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Complex Movements of Skipjack Schools Based on Sonar Observations during Pelagic Purse Seining

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The movements of skipjack schools during purse seine operations were observed by scanning sonar in the Southwest Pacific Ocean in April 2004. Swimming speed and directional changes were analyzed in relation to heading of the purse seine during shooting, speed of the purse seiner and distance to the net. Escaped schools turned clockwise (relative to the heading of the purse seiner during shooting) significantly more frequently than captured schools, who primarily turned counter-clockwise. The swimming speed of a fish school, whether it was caught or escaped, was somewhat related to the ship's speed, but swimming speed did not differ between captured and escaped schools. The behavior of skipjack schools during purse seining consists of very complex movements with changes in swimming speed and direction in relation to the nets or purse seiner. Therefore, these responses of skipjack schools to purse seining can be useful for modeling the capture process of purse seining in relation to fishing conditions.

Key words: Purse seining, Scanning sonar, Skipjack movements

Introduction

The success of purse seining depends mostly on the relationship between fish school behavior and changes in net shape with time. The main factors affecting fishing success are the size, swimming speed, and direction of the fish school in relation to purse seine size, speed, and direction of the setting net, and its sinking speed and pursing speed etc (Shimozaki et al., 1975; Ben-Yami, 1994).

The reaction of Atlantic mackerel during field purse seine operations has been observed by sonar images and analyzed mainly as moving tracks of the fish school in relation to the noise of the fishing vessel (Misund, 1992; 1993; Freon and Misund, 1999). The structure and escape behavior of anchovy and sardine schools have also been observed by sonar (Gerlotto and Paramo, 2003; Gerlotto et al., 2004), and Chang et al. (2003) observed gizzard-shad reactions to a coastal purse seine. Park et al. (1997) observed fish reactions, especially escaping between the wings of a model purse seine, in a relatively small tank without considering the scale effect of fish size. For skipjack responses to purse seines, Yuen (1966; 1970) estimated the swimming speed of a skipjack school, and Shimozaki et al. (1975) described the general reaction of a skipjack school to a tuna purse seine in the Pacific Ocean. Menard and Marchal (2003) investigated the foraging behavior of tuna at the surface of the Atlantic Ocean.

The movements of skipjack schools in offshore purse seining have not been analyzed quantitatively in relation to stimuli from the gear and the reactions of the fish school. Relevant data on the reactions of fish schools to purse seines are necessary to establish a model of fish behavior. The purpose of this study was to examine behavioral differences of skipjack schools that were caught and that escaped, as well as to analyze the basic swimming movements of skipjack schools to model the capture process.

The movements of skipjack schools were observed by scanning sonar while purse seining in the South-west Pacific Ocean and analyzed swimming speed and angular changes with the distance from the net or vessel. The behavior of skipjack schools during purse seining as quantified in this study represents very complex movements, such as changes in swimming speed and relative directions in relationship between stimulus and response. These data are useful for modeling the capture process of purse seining.

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Materials and Methods

The swimming movements of skipjack schools in the Southwest Pacific Ocean near the Solomon Islands were observed by scanning sonar (Furuno-FSV24) onboard a commercial tuna purse seiner (800G/T) of an offshore fisheries company during April, 2004 and February-April 2006 as shown in Table 1. The relevant sonar images were taken with a digital camera (Kodak CX6330, 1,656×1,242 pixels, or Kodak V550, 2,576×1,932 pixels). The general dimensions of the purse seine used in the field observations were 2264m of float line and 2480m of lead line. The general fishing time was 7-10 min of shooting, 3-5 min of towing the wings together, and 20 min of pursing. Total 17 fishing operations out of 20 were categorized as a successful catch (i.e. herding, the school was caught) or a failure (i.e., the school escaped) as shown Table 1. The movements of the fish school were compared between eight caught schools and nine escaped schools.

Photos of the screen color images on the sonar monitor were taken with the digital camera every 1 min and were later printed on A4 paper, including the relevant fishing information; examples are shown in Fig. 1. The horizontal position of the school center, tracks of the purse seiner, and the surrounding net wall were plotted on a sheet of transparency film at 1-min intervals for each purse seine operation. The horizontal position of the skipjack school or the purse seine shape during fishing was measured and converted from the relative coordinates on the printed sonar screen image to the real horizontal distance, as shown in the sonar radius circle, considering that the tilt angle of the sound beam ranged from 3 to 15°. The distance error in the real horizontal coordinates by this conversion method was estimated at less than 5 m per 1 mm of the printed A4 images.

The main movement components of each swimming school were then estimated as swimming speed, relative directional change, and distance to the net and the fishing boat in relation to the geometric changes of the purse seine with fishing time from start of shooting to the end of pursing. Swimming direction was represented as positive values for turning left (i.e., counter-clockwise) and negative values for turning right (i.e. clockwise).

Results and Discussion

An example of the horizontal movement of a herding skipjack school while shooting a purse seine is shown in Fig. 2 and the fish school was caught at last. An escaping skipjack school tracked between the wing ends at the end of shooting as shown in Fig. 3. The general change of fish school tracks was similar to the tracks of mackerel schools in the North Sea (Misund, 1992; 1993). The average swimming speed per minute for the eight caught schools as 214 data points from the start of shooting to pursing and for the nine escaped schools as 65 data points from the start of shooting until escape is shown in Fig. 4.

The average swimming direction per minute for caught and escaped schools is shown in Fig. 5. The

Table 1. Conditions of observed fishing operations and catch of skipjack school as caught cases and escaping cases

Category	Date (y/m/d)	Local time (h:m)	Location (Lat & Long)	School diameter (horizontal, m)	Catch (ton)
Caught	04/04/02	15:00	9°09.8'S 155°09.4'E	40	70
	04/04/03	10:00	9°23.1'S 155°10.7'E	60	100
	04/04/03	14:00	9°29,4'S 155°31.8'E	50	80
	04/04/04	15:00	9°15.8'S 155°24.8'E	40	30
	04/04/05	10:00	9°34.1'S 155°05.1'E	50	50
	04/04/07	09:30	9°23.5'S 155°14.1'E	100	130
	04/04/19	10:30	9°03.5'S 155°20.0'E	70	60
	06/02/23	14:30	9°57.8'S 155°18.7'E	30	20
Escape	04/04/03	12:30	9°21.8'S 155°32.7'E	100	200
	04/04/04	12:00	9°15.7'S 155°24.9'E	30	20
	04/04/04	13:00	9°15.1'S 155°27.9'E	50	70
	04/04/05	09:00	9°34.0'S 155°05.5'E	50	50
	04/04/19	09:30	9°03.9'S 155°20.5'E	100	140
	04/04/19	15:00	9°06.1'S 155°12.8'E	70	100
	04/04/20	14:00	9°00.6'S 155°29.0'E	50	50
	04/04/20	12:00	9°00.2'S 155°29.1'E	40	50
	06/04/28	12:00	9°12.9'S 155°39.6'E	700	100

School size and school weight (especially for escaped schools) were estimated by the experienced operating crew based on the scanning sonar images.

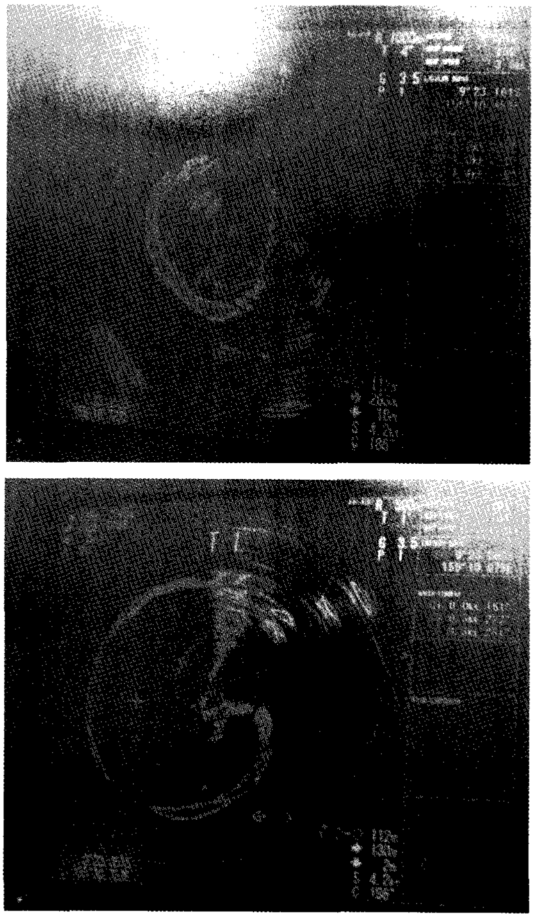

Fig. 1. Examples of the sonar images from 100 ton caught case on 10:00 A.M, April 3, 2004 as the end of shooting (top) and the end of pursing (bottom).

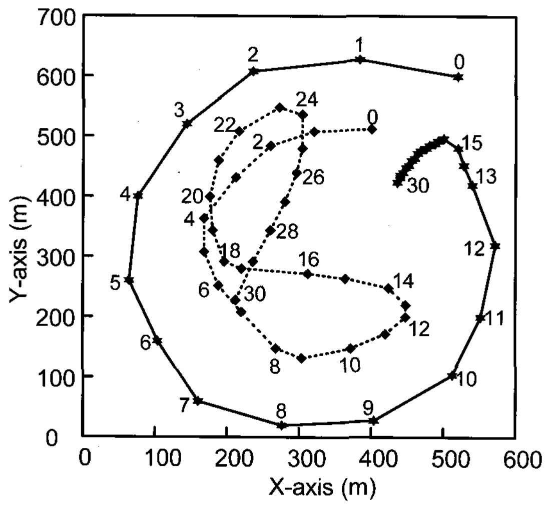

Fig. 2. An example of moving tracks as centers of school when herding behavior of skipjack school (diamond and dotted line) in relation to net shooting (star and solid line). Numbers indicate sequence of time interval as 1 min.

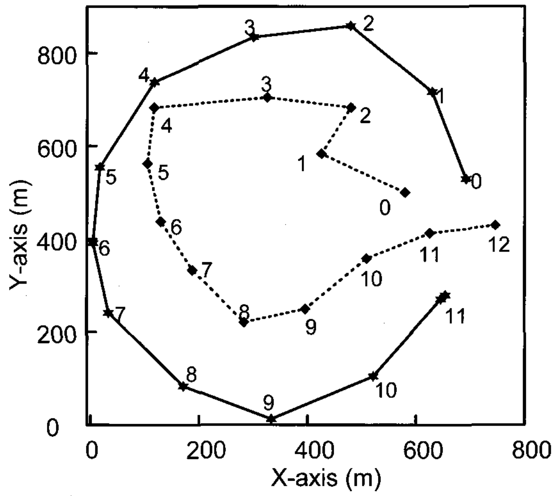

Fig. 3. An example of moving tracks when escaping behavior of skipjack school (diamond and dotted line) in relation to shooting nets (star and solid line). Numbers indicate time as 1 min interval.

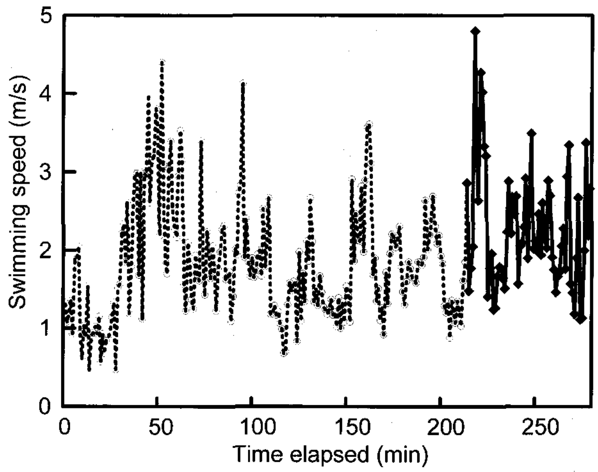

Fig. 4. The time series of swimming speed of skipjack schools when caught cases (circle and dotted line) and escaping cases (diamond and solid line) at right side.

positive symbols indicate counter-clockwise turning and the negative symbols indicate clockwise turning.

The relationship between shooting speed (V_S, in m/s) and swimming speed (Vf, in m/s) of the skipjack schools is shown for caught (n=71, r^2=0.245, $p<$ 0.00001) and escaped (n=62, r^2=0.232, p<0.0001) schools during shooting in Fig. 6. The mean swimming speed (± SD) was 1.7 ± 0.7 m/s for caught schools and 2.2 ± 0.8 m/s for escaped schools; however, these swimming speeds were not significantly different. The mean swimming speeds of skipjack schools with a mean body length (BL) of 0.5 m ranged from 3.4 ± 1.4 to 4.4 ± 1.6 BL/s were faster than Atlantic mac-

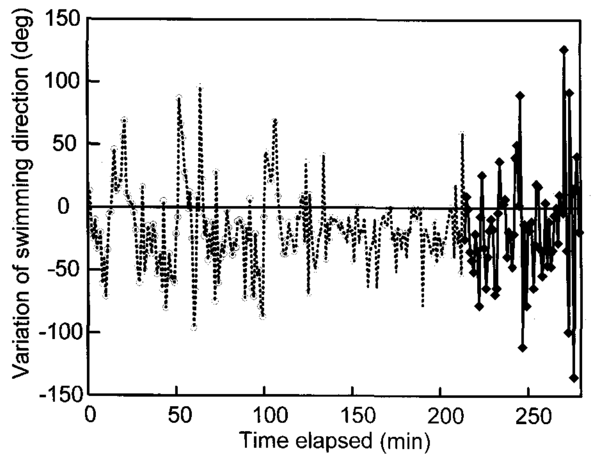

Fig. 5. The time series for variation of relative swimming directions (+, counterclockwise; -, clockwise turning) of skipjack school when herding cases (circle and dotted line) and escaping cases (diamond and solid line).

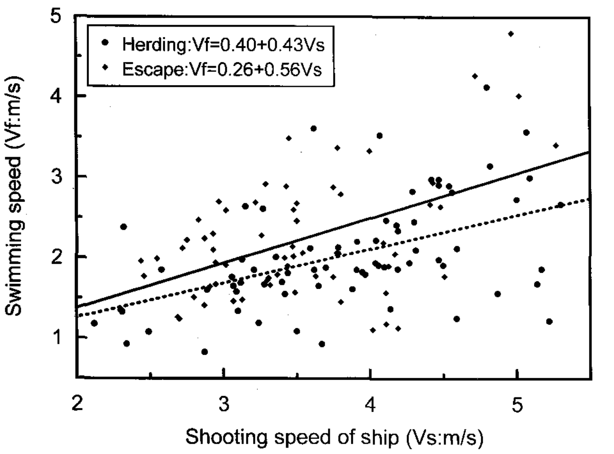

Fig. 6. Relationship between the shooting speed of the vessel and the swimming speed of skipjack school when herding cases (circle and dotted line) and escaping cases (diamond and solid line).

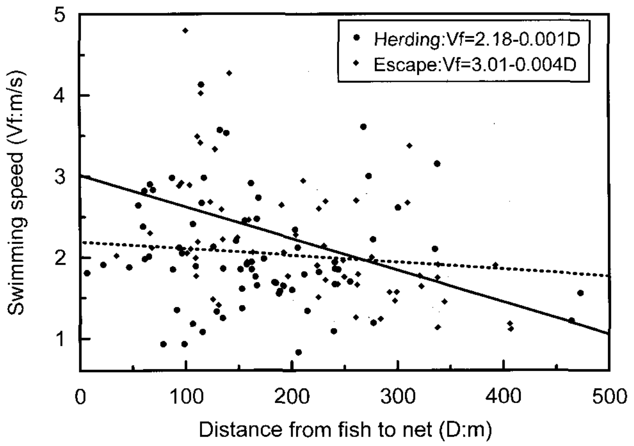

Fig. 7. Relationship between the distance from fish to net and the swimming speed of skipjack school when herding cases (circle and dotted line) and escaping cases (diamond and solid line).

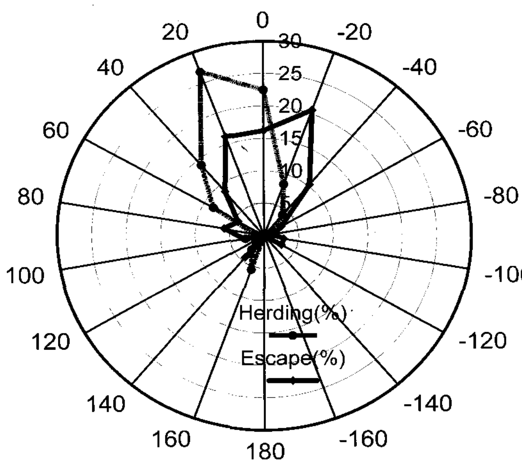

Fig. 8. Frequency (%) of relative heading changes (+, counterclockwise; -, clockwise turning) when herding and escaping skipjack schools in relation to the shooting direction of the purse seiner setting as 0°.

kerel schools (Misund, 1992; 1993). But the swimming speeds in purse seining were still slower than the prolonged swimming speed estimated by a fish swimming model (Kim and Wardle, 1997), observed swimming speeds (Syme and Shadwick, 2002), and the maximum free-swimming speed (Yuen, 1966; 1970). The relationship between the distance from the center of the skipjack school to the net (D, in m) and Vf of the skipjack school during shooting was not significant for caught schools (n=71, r^2= 0.012, p>0.1), but it was significant for escaped schools (n=62, r^2=0.247, p<0.00001) as shown in Fig. 7. The mean distance from the edge of the skipjack school to the net was 119±76 m for caught schools and 177±120 m for escaped schools, or 238±152 BL and 354±240 BL, respectively. However, this distance was not significantly different between caught and escaped schools.

The heading difference as heading change of skipjack school in relation to the heading of the purse seiner (set as 0°) during shooting is shown in Fig. 8. A heading difference of 0° means that the skipjack school and the purse seiner had the same heading (i.e., they moved in parallel), while positive values indicate a counter-clockwise heading change, such as inwards turning relative to the purse seiner, and negative values indicate a clockwise heading change. The relationship between caught and escaped schools at every 20° of heading was significantly different by

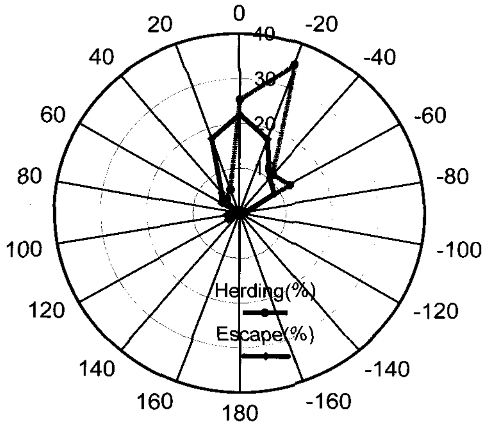

Fig. 9. Frequency (%) of variation of swimming direction (+, counterclockwise; -, clockwise turning) with time interval 1 min by skipjack school responses when herding cases and escaping cases.

a paired t-test ($p<0.007$). The mean heading difference was $19\pm50°$ (n=71) for caught schools and $6\pm57°$ (n=62) for escaped schools. Atlantic mackerel were guided to the inner circle of a vessel with clockwise shooting regardless of whether the school is caught (Misund, 1993).

The change in swimming direction at 1-min intervals during shooting for caught and escaped skipjack schools is shown in Fig. 9; there was no significant difference between caught and escaped schools.

For Atlantic mackerel, purse seine movement tracks from sonar observations were used to estimate swimming speed, shooting speed of the vessel, relative directional changes, and distance to the net with time elapsed during shooting operations (Misund, 1992; 1993; Ferno and Olsen, 1994). There was no significant relationship between the distance to the net and the swimming speed or change of swimming direction for Atlantic mackerel, similar to the skipjack responses observed here. The mean swimming speed of skipjack schools ranged from 1.7 to 2.2 m/s in this study, which is faster than the mackerel school 1.2 ± 0.8 m/s in the Atlantic purse seine studies (Misund, 1992; 1993). There was no relationship between swimming speed and the change in swimming direction in skipjack responses to purse seining. However, Misund (1993) reported that mackerel and herring school during purse seining to horizontally avoid the vessel due to the sound emissions.

The main features of the response behavior of skipjack schools in relation to tuna purse seines are affected by conditions such as water temperature, weather, prey, and predators (Shimozaki, 1975; Ben-Yami, 1994), which were not analyzed in this study. When a skipjack school is feeding without the risk of predation, fish school shows stable movement without panic behavior and is highly likely to be successfully caught (Menard and Marchal, 2003). When Saatchi, sharks, or whales chase the skipjack school, the school moves very sensitively in a panicked state even if they are fed intermittently; this behavior makes it difficult to catch the school (Hall et al., 1986; Fuiman, 1993; Lehodey et al., 1998; Furuichi, 2002). The movements of skipjack schools can be affected by many factors, which should be considered in further studies or in models of the purse seine capture process. Therefore, these responses of skipjack schools provide basic field behavior data that are useful for modeling the purse seine capture process to mimic complex behavior of fish school in relation to fishing conditions.

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