FISH GATHERING EFFECTS OF *ANGUILLA JAPONICA* BY WATER SPRAYING

KOUKI ONITSUKA

Department of Civil and Architectural Engineering, Kyushu Institute of Technology, 1-1 Sensuicho Tobata-Ku Kitakyushu, Fukuoka 804-8550, Japan

JUICHIRO AKIYAMA

Kyushu Institute of Technology, Laboratory of Hydraulic and Water Environmental Engineering, 1-1 Sensuicho Tobata-Ku Kitakyushu, Fukuoka 804-8550, Japan

TOMOYA SAKO

Kyushu Institute of Technology, Laboratory of Hydraulic and Water Environmental Engineering, 1-1 Sensuicho Tobata-Ku Kitakyushu, Fukuoka 804-8550, Japan

When fish gathering device is set in the entrance of fishway, it is possible that this affect the migration rate. It is assumed that eel (*Anguilla japonica*) gathers near the area of water spraying. However, little is known about effects of fish gathering by water spraying. This study was made to analysis effects of fish gathering of eels under the condition that the range and the discharge of water spraying are changed. It was found that water spraying has effects of fish gathering as compared with non-spraying in this experiment. Besides, effects of fish gathering grow with increasing the range of water spraying and the discharge.

1 INTRODUCTION

When river crossing structures like dams and weirs are constructed in the river, the water level of the upper and lower flow becomes discontinuity. This often prevents fish from migrating along the river. Population of the eel (*Anguilla japonica*) has been decreasing in recent years even among fish using fishway. Therefore, 8 species of 19 of eels are designated as an endangered species. The reason given for this include that people catch fish excessively and the river environment has been the deterioration. Santos *et al.* [1] pointed that dams and weirs impede migration of fish. Ministry of Environment reported that it is important for eels to secure continuously of water area in river and coastal area. Therefore, it is desirable that fishway is established in dams and weirs.

Fishway is evaluated in two perspectives: (1) internal elements of fishway and (2) external elements. Internal elements have geometric sharp, hydraulic quantity like the discharge and flow velocity, migrating characteristics of fish and so on. Grasping this internal elements improve migration rate. On the other hand, external elements also have factors affecting migration rate. External elements have location of fishway, guiding to fishway, fish gathering equipment and so on. If there are the method of fish gathering as the external element at the entrance of fishway, it is expected that migration rate increases. However, though there are previous many studies of internal elements about the shape of fishway and migrating characteristics, little has been reported on one of the external of fish gathering like lights and priming water [2-5].

Terazono *et al.* [6] found that *Oncorhynchus masou masou* is attracted to light of each wavelengths under the condition that experimental channel is irradiated with lights having various wavelengths. In addition, it was found that LED (Light-Emitting Diode) is valid for gathering sardine [7].On the other hand, Sato *et al.* [8] reported that priming water improves effects of fish gathering in the front of fishway. Aoki *et al.* [9] pointed out that priming water produces effects of fish gathering under the condition that flow velocity is faster than burst speed of fish. Thus, it is presumed that lights and priming water are effective to fish gathering of swimming fish.

Studies on fish ladder for eels have been started since decades in Europe and America. Brushes and protrusions are set in these fish ladder for eels. Demonstration experiments are also tried. Furthermore, infusing water and spraying water are tested to gather eels. Piper *et al.* [10] pointed that spraying water at the water surface is better than infusing into water in terms of gathering effects for European eels by field observations. Besides, a certain eel farmer gave us the advice that the eel is gathering by spraying water at the water surface. Thus, though it is described as eels are gathering by spraying water in the entrance of fishway, little has been reported on best discharge and range of spraying quantitatively. If this gathering effect is clarified, it is expected that the improvement of the migration rate.

In this study, gathering effects of eels with change of the discharge and the range of spraying were investigated for clarifying this effect at the entrance of the fish ladder.

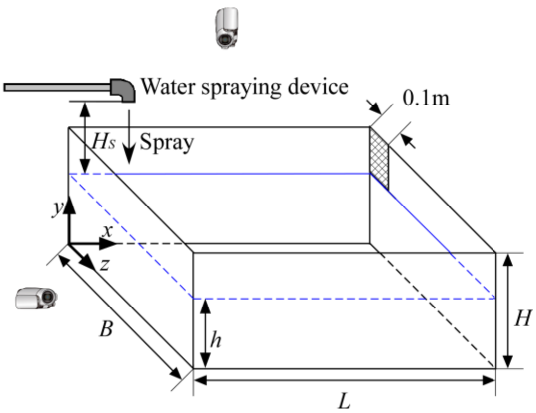


Figure 1. Experimental device

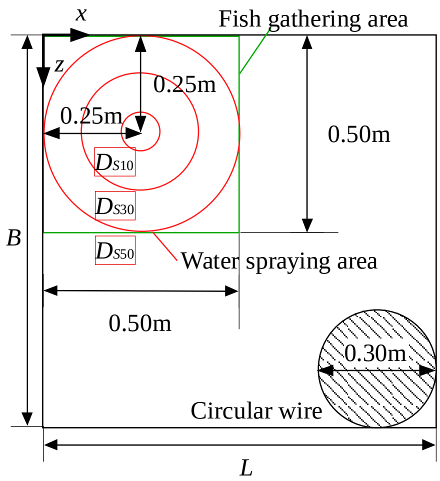


Figure 2. Pool of horizonal section view

Table 1. Experimental case

Discharge Q (ml/s)	Range of water spraying D_s (m)		
	0.10	0.30	0.50
0	Non water spraying		
80	Ds10-80	Ds30-80	Ds50-80
160	Ds10-160	Ds30-160	Ds50-160
240	Ds10-240	Ds30-240	Ds50-240

Figure 3. Eels used in this experiment

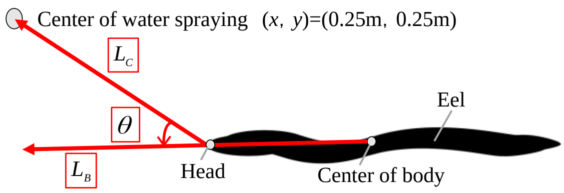


Figure 4. Fish angle of eel

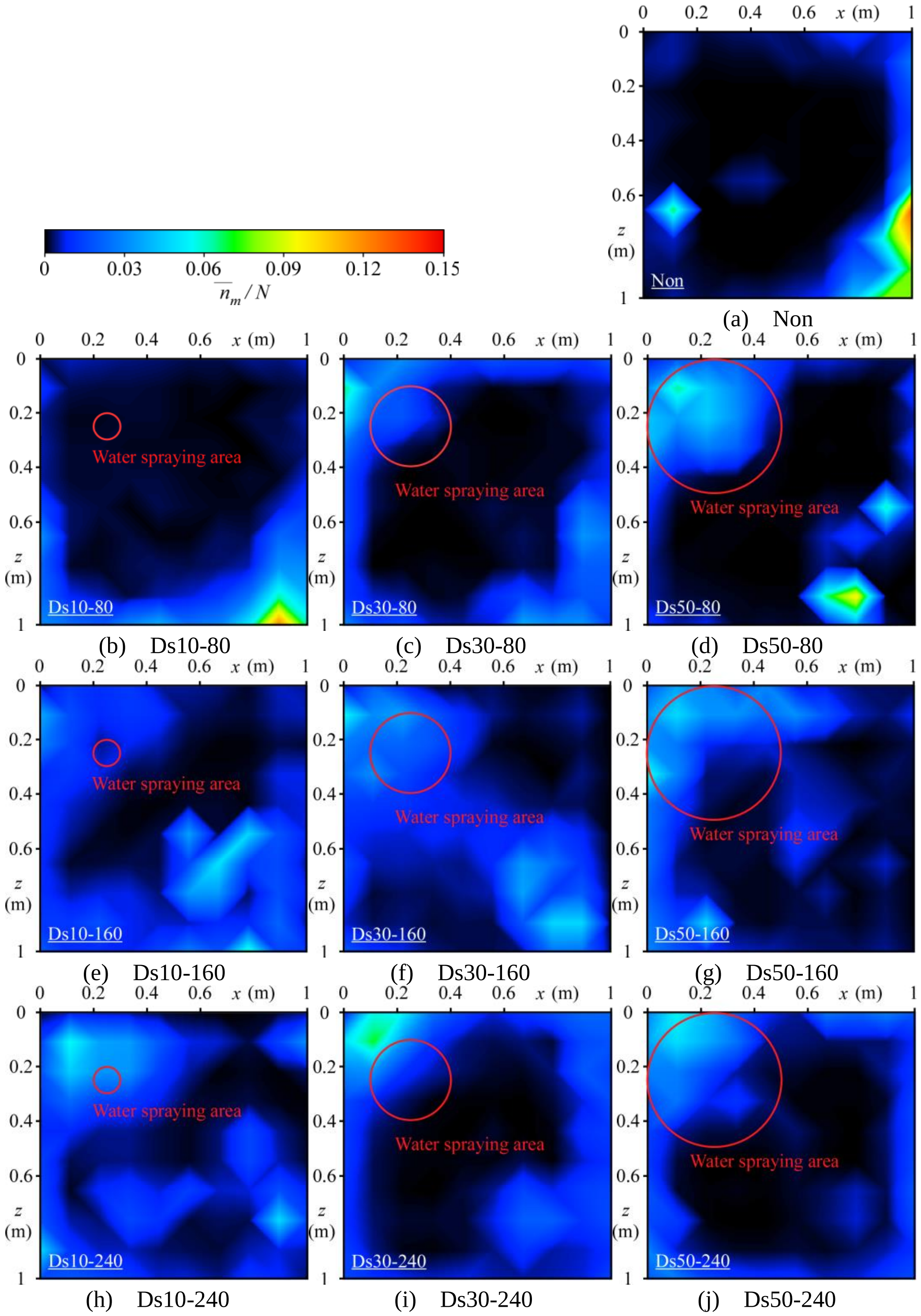
2 EXPERIMENTAL DEVICE AND METHODS

Figure 1. shows the wooden square pool. In this study, it was designed as simple pool for clarifying this effect at the entrance of the fish ladder. Pool length (L) was 1.0m, width (B) was 1.0m and height (H) was 0.45m. x, y and z were the coordinates of length, height and width, respectively. An acrylic wall was used in one of side walls. The water spraying device was set to the position of that height form water surface (H_S) is 0.45m. Besides, the discharge outlet was set to the position of that water depth (h) was 0.30m constantly.

Figure 2. shows the pool of horizonal section view. Middle of the range of water spraying was set to (x, y)=(0.25m, 0.25m). In addition, the fish gathering area of 0.5m square was set a corner of intersection near water spraying.

Table 1. shows experimental cases. The range of water spraying (D_s) was set to three patterns within of 0.10, 0.30 and 0.50m. The discharge (Q) was set to three patterns of 80, 160 and 240ml/s. Cases name is named by the range of water spraying and the discharge. For example, D_s10-80 is the experimental case under the condition of D_s=0.10m and Q =80ml/s. In this study, the experimental value of the discharge and the range of water spraying is set by limit of the spraying device, since the best value of them is unclear. The experiment of not spraying water is conducted to confirm the effects of water spraying. These experiments have been carried out 5 patterns in each case. Besides, water temperature was 20 degree constantly.

Figure 3. shows eels used in this experiment. Averaged body length of eels was 300mm. Eels used in this experiment were captured in Japan, and have been keep in the pond for eel farming. A circular wire net of 0.30m in diameter was set to (x, y)=(0.85m, 0.85m), and fifteen eels are inserted. After eels settled down, the circular



(a) Non (b) Ds10-80 (c) Ds30-80 (d) Ds50-80 (e) Ds10-160 (f) Ds30-160 (g) Ds50-160 (h) Ds10-240 (i) Ds30-240 (j) Ds50-240

Figure 5. Existence rate contour of eels

wire is taken up. 75 eels were parted to 15 eels, and 15 eels were used in order after the experiment of 1 case is finished. Trajectory of eels was recorded with a digital camera set up the upside and the side of the pool for 180 seconds. The pixel of the digital video camera is 1440×1080, and recording speed is 30fps. After recording, the trajectory of eels was analyzed use of pictures in divided every 1 second. Besides, analysis methods and definitions are shown below.

1) Existence rate:The existence rate ($\overline{n_m}/N$) is defined as the value that the time-averaged number ($\overline{n_m}$) is divided by the total number (N).The pool area of 1.0m square are parted to areas of 0.1m mesh respectively, and the number of every 1 second eels (n_m) is counted in each mesh on this occasion.
2) Swimming trajectory: The swimming trajectory is defined as the line connected the head of the eel that was selected at random in fifteen eels each one second.

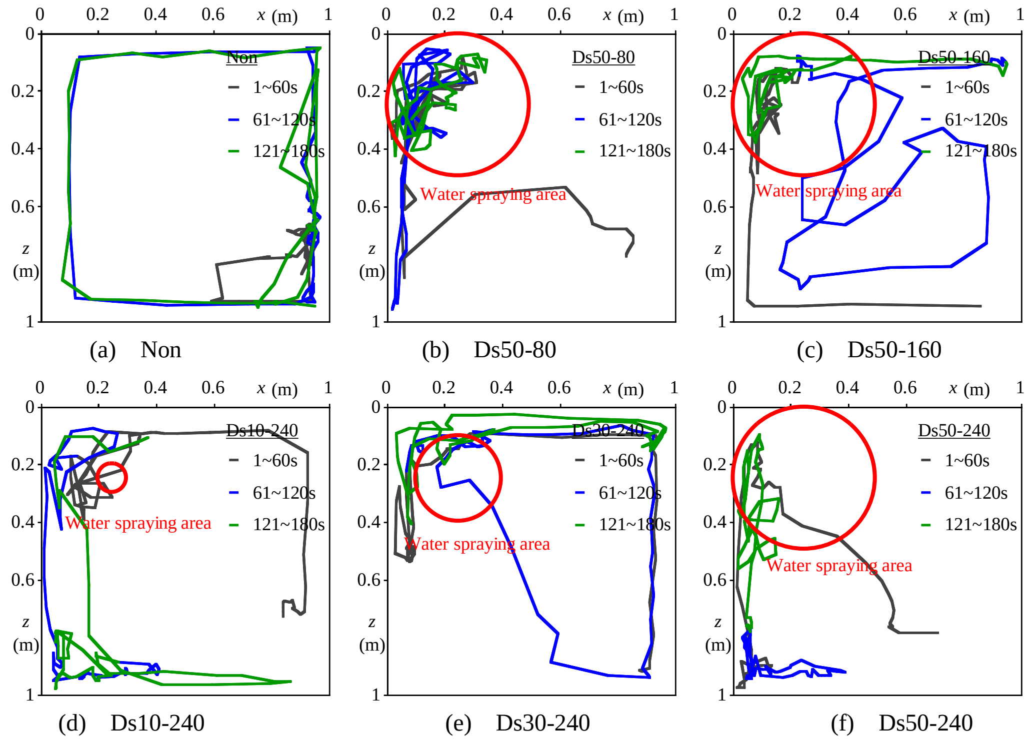


Figure 6. Swimming trajectory of eel

3) Fish angles: Figure 4. shows about fish angles of eels. Fish angles (θ) ware defined as angles between the line connecting the head and center of the waster spraying (L_c) and the line connecting the head and the center of body (L_B). The positive value is set to clockwise direction, and the range of fish angles was set to -180º≤ θ≤180º. Absolute value of fish angles was divided to 20º intervals, and the number of eels in each intervals is counted. The angle frequency that the time-averaged number (n_o) is divided by the total number (N) was calculated.
4) Distance between heads of eels and center of water spraying: Distance between heads of eels and the center of water spraying (d) is divided to 0.10m intervals. The number of eels in each intervals is counted, and the swimming frequency that the time-averaged number ($\overline{n_d}$) is divided by the total number (N) is calculated.
5) Distance between head of eel and bottom: Swimming distance (y) is calculated by pictures from the side of the pool in divided every 1 second for clarifying the swimming position. y is parted to 0.3m intervals, and inside and outside the water spraying area are compared. The number of eels in each intervals is counted, and the swimming frequency that the time-averaged number ($\overline{N_d}$) is divided by the total number (N) is calculated.

3 RESULTS AND DISCUSSION

3.1 Existence rate contour of eels

Figure 5. (a)~(j) show the contour figures of the existence rate. Figure 5. (a) shows that the existence rate of initial position is higher than that of another area. In other words, eels remain at initial position and the area near in the case of non spraying water.

Figure 5 (b)~(d) show that the existence rate of inside the water spraying area increases more than one of outside that area with the increase of the range of water spraying in the case of the discharge Q=80ml/s. Figure 5 (e)~(g) show that the case of the discharge Q=160ml/s has the same quality as the case of the discharge Q=80ml/s. Figure 5. (h)~(j) show that the existence rate is high in the water spraying area at all range of water spraying in the case of the discharge Q=240ml/s. Thus, effects of fish gathering are predisposed to grow by the increase of the range of water spraying and these are high under conditions of large range of water spraying. Besides, the existence rate increases in the water spraying area with the increase of the discharge.

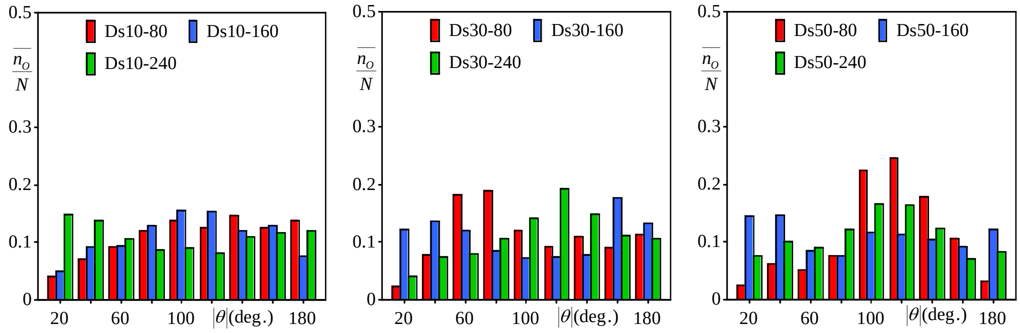
Therefore, effects of fish gathering of eels have increased by the increase of the discharge and the range of water spraying. The discharge is more effective than the range of water spraying above a specified discharge.

3.2 Swimming trajectory of eel

Figure 6. shows the swimming trajectory of the eel. Gray, blue and green lines show 1~60 seconds, 61~120 seconds and 121~180 seconds respectively.
Figure. 6 (a) shows the swimming trajectory of the eel in the case of non spraying water. The eel swims against walls after the eel remains around initial position in 1~60 seconds. Figure. 6 (b)~(f) show the swimming trajectory of the eel in the case of spraying water. The eel enters the water spraying area on several times and often swims against walls outside the water spraying area.
Therefore, water spraying is compared to non spraying water, and the eel repeats entering and leaving the water spraying area.

3.3 Fish angles of eels outside water spraying area

Figure 7. (a)~(c) show the frequent distribution of the fish angles in by the range of water spraying. The change of discharge is focused under the condition of identical range of water spraying. There is no indication to the frequent distribution in the all discharge. The change of range of water spraying is focused under the condition of identical discharge. There is no indication to the frequent distribution in the all range of water spraying too.
Therefore, that changes of the range of water spraying and the discharge hardly influence fish angles is proved.

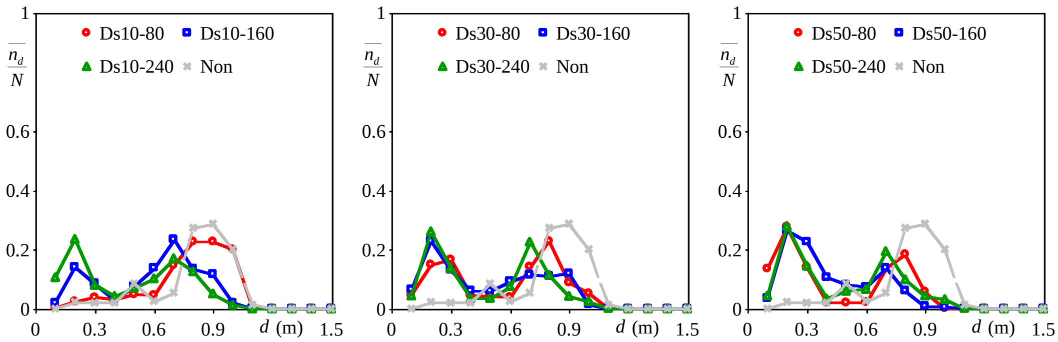


(a) D_S =0.10m (b) D_S =0.30m (c) D_S =0.50m

Figure 7. Frequent distribution of fish angles

3.4 Distance between heads of eels and center of water spraying

Figure 8. shows the frequent distribution of distance (d) by the range of water spraying.. The center of water spraying is set to the same point of water spraying in the case of non water spraying. The swimming frequency is high in $0.7\text{m} \le \overline{n_d}/N \le 1.2\text{m}$ in the case of non water spraying. Thus, that eels swim in separate from center of water spraying is confirmed. Water spraying is compared to non water spraying in cases of the same range of water spraying, and the swimming frequency is high in $0\text{m} \le \overline{n_d}/N \le 0.3\text{m}$ on all cases expect Ds10-80. On the other hand, water spraying is compared to non water spraying in cases of the same discharge, and the swimming frequency is high in $0\text{m} \le \overline{n_d}/N \le 0.3\text{m}$ on all cases expect Ds10-80 too.
Water spraying is compared to non water spraying, and distance between heads of eels and center of water spraying (d) decreases. Therefore, it is confirmed that eels gather around the range of water spraying.

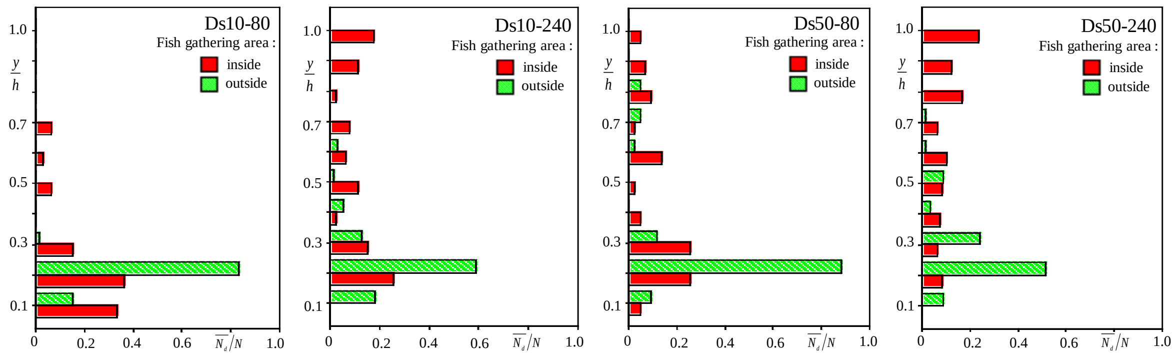


(a) D_S =0.10m (b) D_S =0.30m (c) D_S =0.50m

Figure 8. Frequent distribution of distance between eel and water spraying

3.5 Distance between head of eel and bottom

Figure 9. shows the frequent distribution of the swimming distance (y). Figure 9. (a), (b) show cases that the discharge is difference in same range of water spraying D_s=0.10m. The swimming frequency is high in $0.1 \leq y/h \leq 0.3$ outside the water spraying area on both of cases. The reason given for this include that most eels swim on the pool bed. On the other hand, the swimming frequency increases at the range of $0.7 \leq y/h \leq 1.0$ inside the water spraying area with the increase of the discharge. Figure 8. (c), (d) show cases that the discharge is difference in same range of water spraying D_s=0.50m. The swimming frequency of both cases was high in $0.1 \leq y/h \leq 0.3$ outside the water spraying area. The swimming frequency increases at the range of $0.7 \leq y/h \leq 1.0$ inside the water spraying area with the increase of the discharge. Therefore, the number of eels has increased at the water surface of inside water spraying area with increasing the discharge.
Figure 8. (a), (c) show cases that the range of water spraying is difference in same discharge Q=80ml/s. The swimming frequency was high in $0.1 \leq y/h \leq 0.3$ outside the water spraying area on both of cases. On the other hand, the swimming frequency increases at the range of $0.7 \leq y/h \leq 1.0$ inside the water spraying area with the increase of the range of water spraying. Thus, the number of eels has increased at the water surface of inside the water spraying area with increasing the range of water spraying.
Therefore, inside the spraying area is compared to outside the spraying area, and the number of eels increases around the water surface by effects of spraying water. Besides, effects of fish gathering of eels increase with the discharge and the range of water spraying.



(a) Ds10-80 (b) Ds10-240 (c) Ds50-80 (d) Ds50-240

Figure 9. Frequent distribution of distance between eel and bottom

4 CONCLUSION

In this study, change of the discharge and the range of spraying influencing effects of fish gathering of eels was researched. As a result, it was found following.

(1) Effects of fish gathering increase by the water spraying.
(2) Effects of fish gathering increase with the increase the discharge and the range of water spraying, and the discharge is more effective than the range of water spraying in a concern amount discharge.
(3) The number of eels increases around water surface by water spraying.

It is expected that the migration rate of eels increases by spraying water to the entrance of the eel ladder. The study of migration experiments in the river is developed in the future.

5 ACKNOWLEDGEMNETS

This study was supported by Grants-in-aid for Scientific Research (17K06580) when the study conducts. Finally, the authors are grateful to Marusho Corporation for providing eels treated in this paper.

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