Effects of vegetation density on swimming behavior of Zacco platypus

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EFFECTS OF VEGETATION DENSITY ON SWIMMING BEHAVIOR OF *ZACCO PLATYPUS*

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ABSTRACT

It is important to secure the rest area for fish. Fish has the ordinary and dark muscle. When fish uses ordinary muscle, fish gets tired. In such a situation, fish needs a rest. In this study, vegetation density in open-channel is changed. The trajectories of *Zacco platypus* were observed. It was found that *Zacco platypus* utilized the slow velocity area as rest space. Staying in vegetation area increases with an increase of vegetation density. An approach rate to vegetation area rises with an increase of vegetation density. However, it was not found that clear relationship with a migration rate of *Zacco platypus* and vegetation density.

1. INTRODUCTION

Nakamura (1985) showed the condition that is able to live the fish in the river is securing of flow discharge, securing of water quality, security of the bait, the protection from a natural enemy, security of the spawning ground, the security of paths of excursion, and the security of the place of refuge. In this condition security of the place is thought that is classified in two from the viewpoint of muscle fatigue and scale at time. The muscle of the fish has the dark muscle and the ordinary muscle. Usually the fish uses the dark muscle which does not accumulate for fatigue, and the fish does not want to use the ordinary muscle which fatigue is accumulated. Fatigue is accumulated when swimming speed is over the 2-4 times of the flow velocity divided by the body of fish, so the fish often needs the rest. In this case, rest time is presumed that within few seconds to few minutes. Furthermore, it is necessary to evacuate when fish met the predation risk and met to velocity more than the burst swimming speed at the time of flood. In this case fish evacuates regardless of accumulation of muscle fatigue. Further, the condition that the fish leaves the place of refuge is when natural enemy leaves or the flood goes away, therefore the fish stayed in the place of refuge for the long time.

Many examples of study exist about the fish is using the place of refuge. Takamizu *et al*. (2007) changed vegetation density sistematically and released *Tribolodon hakonensis*. It was found that the number of fish approaching decreased with vegetation density increases. Azuma *et al*. (1999) showed that *Tribolodon hakonensis* which flowed down by flood evacuated to vegetation or wand. However, little is known about the relation of vegetation density or hydraulic functions and swimming behavior.

In this study, simulated vegetation density in open-channel was changed to make clear effects of vegetation density on the swimming behavior of *Zacco platypus*.

2. MATERIALS AND METHODS

Figure 1 shows the open-channel. Open-channel was designed like following. The pool length was 4.0m and width L_z was 0.8m. x axis is taken in the direction of flowing. y axis is taken in the vertical direction from bottom. z axis is taken in the direction of the crossing. Case name was defined as shown in Table 1. The spaces of the round columns d were set to five patterns within the range from 4 to 20cm. Spaces of the round columns was defined as the distance between the center of the spaces of the round columns. The area was defined as vegetation area. Figure. 2 shows the layout drawing of the round columns in vegetation area of D-04 as an example. 10 *Zacco platypus* averaged body length $\overline{B_L}$ is 70mm were used in each experiment. The recording has been carried out for 5 conditions. In this way, the experiment is performed 5 times in each case. The flow velocity divided by average length of *Zacco platypus* was fixed 10 in each case. The number of pixel of the digital video camera is 1440×1080, and recording speed is 30fps. Experiment time is 1minute in each case. After the experiment, the picture of swimming behavior of *Zacco platypus* was captured at 0.5s interval. Approach rate, migration rate, and staying time for vegetation area were calculated with the captured pictures and coordinated plot software. Three components of flow velocity were measured. Average of flow velocity (U, V, W) of each direction axis (x, y, z) and synthetic flow velocity was calculated after measuring. When flow velocity is measured, *Zacco platypus* is not put into the open-channel.

3. RESULTS AND DISCUSSION

3.1. Flow condition

Figure 3 shows vector figures of flow velocity V_V for case D-04, D-12 and D-20. Flow velocity in vegetation area and the down stream decreases with spaces of the round columns narrow. It was found that flow velocity of the left bank side is fast and right bank side is slow in each case. Figure 4 shows mean flow velocity V in vegetation area for case D-04, D-12 and D-20. Mean flow velocity in vegetation area decreases with the spaces of the round columns narrow. It is thought that fatigue accumulates because fish uses ordinary muscle which fatigue accumulates in the area where the flow velocity divided

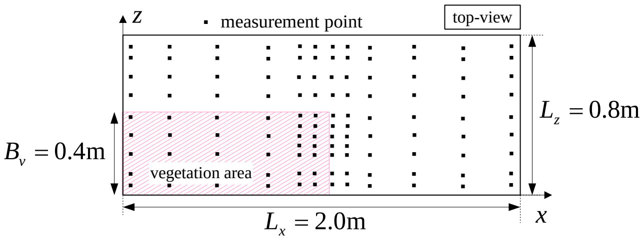


Figure 1. Experimental device

Table 1. Experimental case

case name	D-04	D-08	D-12	D-16	D-20
equal distance(cm)	4	8	12	16	20
velocity $U_m/\overline{B_L}$ (1/s)	10				

D-04

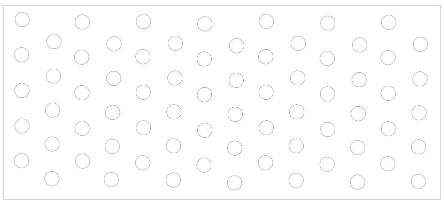
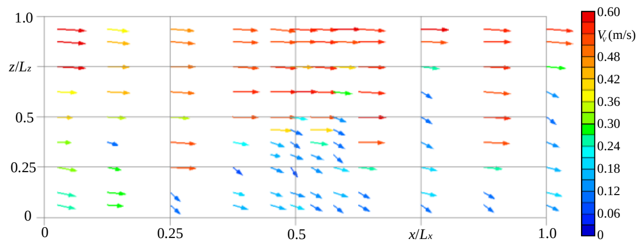
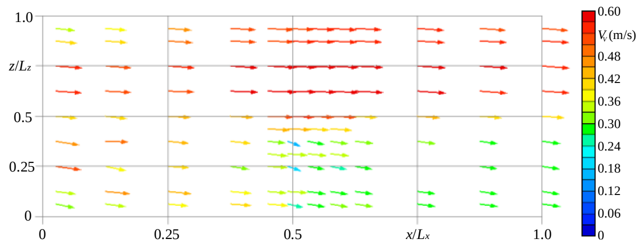


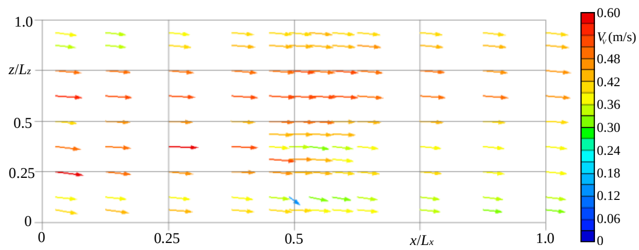
Figure 2. Layout drawing of the round columns



(a) D-04



(b) D-12



(c) D-20

Figure 3. The vector figure of flow velocity

by averaged body length of *Zacco platypus* is 10. Therefore, it is thought that *Zacco platypus* swam in vegetation area and the down stream to avoid accumulation of fatigue.

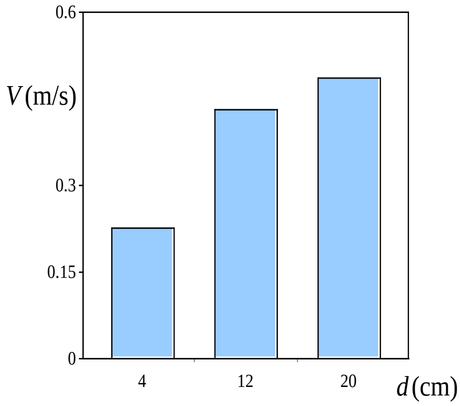


Figure 4. Mean flow velocity

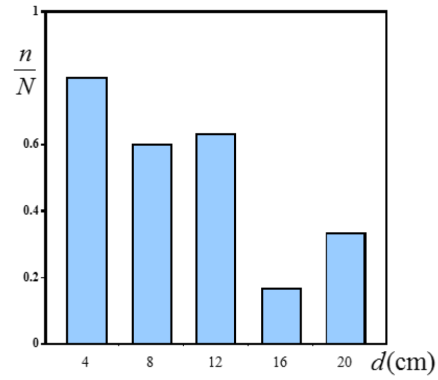


Figure 5. Approaching rate

3.2. Approaching rate

The approaching rate of *Zacco platypus* is defined as follows:

Approaching rate

$$= \frac{\text{Number of fish approached to vegetation area } n}{\text{Number of fish that used to experiment } N} \quad (1)$$

Figure 5 shows the approaching rate for vegetation area of *Zacco platypus* in each case. It is thought that the fish takes a rest in the state that is lower than cruising speed without the accumulation of fatigue when using the dark muscle. Generally, the cruising speed V_{fC} is defined as follows:

$$V_{fC}/\overline{B_L} = 2\sim4 \quad (2)$$

the approaching rate in case D-04 reaches near 80 % and the approaching rate decreases with spaces of the round columns spread. In Figure 3 and Figure 4, flow velocity is restrained around 0.10～0.24(m/s) in vegetation area. This velocity divided by average length of *Zacco platypus* is less than 4. *Zacco platypus* swims in slow velocity area to avoid accumulation of fatigue because *Zacco platypus* accumulates fatigue when flow velocity divided by average length of *Zacco platypus* is 10. Therefore, *Zacco platypus* can swim with the cruising speed V_{fC} that has no accumulation of fatigue. It follows from that *Zacco platypus* approaches to vegetation area to rest

3.3. Swimming trajectory

Figure 6 shows swimming position that were given for each 0.5 second in each case. *Zacco platypus* avoids fast flow velocity area in left bank side in all case. *Zacco platypus* swims in vegetation area when the spaces of the round columns were narrow in D-04, D-08, while the number of *Zacco platypus* in vegetation area decreases in D-12, D-16 and D-20 in comparison with D-04, D-08. *Zacco platypus* staying in down stream of vegetation area moves to vegetaion area with the spaces of the round columns narrow. Therefore, it is clear that *Zacco platypus* uses the spaces of the round columns as a rest area when the spaces of the round columns narrow and flow velocity in the spaces of the round columns decreases.

Figure 7 shows an example of the swimming trajectory of *Zacco platypus* every 0.5 second in any 1 min with each case. Considering D-04 and D-08 shown light blue line and yellow line, *Zacco platypus* turns frequently and stays in vegetation area when the spaces of the round columns narrow. On the other hand, considering D-12, D-16 and D-20 shown green line, red line and blue line, the tendency that *Zacco platypus* migrates and go to main flow area is shown. Therefore, it is shown that *Zacco platypus* uses vegetation area as a rest area when the spaces of the round columns is small and do not like vegetation area with spaces of the round columns spread. It is thought that *Zacco platypus* likes the slow velocity area to avoid using ordinary muscle.

3.4. Fish school radius

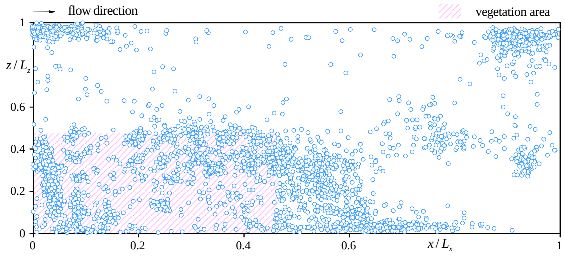
Fish school radius was calculated from the Eq. 3 that Ishikawa (2000) defined.

$$R \equiv \sqrt{\sum_{i=1}^{N} r_i^2 \Big/ N} \tag{3}$$

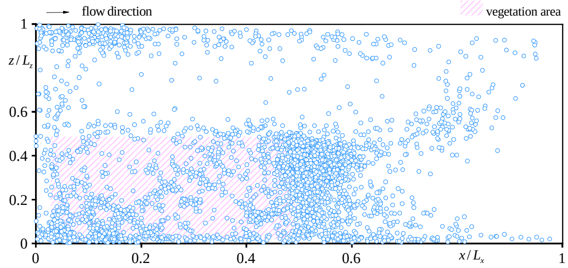
Figure 8 shows frequency distribution of the value in which the fish school radius R divided by the averaged body length of *Zacco platypus* $\overline{B_L}$ in each case. It is defined that R is fish school radius, r_i is distance between centroid of fish school and each test fish, and N is total population in each fish school. The fish school radius R tends to increase with the spaces of the round columns narrow. Considering Figure 6, *Zacco platypus* swims around down stream area of the vegetation area in D-12, D-16 and D-20 which spaces of the round columns area are wide. Fish school radius R is large and *Zacco platypus* swims without crowding after entering vegetation area in D-04 and D-08 which the spaces of the round columns are small. Furthermore, considering Figure 8, frequency distribution of the value in which the fish school radius concentrates on a small value. Thus, it is confirmed that *Zacco platypus* forms fish school. Therefore, *Zacco platypus* forms fish school and swims in the down stream area of the vegetation area when the spaces of the round columns is small.

3.5. Average staying time

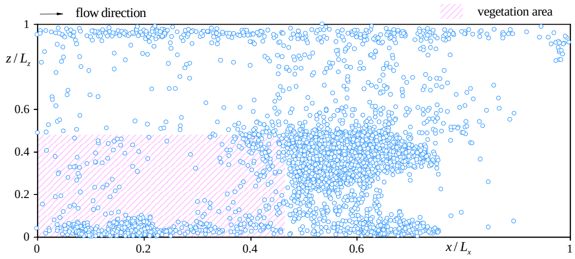
Figure 9 shows the averaged staying time per one *Zacco platypus* $\overline{T}$ in vegetation area in each case. The average staying time increases with the spaces of the round columns narrow. Considering Figure 7, it is thought that this is because *Zacco platypus* swims little by little in



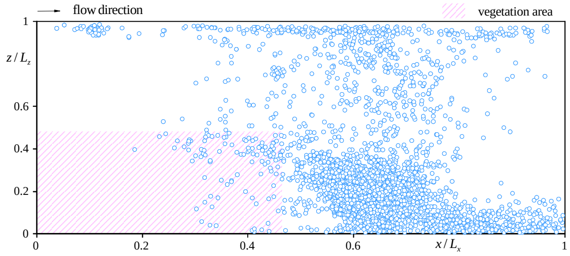
(a) D-04



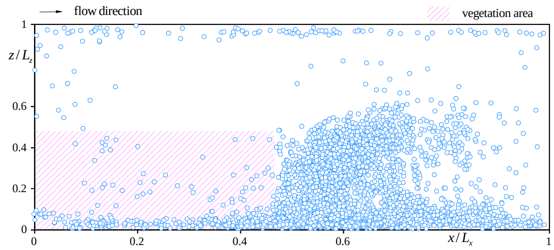
(b) D-08



(c) D-12



(d) D-16



(e) D-20

Figure 6. Swimming position

the vegetation area with the spaces of the round columns narrow.

3.6. Migration rate

The migration rate of *Zacco platypus* is defined as follows:

Migration rate

$$= \frac{\text{Number of fish that migrated } n_m}{\text{Number of fish that approached to vegetation area } n} \tag{4}$$

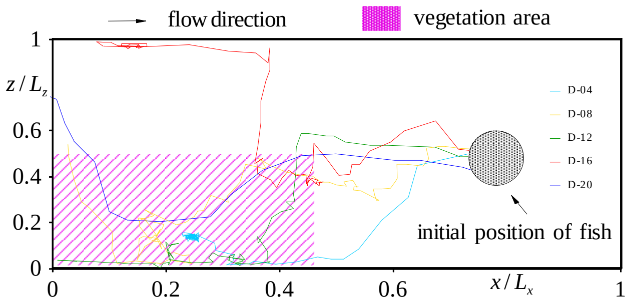


Figure 7. Swimming trajectory

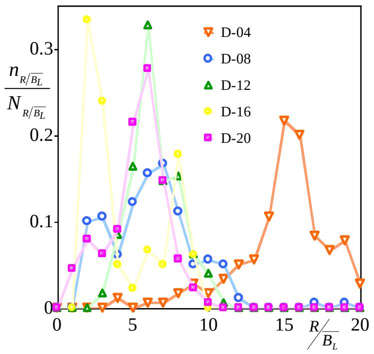


Figure 8. Frequency distribution of this fish school radius

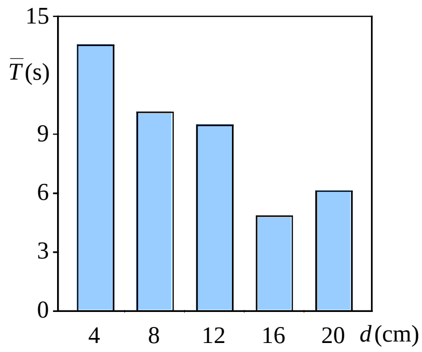


Figure 9. Averaged staying time

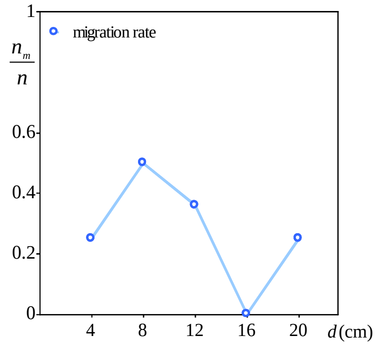


Figure 10. Migration rate

Figure 10 shows the migration rate of *Zacco platypus* which approached to vegetation area. The clear tendency of the relationship between migration rate of *Zacco platypus* and the spaces of the round columns was not confirmed. Takamizu *et al.* (2007) changed density of groyne and observed the swimming behavior of *Zacco platypus*. However, the relationship between density of groyne and the migration was not elucidated. Therefore, the existence of the round columns is ineffective in promoting migration of *Zacco platypus*. However, it is thought that the round columns produce effect as the rest area

4. CONCLUSION

In this study, simulated vegetation density in open-channel is changed to make clear effects of vegetation density on the swimming behavior of *Zacco platypus*. As a result, the following have been understood.

(1) *Zacco platypus* used vegetation area as a rest area when spaces of vegetation were from 4 to 8cm.
(2) *Zacco platypus* stayed in vegetation area when density of vegetation was high, while *Zacco platypus* stayed at downstream side of vegetation area when density of vegetation was low.
(3) The relation of migration rate of *Zacco platypus* which entered vegetation area and vegetation density was not confirmed.

NOMENCLATURE

L length, m
B width, m
d spaces between the round columns and others, cm
$\overline{B_L}$ averaged body length, mm
V_V flow velocity, m/s
V mean flow velocity in vegetation area, m/s
V_{fc} the cruising speed, m/s
R fish school radius, mm
r_i distance between centroid of fish school and each test fish, mm
$\overline{T}$ the average staying time per one *Zacco platypus*, s

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