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Diurnal distribution of fish abundance and size composition in the Danjiangkou Reservoir, China

T. S. ARUNJITH[1, 2], FEI CHENG[1], ZHEN WANG[1, 2], K. R. DIVYA [3] AND SONGGUANG XIE[1]
[1]*Key Laboratory of Aquatic Biodiversity and Conservation of Chinese Academy of Sciences, Institute of Hydrobiology Chinese Academy of Sciences, Wuhan - 430 072, China*
[2]*University of Chinese Academy of Sciences, Beijing - 100 049, China*
[3]*School of Ocean Science and Technology, Kerala University of Fisheries and Ocean Studies, Panangad - 682 506, Kerala, India*
e-mail: chengfei@ihb.ac.cn

ABSTRACT

Abundance and distribution information of fish in reservoirs is fundamental for efficient fishery management and conservation. However, habitat characteristics of large reservoirs usually make the traditional survey techniques impractical in acquiring these information. In this study, we investigated diurnal and vertical distribution of fish abundance and size composition in the middle section of the Danjiangkou Reservoir through hydroacoustic survey. Fish abundance estimated at night was 4.97 times of that during day. Fishes were highly concentrated in the water-depth layers between 10 and 20 m at night and scattered evenly across whole water column during day. Fish was highly dominant by individuals smaller than 5.5 cm total length (TL) at night and by individuals between 6.2 and 7.8 cm TL during day. Size composition was constant across depth between 10 and 25 m at night and between 15 and 25 m during day, while the proportion of small-sized fish was higher than in the other water-depth layers. Our results indicated an intensive diurnal movement of fish in the reservoir which provides basic information for efficient fishery management on juvenile fish in the littoral zone during day and the diurnal movement pattern in the reservoir suggests that hydroacoustic surveys should be conducted at night for accurate abundance estimation in large reservoirs.

Keywords: Depth preferences, Diurnal distribution, Hydroacoustic survey, Reservoir, Size composition

Introduction

Dams are constructed in most large river systems worldwide (Nilsson *et al.*, 2005) and the impoundment of reservoirs provide important water areas for fisheries (Pelicice *et al.*, 2017). Knowledge of the abundance and distribution of fish is fundamental for efficient fishery management and conservation in these reservoirs (Methot and Wetzel, 2013). Large reservoirs are usually deep and have steep rubble-sloped banks and complex shore regions (Kratochvil *et al.*, 2012; Miranda, 2017). Such habitat characteristics of large reservoirs make traditional survey techniques, using fishing gear (*e.g.* fish traps, seine nets), impractical in acquiring the abundance and distribution information of fish (Tan *et al.*, 2011).

Hydroacoustic technique has been widely applied to determine the distribution and abundance of fish (Kubecka *et al.*, 2012). This technique enables researchers to evaluate a substantial area with reliable, non-invasive and non-lethal surveys with low labour costs and a short assessment period (Simmonds and MacLennan, 2005). It is typically suitable for deep water bodies and pelagic regions (Simmonds and MacLennan, 2005; Rudstam *et al.*, 2013). Much of this work was conducted in marine environment (Pollom and Rose, 2016) and been applied in reservoirs mainly in North America (Taylor *et al.*, 2005; Rudstam *et al.*, 2013) and Europe (Prchalova *et al.*, 2009; Sajdlova *et al.*, 2017). Compared to marine habitat, reservoirs usually have complex shore regions with limited pelagic areas, creating a high proportion of blind zones for hydroacoustic survey (Simmonds and MacLennan, 2005). Diurnal migrations of fish have been reported in many large reservoirs, which results in starkly different distribution pattern of fish (Cech *et al.*, 2005; Drastik *et al.*, 2009; Lian *et al.*, 2017). Information about movement pattern of fish is particularly critical to reduce effects of the blind zones using the hydroacoustic technique in large reservoirs (Drastik *et al.*, 2009; Lian *et al.*, 2017).

Many large reservoirs have been impounded in large rivers in China, *e.g.* in the Yangtze River and in the Yellow River (Liu *et al.*, 2009). These reservoirs have usually been used for fish production (Guo *et al.*, 2012). However, abundance and distribution information of fish are rare in these reservoirs, which hinder efficient fishery management and conservation. In the present study, we compared diurnal and vertical distribution of fish in the

Danjiangkou Reservoir (DR) through hydroacoustic survey. The results will provide essential information to understand the diurnal movement pattern of fish in large reservoirs, which is important to fishery management and for the accurate abundance estimation of fish using hydroacoustic technique.

Materials and methods

Study area

The Danjiangkou Reservoir (DR) (32°33′22″N; 111°29′17″E) is located in the upper reaches of the Hanjiang River, which is the longest tributary of the Yangtze River in China (Fig. 1). The reservoir was impounded in 1967 with a water area of 516 km^2 at its highest water level of 157 m. The reservoir was artificially widened in 2010, increasing the highest water level to 170 m and the water area to 1050 km^2 (Wang *et al.*, 2014). The reservoir serves as the water source of the central route of South-to-North Water Transfer Project which is one of the largest water transfer project in the world (Zhang, 2009).

Hydroacoustic survey

Surveys were performed in the middle region of the Hanjiang portion of the reservoir with transects in a zig-zag pattern (Fig. 1). Eight transects were surveyed with an average distance of 4.09 km for each transect. The surveys were carried out on 27 June 2017 with the day survey between 09:00 through 13:00 hrs and the night survey between 19:00 and 23:00 hrs. The vessel maintained a speed of 7-8 km h^{-1} during the survey.

Hydroacoustic survey was conducted using a SIMRAD EY 60 equipped with a split-beam transducer (ES200-7C) at 200-kHz (SIMRAD, Kongsberg, Norway). Echo sounder system was calibrated using a copper sphere with a diameter of 13.7 mm (target strength (TS) = -45 dB, at 1490 m s^{-1} sound speed), according to the calibration procedure of Foote *et al.* (1987). Output power was set at 100 w, pulse duration at 0.128 ms and ping rate at 5 pings s^{-1}. The transducer was installed in a vertical orientation on the forward right side of a 10 m long vessel, 0.5 m below the water surface. The transducer was connected to a laptop computer running the ER 60 software (version 2.4.3) for data storage and real-time display. A Garmin GPS system (Olathe, USA) was coupled to the transducer to record geographical coordinates simultaneously and was used to keep the same routes and acoustic transects between surveys at night and day.

Data analysis

Hydroacoustic data were processed using Echoview software (Ver 6.1, Myriax, Hobart, Australia). The background noise removal variable was applied. In the variable, horizontal extend was 20 pings and vertical units were specified in meters and -125 dB in Maximum noise (De Robertis and Higginbottom, 2007). Vertical beam survey was chosen due to a good image of fish distribution in low background noise (Zhou *et al.*, 2016). During the noise removal process, obvious noise in the echogram was excluded using region editor (Echoview Version 6.1.51: http://supportechoview.com). The cleaned echogram was analysed by the echo-integration method. Data of 1 m depth below surface and 0.5 m depth above bottom were excluded to remove surface and bottom noise (Tan *et al.*, 2011). The remainder of the vertical water column in the echogram was divided into six 5 m depth layers (*i.e.* 0-5, 5-10, 10-15, 15-20, 20-25, 25-30 m) to determine distribution patterns of fish density and size composition.

Single echo detection was used to detect any single fish targets and to determine TS and the average TS was used to estimate fish density (Soule *et al.*, 1997). In single

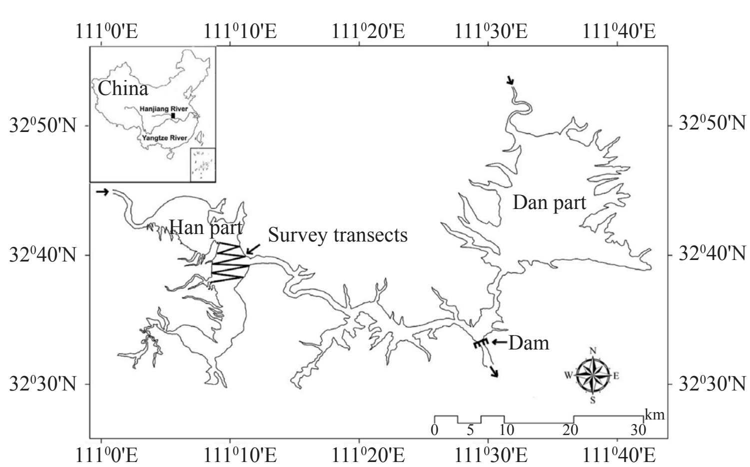

Fig. 1. Map of Danjiangkou Reservoir in China, showing the zigzag-pattern transects employed for hydroacoustic survey

target detection split beam method, two variable operators in the software was applied and created single target detection echogram (Soule *et al.*, 1997). In the single target detection echogram, TS were restricted above -60 dB to ignore those echoes from fishes with total length (TL) less than 3.9 cm (Foote, 1987). The minimum TS were selected based on species and age composition of fish in the study area by analysing *in situ* TS distributions. Total length of single fish target was calculated from the TS-TL regression for swim-bladder bearing fish species developed by Foote (1987).

$$TS = 20 \log (TL) - 0.9 \log (F) - 71.9$$

where TS = Target strength (dB), TL = Total length (cm), and F = Frequency (kHz).

The automatic fish tracking method was used to determine size composition and manual counting rectified results of the method if necessary. In this method, fish tracking algorithm criterion for determination of volume-back scattering strength (Sv) and mean TS was set to receive fish tracks with three single echo detections, minimum number of 3 pings and maximum gap of 2 pings between single targets; integration interval was set to 1000 pings. The Sv and TS echograms were performed with 20 and 40 log R time varied gain (TVG), respectively (Tan *et al.*, 2011). The Sv/TS scaling method (echo integration) was applied to estimate volumetric fish density (Godlewska *et al.*, 2011). Low threshold of the Sv was set to -70 dB for excluding echoes of zooplankton and/or air bubbles (Rudstam *et al.*, 2013).

Water transparency was measured during day surveys at 09 30 hrs using a Secchi disk. Full moon days were avoided for the hydroacoustic night surveys in DR. Two-way analysis of variance (ANOVA) was applied to test the effects of diurnal period (day or night) and water-depth layer, as well as their interaction on fish density. Tukey's HSD multiple comparisons were then conducted to test the differences between means when any of the effects were significant. Data of fish density were log transformed to stabilise the variance. The statistical analyses were done with Statistica12 (StatSoft Inc., Tulsa, USA). Differences were regarded significant when $p<0.05$.

Results

Echogram showed that fish backscattering was obviously visible in the 20-25 m and in the 10-20 m depth layers during day and at night, respectively (Fig. 2). Ten schools of fish were identified during day, but no school was detected at night (Fig. 2). Fish density was significantly affected by diurnal period, depth and their interaction ($p<0.05$). Mean density during day was 0.017±0.005 ind. m^{-3}, which was significantly lower than at night (0.087±0.047 ind. m^{-3}) (Fig. 3). No significant difference was detected in fish density among different depth layers during day ($p>0.05$) (Fig. 3). But still there is a visible gradual increasing trends of fish density up to 25 m. At night, fish density at the 5-10 m, 10-15 m and 15-20 m depth layers was significantly higher than in other depth layers and fish density in the 15-20 m depth layer was significantly higher than in the 5-10 m depth layer ($p>0.05$) (Fig. 3).

During day, detected fishes were dominated by TS values of -56 (equal to 6.2 cm TL), -55 (6.9 cm TL), and -54 dB (7.8 cm TL) with each of them contributing more than 10% of total abundance (Fig. 4a). Size composition of fish was similar between the 15-20 and 20-25 m depth layers, and proportion of small-sized fish at these two depth layers was higher than at other depth layers (Fig. 4a). Fish at 10-15 m tended to be larger than in the other layers (Fig. 4a). At night, detected fishes were dominated by small-sized individuals with the highest percentages at TS-59 dB (4.4 cm TL) (37% of total abundance) and the dominance decreased with increased TS (Fig. 4b). Fish of -57 TS (5.5 cm TL) and smaller individuals accounted for 76.8% of all detected fishes. Size composition of fish in the mid-water column (*i.e.* 10-15, 15-20 and 20-25 m

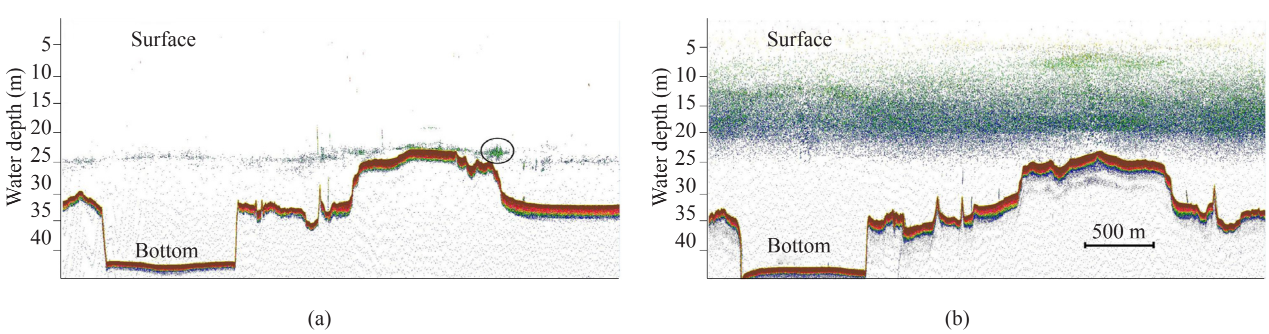

Fig. 2. Echograms displaying the vertical hydroacoustic backscattering of fishes during day (a) and at night (b) in the Danjiangkou Reservoir, China. Circle in the echogram shows the fish school tracked in the daytime survey (a). Echograms are presented with a 20 log time varied gain (TVG) and a lower volume-backscattering strength (Sv) threshold of -70 dB re 1 m^{-1}

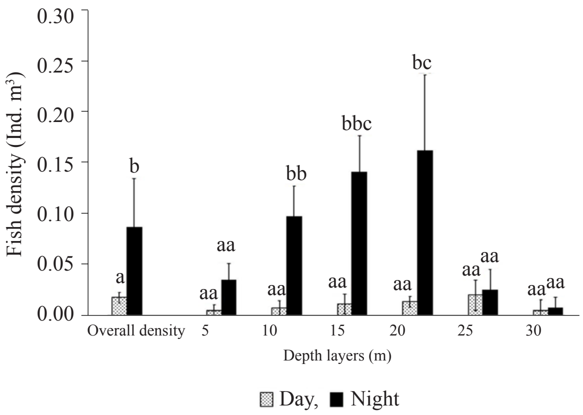

Fig. 3. Fish density among different depth layers during day and at night in the Danjiangkou Reservoir, China. The surface 1 m water layer was excluded, and the remainder of the vertical water column was divided into six 5 m depth layers (*i.e.* 0-5, 5-10, 10-15, 15-20, 20-25 and 25-30 m), which were labeled at the x-axis by 5, 10, 15, 20, 25 and 30 m, respectively. Error bars indicate Standard Deviation (±SD). Letters above the bars indicate results from multiple comparisons. Upper case letters indicate significant differences between day and night; different lowercase letters indicate significant differences between different depth layers

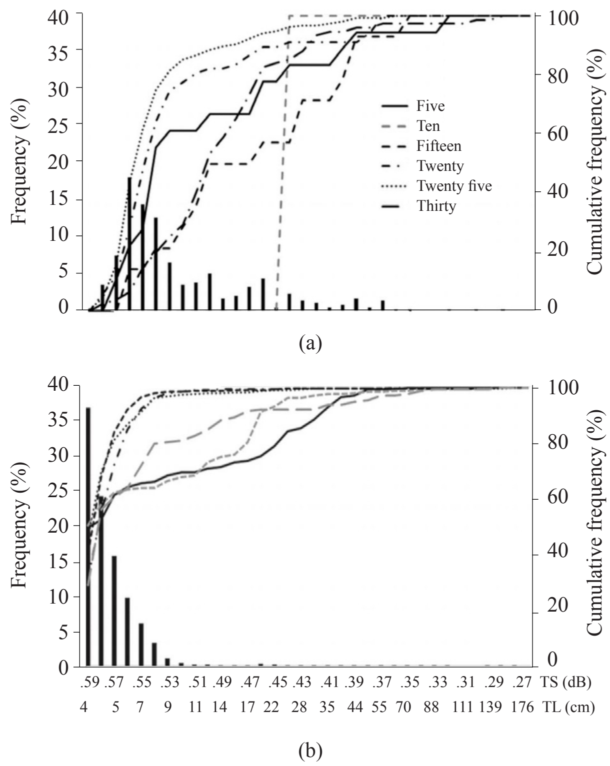

Fig. 4. Percentage frequency of target strength (TS) and total length (TL) of fish (vertical bars and left y axis) and cumulative percentage frequency of that at different depth layers (curves and right y axis) during day (a) and at night (b) in the Danjiangkou Reservoir, China. The surface 1 m water layer was excluded, and the remainder of the vertical water column was divided into six 5 m depth layers, *i.e.* 0-5, 5-10, 10-15, 15-20, 20-25 and 25-30 m, indicated by 5, 10, 15, 20, 25 and 30 m, respectively, in the figure labels representing the curves of cumulative percentage frequency of target strength or total length of fish

depth layers) were similar and the percentage of higher TS in the upper water columns (*i.e.* 0-5 and 5-10 m depth layers) were higher than in other depth layers (Fig. 4b).

Discussion

Our results demonstrated dramatic variations in abundance and size composition distribution patterns of fish during day and at night in the DR, which provides basic information for efficient fishery management and for accurate fish abundance estimation using hydroacoustic techniques in large reservoirs. Fish abundance estimated at night was about five times than that of during day. Fish tended to concentrate in the water column between 10-20 m at night, while density was relatively even across the water column during day. At night, fish communities were dominated by individuals smaller than 5.5 cm (76.8%); while during day, individuals with 7.8, 6.9 and 6.2 cm TL (45.0%) were dominant. Our results indicated intensive diurnal movement of fish in the reservoir, mainly by the small-sized fishes sheltering in the littoral zone during day and scattering and foraging into the open water at night. Based on our results, fishery management of the reservoir should be paid more attention on juvenile fish in the littoral zone during day and hydroacoustic survey should be conducted at night for accurate estimation of fish abundance in large reservoirs.

Dramatic variations in abundance and distribution of fish were detected between night and day by hydroacoustic technique in the DR, which is similar with results of other hydroacoustic surveys in freshwater systems and reflects diurnal movement of fish in large reservoirs (Cech *et al.*, 2005, 2017: Mehner, 2012: Lian *et al.*, 2017). Comparison with hydroacoustic surveys in freshwater systems, over 80% reported higher abundance at night compared to day; among them, 25% reported two to four times and 27% reported over four times fish abundance at night (Fig. 5). Compared with other hydroacoustic surveys in freshwater systems, our results indicated strong diurnal movement of fish which is a typical diurnal migration behaviour in highly transparent large reservoirs. This diurnal movement shows that fish descend to depth or aggregate close to the littoral zone during day and scatter into the open water layers at night (Eckmann, 1991; Knudsen and Sægrov, 2002; Prchalova *et al.*, 2003; Simmonds and MacLennan, 2005; Lian *et al.*, 2017).

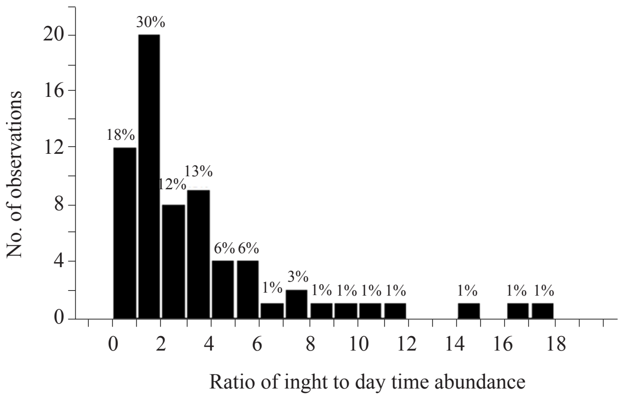

Fig. 5. Frequency distribution of ratio of fish abundance estimated at night to day reported from freshwaters through hydroacoustic surveys. The percentage frequencies are presented above the bars. The literatures were searched in the Web of Science up to April 2018. A total of 29 literatures were included with fish abundance estimated using hydroacoustic techniques during day and at night in freshwaters (reservoirs, lakes and rivers)

Intensity of diurnal movement is usually high in waters with high structural complexity, where fish would shelter around those structures during day and move out for feeding at night (Godlewska, 2002; Warfe and Barmuta, 2004; Shoup *et al.*, 2014). The DR is a typical canyon reservoir with highly structurally complex shore and limited pelagic areas (Han and Liu, 2012). Furthermore, diurnal movement of fish is usually strong in highly transparent waters where fish move to shelter near shore structures during day, which could explain the typically low abundance observed through hydroacoustic surveys (Appenzeller and Leggett, 1995; Simmonds and MacLennan, 2005; Lian *et al.*, 2017). Transparency in the DR reached up to 6 m at our surveys. Thus, high water transparency might be also an important reason for high-intensity diurnal movement of fish observed in this study.

The dominant size classes observed at night were smaller than those observed during day and much higher abundance of fish was estimated at night. These results indicated the high intensity of diurnal movement in the DR and mainly reflected movements of small-sized fish including mainly young-of-the-year (YOY) juveniles of some species, *e.g. Neosalanx taihuensis, Parabramis pekinensis*, *Megalobrama skolkovii* and *Hemiculter leucisculus*. Intensity of diurnal movement varies with species and ontogenetic stages of fish (Mehner, 2012). For many fish species, intensity of diurnal movement was higher for juveniles than adults (Cech *et al.*, 2005; Kratochvil *et al.*, 2008; Cech *et al.*, 2017). Our survey was conducted in June when most species have just completed spawning and YOY juveniles were highly abundant and were dominated by *N. taihuensis* and *H. leucisculus*, followed by *P. pekinensis* and *M. skolkovii* (Wang *et al.*, 2015; Lun *et al.*, 2016; Liao *et al.*, 2018).

Predation risk and foraging opportunities are probably major factors determining the diurnal movement patterns of fish in the DR. Diurnal movement of fishes is considered as an adaptive approach for refuging predation, foraging opportunities and bioenergetics gain (Donner and Eckmann, 2011; Mehner, 2012). Several piscivorous fishes, *e.g. Elopichthys bambusa, Culter alburnus* and *Siniperca chuatsi*, in the DR are abundant and visually oriented (Reid *et al.*, 1999; Tsunoda and Mitsuo, 2012; Zheng and Han, 2012). Both low density of fish and schools of fish detected during day could reflect the result that small-sized fishes escape from predation by the piscivorous fishes. Sheltering during day through diurnal movement is a viable strategy for small-sized fish in large reservoirs (Foster and Treherne, 1981; Magurran, 1990; Pitcher and Parrish, 1993). On the other hand, all of the dominant small-sized fishes in this study are zooplanktivorous (Fish base: www.fishbase.org) and higher abundance of fish in the 10-20 m depth layer at night was associated with higher abundances of zooplankton (unpublished data). Thus, feeding opportunities may be a major factor determining night movement patterns of fish in the DR. Association of diurnal movements of fish with zooplankton has been reported in other studies (Prchalova *et al.*, 2003; Bezerra-Neto *et al.*, 2009).

Although a large number of reservoirs have been impounded and used for fisheries worldwide, fish abundance and distribution surveys have rarely been conducted in these reservoirs to support fishery management. In this study, we observed a much higher density of fish at night than during day, suggesting high-intensity diurnal movement of fish in the DR. Small-sized fish, including mainly YOY juveniles, shelter near shore structures or form schools to escape predation during day and move to the water layers with higher abundances of zooplankton at night, which may account for the high-intensity diurnal movement of fish in the reservoir. Thus, we suggest that fishery management of the reservoir should be paid more attention on juvenile fishes in the littoral zone during day and hydroacoustic survey should be conducted at night rather than during day to accurately estimate fish abundances in reservoirs with high structural complexity and high water transparency. Further research should be conducted to determine species compositions and species-specific abundances by sampling fish at specific depths using a multi-mesh gillnet. It is also important to develop TS-TL specific regression equations for species which is fundamental for estimating fish size in hydroacoustic survey.

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