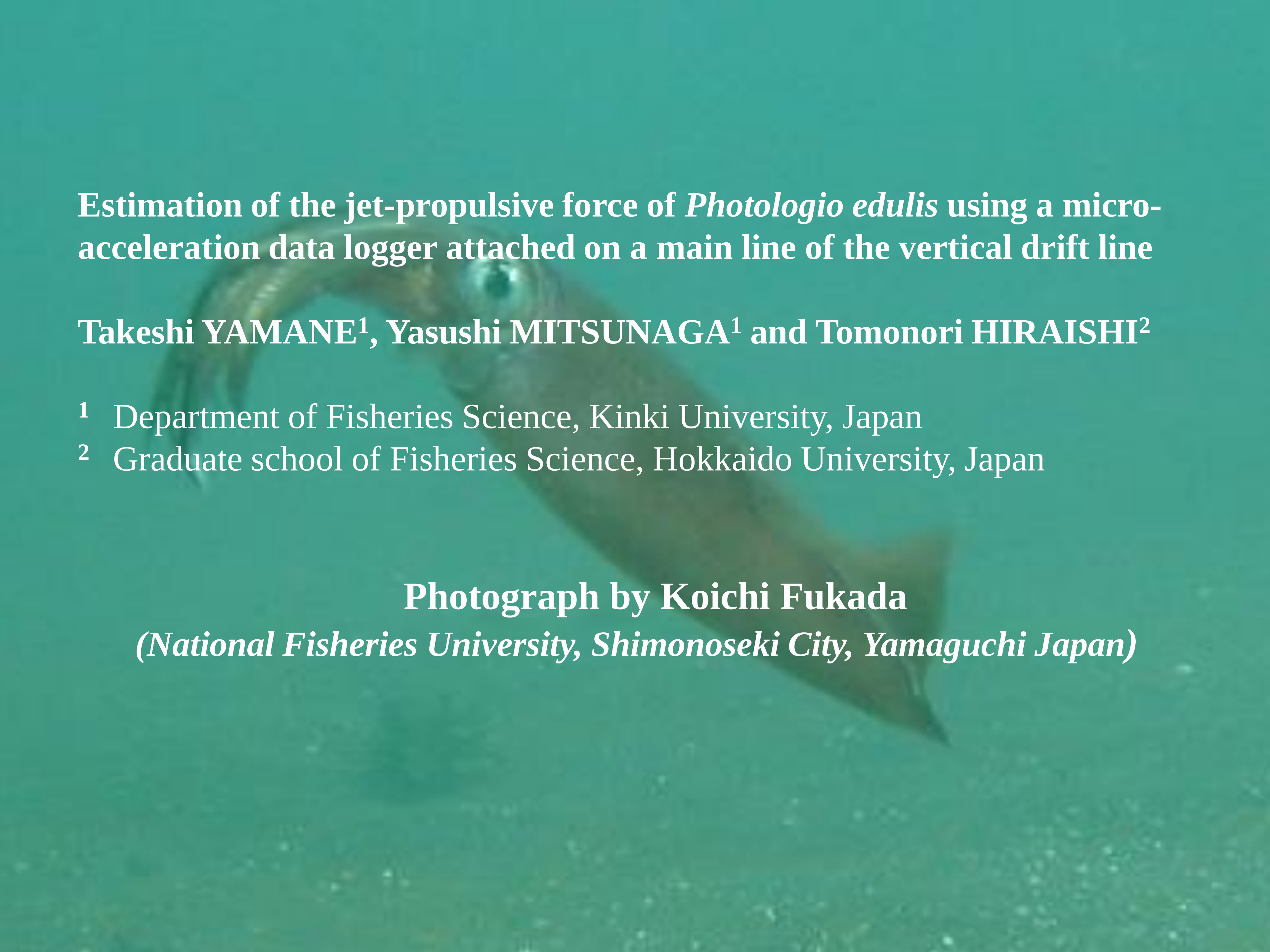
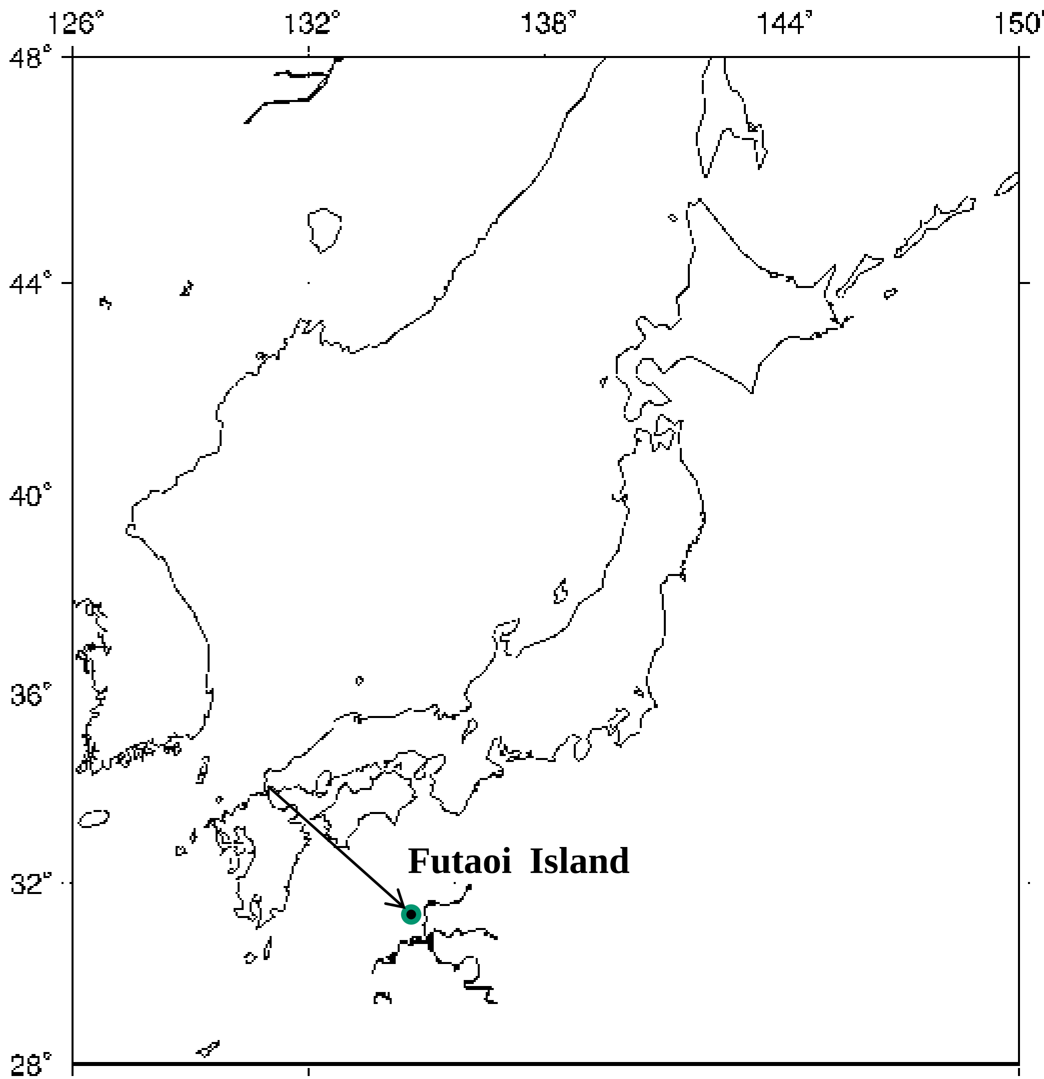


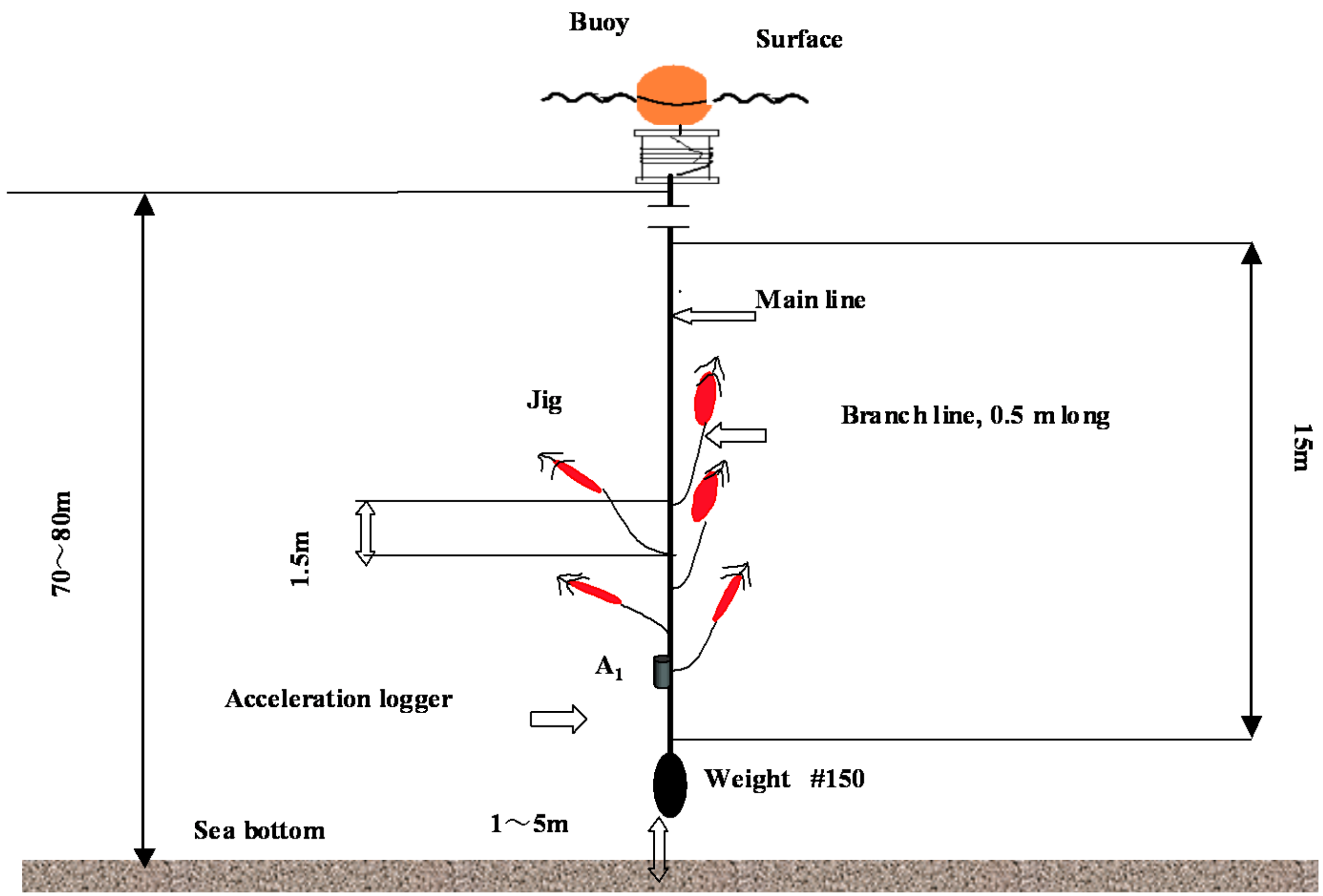
Estimation of the jet-propulsive force of *Photologio edulis* using a micro-acceleration data logger attached on a main line of the vertical drift line

Takeshi YAMANE[1], Yasushi MITSUNAGA[1] and Tomonori HIRAISHI[2]

[1] Department of Fisheries Science, Kinki University, Japan
[2] Graduate school of Fisheries Science, Hokkaido University, Japan

Photograph by Koichi Fukada
(National Fisheries University, Shimonoseki City, Yamaguchi Japan)

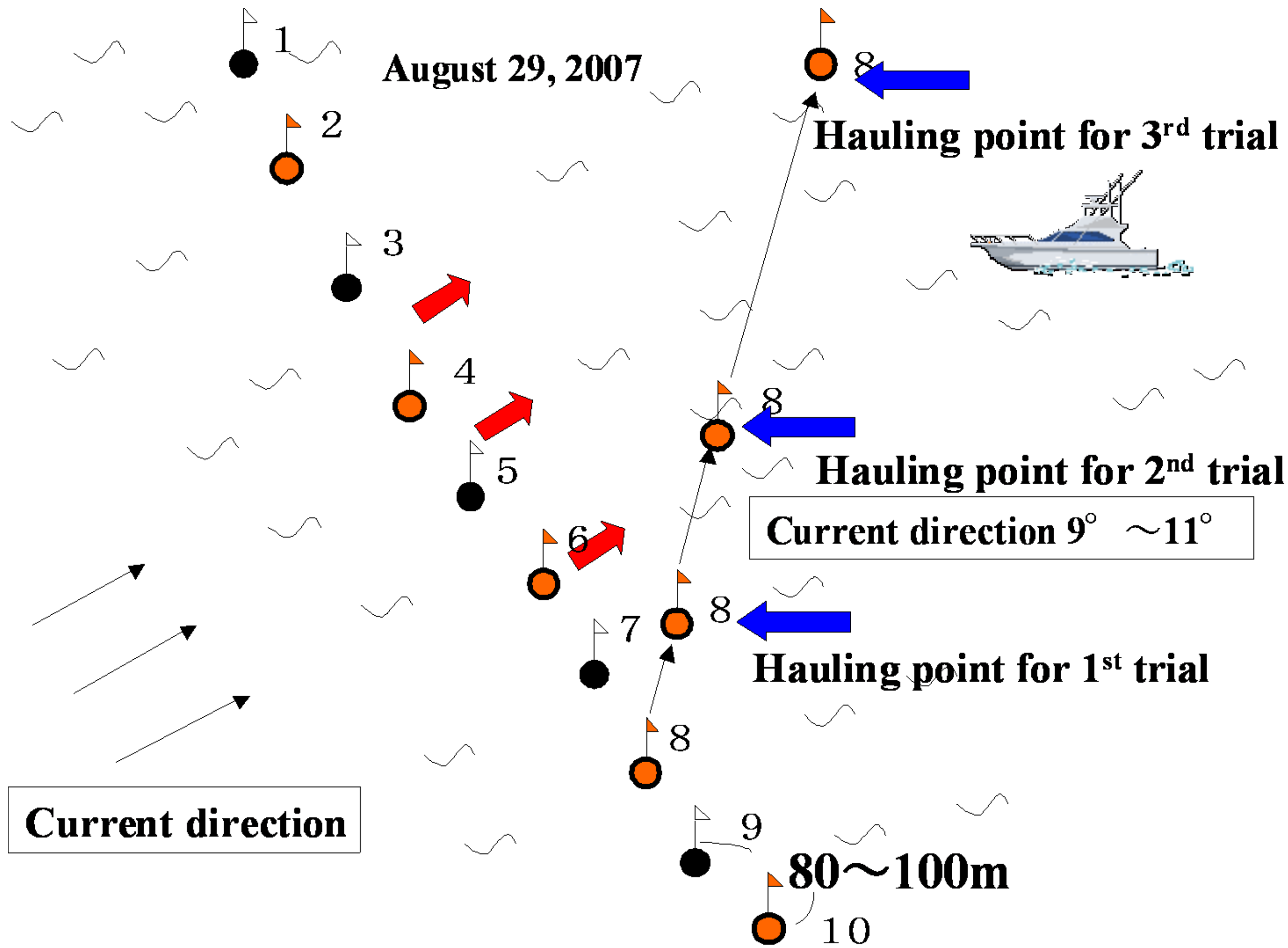

126°
132°
138°
144°
150°
48°
44°
40°
36°
32°
28°
Futaoi Island


Buoy
Surface
Main line
Jig
Branch line, 0.5 m long
15m
1.5m
70～80m
A1
Acceleration logger
Weight #150
Sea bottom
1～5m

Jig length ; 98 mm

Maximum diameter ; 15 mm

C_d = 0.093

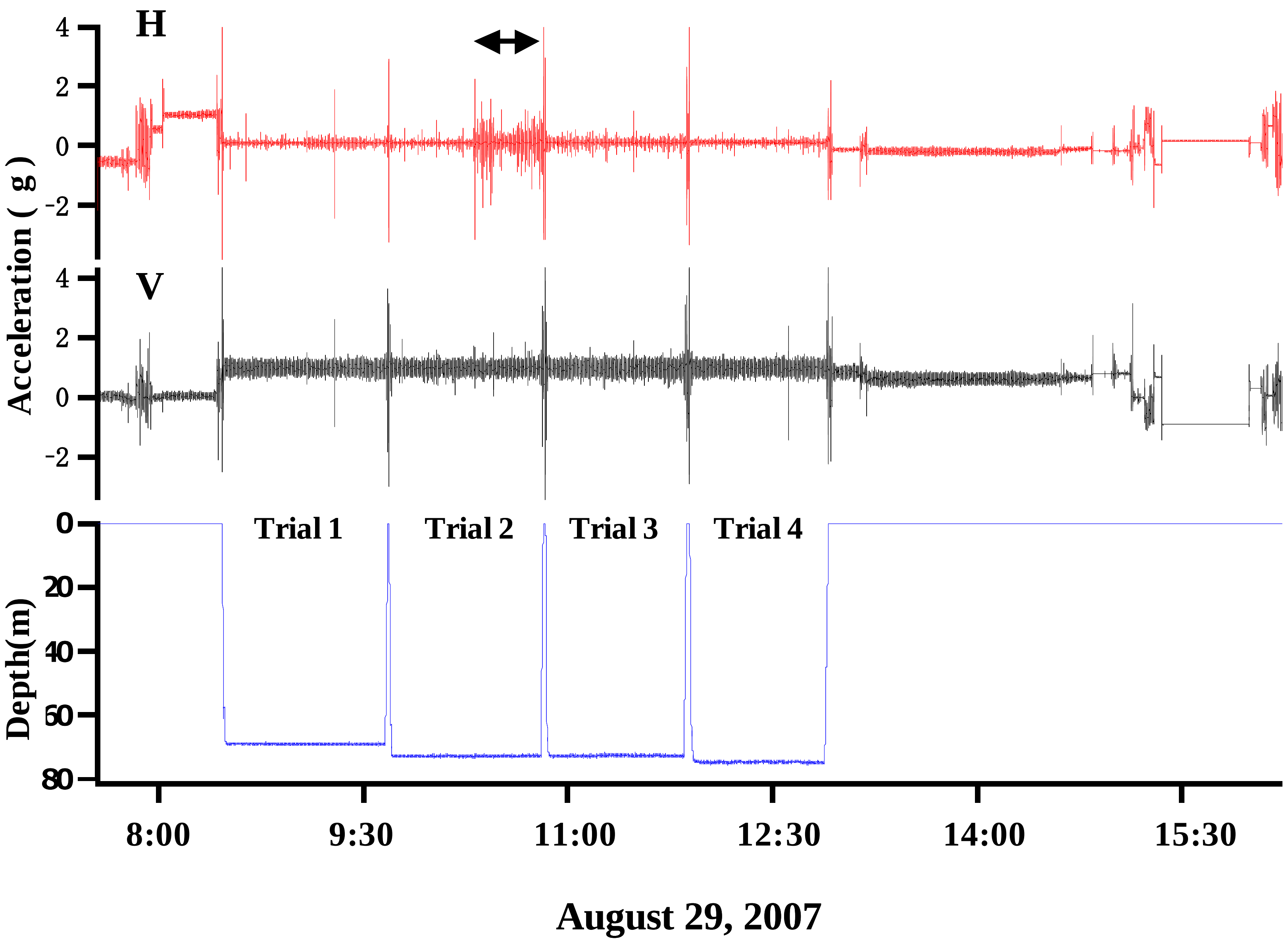


August 29, 2007
1
2
3
4
5
6
7
8
9
10
8
Hauling point for 3rd trial
8
Hauling point for 2nd trial
Current direction 9° ～11°
8
Hauling point for 1st trial
8
80～100m
Current direction

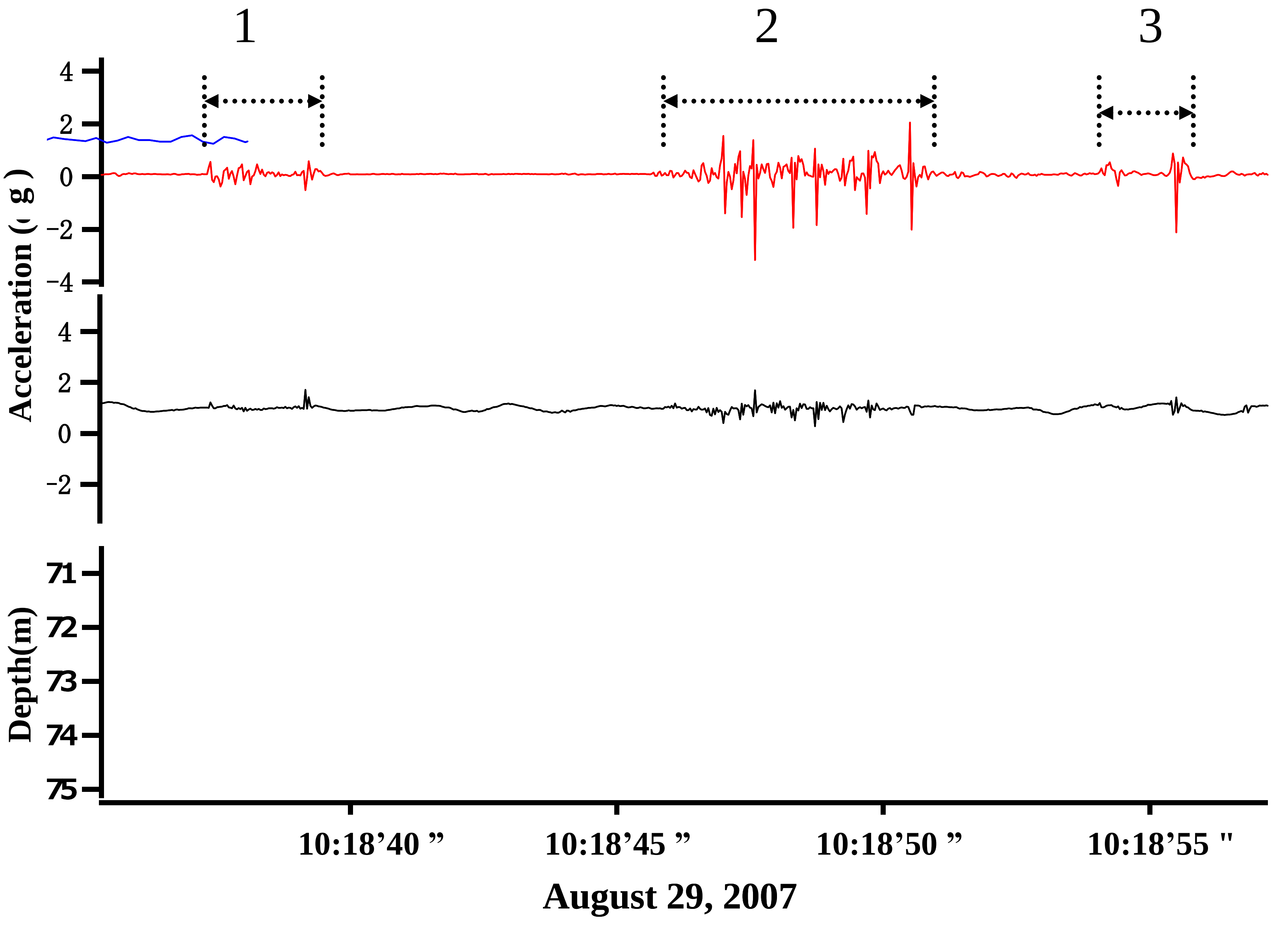
Buoy No. 1							
Trials	Start time	Positions	Hauling time	Positions	Relative positions	Drift distance (m)	Current velocity (cm/s)
1	8:08	Lat 34°11’ .134	9:10	Lat 34°11’ .312	013.1°	338.5	9.1
		Long 130°47’.136		Long 130°47'.192			
2	9:11	Lat 34°11’.338	10:21	Lat 34°11'.753	011.7°	784.8	18.7
		Long 130°47'.196		Long 130°47'.295			
3	10:24	Lat 34°11’ .774	11:16	Lat 34°12'.230	009.6°	856.6	27.5
		Long 130°47’.309		Long 130°47'.402			
4	11:19	Lat 34°12’.275	12:31	Lat 34°12'.998	009.8°	1358.9	31.5
		Long 130°47'.421		Long 130°47'.571			

Buoy No. 10							
Trials	Start time	Positions	Hauling time	Positions	Co	Drift distance (m)	Current velocity (cm/s)
1	8:38	Lat 34°10’ .920	9:50	Lat 34°11’ .330	001.6°	759.6	17.6
		Long 130°46’.775		Long 130°46'.778			
2	10:01	Lat 34°11’.365	11:05	Lat 34°11'.923	008.5°	1044.9	27.2
		Long 130°46'.817		Long 130°46'.917			
3	11:10	Lat 34°11’ .942	12:09	Lat 34°12'.555	009.4°	1150.8	32.5
		Long 130°46’.958		Long 130°47'.080			
4	12:12	Lat 34°12’.597	13:10	Lat 34°13'.258	011.4°	1248.7	35.9
		Long 130°47'.096		Long 130°47'.229			

August 29, 2007		Frequency (Hz)	Mean
	2a273	0.75	0.83
	2a274	0.75	
	PD2GT	1.00	
September 12, 2007			
	2a273	0.75	0.94
	2a274	0.88	
	PD2GT	1.00	
	D2GT	1.13	



H
V
Acceleration (g)
4
2
0
-2
Trial 1
Trial 2
Trial 3
Trial 4
Depth(m)
0
20
40
60
80
8:00
9:30
11:00
12:30
14:00
15:30
August 29, 2007

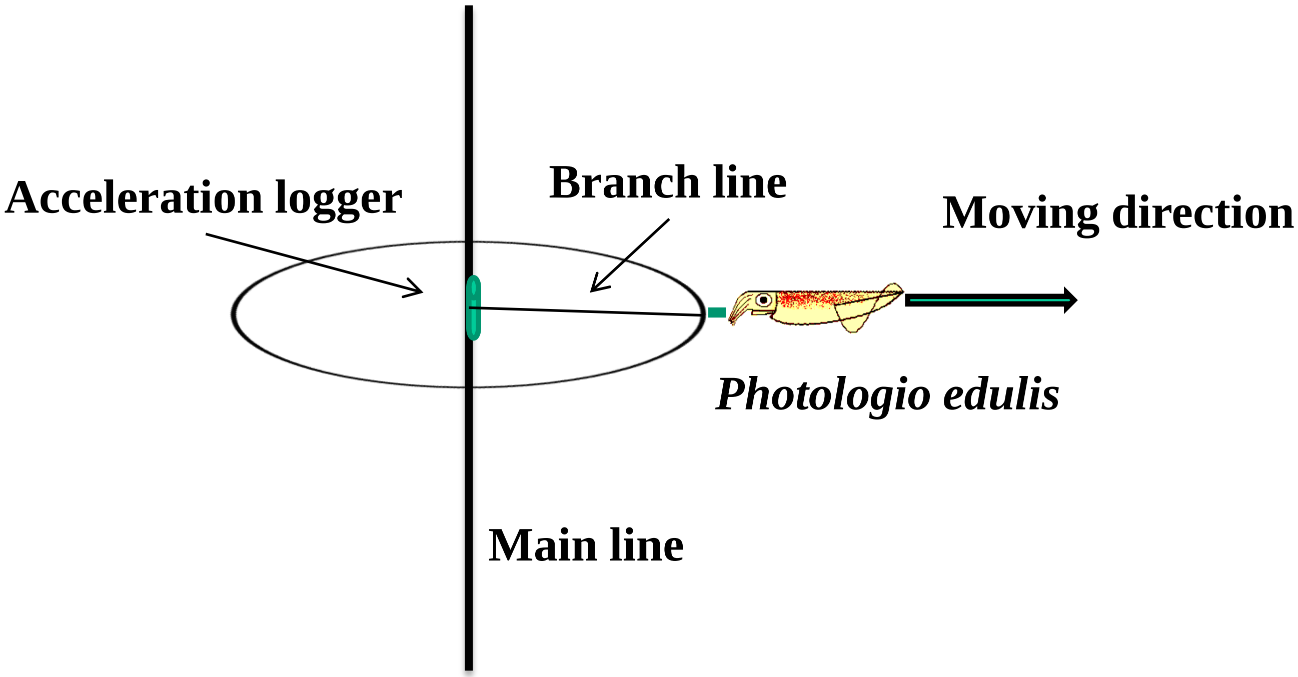


1
2
3
Acceleration (g)
4
2
0
-2
-4
4
2
0
-2
Depth(m)
71
72
73
74
75
10:18'40 "
10:18'45 "
10:18'50 "
10:18'55 "
August 29, 2007

Estimation of the jet-propulsive force;

According to the second law of motion, when a net force acts on a body, it will be accelerated in the direction of the force with the acceleration proportional to the magnitude of the force. As shown in previous figures, when *P. edulis* attack the jig, *first, the individual is in touch with the jig, as can be seen from previous figures, the changes in the acceleration during phase 1* will be probably smaller than that for phase 2.

For an individual running away with the jig by jet-propulsive force after grasping, the changes in the acceleration during this phase becomes large and frequent change as a consequence of the individual bursts out moving with the jig. ***If the assumption is made that the magnitude of acceleration change is proportional to the jet-propulsive force of the individual, it is reasonable to assume that the acceleration change in phase 2 will have considerable escaping motions, since it will be repeated movement during several seconds.*** During the process of acceleration the logger may tilt in a direction toward the moving direction of the individual by the tensile force generating on the jig line by response of the individual.


Acceleration logger
Branch line
Moving direction
Photologio edulis
Main line

The tensile force on the jig line will reach the logger since the jig line is attached to the center of the logger. The logger tilts in the force acting direction, that is, the acceleration changes in proportion to the magnitude of the tensile force caused from swimming away of the individual with the jig. From the results acceleration change in the horizontal direction is not so large than that for the vertical direction. If there are no objections that the individual moves in-plane vertical component, in this case, it is supposed that the individual’s movement is confined in a vertical plane. As a result of that behavior, the tensile force change was recorded in the logger.

Although there is the essential limitation that we can not identify its net moving direction, it is reasonable to assume approximately that the value recorded in the logger may be proportional to the magnitude of burst motion against orthogonal direction. ***If we consider the magnitude of the tensile force as proportional to the magnitude of the jet-propulsive force of the individual, we can easily estimate the jet-propulsive force based on the acceleration change on the logger.*** The net tensile force direction, however, will be probably indistinct. The essential limitation, therefore, is not the ceiling of force that may be reach almost maximum locomotive speed.

Since the response of a body to a net force F is acceleration a proportional to F, we can write

$$F = ma, \qquad (1)$$

where m is a constant of proportionally characteristic of the particular body being subjected to the force.

When a body moves through a fluid, a force acts back ward on it, resisting its motion. In this case, as shown in Fig. 6, the logger is pulled by an individual through the jig line toward its moving direction.

Here, we consider a drag exerting force on the logger, in the direction of motion, we can write

$$ma = F - D \qquad (2)$$

where D is the drag. The size depends on the velocity of the body relative to the fluid, on the properties of the fluid and on the size and shape of the body.

$\frac{1}{2}$

Experiments in water tunnels have shown that it is generally convenient to calculate drag from equation

$$D = \frac{1}{2} \mathrm{Cd} \ \rho \, S \, v^2,$$

where D is the drag, ρ is the density of the fluid, v is the velocity of the fluid relative to the body, S is a characteristic area and C_d is a quantity known as the drag coefficient which depends on the shape of the body and on the Reynolds number.

There is unfortunately no single definition of the area *S* which is convenient for all shapes of body. Here, since the shape of the logger is a finite cylinder, the frontal area, which is the projected area of the cylinder in the direction of flow. In the case of a cylinder of length *l* and diameter *d* this would be $l \cdot d$. Thus, the value of C_d , 0.63 is used in the calculation. And ρ is 1024.76 kg/m^3, *S* is 7.95×10^{-4} m^2, *v* is 0.1 m/s

. *Photologio edulis* swimming speed can-not be measured, therefore, the swimming speed measured for *Todarodes pacificus* (I. Arnaya and N. Sano; 1990) is used as a substitute for *P. edulis*. The maximal value of acceleration data recorded is about 3.0 (Fig. 4; Phase 2, $3 \times 9.8\ m/s^2 = 29.4\ m/s^2$) and mass of data logger is 1.6×10^{-2} kg.

If the assumption is made that a drag force is negligibly small it is to be expected that the equation of motion (2) becomes simple for jet-propulsive force of individual. Indeed, we can calculate the magnitude of the drag force acting on the logger and which is given as an order of magnitude by

$$D = 2.6 \times 10^{-3}\ N,$$

where D represents the drag force acting on the logger.

From calculated D value, it is reasonable to assume that the drag force acting on the data logger will probably have a very small effect on the motion.

On the other hand, the tensile force 4.70×10^{-1} *N* can be understand most easily as the force caused by an individual’s jet-propulsive force acting on the logger, which is very large compared with the drag acting on the logger. In this case, the former is quadruple digits larger than that for the latter. Assuming this picture, it is reasonable to consider that although indirect measuring method is incomplete because when measuring the jet-propulsive force of the individual, it will be very convenient.

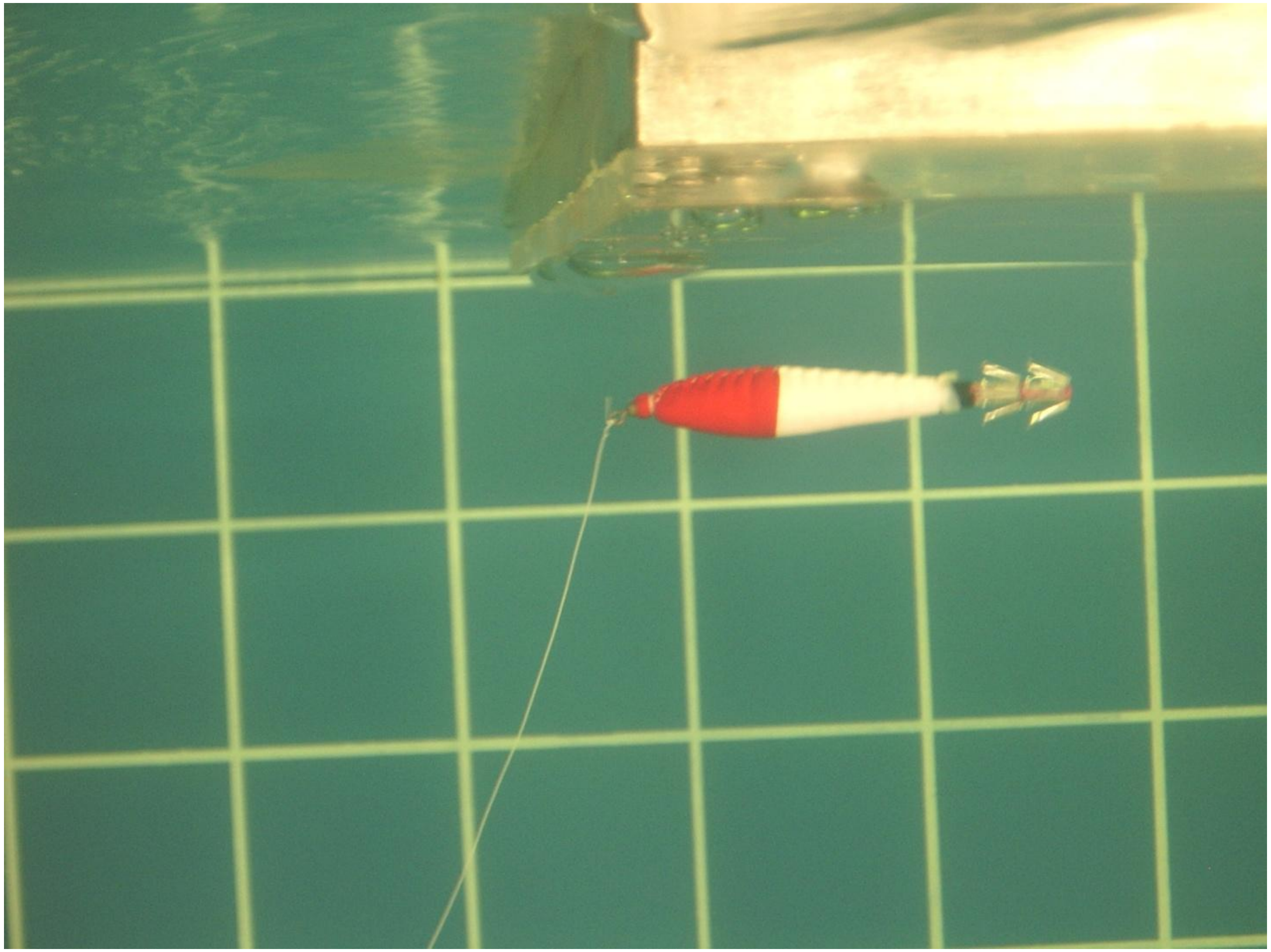
$D \ll F$

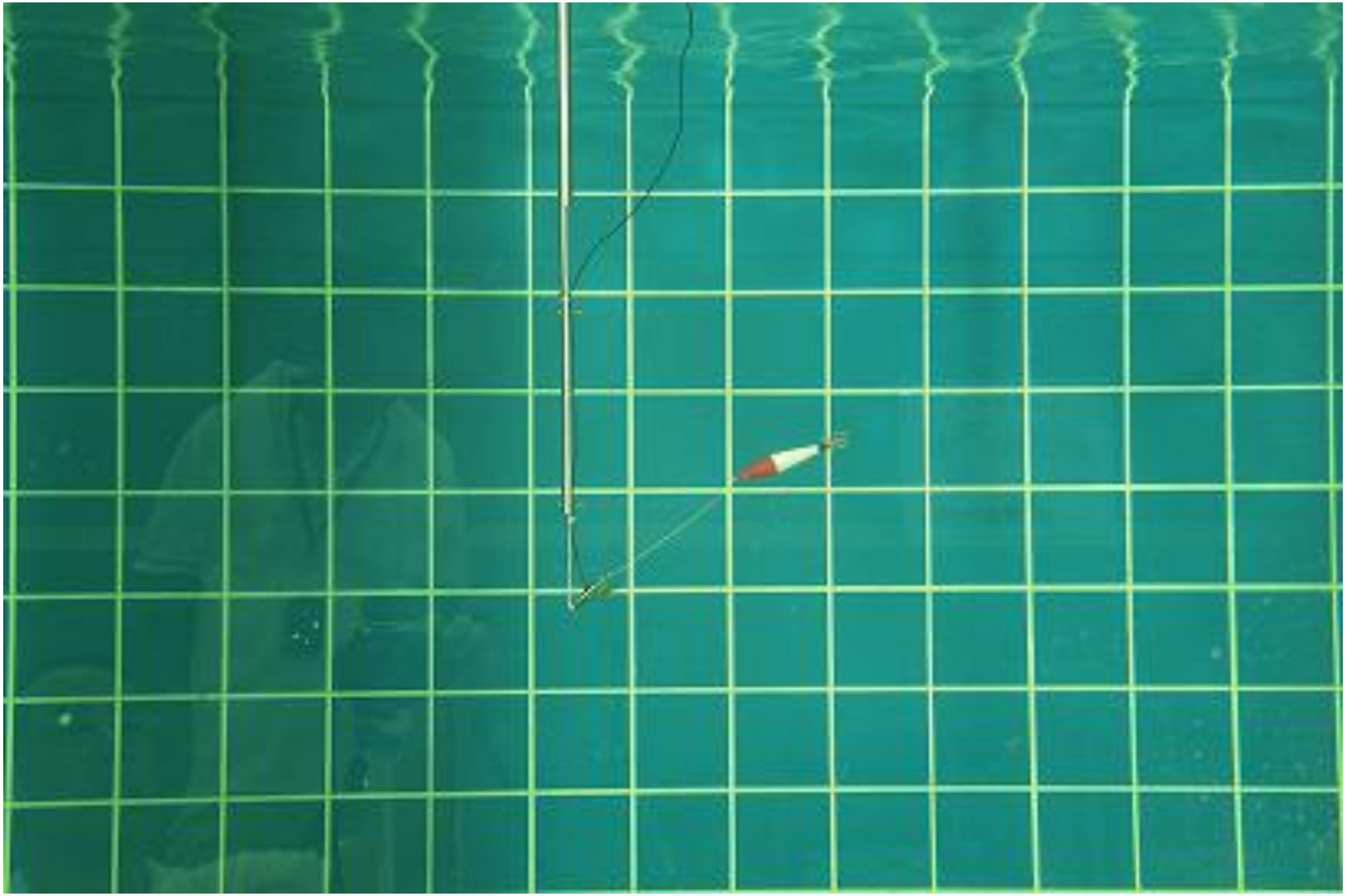
For the logger whose velocity is constant for current direction, and when the tensile force on the string by individual's escape behavior with a jig, we could measure the acceleration g resulting from the logger's tilt against the main line. Since we are restricting ourselves to motion in a straight line in this study, we shall only consider here the acceleration arising from a change in direction against the main line. In this study, when the resistance force acting on the logger against the opposite moving direction is negligible, we can consider only a jet-propulsive force.

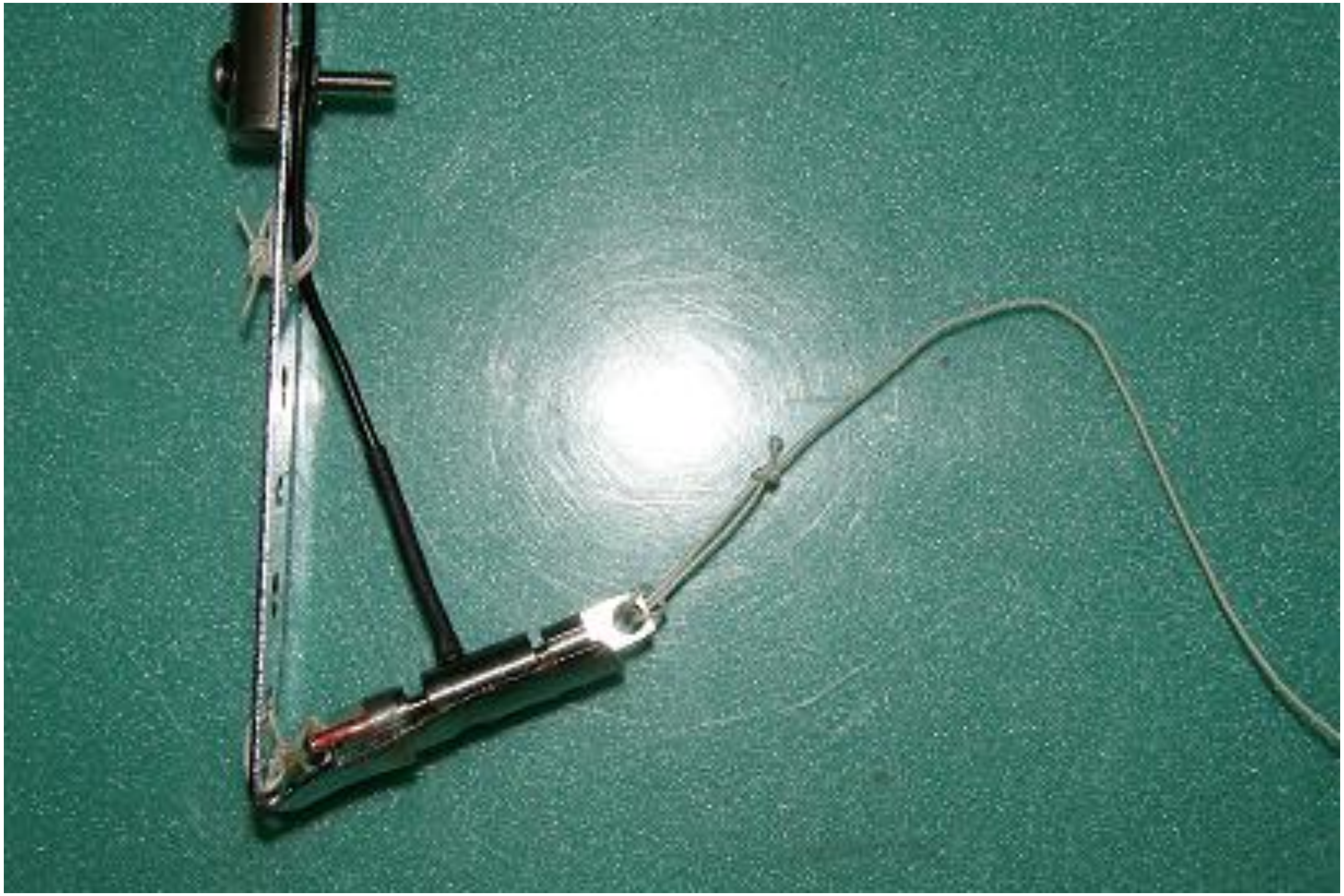
According to the formula, if drag force of the logger is negligibly small than that of F, we can only consider the magnitude of F, that is we can estimate directly using the magnitude of acceleration measured by the acceleration data logger attached on the main line.

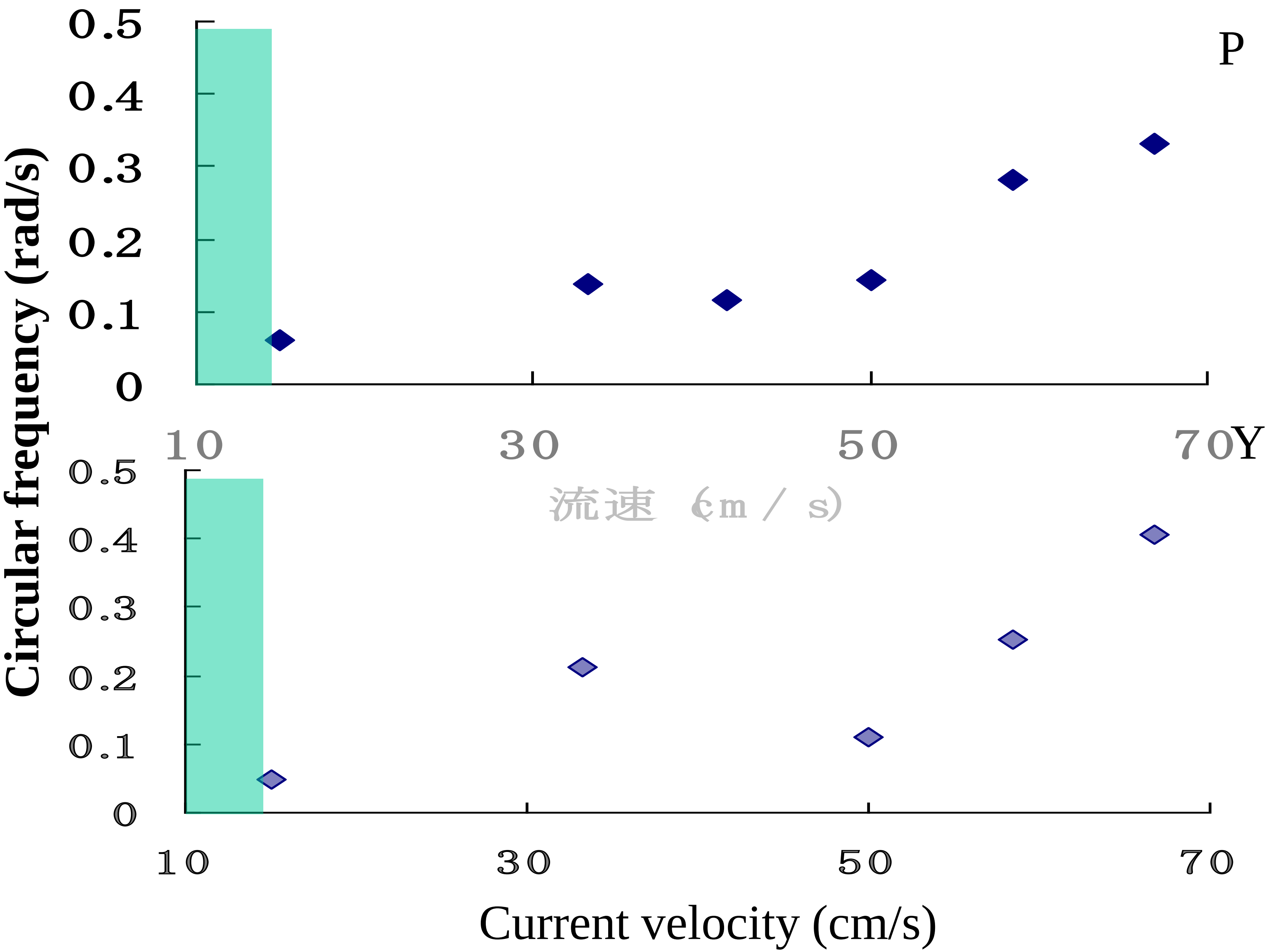
In this study, we calculated the drag acting on the logger and it was estimated as $2.6\times10^{-3}N$. On the other hand, the magnitude of tensile force acting on the logger which was caused by jet-propulsive force by the individual's escapement behavior. As first approximation, it is reasonable to estimate directly the jet-propulsive force using the magnitude of acceleration measured by data logger. In this study, we consider that the elongation of jig line and its mass as negligibly small. Therefore, we write down equation (4),

$$m\alpha = F \qquad (4)$$

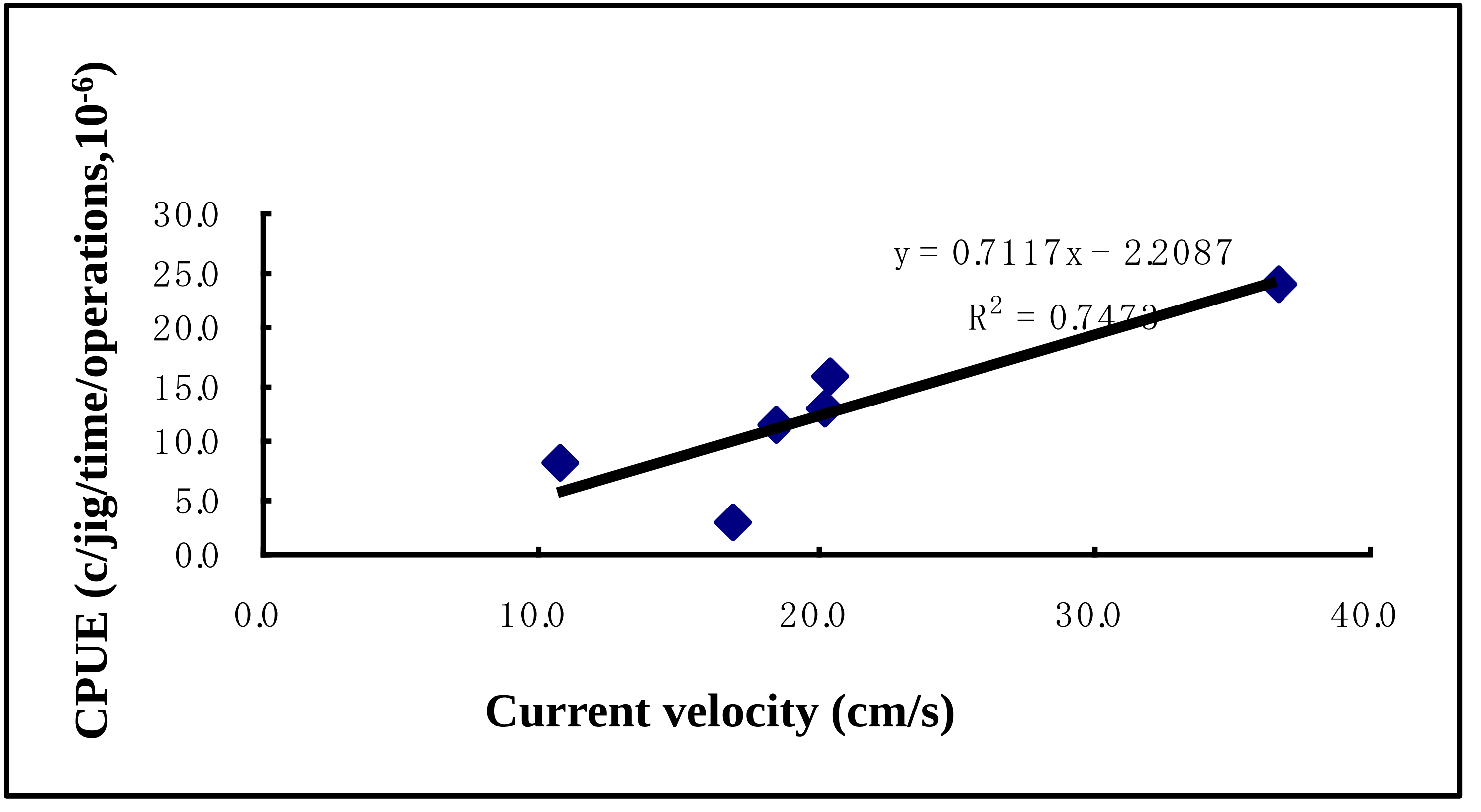








Circular frequency (rad/s)
0.5
0.4
0.3
0.2
0.1
0
P
10
30
50
70
Y
流速（cm / s）
0.5
0.4
0.3
0.2
0.1
0
10
30
50
70
Current velocity (cm/s)



CPUE (c/jig/time/operations,10-6)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
y = 0.7117x - 2.2087
R2 = 0.7473
0.0
10.0
20.0
30.0
40.0
Current velocity (cm/s)