Acoustic assessment of fish resources in subtropical run-off-river hydropower plant in the Pearl River

Z Wu¹, S L Zhu¹, J Li¹, J P Yang¹, Y F Li¹ and X H Li¹,²

¹Pearl River Fisheries Research Institute, Chinese Academy of Fishery Science, No. 1 Xingyu Road, Liwan District, Guangzhou, Guangdong Province, China

E-mail: lxhui01@aliyun.com

Abstract. As the utmost downstream dam in the main stream of Xijiang River, Changzhou Hydro-Junction has changed the original hydrological characteristics and ecological environment of Xijiang River. In order to grasp the fish distribution and standing crops after reservoir impoundment, a split beam echo-sounder EY60 (120 kHz) was used in the river channel from Guiping to Wuzhou in April 2014, 2015, and 2016. The average fish density in the survey area was 0.1215±0.4198 ind.m⁻³ in 2014, 0.0190±0.1232 ind.m⁻³ in 2015 and 0.0107±0.0186 ind.m⁻³ in 2016. According to the horizontal distribution data, fish density showed significant difference in different area and the density in the upper area was significantly higher than that in other areas. Moreover, fish density was negatively correlation with water depth. As a whole, the Target Strength (TS) decreased in the past three year, TS was significantly different among the three areas and showed a decreasing tendency from the dam area to the upper area. Fish resources decreased gradually, as indicated by the decreased fish density and miniaturized fish sizes in the past three years.

1. Introduction

Changzhou Hydro-Junction is located in Xijiang River, the main branch of the Pearl River. It was constructed in 2003 and water impoundment started in 2007. It stretches across the Xijiang River is 3.47 km long and 34.6 m high. As a run-off river hydropower plant, Changzhou Hydro-Junction affects the hydrological conditions and water ecological system, leads to the river fragmentation [1-4], blocks the migrant fish, and threatens fish populations who producing drifting eggs [5, 6]. A large-scale fishery resource investigation was conducted in the 1980s in Xijiang River and 136 fish species were collected [7]. In recent years, the increased river utilization projects, such as water conservancy and hydropower projects, have destructed fish habitats, decreased the diversity and threatened fish species [7, 8].

The Changzhou Dam led to the decrease in fishery resources, reduced complementary groups and postponed annual spawning time [9-11]. In order to reduce its adverse impact on fish, a fish passage was constructed and showed a good fish pass efficiency [12-14] and fish could swim towards the upstream of the dam when the spillways were open [15]. Previous studies on the Xijiang River mainly discussed the downstream area of the Changzhou Dam [15-17]. The dam has been operated for about 10 years and the fish distribution or standing crop in the reservoir was unknown. Fish is the climax community in the water ecosystem and may respond to any change of the water ecosystem, so it is necessary to explore fish resources and their changing trends.
2. Materials and methods

2.1. Survey area

Hydroacoustic surveys were carried out between Guiping (N 23.4455°, E 111.2422°) and Wuzhou (N 23.4298°, E 110.5321°) in late March 2015 and 2016 and were performed in the dam area in 2014. The survey area is 156 km long with the mean depth of 12.29 m and the maximal depth of 65 m. Five sampling sites were set along the survey area (figure 1). Two spillways (Neijiang and Zhongjiang) are across two branches of the river and the other branch Waijiang is regarded as a ship lock.

![Survey area map](image)

**Figure 1.** Locations of the reservoirs studied. Five cycles represent catch sampling site, and the survey area divided into three areas by the dashed line.

2.2. Acoustic sampling

The survey area was canyon-shaped and acoustic sampling was performed according to a zigzag trajectory in the area with the depth exceeding 3 m and the allowable width. Considering the influences of sailing, submerged reef and cages in watercourse, cruise line was adjusted real time during the survey. All the surveys were divided into transects with different lengths, so that for every survey, 450–500 transects with independent estimates of biomass, density and size distribution were available [18].

The transducer was attached to a pole and placed vertically in the water depth of 0.5 m. The boat velocity along water flow direction was between 8 and 10 km.h⁻¹.

A split-beam SIMRAD EY60 echo-sounder was used. Its main characteristics are provided as follows: a frequency of 120 kHz, a sampling interval of 16 ms and 40logR TVG (time varied gain) amplification. The acoustic system was routinely calibrated with a tungsten carbide sphere (-40.4 dB; Diameter: 23 mm) before each measurement series [19].

2.3. Fish sampling

Fish assemblages were collected randomly in early April 2015 and 2016 from the upper area to the dam area. At each site, we sampled fish in three methods: gill nets, fly-fishing, and crayfish traps,
respectively. Fish samples were measured according to the standard length (SL) to the nearest 0.1 cm and total weight (TW) to the nearest 0.1 g. All scientific names, authors and years were checked against FISHBASE (www.fishbase.org).

2.4. Data processing
Acoustic data were processed in Echoview Version4.9 [20]. When the fish density was low, the single target echoes did not overlap. Therefore, echo counting method was adopted [21]. A target threshold of −60 dB was set and all other parameters were set according to previous results [22]. Fish length was calculated from TS according to the empirical formula [23]:

$$TS = 19.1\log(F) - 62.0$$

We used the ordinary Kriging interpolation method to simulate the spatial distribution of fish density. In comparison with other interpolation techniques, ordinary Kriging allows an optimal unbiased simulation and the simulation procedure can be obtained under the normal distribution conditions [24, 25]. Fish density was subjected to natural logarithmic transformation.

Four diversity indices were calculated based on the composition data obtained from typical trawl survey: Species richness $S$ (the number of species), Pielou’s Evenness index $J'$ [26], which measures how evenly abundance is distributed across species, the Shannon–Wiener diversity index $H'$ [27], and the Simpson index D. The indices are calculated as:

$$H' = -\sum_{i=1}^{s} P_i \ln P_i$$

$$J' = \frac{H'}{\ln(S)}$$

$$D = 1 - \sum_{i=1}^{s} P_i^2$$

where $S$ is the total number of species; $n$ is the individual number; $P_i$ is the proportion of the abundance of species $i$ in the total abundance of all fish species.

3. Results

3.1. Feature of fish horizontal distribution

| Year | Survey area | Average density (ind.m$^{-3}$) | Standard error | Maximum | Minimum |
|------|-------------|---------------------------------|----------------|---------|---------|
| 2014 | Dam Area    | 0.1215                          | 0.5945         | 3.9940  | 0.000227|
| 2015 | Dam Area    | 0.0372                          | 0.1952         | 2.3718  | 0.000025|
|      | Middle Area | 0.0069                          | 0.0273         | 0.2718  | 0.000040|
|      | Upper Area  | 0.0089                          | 0.0277         | 0.3502  | 0.000207|
| 2016 | Dam Area    | 0.0037                          | 0.0125         | 0.0838  | 0.000048|
|      | Middle Area | 0.0036                          | 0.0048         | 0.0317  | 0.000048|
|      | Upper Area  | 0.0155                          | 0.0215         | 0.1592  | 0.000183|

The average fish density was 0.1215±0.4198 ind.m$^{-3}$ in 2014, 0.0190±0.1232 ind.m$^{-3}$ in 2015, and 0.0107±0.0186 ind.m$^{-3}$ in 2016, respectively. The lowest density was recorded in the dam area and the highest density was recorded in the area close to the branch river in the upper area (table 1). Test of Homogeneity of Variance showed fish density did not conform to a normal distribution ($P <0.05$), so nonparametric test was used to analyze the results. Fish density in 2014 was significantly larger than
that in 2015 and 2016 in dam area ($P<0.01$ for both) and fish density showed no significant difference in 2015 and 2016. In the survey area, fish showed the scattered distribution (figure 2(a)) except that some fish aggregation areas were detected in Zhongjiang and Neijiang (figure 2(b)). Fish density in Waijiang close to the dam area was very low.

![Figure 2](image)

**Figure 2.** The features of fish echo distribution, (a) fish dispersed, (b) fish assembled.

The spatio-temporal distribution pattern of fish was largely similar in 2015 and 2016, displaying patchy spatial distribution (figure 3). In 2015 and 2016, fish density in the upper area was significantly higher than that in the dam area and middle area and the other patches with the higher fish density were distributed in the river sections which were close to towns.

### 3.2. Fish vertical distribution and water depths

Water depth ranged from 3.1 m to 59.7 m and average water depth was 12.29 m. Target depths differed significantly among different areas in the two years (2016: $F=131.99$, $P<0.01$; 2015: $F=277.25$, $P<0.01$). Fish were mainly distributed in various water depth ranges: 5-15 m in the dam area, 8-28 m in the middle area, and 10-20 m in the upper area. It revealed that the vertical distribution of fish varied with water depth. Spearman correlation analysis results revealed that fish density was negatively correlated with water depth and target depth ($P<0.05$, $r<-0.2$ for both) and that
target depth was significantly positively correlated with water depth ($P<0.01$, $r>0.75$). Figure 4 shows a negative linear relationship between fish density and two depth parameters (average water depth and target depth).

Figure 3. Fish density horizontal distribution in Xijiang river, two pictures use same legend.

Figure 4. Correlation diagram between average fish density and target depths and water depths in 2016. Fish density represent with average and standard error, the red line is trendline.

3.3. Fish target strength
Single Target Detection and Fish Tracks were used to obtain the fish TS in Echoview. The average TS had an annually decreasing tendency and an increased distribution tendency from the dam area to the upper area (figure 5). One-way ANOVA analysis revealed that TS in various years in dam area was significantly different ($F=200.27$, $P<0.01$). The average TS was $-51.45\pm3.46$ dB with the aggregation of $85.32\%$ in $-57$--$-53$ dB (transformed into fish length of $2.3$ cm--$3.7$ cm) in 2014; Average TS was
respectively -52.06±4.77 dB in 2015 and -55.18±4.83 dB in 2016 and showed significant differences among the three areas (2015: $F=79.24$, $P<0.01$; 2016: $F=536.46$, $P<0.01$).

![Figure 5. Target strength distribution.](image)

3.4. *Fish sampling information*

A total of 1564 fish was caught, and 63 fish species were identified. The 63 fish species belonged to 3 orders, 12 families, and 40 genera. The species mainly belonged to Cypriniformes (41), Siluriformes (15), and Perciformes (7). The top ten species were *Leiocassis crassilabris*, *Pelteobagrus vachelli*, *Pseudolauca sinensis*, *Toxabramis houdebari*, *Squalius argentatus*, *Psychidio jordani*, *Cyprinus carpio*, *Carassius auratus*, *Squaliobarbus curriculus*, and *Hemiculter leuciscus*. Species richness S, Pielou’s evenness index J’, Shannon–Wiener index H’, and Simpson index D were 63, 0.797, 1.433, and 0.948, respectively.

4. *Discussion*

The study revealed a clear fish distribution pattern. Estimated fish density was the highest in the upper area (tributary area) and gradually decreased (not monotonically) towards the dam area. The same distribution pattern had been reported by other researchers [18, 28], so this area was considered an important part of the reservoir. Dongta Spawning Ground was the largest natural propagation site in the Pearl River [10], and it had entered the fish breeding season in April [11]. The bigger fish were detected in the area near the dam, whereas the smaller fish were detected in the area close to the tributary (i.e. the upstream area). Small fish may benefit from the better trophic conditions. The tributary area may be the preferred option because some species in the reservoir may spawn in the upstream area.

Another fish distribution feature in the Changzhou reservoir is the high density and large size found in the dam area of Zhongjiang and a very low density in the dam area of Waijiang. The difference may be interpreted as follows. When the spillways were open during flooding discharge, many fish flushed into the reservoir from the downstream area [15] or passed through the Changzhou Fishway [12, 13]. Fish are prone to avoid ships, thus leading to the underestimate results [29, 30]. In the ship lock of Waijiang, the avoidance reactions of fish lead to the low density. Moreover, some species can pass through the ship lock, but he ship lock cannot serve as the fish migration channel [31-33]. Compared to downstream area and Zhongjiang with the high fish density, Changzhou dam ship lock cannot be regarded as a channel for fish migration.

Hydropower projects changed the intrinsic ecotope and influenced aquatic organisms especially fish. Fish density declined year by year and fish length (TS) showed a decreasing trend. Some policies such as seasonal fishing bans from April 1st to June 1st and the release and enhancement programs of rare and economically valuable fishes contributed to the increase in fish biomass and purified water through the biomanipulation action. The compensation mechanism and the relationship between fish...
resources and environmental and hydrological factors remain largely unclear. Further studies should be carried out to further understand the relationship.

Biodiversity is changing at an unprecedented rate on a global scale as a complex response to several anthropogenic changes [27]. Dam construction alters the intrinsic features of rivers, thus causing significant changes in fish communities during and after impoundment, such as habitat fragmentation and blocking, flow regime modification, and hypolimnetic discharges. Compared to previous results [7, 8], the fish ecotype was significantly changed. The most species in the dam area were settling fishes, whereas only less migrating fishes reside in the tributary area, such as Chinese carps (Mylopharyngodon piceus, Ctenopharyngodon idellus, Hypophthalmichthys molitrix, and Aristichthys nobilis). Species richness S, Piellou’s evenness index J’, and Shannon–Wiener index H’ were decreased compared to the previous survey results [34].

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