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Diurnal, seasonal and inter-annual variability of fish density and distribution in the Three Gorges Reservoir (China) assessed with hydroacoustics

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ABSTRACT

Environment conservation of the Three Gorges Reservoir (TGR) requires reliable assessment of fish resources and variation of their distribution. The goal of this study was to determine the best season and the diurnal period to estimate fish density in the TGR using acoustic surveys as a monitoring tool. To find out diurnal migration pattern of fishes in the TGR, we conducted reduplicated 24-h hydroacoustical surveys in the forequarter of the TGR, which covered different habitats (mainstream, tributary bay), seasons (summer, winter) and years (2012–2015). Measurements were performed using SIMRAD EY60 split beam echosounder with frequency 120 kHz. Additionally, zooplankton and environmental parameters were measured. The results showed more than ten times differences between the day and night fish density estimates, probably resulting either from the horizontal migrations between the littoral and open water or vertical migrations. Differences were higher during winter than during summer, and higher in the tributary bay than in the mainstream. Clear vertical migrations were observed both in the tributary bay (amplitude 15 m) and in the mainstream (amplitude 35 m), but only during winter time. Inter-annual estimates of fish density showed generally decreasing trend with years. especially well pronounced in the tributary bay. We also observed high seasonal and diurnal variability in fish distributions, which can significantly affect the accuracy and precision of biomass estimate, indicating importance of choosing appropriate timing for fish monitoring. According to our results, in order to receive the most reliable estimates of fish density in the TGR, hydroacoustic surveys should be performed during summer at night time.

1. Introduction

There are more than 50,000 large dams built on rivers worldwide (Berga et al., 2006), which changed water flow regimes and usually caused great disturbance to fish distribution and diversity (Baxter, 1977; Dudgeon, 2000). The Three Gorges Reservoir (TGR) of China, the largest dam reservoir in the world, was completed in 2009 with a surface area of 1084 km^2 in the upper reach of the Yangtze River (Wu et al., 2003). Its impoundment led to the loss of lotic habitat and gain of lentic habitat, and therefore had a significant impact on biodiversity and ecosystems in the region. Theoretical prediction and empirical monitoring suggested the changes of fish spatial distribution patterns in the TGR (Chang, 2001; Wu et al., 2007; Gao et al., 2010; Yi et al., 2010; Yang et al., 2012; Liu et al., 2013; Yang et al., 2015); however, there is still a lack of knowledge on the variation of temporal distribution patterns of fishes in the reservoir.

The TGR is a typical canyon reservoir surrounded by steep cliffs and has a great water fluctuation (30 m) between summer and winter. This leads to expanded littoral in winter, when wild vegeta-

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tion and crops become submerged. According to Godlewska (2002), acoustic estimates of fish biomass differ significantly between day and night, and this effect to a large extent is related to vegetation coverage in the littoral. The more vegetation coverage, the larger difference between the day and night fish biomass estimates. Most probably it is due to the diurnal horizontal migration of fish between the open water and littoral, which offers shelter for fish (Gliwicz et al., 2006).

For the investigation of fish distribution and abundance, net sampling, underwater observation and acoustic detection are commonly used (Murphy and Willis, 1996). Net sampling takes a long time and is characterized by high selectivity, high labour-cost, and lack of continuity. The range of direct visual underwater observations is limited to few meters, and often much shorter, depending on the water transparency. By contrast, hydroacoustics is an efficient method for the assessment of fish resources and behavior observation in large and deep reservoir, which provides a repeatable, noninvasive approach of collecting high-resolution and continuous data (Horppila et al., 1996; Mehner and Schulz, 2002; Wanzenböck et al., 2003; Mueller and Horn, 2004; Simmonds and MacLennan, 2005; Godlewska et al., 2004, 2009a,b, 2012; Doroszczyk et al., 2013). However, as every method, hydroacoustics has also some limitations such as inability to determine fish species, difficulty in separating fish and non-fish objects (like bubbles), range limitations, and so-called acoustic dead zones at the transducer face and the bottom (Ona and Mitson, 1996). The height of the acoustic dead zone is affected by the pulse length, transmitted frequency, transducer directivity, bottom slope and roughness, varying between few centimeters to even few meters (Simmonds and MacLennan, 2005; Tušer et al., 2011, 2013). It means that acoustics is a very good tool for estimating fish distributions in pelagic waters, but not so good for the areas close to the surface or bottom. All these limitations can result in biased fish biomass estimates. However, at present, hydroacoustic methods are considered as the cheapest and the most reliable tool to study fish distributions, especially when large water volumes have to be sampled in a short time (Simmonds and MacLennan, 2005; Rudstam et al., 2012; Guillard et al., 2014; Djemali et al., 2016).

The TGR, in spite of its comparatively short life, faces many environmental and ecological changes. Rare and endemic fish species are decreasing from year to year and blue-green algae blooms occurred frequently during hot season, the decreased temperature of outflow leads to fish breeding delay, etc. Environment conservation of the TGR especially requires reliable assessment of fish resources and their spatial distribution. In this study, we conducted several 24-h hydroacoustical surveys in the forequarter of the TGR during the year 2012–2015, aiming at assessing the variation in fish distribution and density estimates at three different scales: diurnal, seasonal and inter-annual. The results are expected to contribute towards improving conservation measures and fish management in the TGR by defining an appropriate fish sampling and monitoring strategy.

2. Material and methods

2.1. Study area

Samplings were conducted in the forequarter of the TGR (N 30.845°–30.902°, E 110.895698°–111.004037°), about 6 km upper of the Three Gorges Dam (Fig. 1). To account for the possible differences in fish diurnal distribution between major habitats, we selected one section of the mainstream and one adjacent tributary bay for our hydroacoustical surveys. The mainstream section was 2.5 km in length, with an average width of 1.2 km (area 2.9 km^2) and an average depth of 85.3 m. The tributary bay was 2 km in length, with an average width of 0.37 km (area 0.73 km^2) and an average depth of 40.7 m. The mainstream and tributary bay are quite different habitats, in terms of water velocity, the shore line, and the size of littoral habitat. Additionally, the tributary bay is facing a higher fishing pressure, because the traffic in the mainstream is too heavy to conduct fishery.

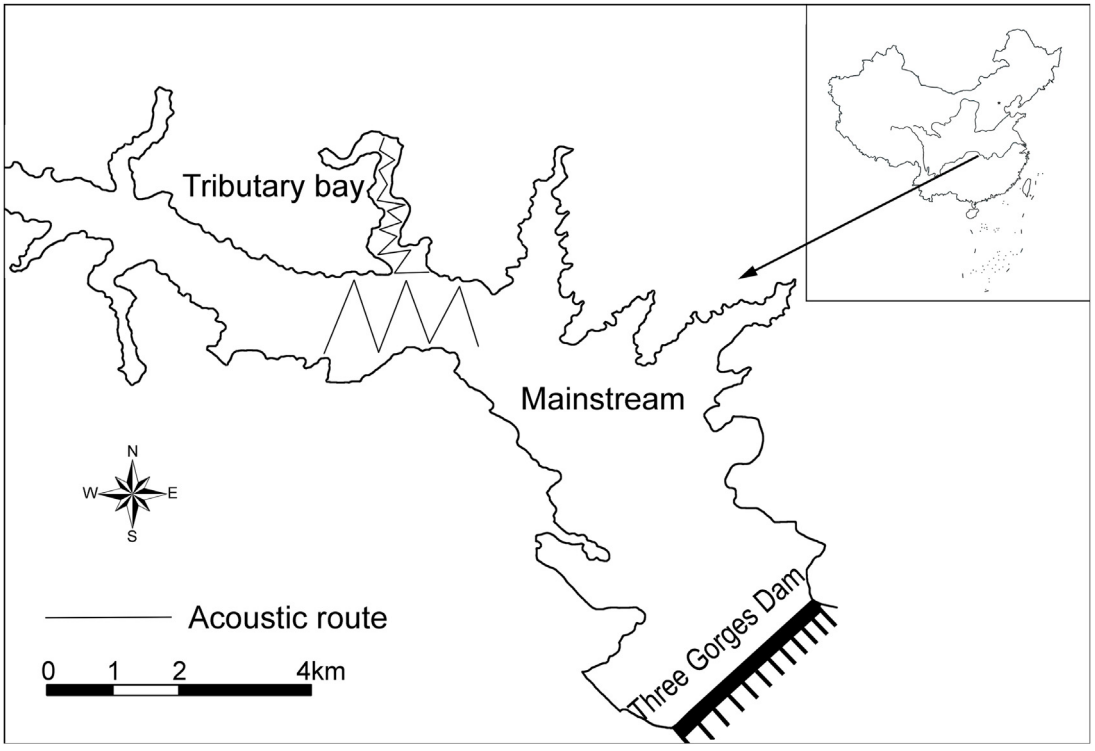

Fig. 1. Study area showing hydroacoustical sampling transects in the forequarter of the TGR.