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EFFECTS OF MAGNETIC FORCE ON SWIMMING BEHAVIOR OF ISOLATED *ZACCO PLATYPUS* IN STATIC WATER

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ABSTRACT

It becomes quite problematic in fishery that a lot of larval fish are lost due to enter intake gates of weirs and dams. Some techniques with air bubble, electricity and light have been developed to avoid fish from entering intake gates. In recent years, action control techniques of fish with magnet are evaluated. Hutchinson *et al.* achieved a certain result to prevent the entrance of several species of sharks into longlines by mounting magnets on longlines. Smith & O'Connell showed that magnet worked on *Raja clavata* to prevent alike. Ward *et al.* reported the research that *Danio rerio* which belongs to fresh water fish changed the swimming speed and the swimming direction near the magnets. However, few studies about action control techniques of fresh water fish with magnet have been conducted. In this study, the magnetic flux density of the magnets put on the bottom of the side wall in the circular pool is changed to make clear effects of magnetic force on the swimming behavior of the isolated *Zacco platypus* in static water. The swimming position, the swimming speed, the fish direction and the turning angle are analyzed by capturing the swimming in the experiment. As a result, *Zacco platypus* is unaffected by magnet force under the condition of this experiment.

INTRODUCTION

It becomes quite problematic in fishery that a lot of larval fish are lost due to enter intake gates of weirs and dams. Some techniques with air bubble, electricity and light have been developed to avoid fish from entering intake gates. Patrick *et al*. (1985) showed that *Osmerus mordax dentex* and *Alosa pseudoharengus* avoided the air-bubble barrier with the oval pool. Sekiya *et al*. (2005) observed the swimming behaviors of *Plecoglossus altivelis altivelis*, *Cyprinus carpio* and *Carassius* when the potential gradient was systematically changed in the 0.1 (V/cm) to 1.0 (V/cm) range under the definite condition that the pulse length was 1/100 s and the pulse interval was 10 Hz. As a result, *Plecoglossus altivelis altivelis* didn't changed the swimming behavior, however *Cyprinus carpio* and *Carassius* avoided the electric screen. Ono & Simenstad (2014) showed that *Oncorhynchus* changed the swimming behavior under the condition that the lighting system only illuminated the area shaded by the river structures. Dawson *et al*. (2006) pointed out that the combination of the electric screen and the air bubble was more effective in limiting the movement of *Gymnocephalus cernua* than using electric screen only.

Walker *et al*. (1997) found that *Oncorhynchus mykiss* bore the organ that could feel the magnetic field of the earth. It is generally recognized that calcium, iron which belongs to magnetic material and zinc which belongs to diamagnetic material are absorbed into the ear stone of fish (see Harada *et al*., 2001). Therefore, in recent years, action control techniques of fish with magnet are evaluated. Hutchinson *et al*. (2012) achieved a certain result to prevent the entrance of several species of sharks into longlines by mounting magnets on longlines. Smith & O'Connell (2014) showed that magnet worked on *Raja clavata* to prevent alike. Ward *et al.* (2014) reported the research that *Danio rerio* which belongs to fresh water fish changed the swimming speed and the swimming direction near the magnets. However, few studies about action control techniques of fresh water fish with magnet have been conducted. In this study, the magnetic flux density of the magnets put on the bottom of the side wall in the circular pool is changed to make clear effects of magnetic force on the swimming behavior of the isolated *Zacco platypus* in static water.

EXPERIMENTAL SETUP AND CONDITION

Figure 1 shows the schematic of the experimental setup that is circular pool, in which D =1.83 m is the diameter of the circular pool. Table 1 shows the experimental condition, in which φ is the diameter of the cylindrical magnet and S_φ is the diameter of the sphere magnet. The values of magnetic flux density B are changed 0.1, 0.2, 0.3 and 0.4 T. Besides, it is pointed out that earth magnetism is 5×10^{-5} T (see Harada *et al*., 2001). Figure 2 shows the picture of the used magnets. The circular pool is divided into normal area or magnet area in line symmetry. 32 magnets are put on the bottom of the side wall of magnet area at equal spaces. The experiment is performed 5 cases in the situation whether the magnets are put on or not. The used fish is *Zacco platypus* and the averaged body length $\overline{B_L}$ is about 0.07 m.

The water depth h is 0.04 m. The circular wire net 0.15 m in diameter is placed in the center of the circular pool and the isolated *Zacco platypus* is put into the circular wire net. After it is confirmed that the isolated *Zacco platypus* settled down, the circular wire net is taken up. The swimming behavior of the isolated *Zacco platypus* are recorded with a digital video camera fastened to the ceiling for 1 minute. In this way, the experiment is performed 30 times in each case. After recording, the swimming position, the swimming speed, the fish

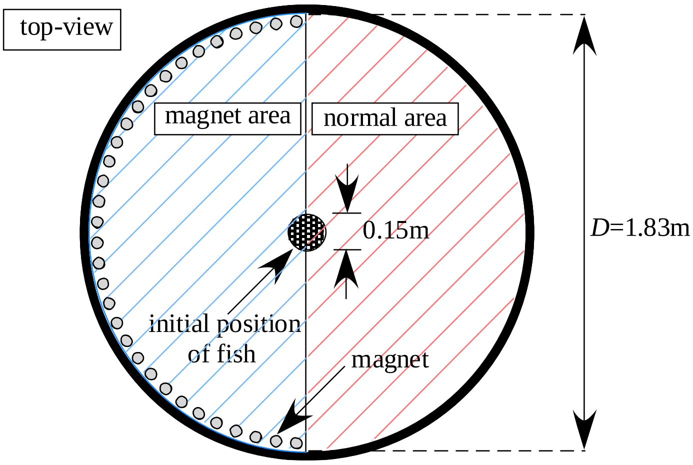

Figure 1. Experimental setup

Table 1. Experimental condition

Magnet			
Type	Shape	Size	B (T)
			0
Ferrite	Cylinder	φ 12mm×3.2mm	0.1
Neodymium	Sphere	S_{φ} 6mm	0.2
	Cylinder	φ 10mm×2mm	0.3
		φ 10mm×5mm	0.4

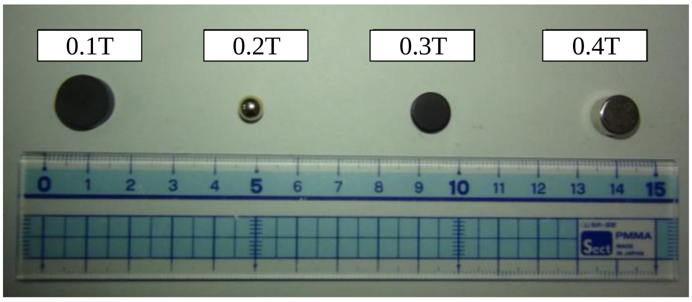

Figure 2. Used magnets

direction and the turning angle are analyzed every 0.5 seconds.

EXPERIMENTAL RESULTS AND ANALYSIS

Swimming position

Figure 3 shows the time ratio of swimming in normal area or magnet area in each case. There are few changes in the time ratio of swimming area associated with magnetic flux density B.

The non-dimensional distance between the fish and the side wall divided by the averaged body length $d/\overline{B_L}$ is calculated. Figure 4(a) shows the frequency distribution of $d/\overline{B_L}$ in each case regarding normal area. The distribution profiles that have a high frequency in low value and decrease with increase of value are described. In addition, there are few changes in the distribution profiles and the peak positions associated with increase of magnetic flux density B. Figure 4(b) shows the frequency distribution of $d/\overline{B_L}$ in each case regarding magnet area.

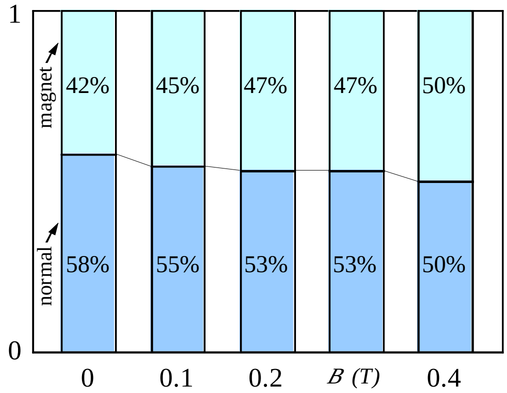

Figure 3. Time ratio of swimming area

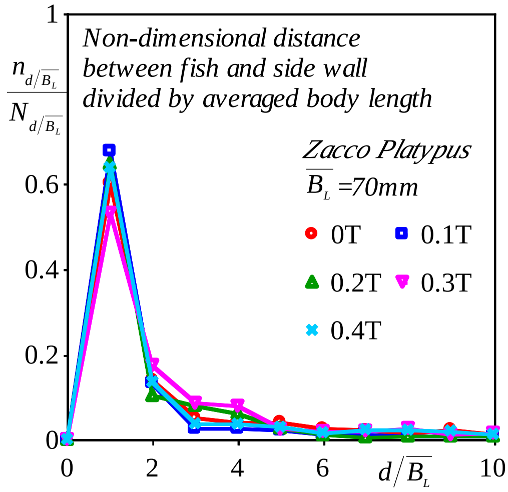

Figure 4(a). Normal area

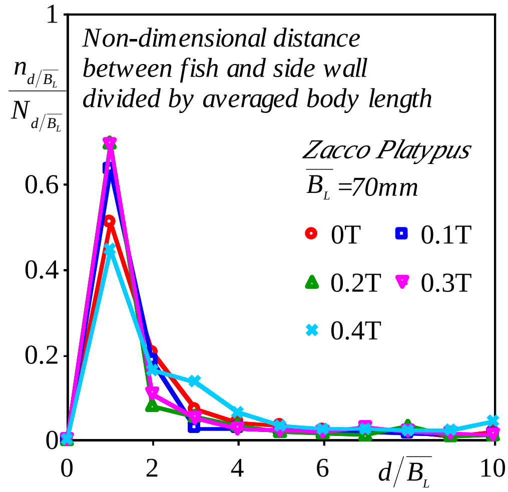

Figure 4(b). Magnet area

Figure 4. Frequency distribution of $d/\overline{B_L}$

The distribution profiles are similar to those of normal area. In other words, there are few changes in the distribution profiles and the peak positions associated with increase of magnetic flux density B.

Judging from these results, it is found that presence or absence of the magnets has few effects on the swimming position in the range of this study.

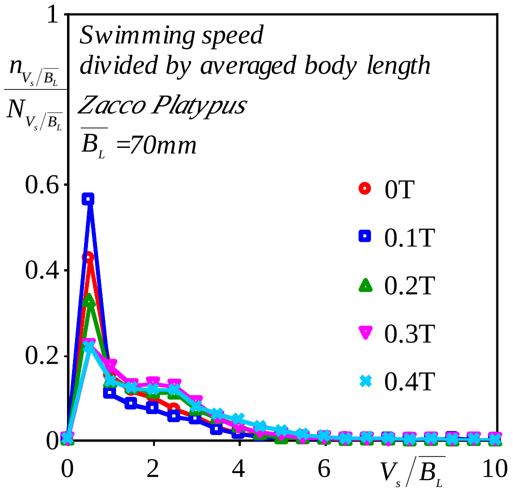

Figure 5(a). Normal area

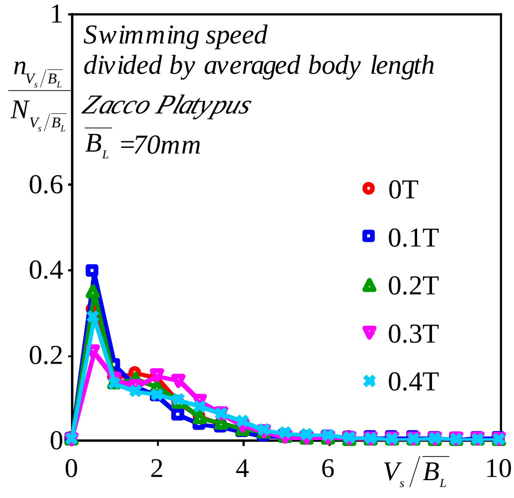

Figure 5(b). Magnet area

Figure 5. Frequency distribution of $V_s / \overline{B_L}$

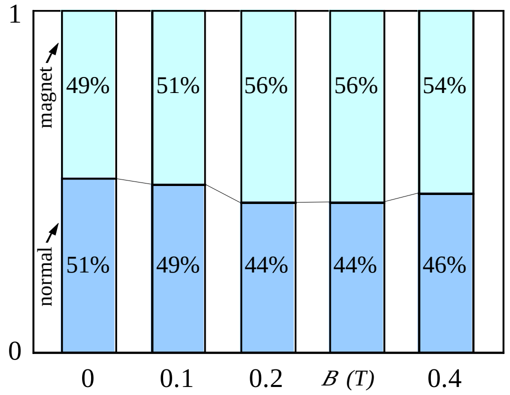

Figure 6. Selected ratio of fish direction

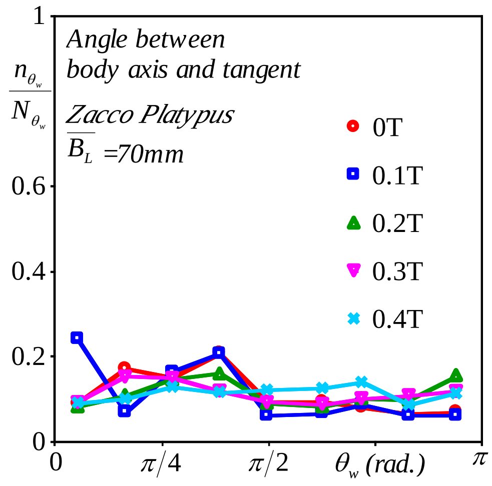

Figure 7(a). Normal area

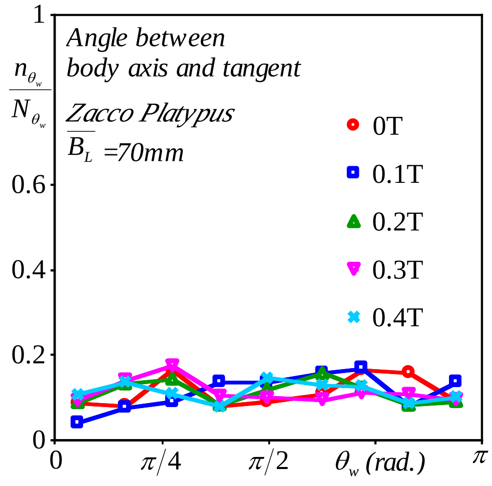

Figure 7(b). Magnet area

Figure 7. Frequency distribution of θ_w

Swimming speed

The swimming speed divided by the averaged body length $V_s / \overline{B_L}$ is calculated. Figure 5(a) shows the frequency distribution of $V_s / \overline{B_L}$ in each case regarding normal area. The distribution profiles that have a high frequency in low value and decrease with increase of value are described. In addition, there are few changes in the distribution profiles and the peak positions associated with increase of magnetic flux density B. Figure 5(b) shows the frequency distribution of $V_s / \overline{B_L}$ in each case regarding magnet area. The distribution profiles are similar to those of normal area. In other words, there are few changes in the distribution profiles and the peak positions associated with increase of magnetic flux density B.

Judging from these results, it is found that presence or absence of the magnets has few effects on the swimming speed in the range of this study.

Fish direction

The selected ratio of the fish direction is defined as the ratio of the number of the intersection between the forward extension of the body axis and the side wall of normal area or magnet area. Figure 6 shows the selected ratio of the fish direction in each case. There are few changes in the selected ratios of the fish direction associated with magnetic flux density B.

The angle between the body axis and the tangent θ_w is defined as the angle that formed by the intersection between the forward extension of the body axis and the tangent to the circular pool. Figure 7(a) shows the frequency distribution of θ_w in each case regarding normal area. The distribution profiles that have a similar frequency in any value are described. In addition, there are few changes in the distribution profiles associated with increase of magnetic flux density B. Figure 7(b) shows the frequency distribution of θ_w in each case regarding magnet area. The distribution profiles are similar to those of normal area. In other words, there are few changes in the distribution profiles associated with increase of magnetic flux density B.

Judging from these results, it is found that presence or absence of the magnets has few effects on the fish direction in the range of this study.

Turning angle

It is observed that there is little difference in the frequency of the turning direction to right or left. Therefore, the absolute value of the turning angle $|\theta_t|$ is calculated. Figure 8 shows the frequency distribution of $|\theta_t|$ in each case. The distribution profiles that there are the peak positions within the 20° to 40° range and have a low frequency in high value are described. In addition, there are few changes in the distribution profiles and the peak positions associated with increase of magnetic flux density B.

Judging from these results, it is found that presence or absence of the magnets has few effects on the turning angle in the range of this study.

CONCLUSIONS

In this study, the magnetic flux density of the magnets put on the bottom of the side wall in the circular pool is changed to make clear effects of magnetic force on the swimming behavior of the isolated *Zacco platypus* in static water. As a result, there is little difference in the swimming position, the swimming speed, the fish direction and the turning angle associated with the change of magnetic flux density B. Therefore, it is found that *Zacco platypus* is unaffected by magnet force under the condition of this experiment.

NOMENCLATURE

D diameter of circular pool, m
φ diameter of cylindrical magnet, m
S_φ diameter of sphere magnet, m
B magnetic flux density, T
$\overline{B_L}$ averaged body length, m
h water depth, m
d distance between fish and side wall, m
V_s swimming speed, m/s
θ_w angle between body axis and tangent, rad
θ_t turning angle, rad

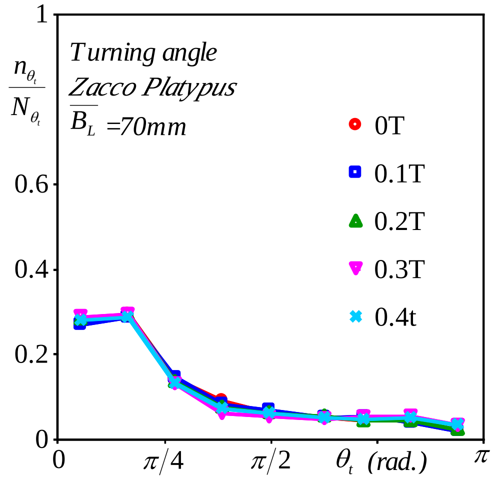

Figure 8. Frequency distribution of θ_t

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