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The Application of Image Processing Technology for the Analysis of Fish School Behavior: Evaluation of Fish School Behavior Response to the Approaching Vessel Using Scanning Sonar

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The response behavior of a fish school to an approaching vessel was observed using scanning sonar. The evaluation using six parameters, which signify characteristics of school shape and behavior by sonar image processing, was proposed. Ten fish schools were analyzed and among them, three fish schools were identified for their changing shape, swimming direction, and swimming speed. Moreover, by tracing fish schools on stack of sonar images, these fish schools were seen to exhibit an apparent change of school shape and behavior. Therefore, the evaluation method of fish school behavior using six characteristic parameters indicating fish school shape and behavior by sonar image processing is useful.

Key words: Fish school behavior, Image processing, Scanning sonar

Introduction

In the acoustic resources survey, the avoidance behavior of fish school in response to the vessel may induce a bias in the estimates of fish abundance (Olsen, 1990; Traynor et al., 1990; Fréon et al., 1993a). The method, which determines a change of fish school behavior caused by the vessel, is divided into two; (1) Observation on the change of fish school behavior and density caused by approaching vessel with the assistance of auxiliary boat and a buoy with echo sounder. Observations of avoidance behavior using this method were reported earlier for herring, capelin and polar cod (Olsen et al., 1983; Ona and Godø, 1990; Fréon et al., 1992; 1993b). (2) The use of the sonar. Studies of fish school avoidance behavior from the vessel using sonar were conducted on the survey of herring and capelin in North Sea. The method to analyze the effect of avoidance behavior is still inaccurate for the acoustic resources survey. However, this method gave merit to the use of the sonar in research, which has wider detection area than the echo sounder. There are several reports on fish school avoidance studies using only sonar (Misund, 1990; 1993 b; Misund et al., 1993; Hafsteinsson and Misund, 1995; Soria et al., 1996; Iida et al., 1998; Gerlotto et al., 1999) and studies using both sonar and echo sounder (Misund, 1993a; Misund et al., 1995).

The studies of fish school avoidance behavior using echo sounder were to quantify a change of fish density. However, this evaluation method of fish school avoidance behavior from the vessel using only sonar is not yet established. Therefore, the existence of fish school avoidance behavior is determined by the change of moving trace and swimming speed, the appearance frequency of lateral distance and depth each unit from the vessel. If the change of fish school behavior in response to an

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approaching vessel is quantified, it improves the precision of resources estimation using quantified echo sounder and developing the method of resources estimation using sonar.

Therefore, we observed changes of fish school behavior in response to the approaching vessel using scanning sonar. This attempt was to obtain the basic data on the fish school behavior change to approaching vessel and the evaluation method of by six parameters, which signify characteristics of school shape and behavior using image processing.

Materials and Methods

The survey was carried out off in Funka Bay, southern Hokkaido, Japan by R/V Ushio Maru, which is equipped with a 180-degree scanning sonar (KCH-1827, Kaijo Co.) during daytime in August 1999. A 180-degree scanning sonar with a frequency of 164 kHz a transmitting beam width of 180°×8° and a receiving beam width of 8°×8° was used. The survey course is shown in Fig. 1.

Survey conditions were determined by sonar detection with a range of 300 m, a tilt angle of 0~30 degrees, and a survey speed of about 9-knot. The sonar beam was directed forward to the survey course. If a fish school was detected, it was tracked by changing a tilt angle manually corresponding to the change of fish school image from the appearance to disappearance of the fish school.

Sonar display showed 16 colors of plan position indication (PPI) image in accordance with the echo intensity. Video signals of the sonar were converted to national television system committee (NTSC) video signals through a video scan converter (XVGA-1V, Micomsoft Co.). These signals were recorded by a videocassette.

The tracked fish school was saved to convert into a fixed sonar image at 5-second interval by an image processing software (Cosmos 32, Library-inc. Co.). After erasing the noise and the other information excluding the marking of the vessel and the tracking fish school, these fixed sonar images were stacked by using 3-dimensional image processing software (Slicer, Fortner Research LLC). The background of stacked image was erased to set a threshold level based on the histogram of the echo level. The schematic diagram of stacking sonar images and image of erased background is shown Fig. 2. Figure 2(A) shows a stack of images each 5-second from appearance of fish school to disappearance. If background was erased from the stacked image, it was possible to observe the own vessel marker and fish school image in each 5-second (Fig. 2(B)). The center position of schools was determined from geographical center of fish school on the stacked image.

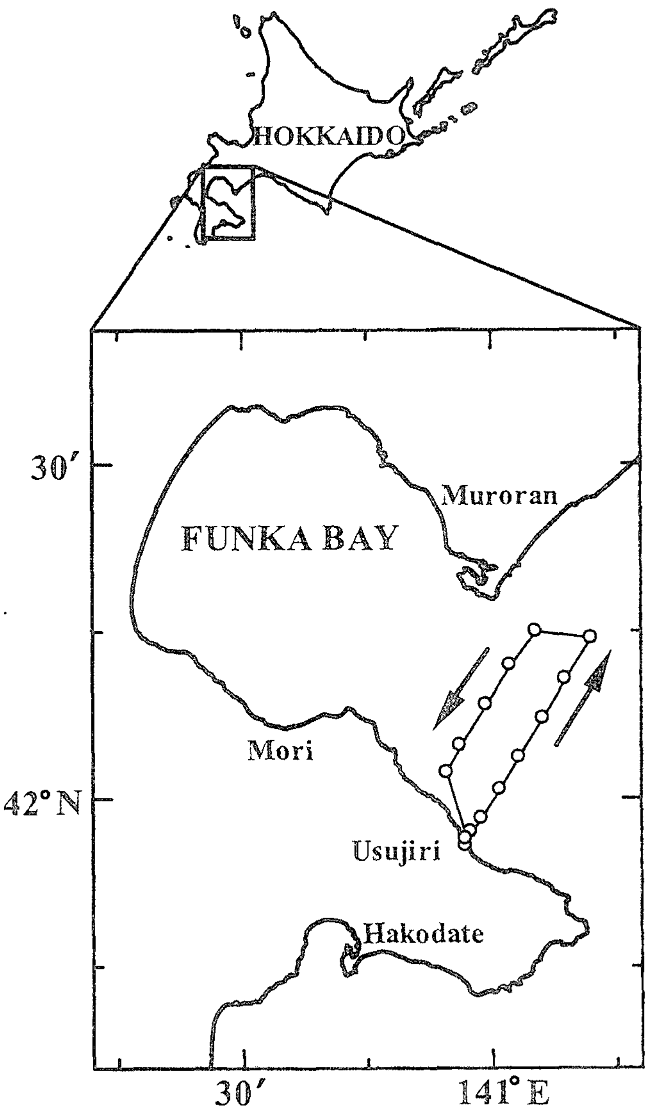

Fig. 1. Location of survey area.

The 3-dimensional relative and absolute coordinates of fish school were calculated from a radial distance of vessel - fish school, a direction angle of beam center - fish school, tilt angle and vessel speed. If the school behavior changed, we think the

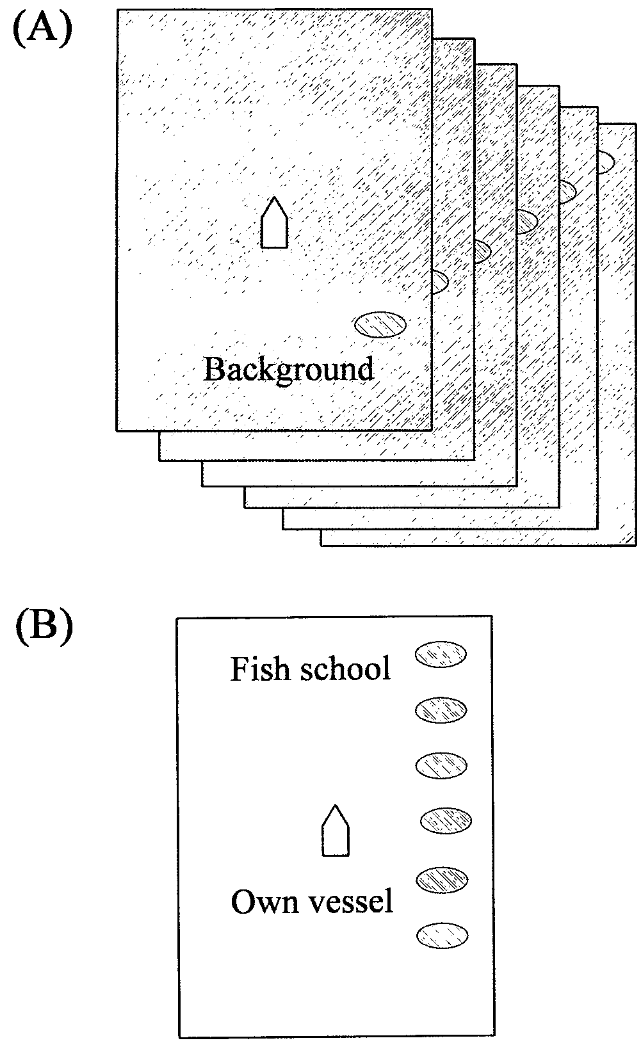

Fig. 2. Analysis of fish school behavior using image processing.
(A), Stack of sonar images;
(B), Extraction of fish school images and the vessel.

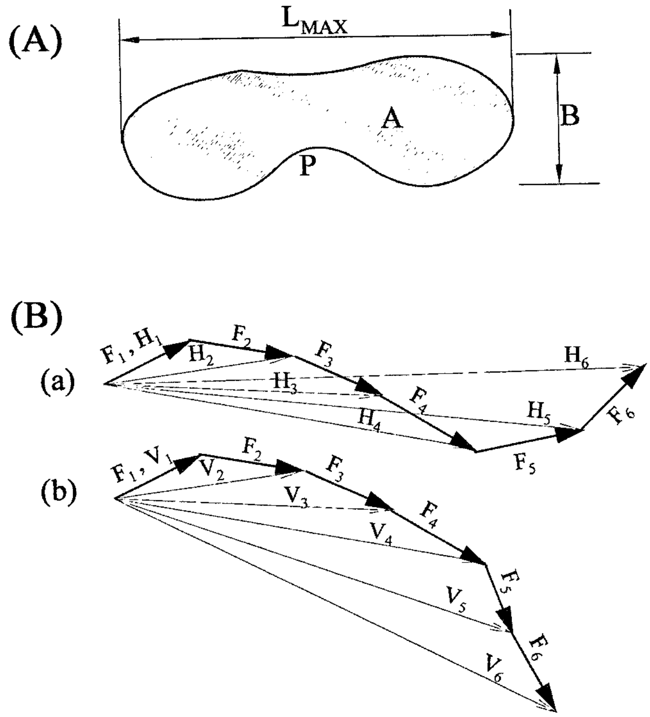

Fig. 3. Factors of (A) school shape and (B) school behavior.
LMAX, Maximum length; B, Maximum width; P, Perimeter; A, Area; F_i, Swimming distance of horizontal (a) and vertical direction (b) of fish school in an observation interval; H_i, Horizontal distance and V_i, Vertical distance from the first fish school position in each observation interval.

shape of fish school also changes. Therefore the shape of fish school was analyzed using an image processing software. The parameters that signify characteristics of fish school shape (FSS) e.g. Elongation (E_{lon}), Circularity (C_{irc}) and Fractal dimension (F_{ract}) were used to identify fish species in the area with mix fish species, and these were defined as follow (Nero and Magnuson, 1989; Scalabrin and Massé, 1993; Weill et al., 1993).

$$E_{lon}=\frac{L_{MAX}}{B}$$

Where L_{MAX} is the maximum length of FSS; B is the maximum width of FSS (Fig. 3(A)). The E_{lon} is closed to 1 if the FSS is an equi-polygon and a circular type and deviated from 1 if its shape is a polygon and an ellipse.

$$C_{irc}=\frac{P^2}{4\pi A}$$

Where P is the perimeter of FSS; A is the area of FSS. The C_{irc} is closed to 1 if the FSS is a circular type.

$$F_{ract}=\frac{\ln(\frac{P}{4})\cdot 2}{\ln(A)}$$

The F_{ract} shows the complexity of FSS from a perimeter and area of fish school. The F_{ract} is closed to 1 if the FSS is very smooth. As the FSS increases a complexity, the F_{ract} value increases further.

The parameters that signify characteristics of fish school behavior (FSB) were swimming speed, horizontal direction index (D_H) and vertical direction index of fish school (D_V). The swimming speed of fish school was quantified from a moving distance of fish school position in each 5-second. The D_H was quantified by the ratio of the horizontal distance from the first fish school position in each 5-second and the sum of swimming distance of horizontal direction of fish school in each 5-second.

$$D_H = \frac{H_i}{\sum_{i=1}^{N} F_H(i)}$$

Where $F_H(i)$ is the swimming distance of horizontal direction of fish school in each 5-second; H_i is the horizontal distance from the first fish school position in each 5-second and the sum of swimming distance of horizontal direction of fish school in each 5-second (Fig. 3(B)). The D_V was quantified by the ratio of the vertical distance from the first fish school position in each 5-second and the sum of swimming distance of vertical direction of fish school in each 5-second.

$$D_V = \frac{V_i}{\sum_{i=1}^{J} F_V(i)}$$

The horizontal and vertical direction index is closed to 1 if the school moves a straight forward and closed to 0 if the school moves in a circular way.

The response behavior of a fish school to an approaching vessel using six parameters that signify the characteristics of school shape and behavior by image processing was quantified.

Results

Ten fish schools were traced. Figure 4 shows stacked fish school dimensions of these fish schools at 5-second interval. The figure shows the relative plotting of the change of appeared school shape in relation to the vessel with a range of 300 m. The dot line and arrow indicated the approaching direction of the vessel. In Fig. 4, fish schools D and G crossed the track line of the vessel and fish school B and J changed their swimming direction at closer distance away from the survey course. Also fish school A and J were observed with their apparent size and shape at 5-second interval. Therefore we showed that the FSS expanded from these fish schools is independent of time (Fig. 5). In this figure, fish schools showed to change a simple shape with vessel approach for fish school A and an apparent difference of FSS before and after half for fish school J.

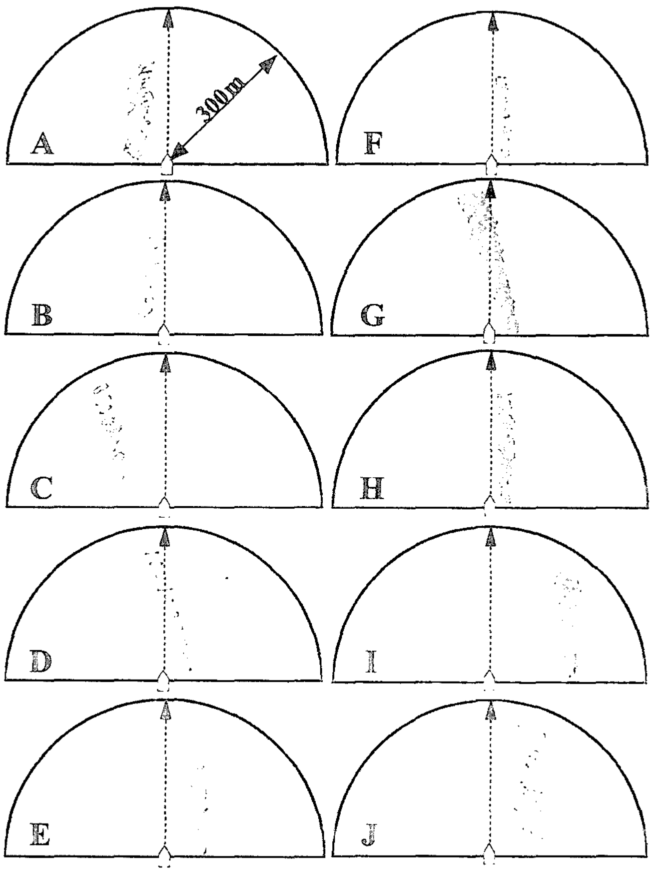

Fig. 4. Pelagic fish schools shape observed using scanning sonar.

Figure 6 shows swimming trace of fish schools by the geographical center position of fish schools on fixed sonar images. Figures 6(A) and (B) showed the change of horizontal and vertical direction of the relative plotting of fish schools in relation to the vessel respectively. Arrows showed the change of direction. Figures 6(C) and (D) showed the true plotting, which was the school real movement to avoid the effect of the speed of the vessel. In the Fig. 6(C), fish schools D and G crossed the track line of the vessel. Fish schools A, B, E and F changed their swimming directions at closer distance away from the survey course. Also fish schools H and J apparently changed their swimming directions. However, fish schools C and I far from the survey course did not show apparent change of their direction.

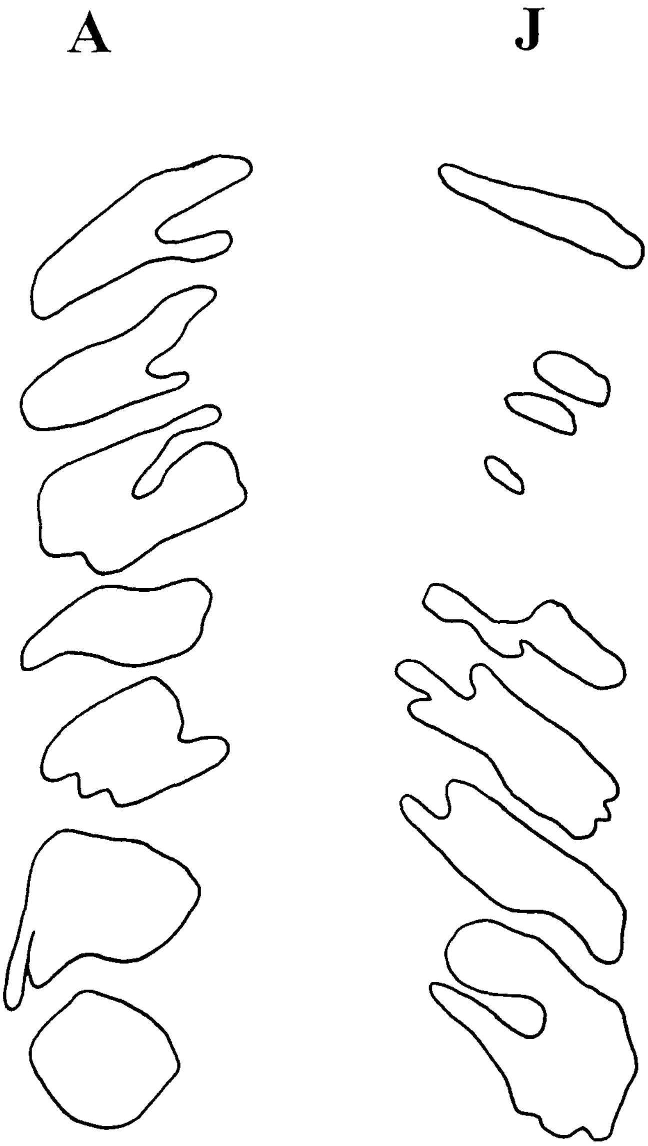

Fig. 5. Change of fish schools shape with vessel approach.

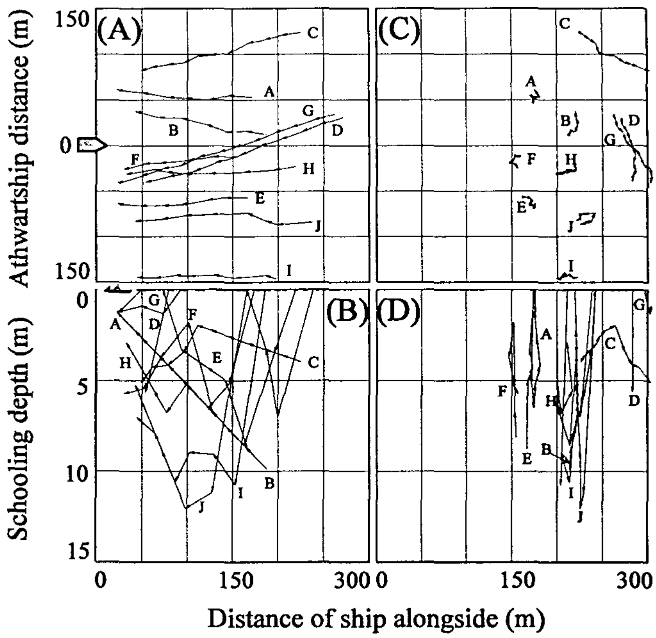

Fig. 6. Traces of swimming behavior of fish schools observed with the scanning sonar. (A) and (B), Relative plotting; (C) and (D), True plotting.

Figure 7 shows normalized values of three parameters indicating characteristics of FSS. These parameters were normalized by the average of each of the parameter respectively. The square (□), circle (○) and multiplication (×) referred to E_{lon}, C_{irc} and F_{ract}, respectively. An apparent change showed fish schools C, D and J for E_{lon}, fish schools F, H, I and J for C_{irc} (Fig. 7).

Figure 8 shows normalized values of three parameters indicating characteristics of fish school behavior, horizontal direction index (D_H), vertical direction index of fish school (D_V) and swimming speed. Also, these parameters were normalized by the average of parameter respectively. In the Fig. 8, the diamond (◇) and inverted triangle (▽), plus sign (+) referred to D_H, D_V and swimming speed, respectively. There was an apparent change showed by fish schools A, I and J for D_H, fish schools J for D_V and fish schools B, E, H, I and J for swimming speed.

Mean and standard deviations (S.D.) were obtained from the normalized values of each parameter to evaluate the change of fish school shape and behavior synthetically. Normalized values at 5-second interval in every parameter and each fish school were scored one point for a mean to ± 1 S.D., two points for ± 1 S.D. to ± 2 S.D., and three points for ± 2 S.D. and up. These obtained values were averaged for a fish school and each parameter, respectively. There was no mark for the average value of over 1 and under 1.5 and asterisk (*) was marked for the over 1.5. No mark means that there was no little changes of school behavior while asterisk (*) mark indicates a little changes.

Table 1 shows the result of shape and behavior of fish school for the each parameter. The numbers on the table indicate the average values of the fish school and each parameter before those became standard value. As can be seen on the Table 1, fish

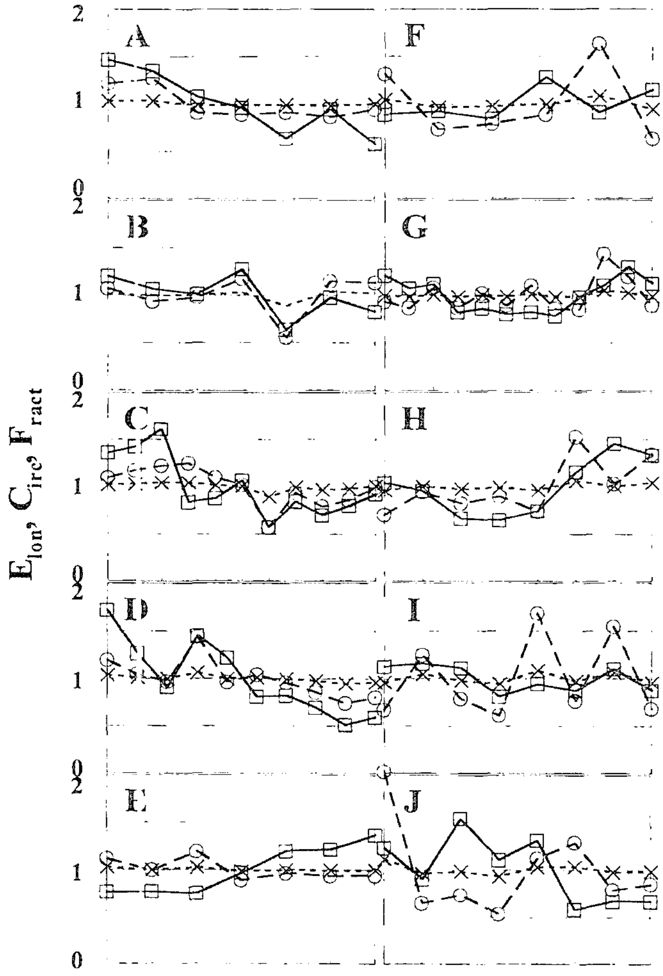

Fig. 7. Change of characteristic parameters of fish schools shape.
□, Elongation; ○, Circularity;
×, Fractal dimension.

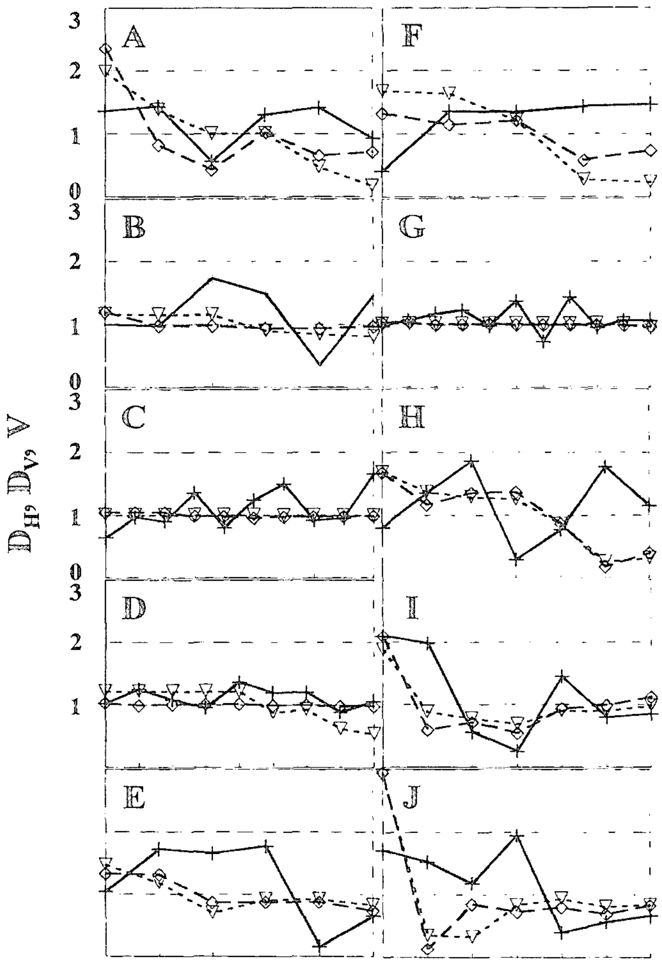

Fig. 8. Change of characteristic parameters of fish schools behavior.
◇, Horizontal directivity; ▽, Vertical directivity; +, Swimming speed.

school having over 50% of asterisk (*) mark were group A, I and J. It could be discriminated that there were some changed on those fish schools.

Discussion

Fish schools A and J showed an apparent change of their size and shape at fixed sonar image of 5-second interval. On the other hand, in the synthetic evaluation of the change of fish school shape and behavior using image processing, fish schools A, I and J were identified by the change of their shape and behavior. The comparison of these two methods did not coincide completely. However, the change of behavior of fish schools A and J were detected by this method. In the analyzed fish

Table 1. Evaluation of characteristic parameters of shape and behavior of fish schools in relation to avoidance behavior toward approaching vessel

Items	Shape parameter			Behavior parameter		
	E_{lon}	C_{irc}	F_{ract}	V	D_H	D_V
A	1.78*	2.70	1.11	0.88	0.42*	0.51*
B	1.95	1.71	1.04	0.98	0.84	0.87
C	2.14*	1.61	1.04	1.70	0.96	1.00
D	1.94*	1.52	1.03	1.56	0.97	0.83
E	1.37	1.57	1.03	0.74*	0.75	0.68
F	1.22	2.18*	1.07	0.96	0.76	0.60*
G	1.28	1.77	1.04	1.54	0.97	0.99
H	1.55*	2.50	1.09	1.36	0.60	0.59
I	1.70	2.47*	1.08*	1.34*	0.48*	0.53
J	2.22*	2.62*	1.09	1.80*	0.34*	0.34*

Unmarked, little change; *, change.

schools, we do not discriminate the apparent avoidance behavior from the approaching vessel. Also, since we cannot catch a fish from the fish school for fish identification, we do not know whether the fish school behavior is normal or not. Moreover we need to identify the efficiency of these parameters with accumulated data.

The values of three parameters, which indicated characteristics of fish school behavior, were changed by the method how to calculate the central position of fish school. Fish school shape observed by scanning sonar is only a part of school volume, and is not always the same part among school volumes. Therefore, in the evaluation of fish school behavior the important thing is to use these parameters synthetically. Furthermore, It need to statistical test with the data accumulation after extracting automation for the characteristic parameters and data processing.

Finally, the avoidance behavior of fish school may induce a bias in the estimates of fish abundance. Also, the change of target strength by tilt and yawing angle of fish may be accompanied by avoidance behavior. Therefore, the fish school avoidance is important topic not to ignore to improve the accuracy of estimation in the acoustic resources survey.

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