博　士（水産科学）　ムハマド　クルニア

学 位 論 文 題 名

Study on the Three-dimensional Target Strength of Fish for Horizontal Sonar

（水平ソナーのための魚の三次元ターゲットストレングスに関する研究）

学位論文内容の要旨

Background

The target strength (TS) of fish is a significant factor in fisheries acoustic, especially when converting acoustic backscattering strength to fish abundance. However, TS of fish is highly variable and it may change due to changes in fish morphological and physiological factors, including body length, tilt angle, and swimbladder morphology.

As for horizontal sonar applications, horizontally-oriented techniques have the advantages of large sampling volume and has a methodology that incorporates the three-dimensional target strength (3DTS) which can improve the precision of TS, including TS of fish can vary with its pitch, yaw and roll angle. Since the acoustic beam can insonify fish from many directions, it is essential to determine the TS as average of 3DTS of the fish.

This study measured the 3DTS of fish in tank experiment. Then, the data were compared with theoretical value using a prolate-spheroid model. Furthermore, characteristics of the averaged 3DTS which is an important factor for estimating the abundance of fish schools using horizontal sonar were measured and compared to theoretically estimated TS values.

Methods

Experiments were conducted in a 3 m in depth and 4 m in diameter freshwater tank. TS data were collected with a echosounder system connected to a 50 kHz transducer. A transducer was mounted on the edge of the rotating arm and suspended at mid-water depth in the tank facing horizontally toward the fish.

Prior to the measurements, the echosounder system was calibrated using a tungsten carbide sphere of 38.1 mm diameter.

The fish used was a defrosted horse mackerel, *Trachurus japonicus* and Japanese mackerel, *Scomber japonicas.* Before the experiment, a soft X-ray imaging system (PRO-TEST100) was used to obtain morphological data of the fish including its internal organs. Outlines of the lateral and dorsal shape of the swimbladder and the body were digitized using the image processing software Didger (Golden software).

The fish was carefully suspended using a pair of nylon monofilament lines of 0.205 mm diameter with two small hooks. The hooks were attached to the head and the caudal part on the dorsal side of fish to change the pitch angle. The fish was lowered to the center of the tank at a depth of 190 cm and positioned 160 cm from the transducer.

The procedure for measuring the 3DTS was as follows. At first, keeping the pitch angle of the fish at 0°, the transducer was slowly rotated in the horizontal plane around the fish from 0° to 360° centered to the lateral aspect of the fish. The echo amplitude from the fish was measured at one degree intervals. Next, the pitch angle of the fish was increased to 10° and the transducer was rotated horizontally in the same way described above. This procedure was repeated at 10° pitch angle intervals between 0° and 90° in horizontal plane from 0° to 360°.

The orientation of the fish was kept stable. The pitch angle of the fish was determined by reading an inclination angle of the hanger that suspended the fish.

Results and Discussions

The results of the experiments were graphically presented. It shows that the reflectivity of several targets can widely vary. Polar diagrams are plotted for illustrating directivity pattern in the orientation and showing fine detail of the variation of the TS. The TS of fish is larger in broadside aspect than in the head and tail aspect.

The largest TS were found when a fish was orientated perpendicular to the transducer (yaw angle 0° and 180°). However, when a fish was aligned in the yaw angle of 90° and 270°, the TS was low and small variation. This is reasonable because this direction is the side aspect for all the pitch angles. Lastly the TS function at pitch angle of 90° showed an Omni-directional pattern with the maximum TS. This shows that the TS pattern of fish depends highly on the orientation of the fish and consistently identified as a major influence on fish TS with respect to the acoustic transducer.

As mentioned the former studies, the sound energy (about 90%) is scattered by the swimbladder of fish (Foote, 1980b). The amplitude of a returned echo from fish is largely dependent on the presence of a swimbladder. Therefore, TS values are higher when the swimbladder is present. The differences of the shapes, sizes, and angle of the swimbladder among different fish significantly affect on the variability of fish TS. Further, these differences will affect the variability of TS as well as on the fish orientation.

The maximum and averaged TS values are plotted on the relationships between the body lengths and pitch angle of fish. The target strength data of the scatter diagram are regressed linearly on the fish body length and assumed linear relationships between maximum or averaged TS and logarithm of fish body length.

The results show that the effects on the TS distribution of variations in body length of fish are increase in body length results in a slight upward shift in TS. Good relations between fish body length and maximum and average TS were obtained at the pitch angle of 0°, 30°, and 60°. Physically, increasing fish body length, so that a increase in target strength should be expected. The variations of TS of smaller fish are smaller compared to the larger samples.

As for the evaluation of characteristic 3DTS using PSM model, the theoretical TS functions were estimated by changing the pitch angle of fish from 0° to 90°. The maximum TS were found at a horizontal incident angle of 0°, and the TS decreased slightly with an increase of the horizontal incident angles. Meanwhile, at a pitch angle of 90°, the TS were the same at all horizontal incident angles for both of the theoretical and measured values. Because these angles correspond to the roll patterns of the fish.

For the comparison between the theoretical and measured TS functions of fish, the result shows that the theoretical estimation and the measurements of fish were not in close agreement. The averaged TS in measurement were 3 to 5 dB lower than the theoretical estimated. Plausible reasons of the discrepancies are the influence of biological change of the swimbladder fish on the TS. The swimbladder might have changed in shape and size. If the swimbladder is deflated to half its volume, the TS of fish could decrease more than 3 dB.

Generally, at pitch angles $<60°$, the horizontally averaged TS of fish gradually increased with an increase of the pitch angle, while at pitch angles $>60°$, the horizontally averaged TS rapidly increased with an increase of pitch angle of the fish. Effects of pitch angle change at small pitch angles on the horizontally averaged TS were insignificant, and errors were 1 dB at pitch angles of 0° to 55° in measurement value and 0° to 30° in theoretical values. This result means that the error due to the change of horizontally averaged TS caused by the change of pitch angle of fish in small pitch angles was insignificant in estimating fish abundance using horizontal sonar.

However, in the measurement of TS of physical model of prolate-spheroid, the comparison between measurement and theory were in close agreement. The differences were small, only 0.03 to 1.3 dB. It means that the affect of near-field effect was not found as described in the measurement of target strength of fish. Nevertheless, these results will be strengthen the previous reason that the biological change of the fish affect the variation of target strength of fish

学位論文審査の要旨

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（水平ソナーのための魚の三次元ターゲットストレングスに関する研究）

水平ソナーは音響ビームを水平方向に走査することにより，表層魚群を広範囲に探知できる利点があり，まき網漁業などに効果的に使用されている。しかしながら，下向き音響ビームを用いた魚群探知機が魚の背方向の音響後方散乱を利用するのに対し，水平ソナーは魚の水平方向の音響後方散乱を利用するため，音響ビームの魚への入射角によって，音響後方散乱強度が大きく変化する。したがって，水平ソナーを用いて，表層魚群を探索したり，資源量を推定するための大きな誤差要因となってくる。そこで，本研究では魚への全ての入射角におけるターゲットストレングスを測定し，その指向特性や体長依存性を検討し，魚群の水平探知に必要な魚の３次元ターゲットストレングスの一般的特性を明らかにしたものである。本研究において以下の知見を得た。

1．回転アームの先端に取り付けたトランスデューサの水平面での回転と，中心においた魚の垂直面での傾斜角の変化を組み合わせたTS測定システムを製作し，アジ，サバ，および回転楕円体模型の３次元ターゲットストレングスを測定した。
2．アジとサバの３次元TSの指向性は魚のYaw角とPitch角の変化で大きく変動したが，Roll角の変化に対しては安定していた。また，魚の３次元TSは背，腹，および側面などのブロードサイドアスペクトで最大を示し，頭部，尾部などのエンドオンアスペクトで最小を示した。
3．魚の浮袋に模したスタイロフォーム製の回転楕円体模型を用いて，３次元TSを測定したところ，

魚の３次元 TS と同様な指向特性が得られた。また，回転楕円体音響散乱理論モデルを用いた計算結果とよく一致した。このことから有鰾魚の３次元 TS の特性は浮袋の音響特性に支配されていることが分かった。

4．水平ソナーを用いた資源調査では魚を水平方向から見た平均ターゲットストレングスが重要になる。魚の３次元 TS を水平入射角で平均した水平方向平均 TS は魚のピッチ角の増加にともなって大きくなり，ピッチ角が０度のとき水平方向 TS は最小を示し，ピッチ角が＋－90 度のとき最大となり，その差は 5.8dB（測定値）および 8.4dB（理論値）だった。しかしながらピッチ角が小さいとき，平均 TS の変化は小さく，ピッチ角が 55 度以下ではその増加は１ｄB 以下であった。

これらのことから，水平ソナーを用いて表層魚群を効率よく探知するためには，魚が音源に対し，直角に定位しており，かつ，魚のピッチ角が大きく傾斜していることが有利であることが明らかとなった。

これらの成果は特に浅海域において水平ソナーを用いた漁業や資源調査の効率化や精度の向上に重要な知見を与えるものである。よって審査員一同は申請者が博士（水産科学）の学位を授与される資格のあるものと判定した。