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Extended summary

Species composition and temporal pattern of fish passing through the navigation locks in the middle reach of Yangtze River: implications for fish conservation

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Introduction

While great attention has been given to fishway design to mitigate the environmental effects of dams (Castro-Santos et al., 2009; Roscoe and Hinch, 2010), few studies have addressed the effectiveness of ship locks for fish migration. The role of ship locks for fish passage is usually ignored or merely underestimated as a potential alternative to fishways and is in need of investigation (Larinier and Marmulla, 2004).

The Gezhouba Dam (GD) and the Three Gorges Dam (TGD) are the only dams in the main channel of the middle reach of the Yangtze River. They have no fish pass facilities and thus totally block fish migration (Wei et al., 1997; Gao et al., 2010). However, commercial catch data indicated that the compositions of the fish assemblages above and below the dams were of considerable similarities (IHB, 2010). Hydroacoustic surveys also showed that fish aggregated around the gates of the ship locks (Lin et al., 2011). These observations suggest that the ship locks might contribute to some connectivity among fish communities upstream and downstream of the dams (Argent and Kimmel, 2010). The aim of this study was therefore to: quantify the role of ship locks in fish transfer through the GD and TGD dams; identify which species use ship locks to pass through the dams; and investigate the temporal dynamics of fish passage through these dams.

Materials and methods

Study site

The Gezhouba Dam was constructed four km upstream of the city of Yichang (Hubei Province). Completed and impounded in 1981, it was the first dam on the mainstream of the Yangtze River (Fig. 1), generating about 2700 MW of electrical power. Three parallel ship locks are in use to overcome the 27 m water level difference. Locks 1 and 2 are 34 m wide, 280 m long and 5 m deep at low level. Lock 3 is 18 m wide, 120 m long and 3.5 m deep at low level. The Three Gorges Dam, the world's largest hydroelectric power station, was completed in 2009 and is 38 km upstream the Gezhouba Dam. The Three Gorges Dam is a concrete gravity type with a height of 185 m and permitting the storage of 39.3 billion m^3 of water. There are two series of five sequential ship locks situated on the left bank. Each lock is 280 m long, 35 m wide and 5 m deep at low level (Fig. 1).

Fish sampling

Fishes were sampled in lock 3 of the GD and in the 3rd stage of the south lock of the TGD during the overhaul of the navigation locks in June and November 2009 (Fig. 1). After draining the water out of the lock chamber, about 20–30 persons using hand-held nets caught the fish that had accumulated at the bottom of the ship locks. All fish were identified and counted. All species were categorized as either river-lake migratory species (RL), potamophilous species (PO), or sedentary species (SE), according to the information on habitat use and distribution available from Ding (1994) and Cao et al. (2007).

Hydroacoustics

A 200 kHz digital split-beam echo sounder (SIMRAD EY60) with circular composite transducer (7°C at 3 dB) was mounted on an adjustable bracket and submersed at 4 m depth, at the upstream gate of GD ship lock 1 (Fig. 1). During our circadian detections eight horizontal fixed detections were conducted from 17.00 hours on 17 June 2010 to 11.00 on the following day, when the upstream gate was opened. Monitoring was from 17.02.25–17.57.55, 18.40.32–19.42.41, 22.47.19–00.47.21, 01.41.46–02.58.43, 03.55.50–04.35.46, 05.27.30–06.21.20, 07.10.54–08.50.14, and 09.41.03–10.37.21, respectively. Echo detections were performed with a threshold of −60 dB, maximum gain compensation of 3 dB and maximum phase deviation of 3 phase steps. A minimum echo duration of 0.7 and a maximum echo duration of 1.3 in the transmitted pulse duration were used. Acoustic data were analyzed with the Sonar 5-Pro software, version 5.9. The acoustic system was calibrated with a standard 23 mm copper sphere before and after field surveys (Balk and Lindem, 2004). Statistical analyses were conducted using SPSS 16.0 (SPSS Inc., Chicago, IL) and the graphic information processed with Origin 8.0 (Origin Lab).

Results

A total of 21 species and 904 fish were sampled in the two navigation chambers and six species were found in the two locks (Table 1). White bream *Parabramis pekinensis* was the most abundant in the two ship locks, accounted for 36.4% and 83.3% of the fish in GD and TGD locks, respectively.

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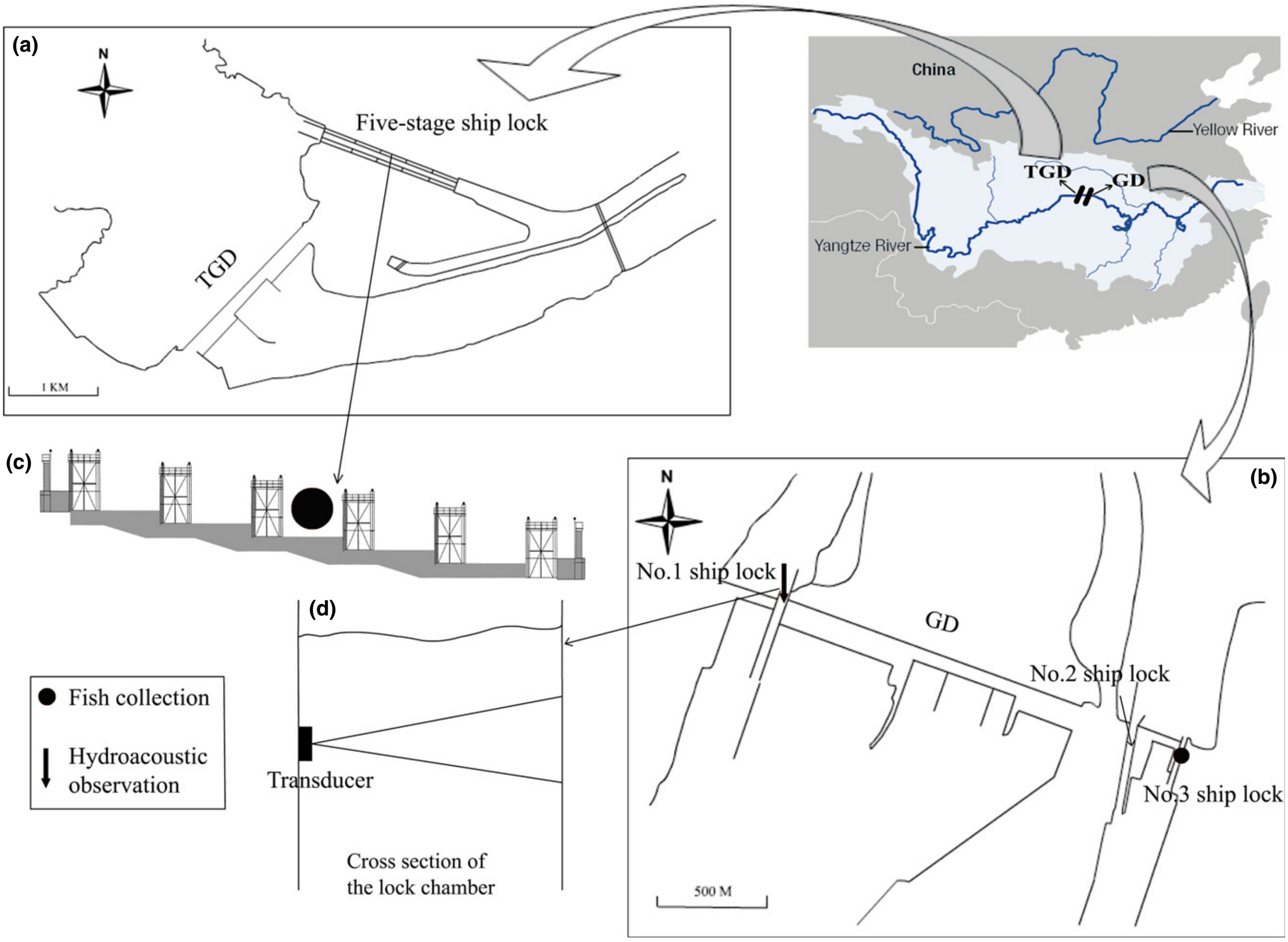

Fig. 1. Sample sites in the Yichang reach of the Yangtze River. (a) five-stage ship lock at Three Gorges Dam (TGD); (b) ship lock 1 and ship lock 3 at Gezhouba Dam (GD); (c) fish collection in chamber lock of the 3rd stage of the south lock of TGD; (d) horizontal fixed-location detections at upstream gate of GD ship lock 1. All fish samplings were conducted in Lock 3 of the GD and in the 3rd stage of the south lock of the TGD and in Lock 1 of GD for hydroacoustic detections

In the GD lock, sedentary fish were dominant (56.4%) and accounted for 11 species, followed by river-lake migratory species (36.4%) although only represented by a single species (white bream). In the TGD lock, river-lake migratory species represented the dominant group (83.5%) with only two species, followed by sedentary species (16.1%) with eight species (Table 1). Few potamophilous species were present in the two ship locks.

A total of 51 fish individuals were detected during the 557 min of hydroacoustic detection. There was a significant trend towards upstream fish movement (Chi-square test, $P < 0.05$), with 34 fish swimming upstream and 17 swimming downstream through the ship locks. Fish movements differed between day and night, as the mean passage rate (ind. h^{-1}) was 7.2 ± 5.0 at night and 2.4 ± 1.8 during the day (Fig. 2). For all detected fishes, the average target strength (TS) was -40.9 ± 5.0 dB, with a maximum of -28.8 dB and a minimum of -49.3 dB. During the day TS was higher than at night ($P < 0.05$) (Fig. 3).

Discussion

Our study is the first significant attempt to quantify fish passage efficiency through the ship locks for a dam located in the Yangtze basin. In this study, we collected 21 species in the lock chambers, including two river-lake migratory species (white bream and grass carp) and four potamophilous species (*Rhinogobio typus*, *Coreius heterodon*, *Botia superciliaris*, and *Leptobotia taeniops*). In particular 12 species, including two river-lake migratory species (white bream and grass carp) and two potamophilous species (*R. typus* and *L. taeniops*) were collected in the middle chamber of the five-stage ship locks of the TGD. This means that these fishes must pass via two locks to reach the middle lock chamber. Meanwhile, we detected 34 individuals that moved upstream and 17 individuals that moved downstream. These results demonstrate that some fish have the capacity to enter the locks and may even migrate through the ship locks to the upstream part of the Yangtze River.

In this study we detected that 40 fishes passed through the gates of the locks from 22.47 to 04.35, accounting for 80.4% of the total amount detected, which indicated that the peak of fish migration through the ship locks occurred during the night in the Yangtze River. This was consistent with the previous studies, which reported that many fish species migrate during the night (Baras et al., 1996; Schilt, 2007). However, to acquire solid proof of certain directional migration, tagging and other tracking techniques are needed. Moreover, no sturgeons were observed during the survey, particularly in November when these fish were definitely known to be present below the GD. It is suggested that the locks are unlikely to be reasonable passways for these large, highly endan-

Table 1
Number and functional group of fish sampled in locks of Gezhouba Dam (GD) and Three Gorges Dam (TGD)

Fish	GD lock		TGD lock		Functional group
	ind.	ind.%	ind.	ind.%	
Cyprinidae					
Parabramis pekinensis (Basilewsky)	91	36.4	545	83.33	RL
Megalobrama amblycephala Yih			1	0.15	SE
Hemiculter bleekeri Warpachowski	28	11.2	19	2.91	SE
Culter alburnus Basilewsky			3	0.46	SE
Squalidus argentatus (Sauvage & Dabry)			2	0.31	SE
Rhinogobio typus Bleeker			1	0.15	PO
Coreius heterodon (Bleeker)	2	0.8			PO
Saurogobio dabryi Bleeker	5	2			SE
Ctenopharyngodon idella (Valenciennes)			1	0.15	RL
Carassius auratus (Linnaeus)	9	3.6	3	0.46	SE
Cyprinus carpio Linnaeus	1	0.4			SE
Rhodeus spp.	6	2.4			SE
Cobitidae					
Botia superciliaris Gunther	2	0.8			PO
Leptobotia taeniops (Sauvage)	14	5.6	2	0.31	PO
Bagridae					
Pseudobagrus truncatus (Regan)	7	2.8			SE
Pelteobagrus vachelli (Richardson)	44	17.6	5	0.76	SE
Pelteobagrus nitidus (Sauvage & Dabry)	15	6			SE
Pseudobagrus spp.			71	10.86	SE
Gobiidae					
Rhinogobius giurinus (Rutter)	1	0.4	1	0.15	SE
Engraulidae					
Coilia brachygnathus (Kreyenberg & Pappenheim)	23	9.2			SE
Salangidae					
Protosalanx hyalocranius (Abbott)	2	0.8			SE
Total	250	100	654	100	

RL, river-lake migratory species; PO, potamophilous species; SE, sedentary species.

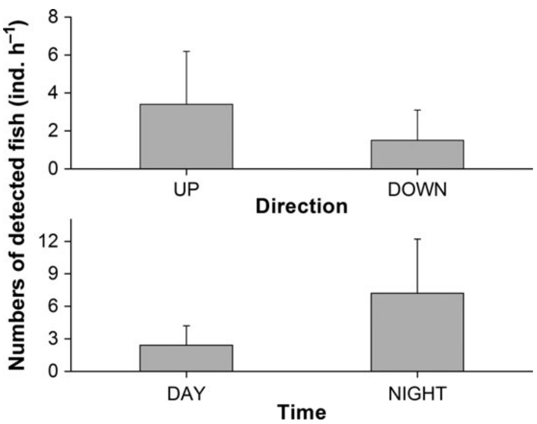

Fig. 2. Number of fish detected according to swimming direction and circadian rhythm by a fix-horizontal acoustic survey conducted in lock 1 of GD, 17 to 18 June 2010

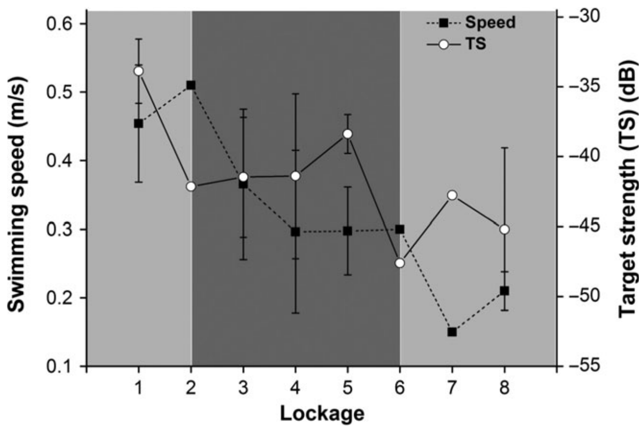

Fig. 3. Average swimming speed and target strength (TS) of fish according to subsequent opening and closing of the lock while transferring ships from upper to lower levels and vice versa. White circle = daytime lockages; black rectangle = night lockages. Data points = mean value; error bars = standard deviation

gered fish species and that there is a need for strong alternative programs to save the Chinese sturgeon from extinction. In spite of this, we believe that navigational locks can provide, at least for some species, a limited corridor between upstream and downstream parts of the dams. It is noteworthy that the operating ship propellers can lead to accidental kills and damage of fish with an increase in the shipping, ship size and stronger engine horsepower. Based on the above points, further research is urgently needed to investigate potential modification of the ship locks or an optimization of the lock operation in order to enhance fish passage efficiency.

Editorial Note

The full paper will be published in the Special Publication of the World Sturgeon Conservation Society (WSCS Spec. Publ. No. 6), presenting the papers of the Workshop on the progress in the application of acoustics in inland and estuarine fishery research (Wuhan, China, November 2012).

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