: Group 1 included the years of 2006, 2007, and 2008; Group 2 included the years of 2009
and 2010. In the LG reach, the four investigated years were divided into two groups using the coefficient value of 54.23%: Group 1 included the years of 2007 and 2008; Group 2 included the years of 2009 and 2010. In the PS reach, the five investigated years were divided into two groups using the coefficient value of 52.08%: Group 1 included the year 2006; Group 2 included the years of 2007, 2008, 2009 and 2010. The results demonstrated that in the reservoir and upstream fish assemblages the structure changed obviously after 2009, but in the downstream fish assemblages, the structure changed in 2007 and 2008 and then became stable after 2009.

SMPER was used to rank each group of fish assemblages according to their contributions (>4%) to the communities’ structural differences. This indicated that nine species had a combined contribution of 69.88% in the YH reach, while twelve species had a combined contribution of 72.31% in the LG reach. Eight species had a combined contribution of 48.43% in Groups 1 and 2 and ten species had a combined contribution of 56.50% in Groups 2 and 3 in the PS reach. Both lotic and lentic species contributed to changes in fish assemblages in the upper stream, but only lotic species contributed significantly to changes in fish assemblages below the dam.

4. Discussion

4.1. Habitat and fish assemblages

Habitat is very important to river ecosystems. Habitat diversity and high heterogeneity, which are linked through the species habitat, affect the structure and function of fish communities [16]. Animal habitat selection is influenced by genetics, acquired experiences, and individual development stages. A fish species finds suitable living conditions only in a selected stretch of an entire river. Kondolf et al. [17] believe that habitat is one of the three most important factors in assessing ecological restoration. As early as the 19th century, ichthyologists used this observation as the basis of a zonation system for river courses [18].

In the Yangtze River Basin, the anadromous Chinese sturgeon (Acipenser sinensis) and several river migratory fishes (Coreius guichenoti, Leptobotia elongate, Rhinogobio ventralis and four major Chinese carps) return during the breeding season in search of suitable breeding habitats for spawning. The Gezhouba Dam and the Three Gorges Dam have blocked spawning migration, and now the Chinese sturgeon’s spawning ground is located in only about a 3km section below the Gezhouba dam. These species, which produce pelagic eggs, lost their spawning grounds because of submersion of the reservoir, and then disappeared in the reservoir. Further, many studies have found that fish assemblage structure and elevation were significantly correlated with drainage area, flow, runoff, slope of cultivated land, grassland, and fish abundance [19][20] .

Prior to dam construction, the Wujiang River was a typical canyon-type river. Before the river was dammed, most fish species in the Wujiang River were lotic inhabitants. Those lotic species varied greatly between species for their swimming capacity and duration [21]. Fish species have formed unique ecological habits through a long-term adaptation and interaction process [22][23][24].

The characteristics of the fish assemblages are: 1) most dominant species are carnivores and omnivores feeding on invertebrates, and 2) most populations are composed of juniors and small fish (weight<50g). The reasons for this could be: 1) overfishing with small mesh nets, hooks, and settled gillnets causing catches to be concentrated with junior and small fish; 2) fish species composition may have changed as a result of changes in food organisms and physical habitats caused by the dams; 3) although their habitat needs are similar, those species with broader diets have a greater chance of survival in a degraded environment.

4.2. Fish assemblages’ dynamics

Fish community structure varied both through space (longitudinal) and time (annual). In the PS reach, in 2006 and 2007 (the years before the PS reservoir impoundment), the fish community structure similarity index was 46.60%, but the similarity index between 2007 and 2008 was 61.57%. The
number of dominant species decreased by 2 species from 2006 to 2007. The PS reach was under pressure from human activity starting in 2007, and the stress increased after impoundment in 2008.

In the LG reservoir area, fish assemblages’ structure similarity indices differed significantly between 2007 and 2008 (18.79%), while the lotic population size among dominant species decreased, and some lentic species were introduced as new dominant species. This means that fish assemblages in the reservoir were influenced more seriously than the fish population in the lower reach, which responded quickly (even in as short a time frame as nine months) to changes in the flow regime caused by dam construction.

Therefore, fish assemblages changed as the lotic species decreased in population and the lentic species became dominant. Fish assemblages may need a longer time to attain a steady state, and a long-term ecological effect to identify this will require further monitoring of fish assemblages.

4.3. Impacts of dam construction and impoundment

Human activities such as hydro-engineering, overfishing, and water pollution have brought serious consequences for the ecological integrity of fish assemblages[25][26]. River damming can completely destroy aquatic ecosystem function[27][28][29]. Dams alter water flow, temperature, and sediment regimes of lotic systems[4][30]. Dams can enhance the clarity and reduce the variability of the river flow, which can also cause an increase in periphyton abundance. Invertebrates below the dam experience reductions in species richness due to the reduction of habitat heterogeneity[31]. Additionally, dams can fragment river systems and isolate fish populations[24]. Finally, river cascade development can amplify these impacts.

It has been proven that dams can cause decreases in habitat diversity and degeneration of fish populations[3][32][33][34]. The effects of the Gezhouba and Three Gorges Reservoirs constructed in the Yangtze River have also been studied. Hu et al.[4] preliminarily reported that aquatic ecosystem dynamics were influenced by the impoundment of Three Gorge Reservoir. However, Wu et al.[5] compared fish assemblages before and after the Gezhouba Dam construction and argue that fish assemblages have not changed radically because ecological conditions below the Gezhouba Dam did not change much. However, the authors suggest that the Gezhouba Dam is different due to its low-head and runoff Hydropower Station.

Usually, it is very difficult to separate the effects of hydro-engineering from other disturbances. Fish catch data showed that most fish populations were composed of junior individuals with body lengths between 100-200mm. This could be because small mesh-size nets are commonly used in this Yangtze River basin. People attempt to gain the greatest economic output and neglect natural fishery resource protection. Long-time and accumulative malpractice has caused damage to native fish populations [25][35]. Therefore, it is important that fishery standards and management strategies be established for the demand of future socioeconomic development and the need for natural resource conservation in the Yangtze River basin.

Acknowledgements
We are grateful to our colleagues Li Wan, Haitao Zheng, Juxiang Hu, Meihua Xiong and Fang Shi for their work and assistance in the field investigation. The authors also appreciate the comments and suggestions of Dr. Elias Dimitriou, who contributed to the clarity and readability of the paper. The use of fish in this study was approved by Hubei Province Association of Laboratory Animal Sciences.

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