THE JOURNAL OF THE ACOUSTICAL SOCIETY OF KOREA VOL.25, NO.3E 2006. 9 pp. 101~109

# Side-Aspect Target Strength Measurement of Swimbladdered Fish Using Multi-Frequencies System: Black Sea Bream (*Acanthopagrus schlegeli*)

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(Received Jun 12 2006; Revised August 22 2006: accepted August 29 2006)

**Abstract**

Besides dorsal-aspect target strength (TS) of the fish, side-aspect TS information is also acoustically important parameter in fisheries acoustics. In this study, the side-aspect TS of 11 black sea bream (*Acanthopagurus schlegeli*) were measured using a split beam echosounder of 120, 200, and 420 kHz; total length of the fish ranged from 12.4 to 23.7 cm, and wet weight from 27.5 to 229.8 g. For the precise TS measurement with side-aspect angle, we used anesthetized and tethered specimens of known size while being rotated through 360° by means of a carousel structure. The side-aspect TS measurements of the fish were conducted by rotating the fish in the horizontal plane at 5° interval. The ping interval was 0.2 second and elapsed time at each angle was 30-60 second. As a result, the measured side-aspect TS data were fitted by sinusoidal function. The relationships between fish length and near full side-aspect TS were as follows: $TS_{120\ kHz}$ = 21.46 log ($TL$)-67.5 (r = 0.70), $TS_{200\ kHz}$= 31.03 log ($TL$)-76.9 (r = 0.83), $TS_{420\ kHz}$= 30.79 log ($TL$)-72.2 (r = 0.77). For comparison, theoretically estimated side-aspect TS from the Kirchhoff ray mode (KRM) model, which based on swimbladder and body morphology, were compared with the measured TS.

***Keywords***: *Black sea bream, Ex situ experiments, Kirchhoff ray mode model, Side-aspect target strength.*

## I. Introduction

During the past several decades, many scientists have been making efforts to calculate fish biomass with acoustic measurements [1]. First of all, it is necessary to measure target strength (TS) accurately for estimating the biomass of interested fish. For measuring it having the smallest error, we have to know many factors, which affect TS such as orientation, activity, behavior, frequency, and physical structure of body and swimbladder [2]. A number of TS measurements have been experimented with fish size and weight under *in situ* or *ex situ* condition [3, 4]. In the measurement, many authors have studied TS in dorsal body aspect to predict fish length from relationships between acoustically estimated size (scattering cross-section or scattering length) and real size [5, 6]. Only a few authors considered other aspects such as side aspects [7, 8]. Unlike echosounder being vertically insonified, sonar system with various types horizontally insonified to detect the fish school in the sea. Therefore, it is indispensable that side-aspect TS measurement should be conducted for estimating fish biomass in the fisheries sonar system.

Black sea bream (Acanthopagrus schlegeli) are abundant, long lived fish that inhabit the shelf region and coastal areas of the northwest Pacific, especially around Japan, Korea, China, and Taiwan, where it is a very important commercial and sport fishing species [9]. The species mainly inhabit around coastal region being composed with sandy or rocky bottom and are commercially

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representative species of marine ranching program in Korea.

Various artificial reefs were installed to make a habitat for the fish in the marine ranching area around coastal area. Generally, SCUBA diving method was used to monitor fish biomass /behavior around the reef. The method, however, has an inherent limitation to produce continuously scientific results, considering working time and depth. As an alternative method, fisheries sonar systems having wide detection area are proposed to survey fish biomass/behavior around the reef. Then, side-aspect or lateral -aspect TS measurements essentially are needed to convert received echo data to abundance estimates. Although the side -aspect TS data is very important parameter, little is known of the TS properties for commercially important fish, whereas almost TS measurements for the fish were focused on the dorsal-aspect TS for downward looking fisheries echosounder [10].

The aim of this study is to measure side-aspect target strengths of black sea bream for applying sonar systems in the marine ranching area. For the TS measurement, we used *ex situ* method with various fish length, weight, and side-aspect angle. Furthermore, measured side-aspect TS data of black sea bream was compared with acoustic models based on fish morphology as input parameter.

## II. Material and Methods

### 2.1. Fish species studied

The side-aspect TS measurement of 11 black sea bream (*Acanthopagurus schlegeli*) was carried out in December 2005 at Ocean Acoustic Laboratory of Hanyang University, Korea. 11 black sea bream, ranging from 12.4 to 23.7 cm in total length (mean, 16.7 cm) and from 27.5 to 229.8 g in wet weight (mean, 95.46 g) were selected for the experiment (Table 1). The relationship between fish total length (cm) and wet weight (g) is shown in Fig. 1.

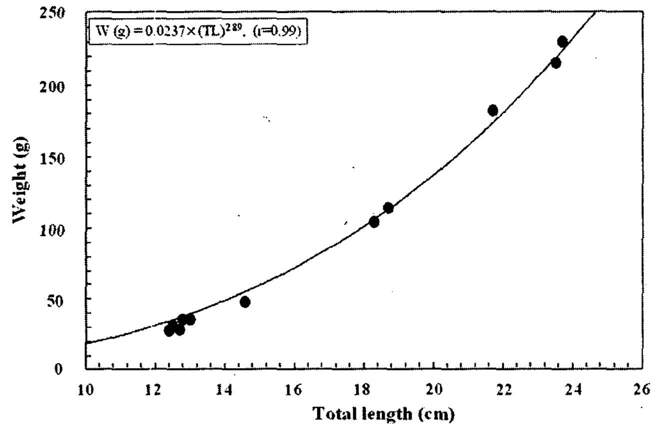


Fig. 1. The relationships between total length (TL, cm) and wet weight (W, g) of the sampled fish, black sea bream (*Acanthopagrus schlegeli*).

Table 1. Fish length and wet weight of black sea bream used in *ex situ* experiment.

| Fish number | Total length (cm) | Fork length (cm) | Wet weight (g) |
|---|---|---|---|
| 1 | 23.5 | 22.4 | 215.1 |
| 2 | 23.7 | 22.3 | 229.8 |
| 3 | 21.7 | 20.6 | 181.5 |
| 4 | 18.7 | 17.3 | 114.1 |
| 5 | 18.3 | 17.2 | 104.1 |
| 6 | 12.8 | 11.9 | 35.1 |
| 7 | 14.6 | 13.5 | 48.0 |
| 8 | 12.5 | 11.7 | 31.6 |
| 9 | 12.7 | 11.6 | 28.1 |
| 10 | 12.4 | 11.4 | 27.5 |
| 11 | 13.0 | 12.1 | 35.2 |
| mean | 16.72 | 15.64 | 95.46 |

Live black sea breams were anesthetized by benzocaine solution in freshwater prior to TS measurement. Then they were tethered within experimental tank. After the *ex situ* experiment, the total length ($L$, m) and wet weight (g) of individual fish were measured and shock-frozen directly.

### 2.2. Acoustic system set-up

The side-TS experiment was conducted at 5 × 5 × 5 m$^3$ tank filled with fresh water (Fig. 2). Anesthetized individual fish was insonified by horizontally fixed transducers and 3.8 m apart from the transducer face. Very small hooks were attached to the mouth and tail of the fish, and the attached vertical lines to the each hook were connected to horizontal bar of a rotator (YAESU, G-1000 DXC). For measuring the side-aspect TS of the fish, side-aspect angle with 5° intervals was adjusted by a rotator,

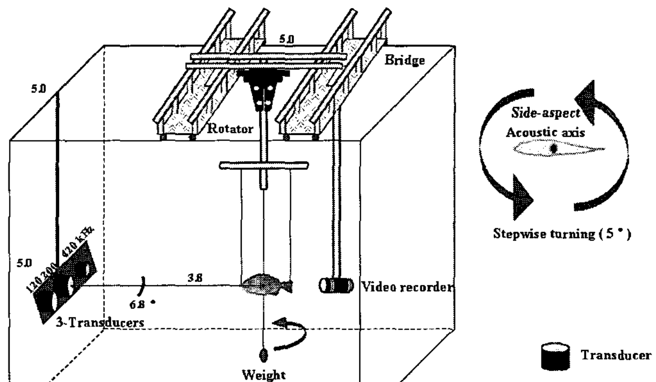


Fig. 2. Schematic of carousel structure used to rotate individual fish through 360° . All unit is meter.

Table 2. The settings of the echosounder for side-aspect TS measurements.

| Parameter | 120 kHz | 200 kHz | 420 kHz |
|---|---|---|---|
| Beam type | Split-Beam | Split-Beam | Split-Beam |
| Source level (dB) | 221.6 | 221.5 | 218.5 |
| Pulse length (ms) | 0.3 | 0.3 | 0.3 |
| Ping rate (pps) | 5 | 5 | 5 |
| Beam width (° ) | 7.5 | 6.6 | 6.8 |
| Absorption coeff. (dB/km) | 3.50 | 9.62 | 42.45 |
| TVG-function | 40logR | 40logR | 40logR |
| Sound speed (m/s) | 1472 | 1472 | 1472 |

which was programmed to be controlled automatically. Pulling or unfastening any vertical line adjusted horizontal state of the fish to the acoustic axis. The thin lines (0.2 mm diameter) used to tether the fish didn't affect TS measurement. In addition, an underwater video camera was installed to monitor the tilt and aspect angle of fish outside the area where acoustic beam did not affect fish echo.

For measuring the side-aspect TS, the transducers were driven by 120, 200, and 420 kHz [15], and every beam types of them were split-beam. The four transducers were mounted on a towing vehicle. Especially, 200 kHz transducer has integrated heading, pitch and roll sensor inside. From the sensors, stability of three transducers was finely controlled. The echosounder transducers were calibrated with calibration sphere before the experiment. The echosounder settings and specifications are illustrated in Table 2. It is known that black sea bream has a closed swimbladder [10]. Generally, results of TS experiments are often expressed in terms of the TS dependence on the fish length, $TS = 20\log L + b$, where $b$ is constants for a given species and called the mean standardized TS values. From the previously study the values of physoclistous (closed swimbladder) fish are ranged between -65 dB and -70 dB [1]. Therefore, minimum threshold level of the received signal for the TS measurement was set to -65 dB for each frequency.

## 2.3. Data analysis

Target strengths (TS) are measured for 30 – 60 s (150 pings) at each aspect angle with ping interval of 5°. The mean TS for a side aspect angle are calculated from the backscattering cross-section ($\sigma_{bs} = 10^{TS/10}$) of the fish prior to logarithmic transformation in the equation (1)

$$\bar{\sigma}_{bs} = \frac{1}{n}\sum_{i}^{n}\sigma_{bsn}$$

$$TS_{mean} = 10 \cdot \log_{10}(\bar{\sigma}_{bs}) \qquad (1)$$

The relationship between TS (dB) and side-aspect angle (Θ) were modeled (all-aspect model) using a function $\cos^3(2\Theta)$ [11]. The dependence of TS on fish length was also included in the model:

$$TS_{All-aspect} = A\log_{10}(L) + B\cos^3(2\theta) + C \qquad (2)$$

, where $L$ = fish length (cm), Θ = side-aspect angle (°) and $A$, $B$, and $C$ are the empirically determined constants which vary with fish species. For determining coefficients in the equation (2), the TS data obtained from all side-aspect angles of 11 specimens were used.

## 2.4. Acoustical scattering model of fish

For theoretical scattering model, Kirchhoff ray mode (KRM) model was used to predict the TS of the black sea bream. The KRM model represents the fish body as a set of fluid-filled cylinders surrounding the swimbladder modeled as a set of gas-filled cylinders [12, 13, and 14]. Fish morphological data such as external outlines of the fish body and the swimbladder are needed to calculate TS value.

After the experiment, the X-ray (SOFTEX M-1005, JIRA) image (Fig. 3) of the frozen fish was taken in the dorsal and lateral views to obtain morphological data for the KRM model. Then, we flexibly changed the exposure conditions of the X-ray machine such as voltage (18 - 35 kVp), milliampere (2 mA), and time (120 sec) for obtaining the more finely images of fish body and swimbladder.

Among the X-ray images of all fish, the largest (TL: 23.7 cm, Fish # 02) and smallest (TL: 12.4 cm, Fish # 10) fish were digitized to make input parameters of acoustic scattering model, based on the 3-dimensional coordination (XYZ-rectangular coordinate). In the coordinate, X, Y, and Z mean fish axis, fish width, and fish height, respectively. The number of segments for the fish body ($N_b$) and swimbladder ($N_s$) to be used in the model

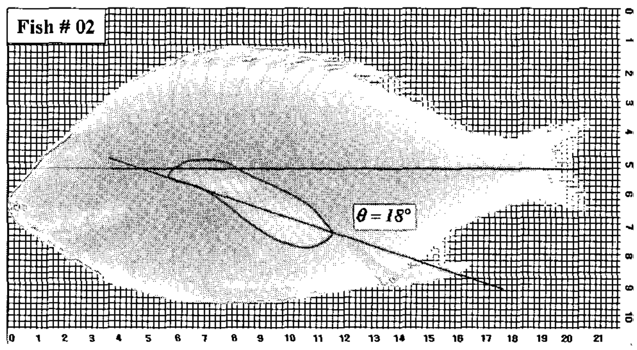


Fig. 3. Lateral X-ray image of black sea bream (body length =19.7 cm, swimbladder tilt angle = 18° ). This image is scaled by one-to-one correspondence with real fish size.

Table 3. The number of segments for fish body ($N_b$) and swimbladder ($N_s$) of black sea bream (*Acanthopagrus schlegeli*).

| Fish sample # | TL (cm) | Weight (g) | $N_s$ | $N_b$ |
|---|---|---|---|---|
| Fish # 2 | 23.7 | 229.8 | 28 | 101 |
| Fish # 10 | 12.4 | 27.5 | 15 | 49 |

computation were accurately picked at 2 mm intervals along the axis of the fish (Table 3).

In the previous study on the theoretical TS prediction, many authors have been used 3-dimensional coordinates in the dorsal aspect [6, 10, 12, and 13]. However, the TS measurement in the study was focused on the side-aspect TS. Therefore 3-dimensional coordinates to be used in the previous study must be needed some modification. Details of how 3-dimensional coordinates were modified are given in Fig. 4. As the incident wave in this experiment propagates along the Y-axis, Y-axis and Z-axis must be conversely changed. This means that XYZ coordinates is changed to the XZY coordinates. Therefore, for the model computation, fish height of the dorsal-aspect changed into fish width of the side-aspect, and fish width of the dorsal-aspect changed into fish width of the side-aspect, and width of the dorsal-aspect changed intp fish height of the side-aspect (Fig. 4).

The outlines of the fish body and swimbladder are digitized as sets of $x(j)$ along the X-axis. When the incident wave arrived at side-aspect of the fish, contact surface between propagated wave and fish body (or swimbladder) are separated front and rear side. Then, the front and rear coordinates for fish body are $w_{BF}(j)$ and $w_{BR}(j)$, where w represents fish width and subscript BF and BR indicate the front and rear coordinate. In the mean time, $w_{SF}(j)$ and $w_{SR}(j)$ are input coordinates for swimbladder, where subscript SF and SR indicate the front and rear coordinate. The scattering lengths of fish body ($L_{body}$) and swimbladder ($L_{blad}$) with each side-aspect angle ($\theta$) are calculated by rotating the fish coordinate system:

$$W(i) = x(i)\cos\theta + w(i)\sin\theta$$

$$\Delta U_i = [x(i+1) - x(i)]\sin\theta$$

$$a_i = \frac{[z(i) + z(i+1)]}{4} \quad (3)$$

The scattering length of fish body ($L_{body}$) and swimbladder ($L_{blad}$) are as follows:

$$L_{blad} \approx -i\frac{R_{bc}(1-R^2{}_{wb})}{2\sqrt{\pi}}\sum_{0}^{N_s-1} A_{sb}[(k_b a_j + 1)\sin\theta]^{1/2} e^{-i(2k_b W_j + \Psi_{sb})}\Delta u_j \quad (4)$$

where

$N_s$: number of segmented bladder cylinder

$a_j$: radius of *j-th* segmented bladder cylinder

$k_b$: wave number in the fish body ($=2\pi f/c_b$)

$A_{sb} \approx \frac{ka_j}{ka_j + 0.08}$: empirical amplitude for small *ka*

$\Psi_{sb} \approx \frac{ka_j}{40+ka_j} - 1.05$: phase adjustment for small *ka*

$R_{bc} = \frac{gh-1}{gh+1}$: reflection coefficient at the body-bladder interface

$R_{wb} = \frac{\sigma_b c_b - \sigma_w c_w}{\sigma_b c_b + \sigma_w c_w}$: reflection coefficient at the water-body interface

$g = \frac{\rho_c}{\rho_b}$, $h = \frac{c_c}{c_b}$ : density ratio and sound speed ratio at bladder cylinder-body

$$W_j = \frac{[w_{B_j} + w_{B_{j+1}}]}{2}$$

$$L_{body} \approx -i\frac{R_{wb}}{2\sqrt{\pi}}\sum_{0}^{N_b-1}(ka_j)^{1/2}\Delta u_j[e^{-i2kW_{Fj}} - (1-R^2{}_{wb})e^{\{-i2kW_{Fj} + i2k_b(W_{Fj} - W_{Rj}) + i\Psi_b\}}] \quad (5)$$

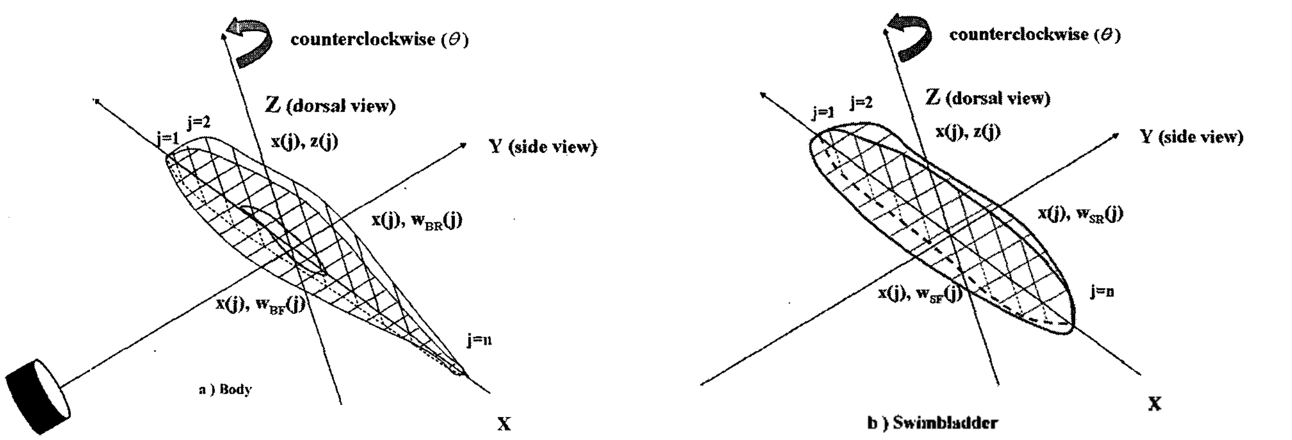


Fig. 4. 3-dimensional rectangular coordinate XYZ of fish body (a) and swimbladder (b). Coordinate Z is parallel to the incident wavefront, and Y is parallel to the incident ray. Based on Z coordinate, fish is turned by the counterclockwise. If the acoustic beam axis lies at right angles to the direction of the fish tail, Side-aspect angle ($\theta$) starts from 0° to 360° in the counterclockwise direction.

where

$N_b$: number of segmented body cylinder

$\Psi_b \approx \frac{\pi k_b w_{b_w}}{2(k_b w_{b_w} + 0.4)}$: empirical phase correction

To calculate theoretical TS, the KRM model was applied to calculate the scattering length of the whole fish ($L_{wf}$). Particularly, coherent backscattering was assumed and the scattering lengths as a result of the swimbladder ($L_{blad}$) and fish body ($L_{body}$) were added as complex functions.

$$L_{wf} = L_{blad} + L_{body} \qquad (6)$$

The backscattering cross-section ($\sigma_{bs}$) can be computed from the complex $L_{wf}$ using $\sigma_{bs} = |L_{wf}|^2$ and TS=20log$|L_{wf}|$.

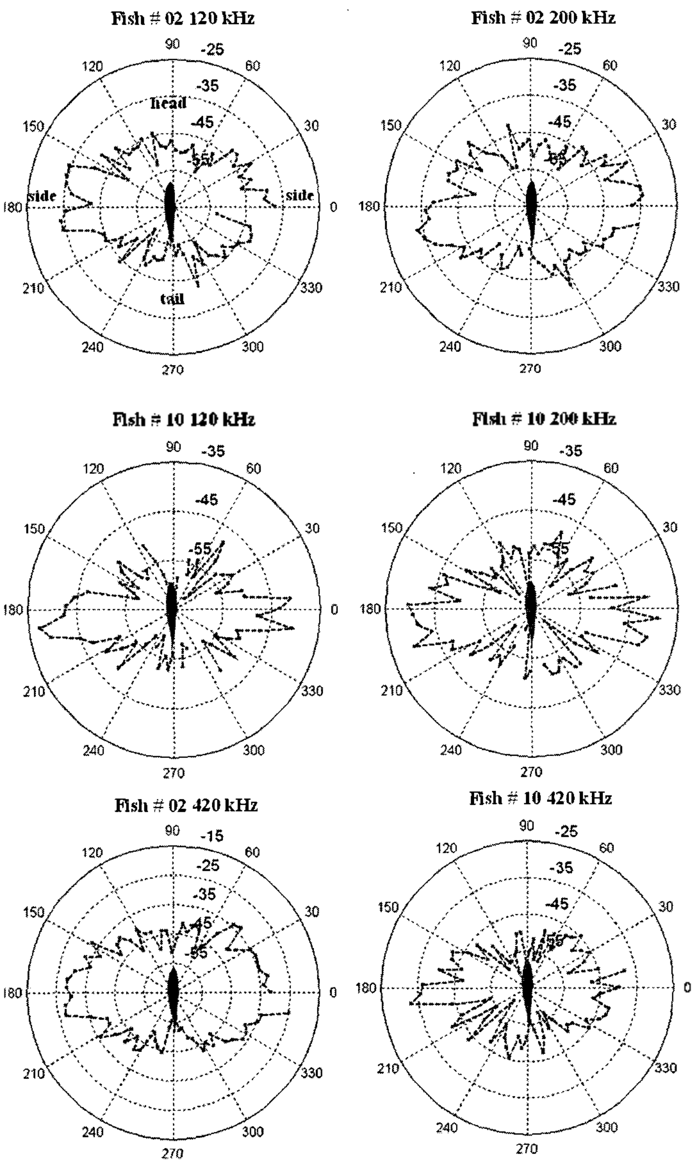


Fig. 5. The examples of side-aspect TS of the fish with different length.

Table 4. The overall side-aspect TS range estimated from *ex situ* experiments.

| Fish | 120 kHz (dB) | 200 kHz (dB) | 420 kHz (dB) | dB difference (max TS200-120) | dB difference (max TS420-120) |
|---|---|---|---|---|---|
| 1 | -62.54~-33.48 | -56.29~-31.14 | -58.89~-26.90 | 2.34 | 6.58 |
| 2 | -58.17~-34.00 | -53.83~-33.41 | -56.33~-27.52 | 0.59 | 6.48 |
| 3 | -60.54~-33.75 | -56.44~-29.30 | -56.50~-25.50 | 4.45 | 8.25 |
| 4 | -59.48~-35.18 | -62.69~-35.41 | -57.87~-32.20 | -0.23 | 2.98 |
| 5 | -60.55~-37.52 | -64.70~-34.11 | -58.73~-28.50 | 3.41 | 9.02 |
| 6 | -60.48~-38.85 | -64.59~-39.86 | -61.14~-38.46 | -1.01 | 0.39 |
| 7 | -63.02~-35.64 | -63.72~-38.61 | -56.89~-35.23 | -2.97 | 0.41 |
| 8 | -64.70~-39.27 | -63.73~-37.63 | -63.59~-32.25 | 1.64 | 7.02 |
| 9 | -63.67~-38.52 | -64.23~-41.31 | -61.19~-32.17 | -2.79 | 6.35 |
| 10 | -63.84~-37.23 | -63.67~-39.72 | -60.40~-32.92 | -2.49 | 4.31 |
| 11 | -62.68~-40.28 | -64.26~-36.18 | -62.40~-38.64 | 4.10 | 1.64 |

## III. Results

Eleven black sea breams (*Acanthopagurus schlegeli*) with various lengths ranging from 12.4 to 23.7 cm were insonified using the three split-beam echosounders. As a result from the *ex situ* experiment, the maximum and minimum TS for the fish on side-aspect angle are shown in Table 4.

Almost TS data has a tendency to increase for both fish length and frequency, although a bias in the data could exist. Frequency and fish length dependency at the TS data was apparent. The maximum TS are -33.48, -29.3, and -25.5 dB at 120, 200, and 420 kHz, respectively. Overall, the maximum TS of 420 kHz were higher than those of 120 kHz, and the differences ranged between 0.39 and 9.02 dB. On the other hand, TS differences between 200 and 120 kHz didn't show consistent pattern.

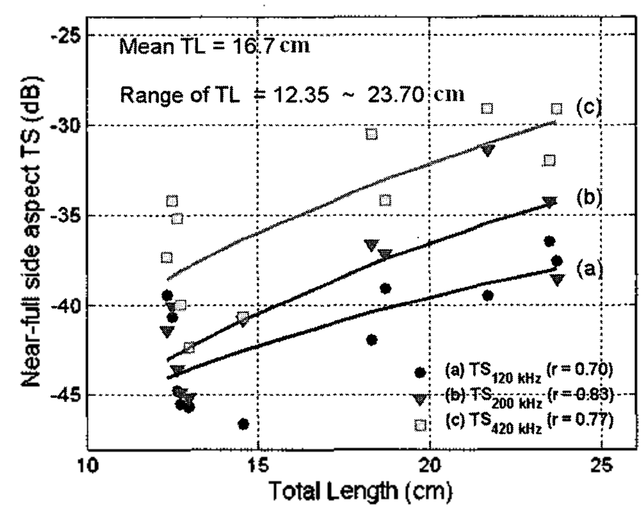


Fig. 6. Regression curve between near-full side-aspect TS and total length. The filled square (a), filled triangle (b), and filled circle (c) indicate $TS_{120kHz}$, $TS_{200kHz}$, and $TS_{420kHz}$, respectively.

In this study, incident angle was defined that full side aspect was 0° and 180°, the other side, head and tail side aspect was 90° and 270°, respectively. Overall, the TS of the side-aspect are much larger than those of head and tail (Fig. 5). Especially, when the incidence angle is over ±15°, the TS has a tendency to rapidly decrease with incidence angle. Comparing the TS variations with a different fish length class (fish #02, 23.5 cm; fish #10, 12.4 cm), the TS fluctuations with aspect angle of the small fish were more complex than those of the large fish.

In the TS data obtained from all aspect angle, the TS values with incidence angle within ±5° were expressed to near full side-aspect TS. Then, mean TS of individual fish within the near full side-aspect angle was calculated from the equation (1), and were fitted a linear function with fish lengths to be used in fisheries acoustics (Fig. 6).

$$TS_{120\ \mathrm{kHz}} = 21.46 \log (TL) - 67.50 \ (r = 0.70)$$
$$TS_{200\ \mathrm{kHz}} = 31.03 \log (TL) - 76.95 \ (r = 0.83) \qquad (7)$$
$$TS_{420\ \mathrm{kHz}} = 30.79 \log (TL) - 72.16 \ (r = 0.77)$$

, where $r$ is correlation coefficient.

As this study focused on the TS and side-aspect angle of the black sea bream, we empirically fitted the best regression

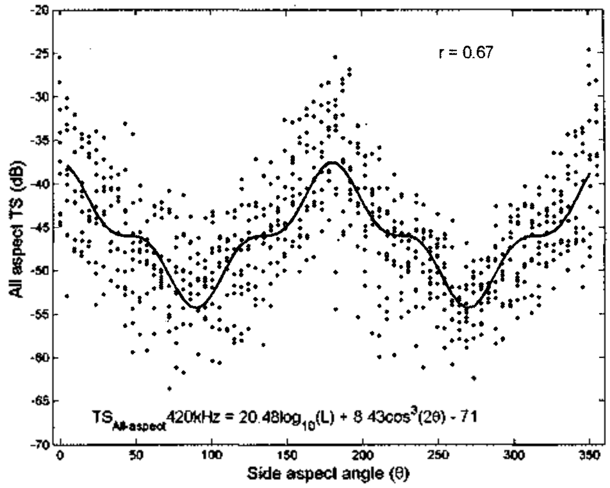


Fig. 7. All - aspect model between TS (dB) and side-aspect angle ($\theta$) using a function $\cos^3(2\theta)$. The fitted line is best regression curve, assuming fish length and frequency were 16.7 cm and 420 kHz, respectively.

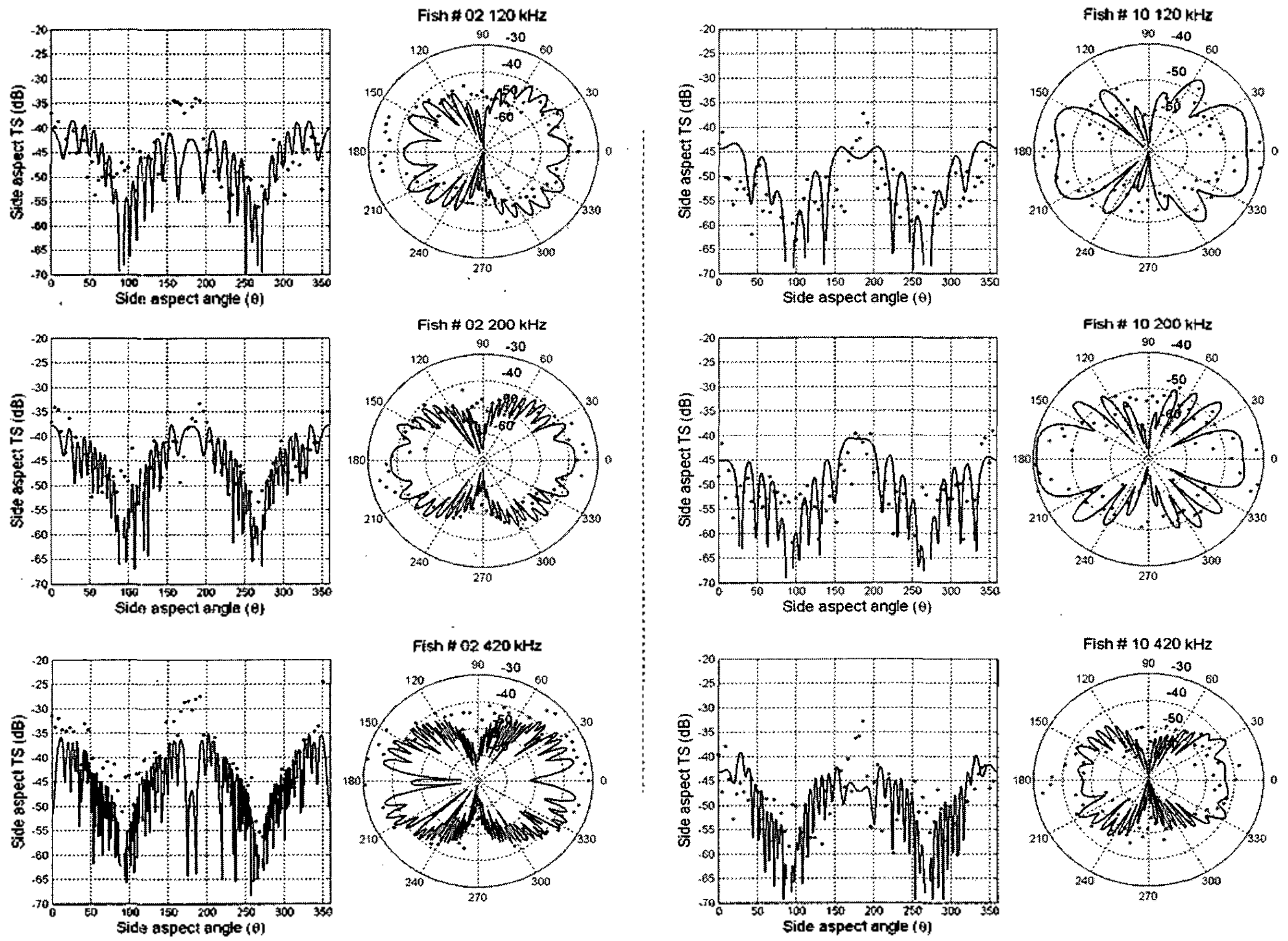


Fig. 8. Comparison the measurement TS data and theoretical TS data at side-aspect angle. The filled circle and solid line represent measurement data and theoretical data, respectively.

(equation 2) to determine the influence of side-aspect angle with fish length. For determining coefficients in the equation (2), the TS data from all side-aspect angles of 11 specimens were pooled. Then, the coefficient $C$ was conveniently fixed as a constant, -71 dB, because coefficient $A$ must be positive value. Because all side TS data were pooled, mean fish length (16.7 cm) for 11 specimens was used for calculating coefficient $A$ and $B$. The resultant fitted equation at three frequencies as follows:

$$TS_{\text{All-aspect, 120 kHz}} = 17.61 \log (TL) + 5.96 \cos^3(2\Theta)\ 71 \quad (r = 0.56)$$
$$TS_{\text{All-aspect, 120 kHz}} = 17.76 \log (TL) + 7.18 \cos^3(2\Theta)\ 71 \quad (r = 0.61) \qquad (8)$$
$$TS_{\text{All-aspect, 120 kHz}} = 20.48 \log (TL) + 8.43 \cos^3(2\Theta)\ 71 \quad (r = 0.67)$$

, where r is correlation coefficient.

Fig. 7 shows that the relation between TS (dB) and all side-aspect angle (Θ) for 420 kHz. Considering mean fish length, the differences between full side-aspect and head/tail aspect TS are 11.9, 14.3 and 16.8 dB at 120, 200 and 420 kHz, respectively.

Generally, the KRM model is representative scattering model that computes the changes in TS with tilt angle more accurately at high frequency ($ka > 1$, where $k$ is wave number, and $a$ is equivalent radius). The variations on the TS with side-aspect angle, calculated from the measurement and the theoretical model (120, 200, 420 kHz), are shown in Fig. 8. The measurement data (filled circle) for the overall side-aspect angle were compared with estimating data from the theoretical model. The side-aspect TS varied from -70 to -35 dB for all aspect angles. From the two data, there is reasonable agreement on the totally trend of the TS value with aspect angle, even though partly method must be modified.

## IV. Discussion

Actually, it is very difficult to measure the side-aspect or dorsal-aspect TS for all fish length classes. As an alternative method, established acoustic scattering models are preferred. From the model, theoretical prediction for fish length not to be conducted TS measurement are inversely calculated from its fractions of the acoustical parameters (equivalent radius of the fish body and swimbladder) of the measured fish. Generally, the relationship between swimbladder lengths (*SBL*, cm) and fish length are known to be the $SBL=0.3L$ [14]. For 11 black sea breams to be used in this study, the relationship of the two parameters was given by $SBL=0.31L$ (Fig. 9). The relationship can be used to the TS estimation of the black sea bream with various lengths from the acoustic scattering model.

Although black sea bream is one of the marine fish species, the TS measurements were carried out under the anesthetized condition in a tank filled with fresh water. Thus, there is possible to have some argument on the physical parameter's variability ($g$ and $h$) under the circumstance of the freshwater, especially fish body. The argument is caused by rigor mortis of the measured fish's body. Unlike almost marine fish, black sea bream have a physiological ability to survive in the fresh water through some adaptation term. Although the anesthetized condition, some black sea bream revived and actively moved during side TS measurement. The survival characteristics of the fish suggest that possibility to be changed the physical parameter in the fresh water is relatively little than that of marine fish. Therefore, we can guess that the side TS data for the reason may change within narrowly fluctuations in the experimental condition.

In the measurement, a rotator was automatically controlled with 5° intervals using programmed rotating device, and TS data were saved during 30 – 60 s (150 pings) at each aspect angle. Because we used automatically control system to change side-aspect angle, acoustic data were continuously saved. In the saved TS data, TS level of the some data has a relatively high variation around the early period during measuring time. As a result of TS data analysis, it takes some time to stabilize rotated fish at each angle, at least 18-20 s.

Almost target strengths for marine fish are focused on the dorsal aspect measurement. The main reason is that fisheries acoustic surveys are conducted to estimate density and to know distribution pattern of the marine organisms by scientific echo sounder with downward looking system. Because the systems

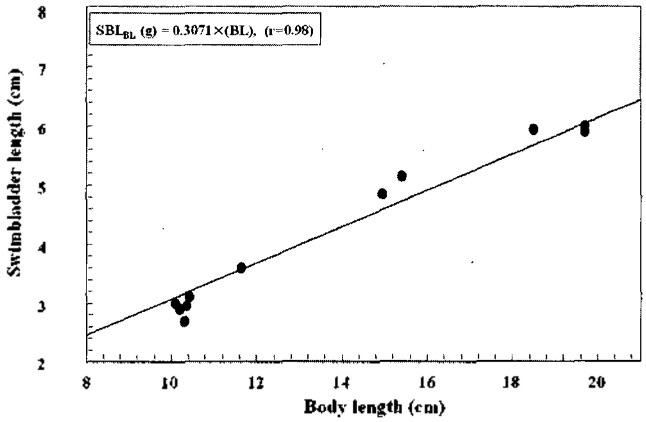

Fig. 9. The relationship between swimbladder length (SBL) and body length (BL).

have a narrow beam angle, there is growing recognition that the systems are not sufficient to cover large area in the actual condition. As an alternative method, various sonar systems that have a strong advantage in the detected volume are preferred. Unfortunately, the sonar systems have been provided not biomass data but spatial distributed data of the marine fish, because 3-dimensional TS measurement data are not sufficient to calculate fish biomass from acoustic volume scattering data, obtained from side looking sonar system. As the side-aspect TS data in the study are one of the 3-dimensional TS data, the data can be directly applied to convert acoustic data into the fish biomass.

In the military acoustics, the volume scattering strength from the swimbladdered fish is one of the essential parameters to detect underwater target in the process of sonar or torpedo system. The maximum side-aspect TS of individual black sea bream ranged from -38 to -28 dB at 120 kHz. The side TS values are very similar to maximum dorsal aspect TS of the same species [10] (Fig. 10). The relationships between maximum side/dorsal aspect TS and fork length were as follows, respectively: for side-aspect, $TS_{max120\ kHz} = 21.23 \log (FL)-59.84$; and for dorsal aspect, $TS_{max120\ kHz} = 21.31 \log (FL)-59.83$. Assuming 15 cm fish length, the side/dorsal aspect TS at 120 kHz is high, approximately -32.2 dB. Considering the higher TS value, if large fish school presents at same depth as that of traveling path of propagated signal, the fish school might be acted on obstacle of the acoustic wave or false target. Then, as acoustic wave bundles arrive at the fish school with various incidence angles, individual or volumetric TS information due to the swimbladdered fish is indispensable to the military acoustics. At this *ex situ* experiment, the side-aspect TS of individual fish

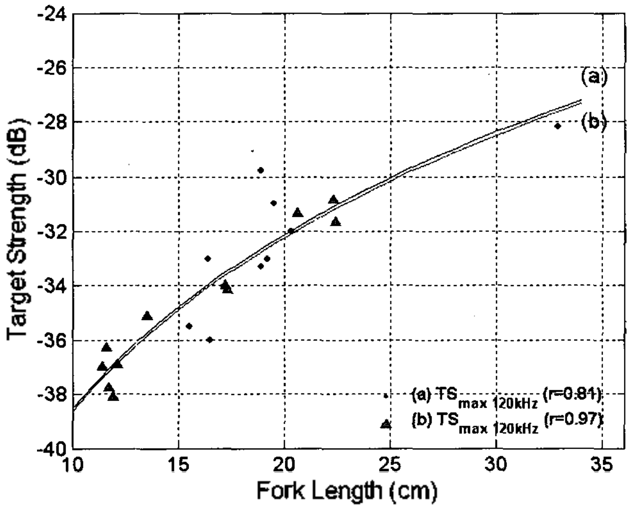

Fig. 10. The relationships between maximum dorsal (a) and side (b) aspect TS and fork length.

were measured. In the future study, the TS or volume scattering strength measurement of the volumetric fishes must be accompanied to apply fisheries or military acoustics.

These results can be used to understand the influence of side-aspect angle on TS of black sea bream (*Acanthopagurus schlegeli*) and thus improve the accuracy of biomass estimates from side-aspect volume scattering strength data that were obtained from various fisheries sonar systems.

## Acknowledgment


This study was supported by Ministry of Maritime Affair and Fisheries of Korea through the Jeonnam Archpelago Marine Ranching Program in Korea.


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## [Profile]

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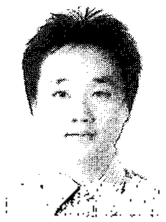

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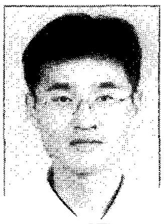

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The Journal of the Acoustical Society of Korea, Vol. 23, No. 4, 2004.

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