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Swimming Characteristics of the Black Porgy *Acanthopagrus schlegeli* in the Towing Cod-End of a Trawl

Yong-Hae Kim* and Chi Yeong Jang

Institute of Marine Industry & Department of Marine Production, College of Marine Science, Gyeongsang National University, Tongyoung 650-160, Korea

Fishing selectivity is determined by the level of voluntary escaping behavior in accordance with decision-making based on the relationship between fish size and mesh size. This study examined movement during the swimming behavior of black porgy in a trawl's towing cod-end and analyzed the movement components such as swimming speed, angular velocity of turning, and distance to the net over time. Most of the observed fish exhibited an optomotor response, maintaining position and swimming speed without changing direction. Others exhibited erratic or "panic" behavior with sudden changes in swimming speed and direction. The latter behavior involved very irregular and aperiodic variations in swimming speed and angular velocity, termed "chaotic behavior." Thus, the results of this study can be applied to a chaotic behavior model as a time series of swimming movements in the towing cod-end for the fishing selectivity.

Key words: Black porgy, Swimming movements, Towing cod-end.

Introduction

Fish behavior is a main factor affecting fishing selectivity in the cod-end of towed fishing gear (Wardle, 1993; Glass and Wardle, 1995; Herrmann, 2005). It includes voluntary escaping or herding behavior based on the sieving and filtering effects dependent on fish size and mesh size (Lowry and Robertson, 1996). These selective properties also depend on towing speed, gear specifications (Dahm et al., 2002; Tokac et al., 2004), sea state-induced vessel motion (O'Neill et al., 2003), and changes in the shape of cod-end mesh resulting from catch size (Erickson et al., 1996; Kynoch et al., 2004; O'Neill et al., 2005). Selectivity is entirely a result of voluntary escape behavior (Wardle, 1993; Kim and Wardle, 2003) in response to stimuli from the net or water flow in relation to swimming ability (Main and Sangster, 1991; Winger et al., 2000; Kim and Wardle, 2003; Breen et al., 2004; Winger et al, 2004) and involves both memory and learning (Soria et al., 1993; Özbilgin and Glass, 2004).

Previous research has used underwater RCTVs (remote-controlled towed vehicles) to record general swimming behavior of fish in towing cod-ends (Wardle, 1993; Glass and Wardle, 1995); results have indicated that most fish tend to exhibit an optomotor response, maintaining position and swimming speed without directional turning for extended periods and then falling to the back of the bagnet when exhausted. Other fish exhibited erratic or "panic" behavior characterized by sudden irregular changes in swimming speed and direction, followed by attempts to pass through the mesh.

However, while researchers have observed optomotor and erratic responses in fish located at the front of trawl gear (Kim and Wardle, 2003), which was subsequently used as basic data to develop a behavior model (Kim and Wardle, 2005), researchers have not reported variation in swimming speed and angular velocity during escaping or herding behavior in the cod-end. To establish a numerical model for fishing selectivity, this study observed and analyzed the movement of black porgy swimming behavior, including the components of swimming speed, angular velocity of turning, and distance to the net over time.

Materials and Methods

Black porgy *Acanthopagrus schlegeli* were caught using longline and set nets off the Tongyoung coast on 7-8 October 2004. Early each morning, fish were immediately transferred to five 450-liter plastic aerated tanks aboard the training ship SAEBADA and held in a resting state. Each tank held 30 fish; over

*Corresponding author: yonghae@gsnu.ac.kr

the two days, a total of 300 fish were held for use in the towing experiments. Following the towing experiments, each fish was measured for total length, weight, and girth.

Towing experiments were conducted at sea using a towing frame (5.0 [L]×2.0 [B]×1.5 [D] m, constructed from 10-mm diameter stainless steel) with the cod-end fitted following the method described by Main and Sangster (1991), as shown in Fig. 1. The experimental cod-end was constructed from 120-mm diamond mesh using PE 120-ply twine. The cod-end perimeter consisted of 75 meshes laced onto a stainless steel ring (1.5 m diameter); it had a 50-mesh length, and the hanging length was 5 m. A mesh disk closed the end of the cylinder to prevent fish from escaping. Fish rested for at least four hours prior to experimentation.

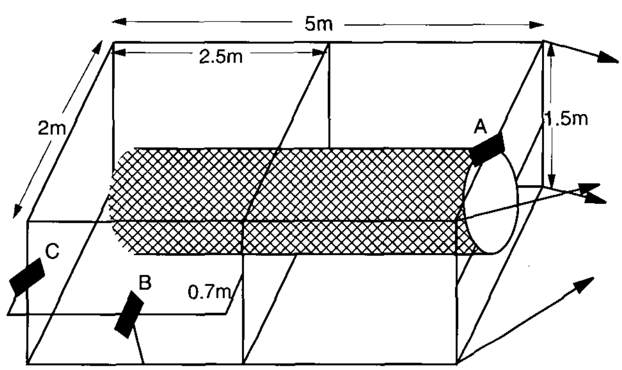

Fig. 1. The experimental set up for the sea towing experiments (A, B and C are underwater video cameras, towing direction is to the right).

Towing trials were conducted in the Sea of Chudo, Tongyoung, Korea, using fresh groups of about 30 rested fish in 10 different tows. Fish were moved from the plastic tanks to the cod-end using a dip net and then towed at a speed of 1.1 to 1.6 m/s and a depth of 7 to 10 m measured by the SAEBADA's Simrad Trawl Eye System. Fish movement was monitored by three underwater video cameras (Simrad OE1324, Hydroseacam 1050, Huhu UVC-150) mounted on the towing frame (see Fig. 1) and recorded by three video recorders (two Samsung SV-300WD and one LG LV-R33). Each group of 30 fish was towed for approximately 30 min or until most of the fish were exhausted. Towing speed was measured using the Doppler log (Tokimec TD-310) aboard the training ship. During the experiments on 7-8 October 2004, the seawater temperature was 22°C and salinity 32 psu measured by YSI85 .

The erratic or "panic" behaviors exhibited in 57 scenes were analyzed; these were characterized by active variations in swimming position from the lateral view on the LCD monitor (IMR, 15 inches). The lateral fish position was defined in two dimensions (depth and towing) and relative coordinates were measured in millimeters to scale with OHP films depicted on the monitor. The actual change in fish position was recorded in 0.3 to 0.5 s intervals using a scale derived from visible mesh size. The actual fish swimming speed in the cod-end was calculated in meters per second as the straight moving distance of fish snout, referring to towing distance divided by moving time of 0.3 to 0.5 s. The relative fish swimming speed can therefore be represented by actual swimming speed minus towing speed, producing a positive number when it is faster than the towing speed and a negative number when it is slower than the towing speed.

The angular velocity of turning movements were defined in radians per second and calculated as the difference in moving direction divided by the moving time of 0.3 to 0.5 s and represented by a positive symbol when turning upward from the towing direction and a negative symbol when turning downward from the towing direction. The nearest distance from a fish to the net was defined and estimated as the distance from the fish snout to the upper or lower net panel of the cod-end derived from the lateral view.

Results and Discussion

The relationship between total length (L: cm) and fish weight (W: g) or body girth (G: cm) of black porgy used in these towing experiments are represented in Fig. 2.

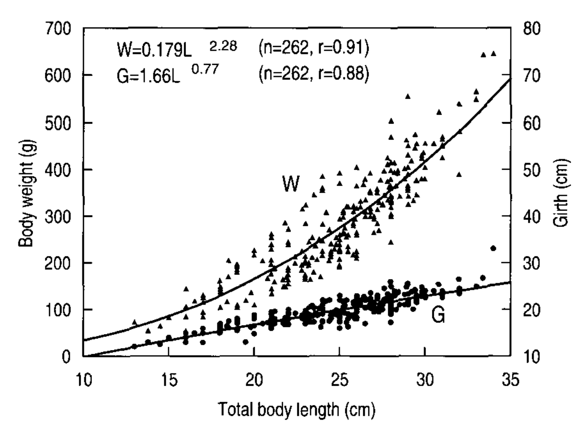

Fig. 2. Relationship between total body length (L) and body weight (W) or body girth (G) of black porgy used in these towing experiments (n=number of fish, r=correlation coefficient).

Black porgy mainly exhibited an optomotor response in their swimming movements during the cod-end towing experiments; they maintained a stable swimming speed and position relative to the towed cod-end, similar to results observed in North Sea haddock (Wardle, 1993). However, Fig. 3 illustrates two examples of the other response: active erratic or "panic" behavior. Fish A exhibits the behavior pattern of moving up toward the front, then turning and swimming back again. Fish B exhibits the other pattern of swimming back away from the front and then moving forward again, maintaining this position, and then gradually dropping back.

Fig. 4 illustrates how these two patterns can be combined to form complicated variations of swimming positions, speed, moving time, and turning directions. Therefore, the chaotic swimming movements in the towing cod-end, which varied between the extremes of swimming in stable linear patterns and irregular sudden movements appear to be similar to fish movement in the front part of a trawl (Kim and Wardle, 2003).

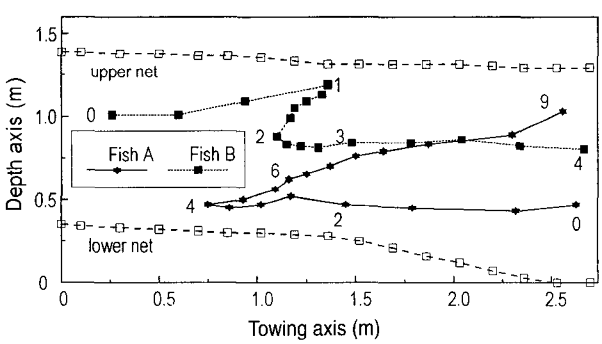

Fig. 3. The lateral coordinates of swimming tracks by black porgy in the towing cod-end as two typical patterns (towing direction is to the left and numbers represent time elapsed in seconds).

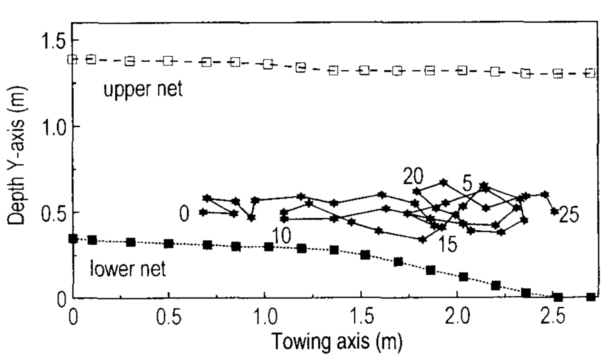

Fig. 4. The lateral coordinates of swimming tracks by a black porgy in the towing cod-end as an example of chaotic behavior (towing direction is to the left and numbers represent time elapsed in seconds).

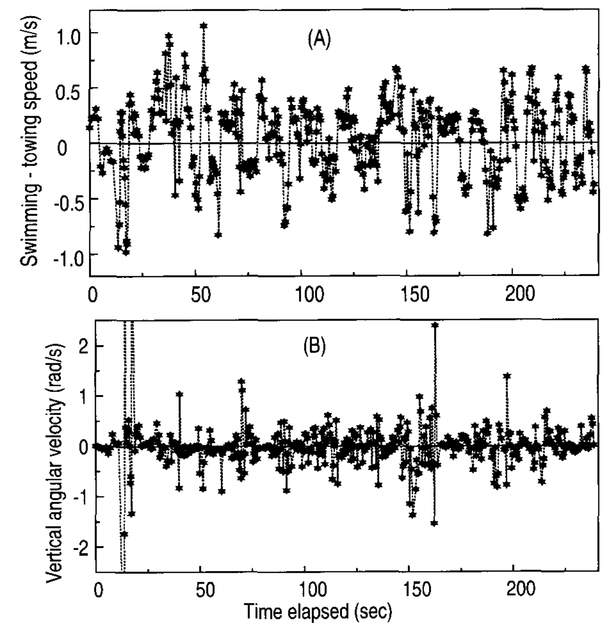

Fig. 5. Examples of time series for relative swimming speed (A) and angular velocity (B) of black porgy in the towing cod-end when towing speed is less than 1.3 m/s.

Fig. 5 shows the time series of relative swimming speeds and angular turning velocity as erratic or "panic" swimming for 25 consecutive scenes of black porgy when towing speed was slower than 1.3 m/s. Relative swimming speed varied by ±1.0 m/s (actual swimming speed 0.3-2.3 m/s) and angular velocity varied by ±1.5 rad/s and was irregular and unpredictable without harmonic period. These ranges in variation were smaller than in results from a study of haddock in the front part of a North Sea trawl (Kim and Wardle, 2003). However, these variation tendencies can be applied in the numerical modeling of fishing selectivity in the towing cod-end as fish behaviors such as swimming ability (Kim and Wardle, 1997) or reaction to trawl gear (Kim and Wardle, 2005) were in previous models.

Fig. 6 shows the relationship between relative swimming speed and angular velocity as polar coordinates using three steps of towing speed: slower than 1.3 m/s; between 1.3 and 1.5 m/s; and faster than 1.5 m/s. Only when towing speed is slower than 1.3 m/s, the range of the angular velocity was increased with slower relative swimming speed (<0 m/s) while the range of the angular velocity was decreased with faster relative swimming speed (>0 m/s). However, towing speed did not affect relative swimming speed or angular velocity. When towing speed was slower than 1.3 m/s or faster than 1.5 m/s, black porgy an-

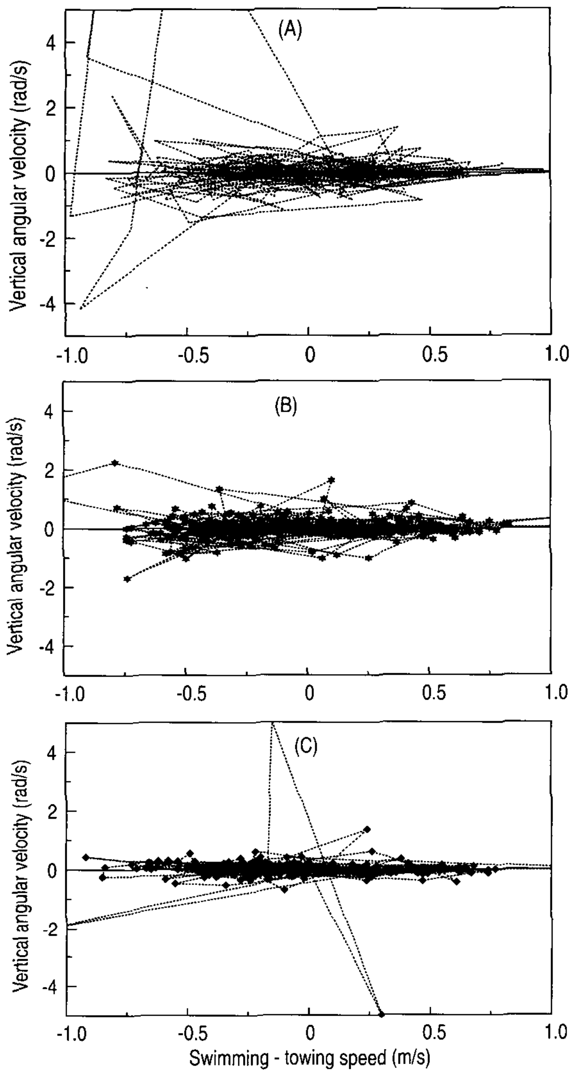

Fig. 6. The relationship between relative swimming speed and angular velocity at three different towing speeds: slower than 1.3 m/s (A), between 1.3 and 1.5 m/s (B), and faster than 1.5 m/s (C).

gular velocity exhibited a normal distribution, while at other towing speeds, neither swimming speed nor angular velocity exhibited a normal distribution.

Fig. 7 shows the relationships between distances from fish snouts to the upper or lower cod-end net and the swimming speed and angular velocity for all sampling data with time and towing speed. Results indicate that distance to net or towing speed does not affect swimming speed or angular velocity.

The tail beat frequency (F: Hz) during 14 sampling scenes of black porgy swimming to the front of the cod-end had a range of 7.0 to 9.6 Hz and a mean and S.D. of 8.3 ± 0.7 Hz. The use of Videler and Wardle's (1991) equation of V=0.75F-1 resulted in an es-

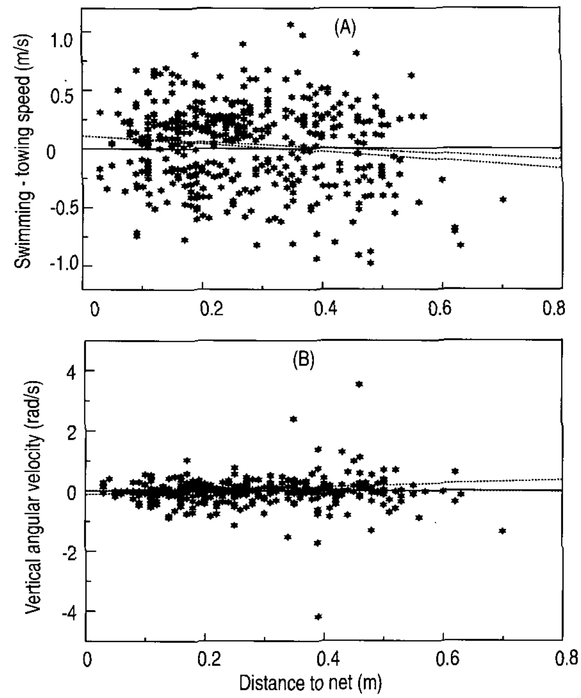

Fig. 7. The relationships between the distance from the fish to the closest upper or lower net panel of the cod-end, and relative swimming speed (A) or angular velocity (B).

timated mean swimming speed (V: L/s) of this tail beat of 5.2 L/s (L is total body length). Therefore, the actual swimming speed of a black porgy with a total length of 28 cm would be 1.46 m/s.

The movements of the black porgy swimming in a towing cod-end have revealed substantial variety and irregularity in components such as swimming speed and angular velocity; the erratic, panic, and chaotic behaviors were very similar to behavior exhibited by haddock during field fishing experiments in the North Sea (Kim and Wardle, 2003). However, black porgy exhibited lower absolute values in swimming speed and angular velocity than did haddock, likely because of differences in fish species and experimental fishing methods such as net construction and water flow in the cod-end (Kim, 1997). In addition, a few black porgy were able to pass through the 120-mm mesh of the towing cod-end only while a lot of haddock's penetration has been observed during fishing operations using whole gear (Glass and Wardle, 1995). Future research could investigate escape behavior, focusing on mesh size and fish size, and then apply the results of this study using chaos theory and neural networks to model cod-end selectivity in towed fishing gear.

Acknowledgments

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