Chinese Journal of Oceanology and Limnology
Vol. 30 No. 4, P. 554-562, 2012
http://dx.doi.org/10.1007/s00343-012-1218-4

Measurement of single-fish target strength in the South China Sea*

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Received Oct. 26, 2011; accepted in principle Dec. 13, 2011; accepted for publication Feb. 22, 2012

Abstract We measured the target strength (TS) of three commercial fish species: whitespotted spinefoot (*Siganus canaliculatus*), black porgy (*Acanthopagrus schlegelii*), and creek red bream (*Lutjanus argentimaculatus*), in the South China Sea. The TS of caged or tethered fish (n=76 total) was measured using a Simrad EY60 portable scientific echosounder at 120 kHz. We evaluated the relationship between TS and total length (TL, cm) for the three species. This is the first attempt to use split-beam acoustics to measure single-fish TS in the South China Sea by Chinese researchers. Our results will improve the accuracy and precision of acoustic abundance estimates of commercially important species and further the development of underwater acoustic survey techniques in fisheries in the South China Sea.

Keyword: target strength (TS); single-fish; caging experiment; tethering experiment; South China Sea

1 INTRODUCTION

Underwater acoustic survey techniques have become increasingly sophisticated in recent years, improving their utility for fishery research (Misund, 1997; Simmonds and MacLennan, 2005). As a result, the data collected during acoustic surveys has made a significant contribution to our understanding of life in marine and fresh waters. For example, such surveys provide information on how the abundance and size structure of wild populations varies in space and time (Midttun, 1984; Misund, 1997; Simmonds and MacLennan, 2005). The target strength (TS, dB re 1 m^2) of an object is defined as the ratio of the backscatter intensity and the incident (measured in dB) and the backscattering cross-section is the ratio of the intensity in linear terms. TS is a physical quantity that indicates the size of the echo (Foote, 1987a; Misund, 1997; Simmonds and MacLennan, 2005) and may be used to estimate population abundance, an important application of acoustic fisheries research (Gunderson, 1993), (Midttun, 1984; Misund, 1997). Knowledge of the TS is essential to convert echo integrator measurements to absolute abundance (Foote, 1987a). Quantitative information about fish targets (e.g., number per unit volume) requires knowledge of the appropriate TS value for the species contributing to the echo (Foote, 1987a; Simmonds and MacLennan, 2005).

In general, there are three experimental techniques for determining the TS of fish based on the state of the fish being studied, depending on whether they are (1) immobilized and unconscious, (2) active but confined within a cage, or (3) wild and free to behave normally in their natural environment (Nakken and Olsen, 1977; Edwards and Armstrong, 1984; Foote and Traynor, 1988; Simmonds and MacLennan, 2005). In

* Supported by the National High Technology Research and Development Program of China (863 Program) (No. 2006AA100303), the Science and Technology Project of Guangdong Province, China (No. 2007B020708001), the Special Funds for Operating Expenses of Basic Researches in the Central Nonprofit Scientific Research Institutes (Nos. 2008TS01, 2007ZD03), and the Natural Science Foundation of Guangdong Province, China (No. 04001263)
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addition, theoretical modeling of acoustic scattering caused by fish has been developed to estimate TS at various frequencies and fish lengths, taking into account experimental data and fish morphology (Clay, 1992; Medwin and Clay, 1998; Gorska and Ona, 2003). A number of studies been conducted to measure the TS of fish using a range of techniques. In developed countries, there has been increasing attention towards the development of methods for the measurement of single-fish TS and TS for a range of commercially important pelagic fish (Nakken and Olsen, 1977; Edwards and Armstrong, 1984; Nielsen and Lundgren, 1999; Kang and Hwang, 2003, 2005; Simmonds and MacLennan, 2005; Pena, 2008). Methods for single-fish TS measurement have been investigated for a number of years (Foote, 1980b; Foote and Traynor, 1988; Blaxter and Batty, 1990; Ona, 1990; Simmonds and MacLennan, 2005). However, there are few reports of single-fish TS research in China, particularly in the South China Sea. The South China Sea is one of the three Asian marginal seas (the East China Sea, the South China Sea, and the Bering Sea) and has an average depth of 1 212 m. It contains tropical and subtropical waters and has a rich species diversity (Zeng et al., 1985; Zhao et al., 1990). The seawater density and the acoustic characteristics of fish in the South China Sea are quite different from that of other sea areas, and such differences challenge the application of fishery acoustic technology. Although in recent years underwater acoustic techniques have been used in the region, their application is still at a preliminary and exploratory stage; many key technical problems need to be resolved. Factors such as fish tilt angle, fish length, depth, and transducer frequency all contribute to the variability and influence the backscattering intensity during acoustic TS measurement (MacLennan et al., 1989; Hazen and Horne, 2003; Simmonds and MacLennan, 2005).

First used in China in 1984, acoustic fish abundance estimation has become increasingly important for monitoring and researching marine fishery resources and the marine ecosystem within Chinese territorial waters (Zhao et al., 1990, 2000, 2003a, 2003b; Tang et al., 2006). As in other countries, Chinese scientists have focused their attention on the measurement of single-fish TS, especially in-situ TS measurement, for a range of commercially important species, (Zhao, 1996, 2006; Zhao et al., 2008). In recent years, hydroacoustic techniques have been used extensively to assess the status of marine fishery resources in the South China Sea (Li et al., 2002, 2003, 2005; Jin et al., 2005). However, measurements of single-fish TS are lacking for this area so acoustic assessments of fish abundance have relied on TS measurements for the same or similar species in other areas (Jia et al., 2003). Our objective was to obtain measures of single-fish TS to improve the accuracy and precision of acoustic estimation of fishery resources studying the South China Sea.

Table 1 Technical data and primary parameter settings of acoustic instruments

Main technical data	Value
Sounder type	EY60 Version 2.1.0
GPT type	120 kHz ES120-7C
Frequency	120 000 Hz
Power	200 W
Beam type	Split-beam
Receiver bandwidth	10.92 kHz
Pulse duration	0.128 ms
Sample interval	0.025 m
Target strength gain	26.80 dB
	27.46 dB
Reference TS	-40.80 dB
Reference TS deviation	5.0 dB
Two way beam angle	-21.0 dB
Athw. angle sens	23.00
Along. angle sens	23.00
Athw. beam angle	7.00 deg
Along. beam angle	7.00 deg
Athw. offset angle	0.00 deg
Along. offset angle	0.00 deg
Sa correction	0.00 dB
Fix depth	0.35 m
Absorption coeff	39.7 dB/km
Sound velocity	1 546.4 m/s

2 MATERIAL AND METHOD

2.1 Echosounder system set-up and calibration

We measured the TS of three economically important fish species: whitespotted spinefoot (*Siganus canaliculatus*), black porgy (*Acanthopagrus schlegelii*), and creek red bream (*Lutjanus argentimaculatus*) in Daya Bay in the South China Sea in October 2008. We measured the TS of 76 individuals using a Simrad EY60 portable scientific

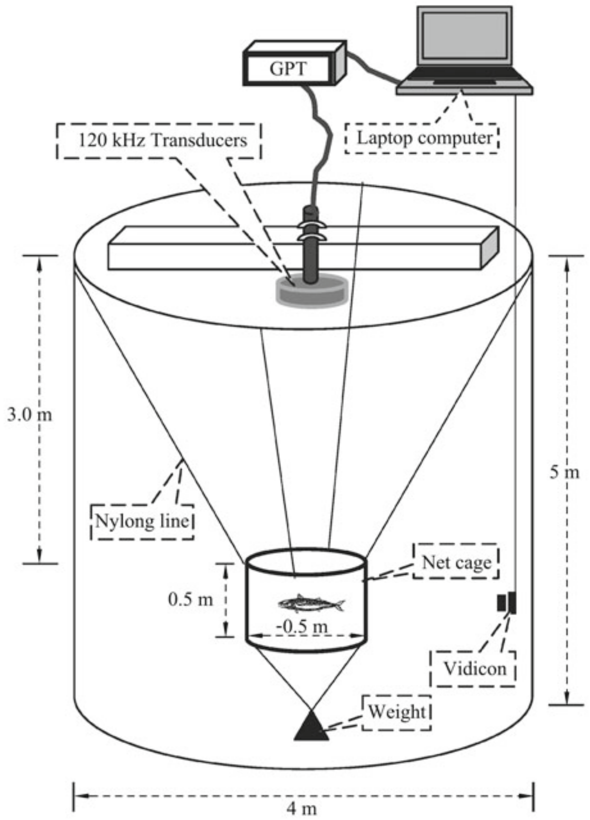

Fig.1 Schematic diagram of the caging experiment

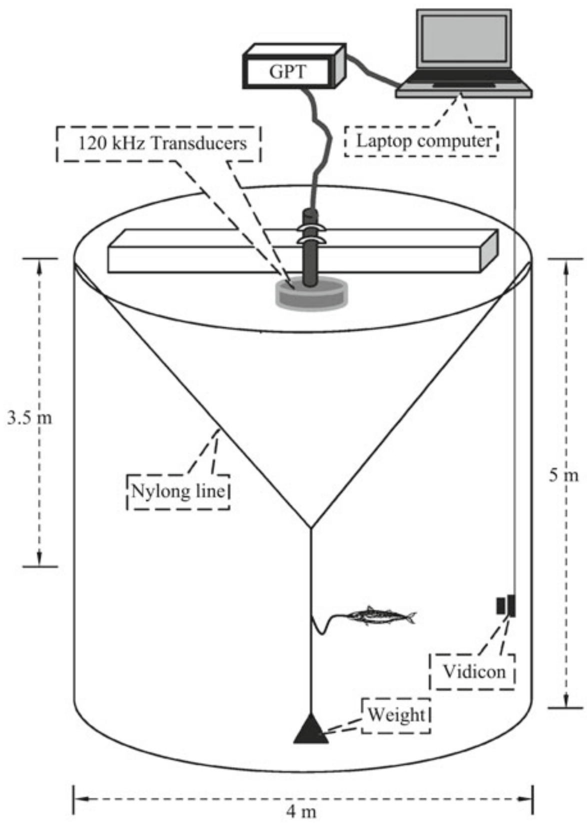

Fig.2 Schematic diagram of the tethering experiment

echosounder (120 kHz) connected to a split-beam transducer. Technical data and the primary parameter settings of the acoustic system are given in Table 1.

The echosounder system was calibrated using the standard target method with a 23 mm diameter copper sphere at 120 kHz (the TS of the copper sphere was -40.8 dB) (Foote, 1982; Foote et al., 1987b). The calibration process was conducted in seawater (salinity of 32 and 30°C) that was representative of environmental conditions during the experimental trials. The copper sphere was suspended 3.2 m below the transducer and the range was in the far field (the near field range boundary was 0.9 m and the range for far field conditions was 1.8 m). After calibration, the parameters of the transducer were updated based on calibration results. The calibration of the transducer was carried out before and after measurement and there was no obvious variation from the theoretical TS.

2.2 Caging and tethering experimental setups

The ex-situ experimental device used for the caging experiment is shown in Fig.1. A small cylindrical cage, 0.5 m in diameter and 0.5 m in height, was made from 0.25 mm diameter single nylon line (1.5 cm mesh) and was placed vertically below the transducer. The sample fish was placed vertically below the transducer beam within the detection range and the TS of each fish was measured individually. The tethering device is shown in Fig.2. Live fish were tethered using a single nylon line (length: 0.2 m, diameter: 0.25 mm), which did not affect the measurement of TS, that was attached to the mouth of the fish. The nylon line was tied to a vertical line at a depth of 3.5 m. The vertical line was connected to a 1 kg weight and the distance between the weight and the connecting line was 1.1 m, which was sufficient to separate the echo from the tethered fish from those of the bottom and the weight. A large plankton net (inner diameter: 0.5 mm mesh) was set up outside the device to form a cylindrical measuring space and the net was supported by a bracket to prevent interference by other marine organisms. An underwater video camera pre-installed outside the acoustic beam to avoid interfering with echoes from the fish was used to continuously monitor the movement of free-swimming fish (Foote, 1983; Edwards and Armstrong, 1984).

2.3 Experimental fish samples

The three commercial fish species were captured by purse seine and basket pot in situ in the South

Table 2 The composition of fish samples

Methods	Species	Numbers	Weight range (g)	Total length range (mm)
Caging experiment	Whitespotted spinefoot	12	9.2–140	94–205
	Black porgy	12	22–443	110–275
	Creek red bream	12	11–850	85–356
Tethering experiment	Whitespotted spinefoot	16	4.6–135	78–200
	Black porgy	11	24–454	109–267
	Creek red bream	13	5.9–875	69–358
Total		76	4.6–875	69–358

China Sea. The fish were held in a cylindrical cage (4 m diameter × 5 m height) for at least two days to allow acclimation. The three species belong to the Order Perciformers, Class Actinopterygii. We measured the total length (TL) and weight of each fish after measurement of the TS (Table 2). To avoid injury, the fish were sedated with MS-222 prior to being attached to the tether. The fish were allowed to recover before measurements of TS were collected.

2.4 Data logging and analysis

The raw echo data were logged using an EY60 echosounder serial port and recorded in a computer. The TS of the empty net cage was <-70 dB, hence the impact of the cage and tether system was negligible in comparison with the TS of the fish echoes. The threshold level was set to -70 dB in the data post-processing. An example of echogram of TS raw pings from an empty cage and a cage containing a fish is illustrated in Fig.3a and b, respectively. Data for analysis were selected based on the distance from the transducer to the fish and the position of the target in the beam. Echo data were selected for targets within 3.0 m to 3.5 m and ±3.5° of the transducer axis. The mean TS was calculated from the mean acoustic cross-section (σ_{bs}, m^2) and the averaging was performed in the linear domain (Foote, 1980a). Analyzer units were always on-line and we used regression analysis to evaluate the relationship between TS and TL. The relationship between TS and TL was given by the best fit of the standard equation, $TS=20\log_{10}TL+b_{20}$, in which the slope was fixed at 20 and b_{20} value (dB) was estimated.

3 RESULT

3.1 Whitespotted spinefoot

We measured the TS of 12 whitespotted spinefoots in the caging experiment and 16 in the tethering experiment.

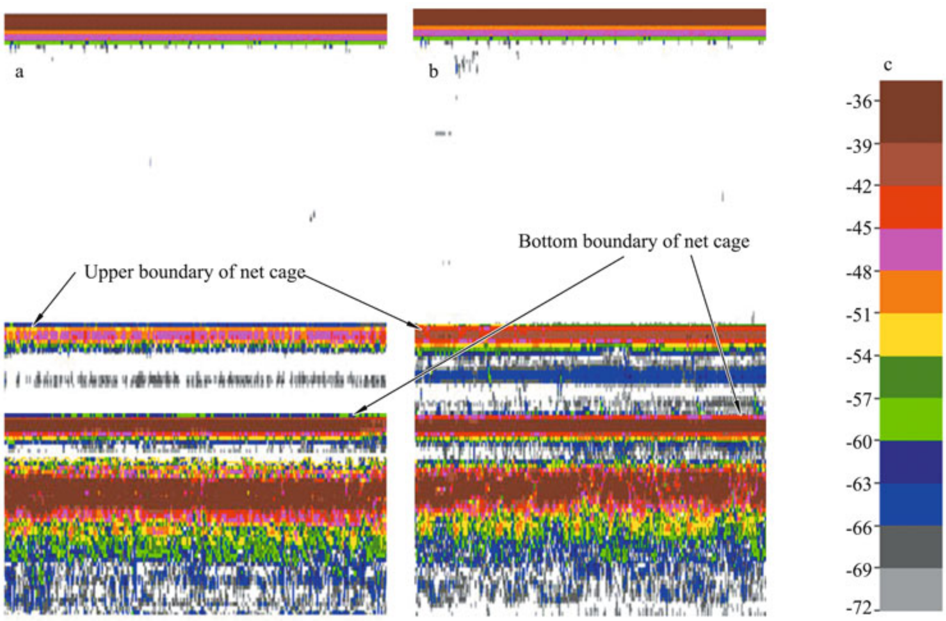

Fig.3 TS raw ping echogram showing the echoes from an empty cage (a) and a cage containing a fish (b), (c) legend

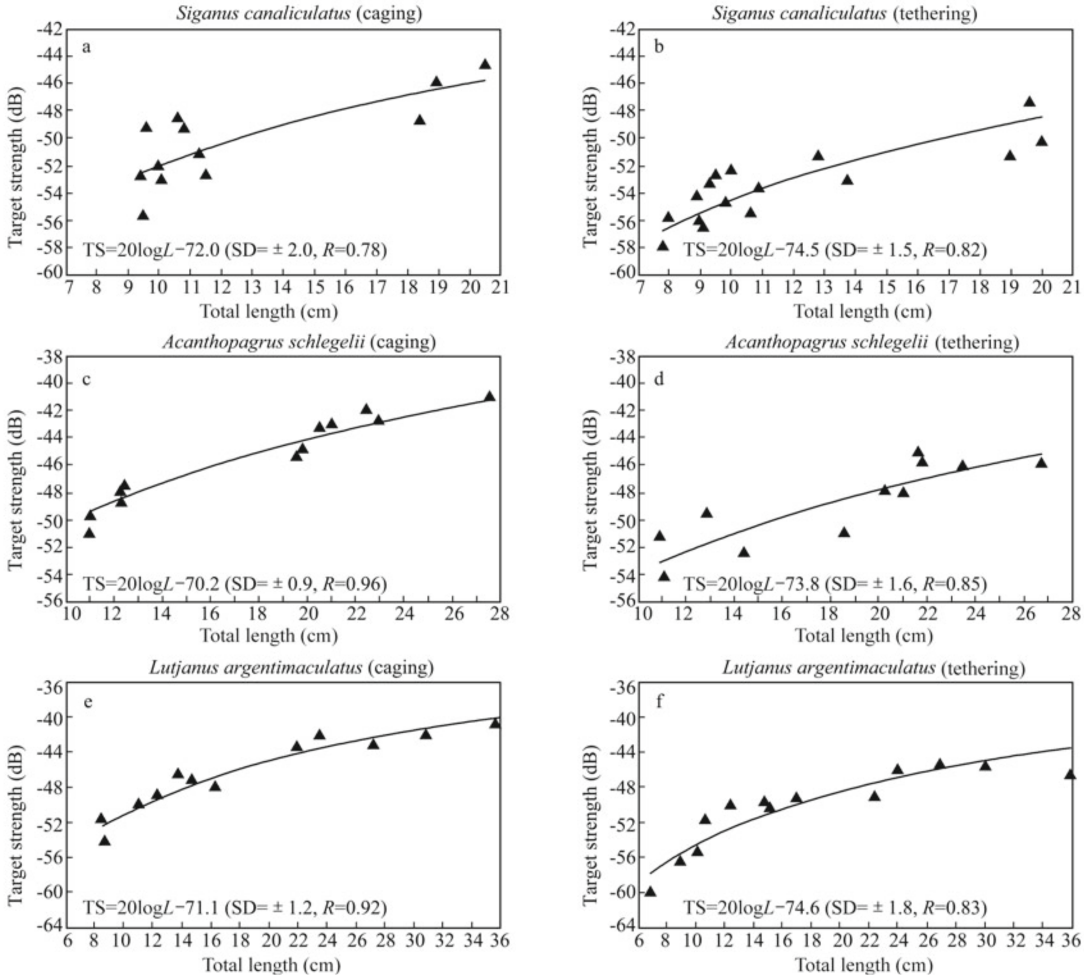

Fig.4 The relationship between the TS and total length of whitespotted spinefoot, black porgy, and creek red bream in the caging and tethering experiments

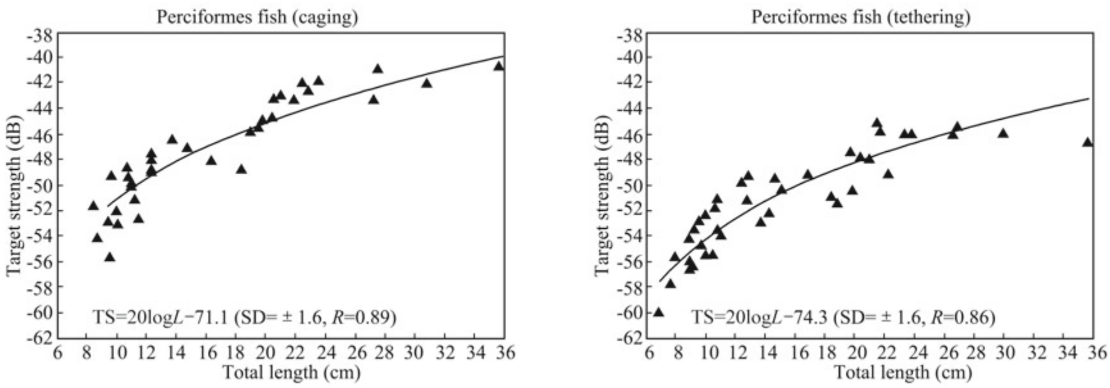

Fig.5 The relationship between the TS and total length of Perciformes (perch-like) fish in the caging and tethering experiments

The mean b_{20} value for caged fish was -72.0 dB and the standard form relationship between TS and TL was: TS=20Log$L$−72.0 (SD=±2.0, R=0.78, SD: standard deviation) (Fig.4a). The mean b_{20} value for tethered fish was -74.5 dB and the relationship between TS and TL was TS=20LogTL−74.5 (SD=±1.5, R=0.82) (Fig.4b).

3.2 Black porgy

We measured the TS of 12 black porgys in the caging experiment and 11 in the tethering experiment. The mean b_{20} was -70.2 dB in the caging experiment and the relationship between TS and TL was described by the equation: TS=20LogTL−70.2 (SD=±0.9, R=0.96) (Fig.4c). The mean b_{20} for tethered fish was -73.8 dB and relationship between TS and TL was described by the equation: TS=20LogTL−73.8 (SD=±1.6, R=0.85) (Fig.4d).

3.3 Creek red bream

We measured the TS of 12 creek red breams in the caging experiment and 13 in the tethering experiment. The mean value of b_{20} was -71.1 dB for cage fish and the relationship between TS and TL was: TS=20Log$L$−71.1 (SD=±1.2, R=0.92) (Fig.4e). The mean value of b_{20} was -74.6 dB for tethered fish and the relationship between TS and TL was: TS=20LogTL−74.6 (SD=±1.8, R=0.83) (Fig.4f).

3.4 Comprehensive analysis

The empirical relationships between TS and TL were fitted for the three fish species from the caging and tethering experiments. In the caging experiment, the mean value of b_{20} was -71.1 dB and the standard form relationship between TS and TL was: TS=20LogTL−71.1 (SD=±1.6, R=0.89). In the tethering experiment, the mean value of b_{20} was -74.3 dB and the standard form relationship between TS and TL was: TS=20LogTL−74.3 (SD=±1.6, R=0.86). The regression curve for TS and TL is shown in Fig.5.

4 DISCUSSION

We successfully measured the TS of three common, and economically important, fish species in the South China Sea using caging and tethering methods. Ex -situ TS measurements allow fish of known size to be measured under known environmental and behavioral conditions. However, the behavior of captive fish may not be representative of those in the wild because of the stress associated with capture and the physical restraint associated with the experimental setup. Together, these factors may alter the TS to some degree, (Simmonds and MacLennan, 2005). Furthermore, because we measured single-fish TS in open marine waters we cannot rule out the possibility of errors due to movement of the transducer associated with wave or current action. The influence of ocean currents and the handling associated with the experimental manipulation of the subjects also make it difficult to analyze the relationship between TS and tilt angle (Simmonds and MacLennan, 2005; Kang et al., 2005). However, understanding the inherent variability in TS is not critical for acoustic assessment of fishery resources as the average TS is a more useful value (Simmonds and MacLennan, 2005). Using our approach we were able to calculate the single-fish average TS, therefore we feel our results can be used to calibrate data from acoustic surveys.

The calibration process was conducted in waters that were representative of the South China Sea. However, differences in environmental conditions are likely to affect fish behavior, and hence TS. Indeed, differences in environmental conditions may explain the lower b_{20} value obtained by Kang et al. (2004) for black porgy (Foote, 1980a; Hazen and Horne, 2003; Kang et al., 2004). Using our value for b_{20} will result in a higher abundance estimate relative to that of Kang et al.

Although our approach imposes certain restrictions on fish behavior, it has the advantage of being able to accurately quantify species and size. Furthermore, because the fish can move freely within a certain area, the measurement is likely close that of fish in the wild. Using the underwater camera we are able to monitor the change in tilt angle of fish to better estimate the single-fish average TS. Because the EY60 is a split-beam echosounder, the position of a reflecting target within the beams can be calculated, and the directionality of the transducer compensated accordingly. Thus, we were able to take direct measures of single-fish TS with relatively easily and with high precision.

According to Foote (1980b), the swimbladder reflects most of the backscattering energy (in species that possess one). However, the TS is highly variable among individual fish, even for those of the same size and species. This is because of differences in internal morphology, such as the shape of the swimbladder, and behavior, particularly the orientation of the body with respect to the transmitted beam (MacLennan et al., 1990). In addition, tilt angle (Blaxter and Batty, 1990), fish length (Foote, 1987a), depth in the water (Thomas et al., 2002), physiological state (Ona, 1990), and additional physical factors such as frequency (Horne and Jech, 1999), all influence the results of TS measurements. Given the variation that can occur in these and a number of additional factors, TS is likely not constant (Simmonds and MacLennan, 2005). The variation of TS with the tilt angle is often significant (Foote, 1980a). While length is often the main factor in TS regressions, the influence of tilt and frequency on TS can be greater than that of length per-unit-change: Tilt > Frequency > Length > Depth (Hazen and Horne, 2003). We measured TS at a depth of 4.5 m, however, TS may decrease if fish are deeper due to contraction of the swimbladder (Ona, 1990).

The TS values we obtained from tethered fish were generally lower than those obtained from caged fish (by 2.5–3.5 dB). The experimental environment and the echosounder system were similar and consistent between experiments, so are unlikely to have caused such cause systematic bias. We speculate that the differences are due to behavioral or physiological changes (MacLennan et al., 1989, 1990). The behavior of the tethered fish is likely less natural than those in the cages and fish may be more stressed because of the tether (Kang et al., 2004). We noted that the tethered fish tended to orient their head upward and the tail downward. Thus, there was considerable variation in the frequency of angle, with few fish remaining horizontal. Unfortunately, we were unable to collect detailed orientation information and quantify the relationship between TS and behavioral factors, such as orientation. We acknowledge that both the tethering and caging methods have advantages and disadvantages (Simmonds and MacLennan, 2005). For practical abundance estimates, we suggest using the results from the caging experiments, which were more consistent with the results of Kang et al. (2004).

Kang et al. (2004) estimated that the relationship at 120 kHz between ex-situ TS and fork length (FL, cm) of black porgy was $TS_{120kHz}=20\log_{10}FL-65.2$ (95% confidence interval (CI): -63.0 to -67.4, R=0.70), and the KRM model was $TS_{120kHz}=20\log_{10}FL-65.4$ (95% CI: -64.6 to -66.2, R=0.80). In our study, the relationship between mean TS and FL for tethered fish at 38 kHz was $TS_{38kHz}=20\log_{10}FL-69.3$ (95% CI: -67.6 to -70.9, R=0.42). The b_{20} value we obtained for black porgy was lower than that from Kang et al. (2004) and the difference may be attributed to the form of the fitted equation between TS and length, the size of fish selected during measurement, and the environment. We expressed our results in terms of total length whereas Kang et al. used fork length. Adjusting our results to take account of FL yields more similar results to those of Kang et al. The TL of the black porgy in our study ranged from 10.9 to 26.7 cm (mean: 17.7 cm). In contrast, the fish used by Kang et al. (2004) were somewhat larger, ranging from 15.5 to 32.9 cm (mean: 19.8 cm). This difference in size likely contributed to the differences in TS between the two studies (Love, 1971; Foote and Traynor, 1988; Hazen and Horne, 2003). The difference may also be due to environmental conditions. The water temperature was 30°C during our study and about the acoustic signal travelled at 1 546 m/s. Conversely, based on the speed of sound in Kang et al. (1 529 m/s), we believe the temperature was <30°C (based on the relationship between temperature and speed of sound in water: Leroy, 1969). Such a difference in temperature likely affects the behavior of fish, thereby influencing the measurement of single-fish TS (Foote, 1980a; Hazen and Horne, 2003). To our knowledge, TS has not been measured previously for whitespotted spinefoot and creek red bream. However, measurements have been carried out for similar shaped fish such as the red sea bream (*Pagrus major*). The b_{20} value for red sea bream was -74.0 dB at 120 kHz (Kang and Hwang, 2003) based on ex-situ TS measurements. Similarly, our data suggest that creek red bream have a TS of -71.1 dB and -74.6 dB at 120 kHz (caging and tethering method, respectively). Although creek red bream and red sea bream are both demersal and occupy similar aquatic habitat, the differences in swimbladder shape and size mean the data cannot be compared directly.

5 CONCLUSION

We measured the TS of three commercial fish species (whitespotted spinefoot, black porgy, and creek red bream) in the South China Sea. This is the first attempt to use split-beam acoustic technology to measure single-fish TS in the South China Sea by Chinese researchers. Our experimental approach was suitable for measuring single-fish average TS; however, the TS of apparently similar fish is highly variable. Changes in the behavior and physiology of fish may result in changes in TS. Likewise, the frequency has a significant influence on TS. Given this, the single-fish TS of these species should be evaluated at different frequencies and tilt angles in the South China Sea. Our data may be used to improve the accuracy of acoustic abundance estimates of commercially exploited species in the region. In the future, we will focus on resolving the following issues in the South China Sea:

(1) Evaluating the effect of acoustic frequency on

single-fish TS;

(2) Measuring the TS of the major marine fish species in the South China Sea and identifying as many possible variations of species and size;

(3) Investigating the effects of tilt angle and shape of swimbladder of some important fish species on TS by single-fish TS measurement.

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