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# Combined Use of Quantitative Echo-Sounder with Scanning Sonar to Visualize Semi-Quantitative Three-Dimensional Image of Fish Schools

Akira Hamano*1 and Takeshi Nakamura*1

An acoustic survey involving the concurrent use of a quantitative echo-sounder and a sector-scanning sonar was conducted in December, 2000, off the Japan sea coast of Yamaguchi Prefecture. To visualize the semi-quantitative image of fish schools, the density information, including its variation, was extracted in range bins from the echogram of the quantitative echo-sounder. A sonar image of the school cross-section perpendicular to the transect was used to construct the three dimensional image of fish schools. The sonar images sampled at 12 sec intervals were digitized and stored in the computer memory as volume information with the x- and y-axes in the athwart and alongship directions, respectively. The z-axis represents depth. The volume of the fish schools is calculated by multiplying the number of voxcels by their size in the x-, y- and z-direction. The standing stock of schools was then semi-quantitatively estimated by multiplying the density of the schools by their volume.

The present report describes an acoustic survey method to better assess school shape and offers a method to use the shape information for improved stock estimation. The necessity of geometric approach is pointed out to provide a correction for the location and extent of the non-scanned area in the surveyed water mass.

## 1 Introduction

The invention of the echo-sounder made it possible to detect the presence of fish through deep layers of water. Some trials were made to assess the standing stock before the time varied gain (TVG) correction was introduced. However only with the invention of the scientific echo-sounder, an accurate gain correction could be done, which made it possible to provide quick and accurate stock assessments. [1-3]

The scientific echo-sounder collects information in the two dimensions, *i.e.*, along the sailing course and in the vertical direction. However, little information is collected athwartship direction, *i.e.*, perpendicular to the transect direction or the sailing course. How to collect information in this direction is an urgent problem that needs to be addressed. A sector-scanning sonar was used for this purpose. For our purposes the density information from the sonar is not accurate enough, however, successive sonar tomographs can be use to obtain the extent of schools in three dimensions and thus provide an improvement in biomass estimate through improving the volume estimate. As computer imaging techniques and technology have evolved dramatically, it now is possible to obtain three-dimensional visualization of schools from scanning sonar data with relative ease. [4]

This paper reports an example of the standing stock estimation of fish schools off the Japan sea coast of Yamaguchi Prefecture by combining density information from a quantitative echo-sounder with the geometrical information of school shape from a sector-scanning sonar.

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＊1 Department of Fishery Science and Technology, National Fisheries University （濱野　明・中村武史：水産大学校海洋生産管理学科）

# 2 Materials and Methods

## 2.1 Acoustic survey

The echo data for the present study, were collected in December, 2000, in the Japan Sea off Nago, Yamaguchi Prefecture. The survey was conducted from the research vessel *Kuroshio*(119 tons) while travelling at 1.5 to 3.5 knots. East-west transects of 1 nautical mile were settled at 0.1 nautical mile intervals. A quantitative echo-sounder with 50 kHz quasi-ideal beam transducer (Furuno FQ-70), and a sector-scanning sonar operating at 162 kHz (Furuno CH-34) were used. The sampling geometry is shown in Fig. 2. Note that the sonar sampling volume will have a spiral-like shape as the ship moves forward and the sonar scans form side to side. The measurement parameters are listed in Table 1.

The echo envelope and other signals from the echo-sounder were recorded on a data recorder (Sony PC 208A). The sonar images were captured on videocassette through the video scan converter (Digital arts DSCO5d) and then transferred as images to a computer. Images were then converted to 640×480 pixels with 24-bit resolution using image processing software (COSMOS 32 Library Co., Ltd.).

The targets, that were responsible for the echo traces, were verified by jigging with handlines (or "sabiki" in Japanese). The total length *TL*, and body weight *BW* of these fish specimens were measured at a later time in the laboratory.

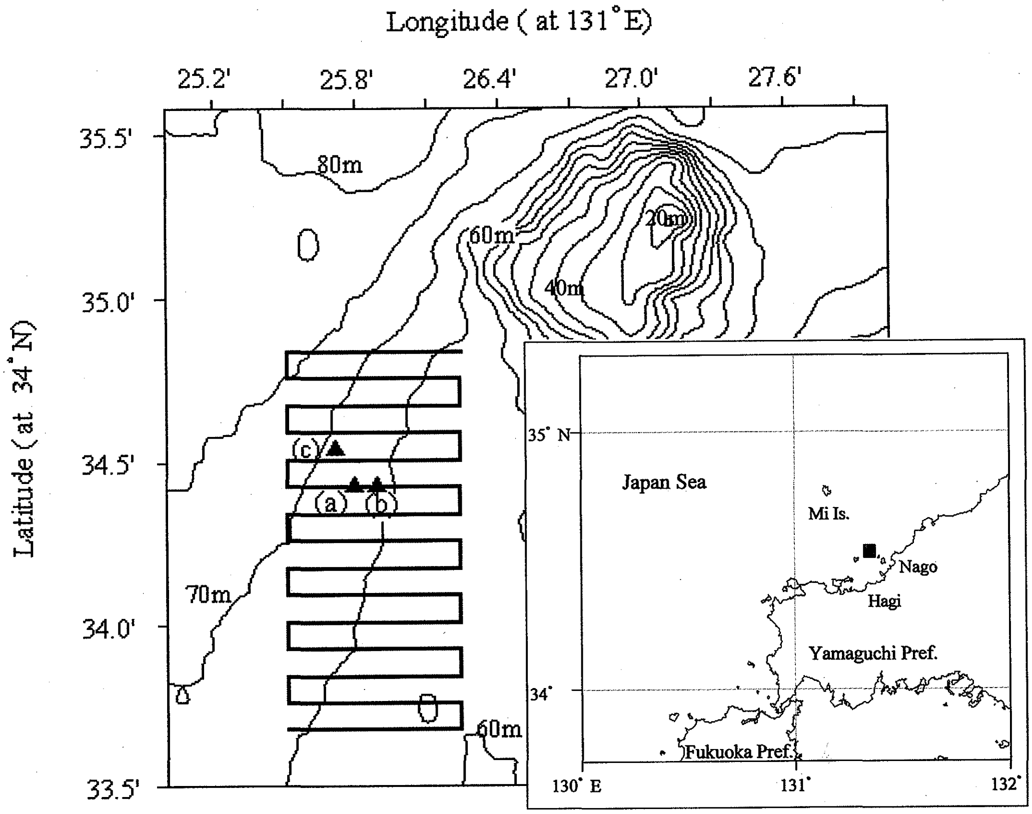


**Fig. 1.** Location of the survey area in the Japanese Sea and detailed location of acoustic transects with bathymetry and location (a), (b) and (c) for the detected schools.

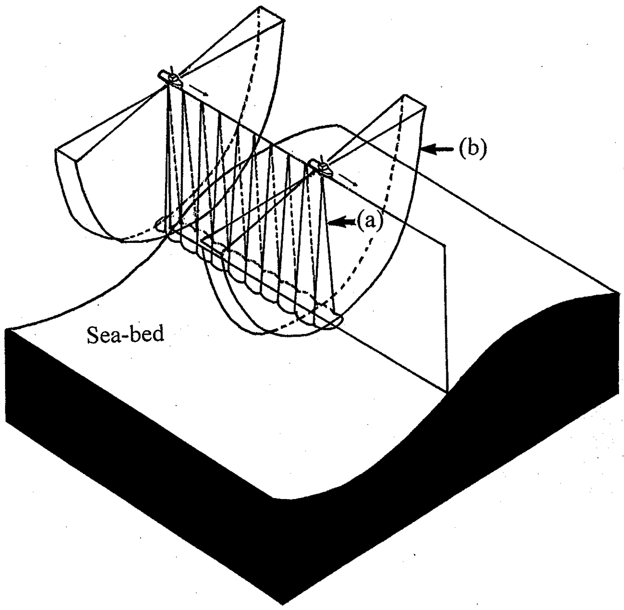


**Fig. 2.** Schematic representation of the volume insonified by the echo-sounder and sonar.
The figure is not to scale and does not show the cork screw like volume that is insonified by the sonar due the superposition of the consecutive sonar scans and the vessel motion.
Note : (a) echo-sounder beam
(b) scanning sonar beam

**Table 1.** Technical specifications of echo-sounder and sector-scanning sonar

| | Quantitative Echo-sounder | Sector-scanning sonar |
|---|---|---|
| Model Type | Furuno FQ-70 | Furuno CH-34 |
| Frequency (kHz) | 50 | 162 |
| Source level (dB) | 208.7 | 224 |
| Beam width (degree) | | |
| horizontal | — | 12 |
| vertical | — | 9 |
| alongship (=athwartship) | 12.2 | — |
| Pulse length (ms) | 0.6 | 0.33 |
| TVG (Time varied gain) | 20 log *R* | varied depending on gain control level |
| Absorption loss (dB/km ) | 13.7 | — |
| Ping rate (rate/s) | 1 | — |
| Time to complete a sonar scan(s) | — | 12 |

## 2.2 Processing of echo-sounder and sonar information

Figure 3 (a) and (b) show an echogram from the quantitative echo-sounder and a concurrent sonar image of the same school, respectively. The information was collected at the location marked (a) in Fig. 1.

The variation in fish density within a school echogram from the quantitative echo-sounder is shown in Fig. 4. A mean volume back-scattering strength,[5] SV(dB), was calculated for 1 m (depth) ×5 m (distance) cell. Sample data from the upper and lower school boundary are shown in insert (a) and (b). Echoes from schools were extracted by setting an appropriate SV threshold value that was based on the SV distributions shown in Fig. 4. School echoes were extracted by setting a threshold of −80 dB to remove back-

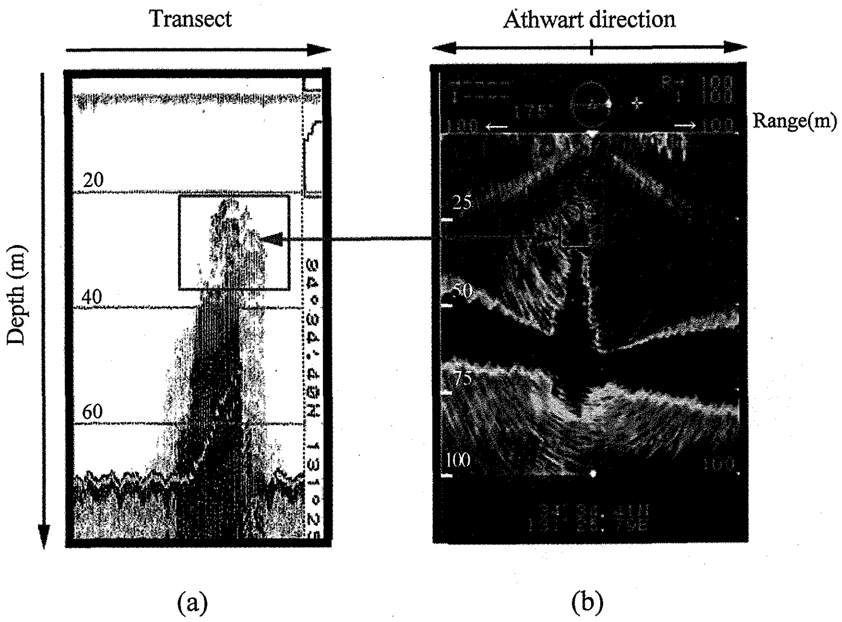


**Fig. 3.** Paper recorded echogram of quantitative echo-sounder (a) and an example of scanning sonar image on CRT display (b).

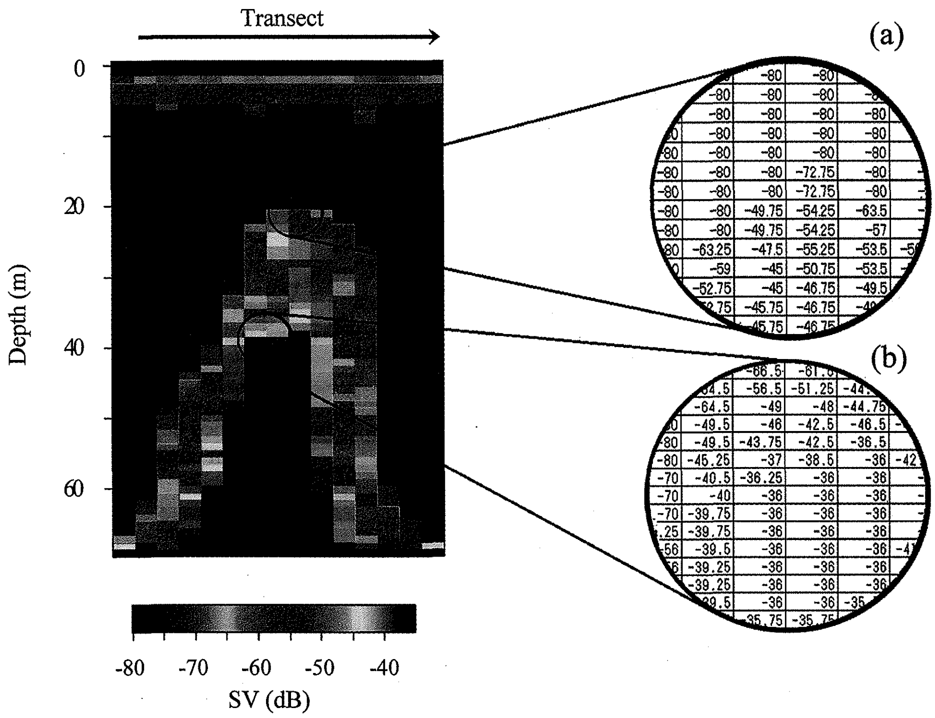


**Fig. 4.** Echogram like display of echo integration bins (left) and representative SV values (right) from (a) the school water and (b) the school bottom boundaries.

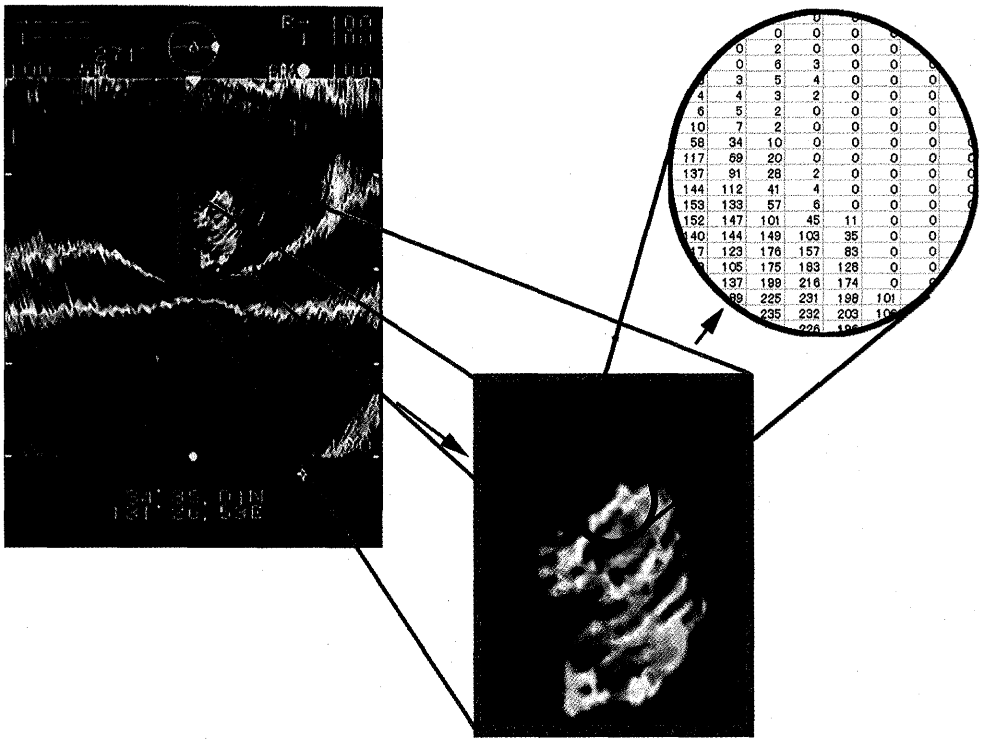

**Fig. 5.** Example of digitized sonar and sample pixel values from the school water boundary.

ground noise. A bottom tracking level of −40 dB was chosen to remove the echoes from the sea-bed and artificial reefs.

Next, the across transect extend of the fish distribution was estimated from the sonar images. Although the sonar images were colored according to echo-strength, this information was only used to find the school boundary, in Fig. 5. In this study, the colors of the 640×480 pixels sonar images were assigned a scale from 0 to 255, and a school region was extracted by setting a threshold value of three. Figure 6 (a) shows the basic idea to obtain our underwater acoustic tomography[6]: As the name implies, a three-dimensional image is constructed by stacking a series of two-dimensional athwartship sonar images as in Fig.6 (a) and (b). These were obtained at 12 sec intervals. Furthermore, by stacking the thresholded pixel data, three-dimensional school shapes are stored in computer memory. The number of voxcels in the school was counted with the three-dimensional processing software SLICER (Spyglass Software, Inc) and the volume of the schools was calculated by multiplying the number of voxcels by their size.

## 2.3 Standing stock of school

The density of the fish in a school was estimated from the quantitative echo-sounder information. A suggestion of the school density could also be obtained from the sonar echogram. However, at this time, sonar has not yet been developed to extract the density information as accurately as from the quantitative echo-sounder. Thus sonar data were not used to obtain density information. The data processing procedure for the acoustic data from the echo-sounder is as follows:

(1) The fish density per volume $\rho_{i,j}$ (g/m$^3$) is estimated by

$$\rho_{i,j} = (sv_{i,j} / \sigma_{bs}) \times w \qquad (1)$$

where $\rho_{i,j}$ is the fish density per unit volume for the $j$-th depth layer in the $i$-th integration section (the $i$-$j$ cell), and $w$ is the body weight of

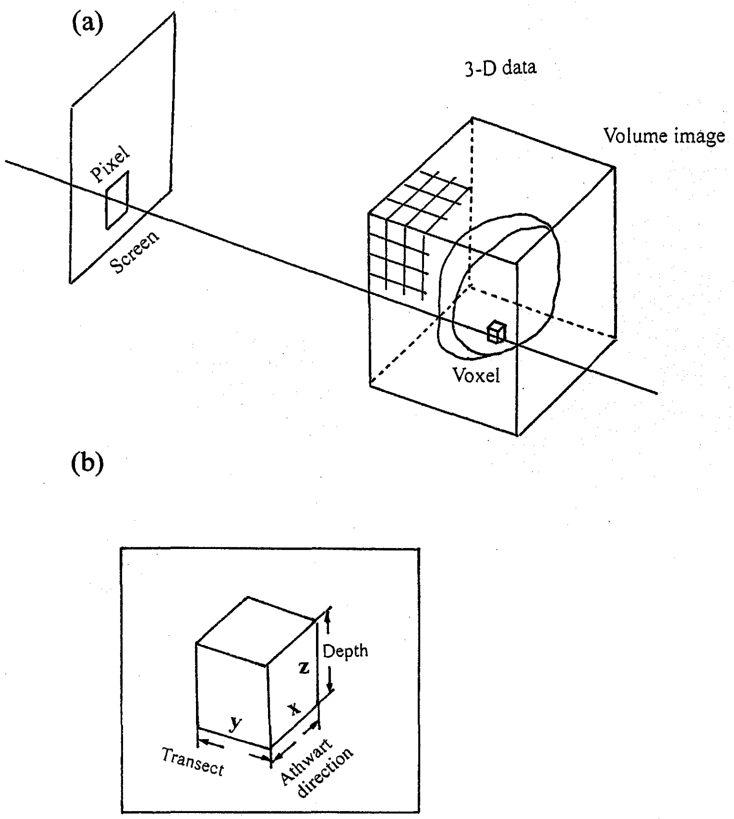


**Fig. 6.** Principle of projecting 3-D image data onto 2-D screen (Cited and reformed from Y.Aoki, T.Sato, P.Zeng, and K.Iida,1991).

the target estimated from the regressive relation of body weight on fork length. The backscatter strength $sv_{i,j}$ is $sv$ for the $j$-th depth layer in the $i$-th integration section (the $i$-$j$ cell), which is given by

$$sv_{i,j} = 10^{\frac{SV_{i,j}}{10}}$$

and $\sigma_{bs}$ is the acoustic backscatter cross-section defined in terms of a specific TS for a target fish species as

$$\sigma_{bs} = 10^{\frac{TS}{10}}$$

(2) Therefore, the mean weight density of fish in the school per volume $\bar{\rho}$ is expressed as

$$\bar{\rho} = \frac{1}{k} \sum_{i=1}^{n} \sum_{j=1}^{m} \rho_{i,j} \qquad (2)$$

where $k$ is the number of cells within the thresholded school, $n$ and $m$ show the number of integration section and depth layer, respectively.

(3) The standing stock of a school $Q$ can then be estimated by multiplying the mean weight density $\bar{\rho}$ per volume from equation (2) by the volume $V$ estimated from sonar data using SLICER;

$$Q = \bar{\rho} \times V \qquad (3)$$

## 3 Results

### 3.1 Target strength

It is necessary to define target strength as a scale factor in order to correctly estimate the weight density of fish in a school. To verify the probable source of the echoes with gear selection as small as possible, jigging (pilking) with

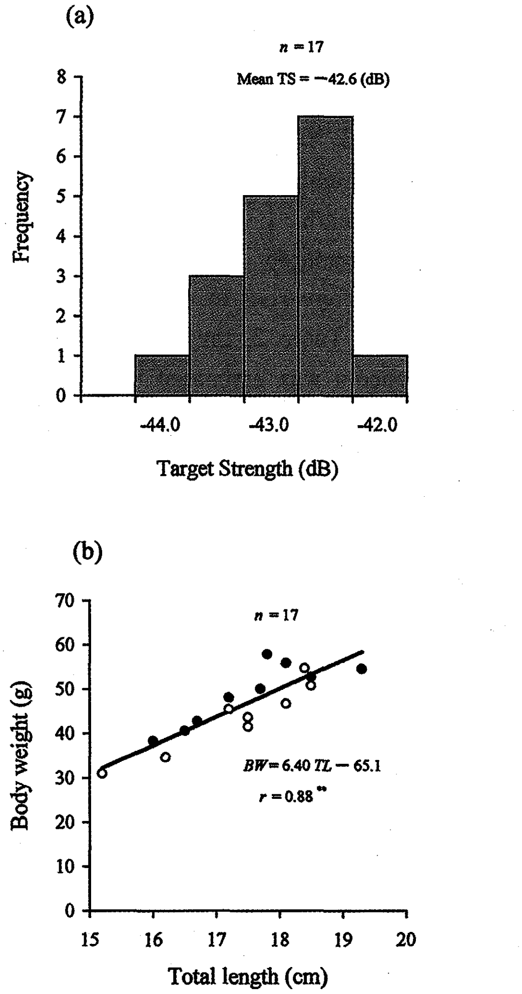


Fig. 7. Histogram of calculated target strengths and length weight relation from the sampled carangids (Japanese horse mackerel (●) and round scad (○))

handlines (or "sabiki" in Japanese) was carried from a chartered commercial fishing boat on the detected school. The fish caught were predominantly carangids (17 individuals; Japanese horse mackerels *Trachurus japonicus* and round scads *Decapterus maruadsi*). The average total length and body weight of the samples were 17.4 cm and 46.5 g, respectively. The target strength of carangids was estimated using the equation proposed by Foote; [7]

$$TS = 20 \log L + A \qquad (4)$$

Here, TS is the target strength (dB), $L$ is the total length (cm), and $A$ is a constant, in the case of physoclists, being −67.4 dB given by Foote.[7]

The frequency of the target strength of the carangids obtained using Eq. (4) is shown in Fig. 7 (a). The mean target strength in this case was estimated to be −42.6 dB, Figure 7 (b) indicates the relationship between the total length and body weight. Using this equation, the average body weight of the sampled carangids was estimated to be 46.3 g.

## 3.2 Standing stock of school

The SV from the quantitative echo-sounder data was converted to density using Eq. (1). As shown in Table 2, the average density of the fish in

**Table 2.** Estimated dimensions of schools

| Size (in m) height×width×length | Volume $\times 10^3$ ($m^3$) | Average density ($g/m^3$) | Standing stock (t) |
|---|---|---|---|
| (a) 40×67×56 | 33.4 | 8.89 | 0.30 |
| (b) 36×63×67 | 37.3 | 3.86 | 0.14 |
| (c) 40×46×89 | 21.6 | 7.73 | 0.17 |

schools was estimated to be 3.86 to 8.89 g/m$^3$, under the assuption that the school was composed mainly of carangids.

As shown in Fig. 8, the sweep axis of the sonar beam is set to be perpendicular to the transect. And stacking the cross section images in the transect direction, it is possible to construct a three-dimensional image of the schools shape. To eliminate the school image from the background noise of the sonar information, the value of three on the intensity scale was adopted as the threshold, which is deduced from Fig. 8 (b) as the background noise level. Figure 9 shows examples of the three-dimensional shape of schools produced using SLICER.

The volume of the school (a) was calculated to be 33.4 $\times$ 10$^3$ m$^3$. The three-dimensional images of two other examples of schools are shown in Figs.9 (b) and (c), and the size and volume of these schools are shown in Table 2. The characteristics of the schools were found to be a volume of 21.6 to 37.3 $\times$ 10$^3$ m$^3$, with dimensions of 36 to 40 m in height, 46 to 67 m in width, and 56 to 89 m in length.

The SV measured by the quantitative echosounder was converted to density using Eq.(2). As shown in Table 2, the density of the carangids in schools was estimated to be 3.86 to 8.89 g/m$^3$. Next, the standing stock of schools was estimated using Eq.(3). The substantial density and size variation in the schools resulted in standing stocks of schools varying from 0.14 to 0.30 tons.

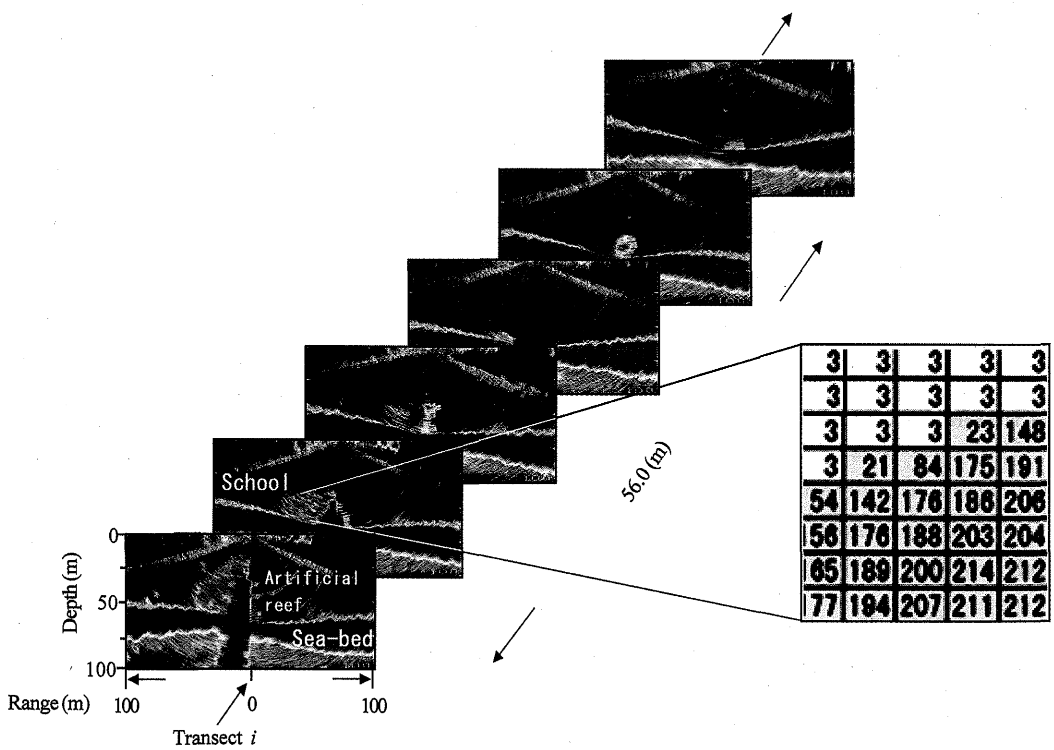


**Fig. 8.** Sequence of school sonar images (a) and sample pixel values from the school water interface (b).
Note: The interval between successive sonar images was 12 sec or 9.3 m at 1.5 knots. The size of pixel is 9.33 m in alongship direction, 0.3 m in athwardship one, 0.15 m in depth, respectively.

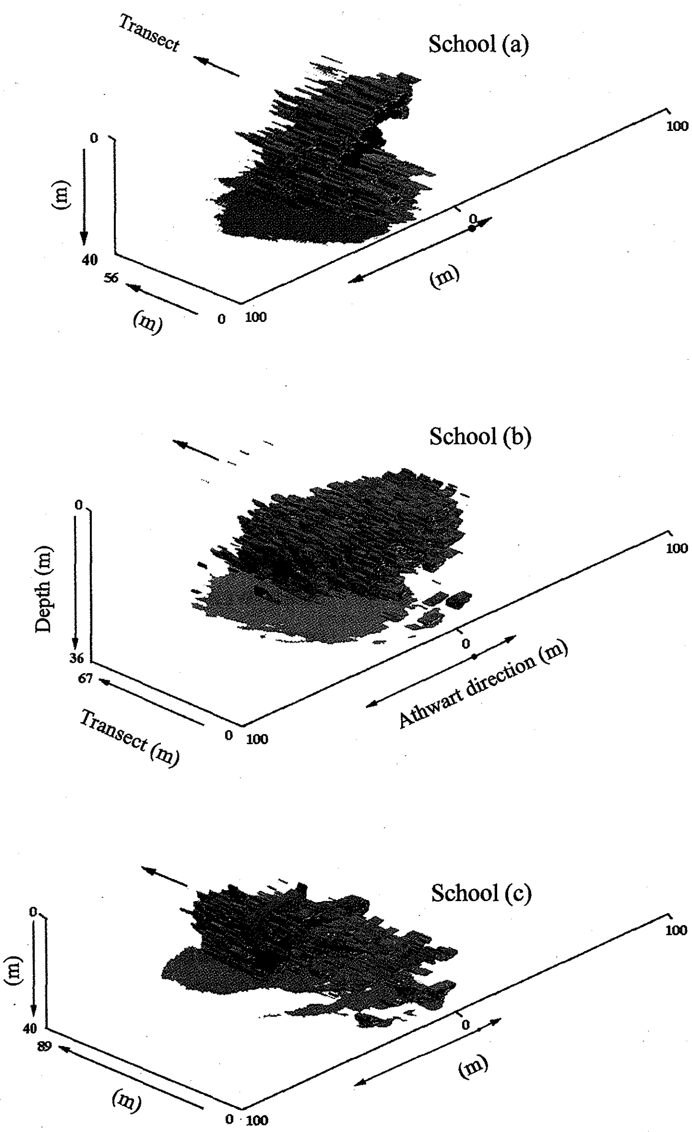


**Fig. 9.** Three-dimensional illustration of school basing on shape information from sonar topographs by applying the 3-D software SLICER.

## 4 Discussion

The three-dimensional analysis of schools is fundamental to the study of the distribution of pelagic fish communities, and is especially useful for characterizing the distribution of fish in specific areas such as near artificial reefs. Furthermore, the development of such measurement techniques allows the beneficial effects of the presence of artificial reefs to be semi-quantitatively determined in terms of fish standing stock and the three-dimensional structure of fish schools. The method proposed in this report, that is, the combined use of quantitative echo-sounder with sector-scanning sonar, is an important techniques to measure the spatial distribution of schools and their shapes. This enabled us to get better estimate of the standing stock. Even with this technique accuracy and precision of the obtained estimates may be limited, however, development is expected to bring some improvements

First, it is necessary to examine whether the sound beam of the echo-sounder and sector-scanning sonar can pick up the distribution of fish without a non-scanned area or if some areas are examined without being scanned. In regard to the area covered by the sound beam of the echo-sounder, a pulse was transmitted, in the present case, at 1 sec intervals. Between the successive transmissions, the ship sailed 0.77 m (when sailing at 1.5 knots). The schools were detected below 20 m. At this depth, the sound beam of 12.2 degree full width can horizontally cover 4.27 m, *i. e.*, the non-scanned area did not exist between the sound beams. In the vertical direction, the entire water column below 3.6 m is insonified.

The non-scanned area by a sound beam of the sonar is discussed here. The sonar scan interval is 12 sec. During this time intervals, the ship sailed 9.2 m at a speed of 1.5 knots. The 12 degree sonar beam will provide complete coverage along the transect for targets that are at a range of 43.8 m or more apart from transect. The fraction of the along transect distance that is not insonified decreases linearly from 100 to 0 % from the transducer to a range of 43.8 m. The above-mentioned description is related to the non-scanned area in the horizontal detection or the vertical section. A three-dimensional consideration is needed. Furthermore, the above-mentioned discussion does not include that of the projected size of the schools. When the projected size of school is taken into account, the rate of school, which escapes from being scanned, decreases in accordance with the increase in its size. If the fish scatter into small patches seasonally or ecologically, this problem is significant.

Next, reasonable attention should be paid to the possibility of error caused by the relative movement of a school.[8-13] The size of a school observed while swimming in the same direction as the ship will be overestimated, and schools travelling in the opposite direction are likely to be underestimated. Despite these indications, the schools detected here remained around the artificial reefs. The modification of estimation due to the above-mentioned reasons rarely occurred.

Another source of error is the distortion in an image originating from the angular resolution of the scanning sonar (see Fig. 2). This effect is observed as a bending and rising of the sea-bed echo toward the middle of the sweep, and the magnification of the school dimensions with increasing range from the sonar transducer. This problem was not dealt with in this report; further study to correct such distortions where possible is therefore necessary.

Lastly, as fish do not distribute uniformly within a school, the frequency distribution of the weight density ($g/m^3$) does not necessarily follow a normal distribution. Therefore, the weight density of fish in the school per volume obtained from the quantitative echo-sounder also varies according to cell. The color variation of sonar information shown in Fig.9 supports the density variation of fish within a school. The arithmetic mean weight density from echo-sounder information was used in this analysis, however, it will be important to use a more appropriate statistical technique to derive a more accurate estimation of the biomass from the survey data in the future. Distributions that depart seriously from the normal may require transformation to force the data into a better approximation of normality.

The quantitative echo-sounder is a suitable tool for collecting two-dimensional information along the sailing course, however, it is not effective for determining the three-dimensional spatial distribution of fish schools. The technique proposed in this report is one of the way of making use of such a system; combining size information from sector-scanning sonar with density information from the quantitative echo-sounder using commonly available computer software. This three-dimensional analysis technique allows us to quantitatively determine the standing stock of schools around reefs. In particular, this method increases the sampled volumes, which could improve the precision of the estimate, and allows counting of the schools far from the boat, which limits the bias due to lateral avoidance.

Improvements in the acoustic survey method that is based on this technique are expected to give a greater understanding of the distribution and behavior of fish schools and fish abun dance.

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## 計量魚探機とスキャニングソナーを用いた魚群の定量的三次元画像化

濱野　明・中村武史

計量魚探機とスキャニングソナーを同時使用した三次元画像化による魚群の半定量的評価手法について検討した。実例として用いた資料は、2000年12月に山口県奈古沖の造成漁場で行われた音響資源調査結果である。魚群の定量的画像化のために、計量魚探機によって魚群密度を求めた。さらに、スキャニングソナーより断層画像を船の針路の左右方向の魚群情報として取り出し、これらを進行方向に重ね合わせることにより三次元画像を作成した。本手法ではスキャニングソナーの断層画像を12秒間隔でコンピュータに取り込み、魚群分布の三次元画像を再現した。さらに、計量魚群探知機によって得られた魚群内の魚の分布密度と三次元画像から推定した魚群体積を掛け合わせることにより、現存量を半定量的に推定した。本報告では、これら音響機器を用いた魚群形状及び現存量推定のための調査解析手法について述べるとともに、本手法の改善のため、音響探査される際の探査もれの広がりが音源からの距離の増加に伴いどのように変化するかを考察した。