Fundamental studies on the hydrodynamic resistance of small pot traps

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ABSTRACT: The hydrodynamic resistance of small pot traps has been conducted in order to establish some basic information. The specific objectives of the study was to measure the hydrodynamic force and estimate the critical setting condition for traps. Five types of traps with different materials were used in the experiment: a netted semi-cylinder shape, a wire semi-cylinder shape, a heart shape, a box shape, and a cylinder shape. The hydrodynamic force of each trap was measured in a flume tank. Flow speeds in the flume tank were 0.1, 0.2, 0.3, 0.4, and 0.5 m/s. Attack angles for this study were 0, 15, 30, 45, 60, 75, and 90 degrees. At an attack angle of 0 degrees the main axis of the trap was parallel to the water flow and at 90 degrees it was vertical. The values of the hydrodynamic drag coefficient varied with traps: netted semi-cylinder shape, 2.75–5.96; wire semi-cylinder shape, 2.81–4.49; heart shape, 2.77–3.66; box shape, 2.39–2.97; and for cylinder shape, 3.57–3.67. The flow speed (0.5 m/s) was effective to set the netted semi-cylinder, wire semi-cylinder, box, and cylinder shaped traps. The same flow speed applied to the heart-shaped trap was only effective to a maximum of 30 degrees attack angles and below.

KEY WORDS: drag coefficient, frictional force, hydrodynamic resistance, lift coefficient, trap.

INTRODUCTION

Hydrodynamic resistance is an important factor affecting the setting of traps at the fishing ground, because if current speed is high the traps will not settle but move on the seabed. Traps are used all over the world and many varieties of dimensions, material, and mesh sizes are available. The hydrodynamic resistance of traps of different dimensions, material, and mesh size plays a significant role in fishing. A number of factors affect the catch rate of traps, such as, soak time,1 trap saturation,2 the physical habitat,3 trap design,4 bait, and the life cycle stage of the target species.5 However, there are few studies on the hydrodynamic characteristics of traps.

Stewart has reported several studies on the hydrodynamic resistance of different materials of fishing gear in a flume tank and found that the drag of monofilament nets is significantly higher than that of twisted multifilament nylon tests.6 Hu has reported that the drag of the high-strength polyethylene net design was considerably lower when compared with that of a net made from nylon material.7

Fuwa et al., who used a heart-shaped bamboo trap to investigate the drag and the flow distribution, published the first study of hydrodynamic resistance on traps.8 Li estimated the trap stability, drag, and static frictional force of conical and rectangular traps.9 The present work addresses experiments in a flume tank using actual traps to measure the hydrodynamic forces developed by them at different orientations in respect to water flow, and to elucidate the critical setting condition of the traps.

MATERIALS AND METHODS

Experimental materials

Five different types of traps were used in the experiment. The various shapes of traps are shown in Fig. 1. The specifications of the traps are shown in Table 1. The netted semi-cylinder shape (Fig. 1a) consisted of a bamboo frame that was covered with mesh netting of polyamide material. The frame consisted of three half ellipses of split bamboo that were connected with five strips of split bamboo 0.98 m in length. The trap entrance was defined by incurving walls that tapered to the opening and these funnel entrances were reduced from a vertical slit of 0.58 m to a 0.10-m width vertical opening.
in the center of the trap. This trap is commonly used on the west coast of Kagoshima Prefecture, Japan, and its target species is leather fish.

The wire semi-cylinder trap (Fig. 1b) was identical in shape to the netted semi-cylinder type and is also used in Kagoshima Prefecture. Frames were constructed of steel rod and were covered with galvanized wire mesh. The shape of the mesh was hexagonal with a mesh size of 43 mm \( \times \) 30 mm. The entrance of the trap has a slight downward curvature at the rear end. The diameter of the outer funnel is 180 mm and the entrance ring frame was interconnected with 22 wires of 180 cm long and 1 mm in diameter. This trap is commonly used to catch puffer fish.\(^{10-14}\)

The heart-shaped trap (Fig. 1c) was constructed completely from bamboo strips. This trap is usually used in Manado (North Sulawesi), Indonesia. It has no frame and the openings in the wall are both hexagonal and triangular. The entrance is provided with a truncated funnel, having a slight curvature at the rear in order to prevent catch escaping. The diameters of the outer and inner rings of the funnel are 200 mm and 120 mm, respectively. This trap is used to capture various species of coral fish.

The box-shaped trap (Fig. 1d) has its frame constructed from iron rods coated with plastic. These are covered with polyethylene square mesh and have two funnel entrances at either end instead. The trap entrance is defined by incurring walls that taper to the opening and these funnel entrances were reduced from the width of the trap. The trap is usually used on the west coast of Kagoshima Prefecture and targets various species of crab and octopus.

The cylinder-shaped trap (Fig. 1e) was constructed of iron. The frame was covered with black diamond-shaped mesh netting made of polyethylene twine. The trap had two opposite funnel entrances which were reduced from the width of the trap. The trap is usually used on the north coast of Kyushu Island, Japan and targets various species of crab and octopus.

**Hydrodynamic resistance**

Each of the traps was set in duplicate in the middle layer in the flume tank as shown in Fig. 2. To measure the hydrodynamic drag forces it is necessary...
<table>
<thead>
<tr>
<th>Trap shapes</th>
<th>Material</th>
<th>Wall</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
<th>Target species</th>
<th>Location of trap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Netted semi-cylinder</td>
<td>Bamboo strips 25 mm</td>
<td>Polyamide d = 0.9 mm l = 25 mm</td>
<td>0.98</td>
<td>0.58</td>
<td>0.43</td>
<td>2.60</td>
<td>Leather fish</td>
<td>Kagoshima Japan</td>
</tr>
<tr>
<td>Wire semi-cylinder</td>
<td>Stainless steel 4 mm</td>
<td>Steel wire d = 1 mm l = 21.2 mm</td>
<td>0.55</td>
<td>0.45</td>
<td>0.29</td>
<td>0.45</td>
<td>Puffer fish</td>
<td>Kagoshima Japan</td>
</tr>
<tr>
<td>Heart</td>
<td>No frame</td>
<td>Bamboo strips width = 9 mm thick = 1 mm</td>
<td>0.98</td>
<td>0.75</td>
<td>0.20</td>
<td>1.10</td>
<td>Coral fish</td>
<td>Manado Indonesia</td>
</tr>
<tr>
<td>Box</td>
<td>Iron rod 5.5 mm</td>
<td>Polyethylene d = 0.55 mm l = 12 mm</td>
<td>0.60</td>
<td>0.45</td>
<td>0.20</td>
<td>1.75</td>
<td>Crabs and octopus</td>
<td>Kagoshima Japan</td>
</tr>
<tr>
<td>Cylinder</td>
<td>Iron rod 6 mm</td>
<td>Polyethylene d = 1 mm</td>
<td>0.70</td>
<td>0.70</td>
<td>0.34</td>
<td>1.75</td>
<td>Crabs and octopus</td>
<td>North coast Kyusu Island Japan</td>
</tr>
</tbody>
</table>

d, Diameter; l, length of leg.
to couple the traps because there is a bottom effect on the trap that is actually set on the seabed. Attack angle is the angle between flow and the main axis of the trap. Flow speed and attack angle was selected by taking the conditions at the fishing ground into consideration. Flow speeds in the flume tank were 0.1, 0.2, 0.3, 0.4, and 0.5 m/s, respectively. Attack angles for this study were 0, 15, 30, 45, 60, 75 and 90 degrees. At an attack angle of 0 degrees, the main axis of the trap was parallel to the water flow and at 90 degrees it was vertical. Hydrodynamic resistance was measured using a three-component load cell and the values were amplified and an A/D-converter recorded at 20 Hz for 20 s. The values were stored in a computer and used to calculate the drag force coefficient ($C_D$) and the lift force coefficient ($C_L$). Since the drag of doubled traps was measured, the hydrodynamic drag force of one trap was calculated by dividing the value. The values were adjusted according to the Reynolds’ number $Re = VL/\mu$, where $V$ = flow speed, $L$ = body length, and $\mu$ = kinematics viscosity of water, which was between $1.0 \times 10^3$ and $6.7 \times 10^4$. Water temperature was 25°C.

**Frictional force**

The experiment on static frictional force was carried out in the field (Fukiage beach, Western Kagoshima Prefecture). Each of the traps was connected to a spring balance and set at the bottom of the sea. The trap was pulled with an attached rope and the initial force was measured immediately.

**Data analysis**

The measurement of drag and lift force was expressed in terms of drag and lift coefficients using the basic hydrodynamic resistance formula:

$$C_D = \frac{2D\theta}{\rho S\theta V^2}$$

$$C_L = \frac{2L\theta}{\rho S\theta V^2}$$

Where, $D\theta$ is drag force at a given attack angle, $L\theta$ is lift forces at a given attack angle, $\rho$ is the water density, $V$ is the flow speed, and $S\theta$ is the projective area at a given attack angle.

The whole projective area $S\theta$ of the trap was given as the sum of the frontal and side of the trap.

$$S\theta = S_0 \cos \theta + S_{90} \sin \theta$$

Where, $S_0$ is the frontal area (when attack angle is 0 degree), $S_{90}$ is the side net area (attack angle 90 degrees), and $\theta$ is the attack angle. The value of $S$ does not include the holes in the mesh, since we considered only the projected area in this study.

To calculate the hydrodynamic coefficient, we used the total area of the twine in the net $S_{(At)}$ using the formula reported by Reid:\footnote{15}

$$S_{(At)} = \frac{(N+M)}{2} \cdot \frac{K_1}{2} \cdot M_s TD$$

Where, $N$ is the number of meshes along the top of the panel, $M$ is the number of meshes along the foot of the panel, $K_1$ is the number of rows (of knots) in the panel, $M_s$ is the mesh size in the panel, and $TD$ is the twine diameter in the panel.

**RESULTS AND DISCUSSION**

**Hydrodynamic resistance**

The value of the hydrodynamic drag force and lift force at the assigned attack angles is shown in Figs 3 and 4, respectively. For the netted semi-cylinder-shaped trap, the hydrodynamic drag force increased with an increase in attack angle. An increase in flow speeds also resulted in increased drag force, and increased flow speeds show some degree of constancy in hydrodynamic drag force. For the wire semi-cylinder-shaped trap, the hydrodynamic drag force was constant against attack angles and increased only slightly as flow speed increased. The heart-shaped trap showed hydrodynamic drag force increases with an increase in attack angle and reached a maximum at 75 degrees. For the box-shaped trap the hydrodynamic drag force increased with increases in flow speeds and was almost constant against all attack angles. The cylinder-shaped trap showed an
almost constant drag force against all the attack angles. An increase in flow speed systematically increased the drag force.

The hydrodynamic force for the netted semi-cylinder and heart-shaped trap gave higher values while the wire semi-cylinder, box, and cylinder-shaped traps showed smaller values which were almost constant against all of the attack angles. The netted semi-cylinder and heart shaped-traps were constructed of bamboo frame and strips and this affected the drag force.

The hydrodynamic lift force for the netted semi-cylinder showed a parabolic pattern which reached its maximum at 60 degrees. For the wire semi-cylinder and cylinder-shaped traps, the hydrodynamic lift force was relatively low, indicating that it was inefficient in producing hydrodynamic lift force. In the heart-shaped trap, the hydrodynamic lift force expressed a parabolic pattern with a maximum at 45 degrees. The box-shaped trap showed the same tendency as the wire semi-cylinder-shaped trap, increasing to a maximum at 60 degrees, however, there was relatively little difference at the other attack angles.

The results of the hydrodynamic force coefficient ($C_d$) are shown in Fig. 5 in the form of non-dimensional hydrodynamic drag coefficient against the attack angles. The hydrodynamic drag
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coefficient for the netted semi-cylinder decreased from a maximum at 0 degree to a minimum at 45 degrees and then stabilized into a horizontal line. The wire semi-cylinder-shaped trap showed a curve where the hydrodynamic drag coefficient decreases from a maximum at 0 degrees to a minimum at about 60 degrees and then increased thereafter. The change of the hydrodynamic drag coefficient of the heart-shaped trap changed; a decrease from 0 degrees to a minimum of 15 degrees then rose slightly to a maximum at 75 degrees, and decreased again at 90 degrees. For the box-shaped trap, the hydrodynamic drag coefficient was relatively constant against all attack angles. In the cylinder-shaped trap the hydrodynamic drag coefficient was almost constant and not affected by the attack angles because the plan form area was constant at different attack angles.

The values of the hydrodynamic drag coefficient ($C_D$) showed variations between 2.43 and 5.81. The hydrodynamic drag coefficient showed little variation between the results obtained at the different attack angles except at 0 degrees attack angle in the netted semi-cylinder and wire semi-cylinder-shaped traps that indicated relatively higher values. The difference in the hydrodynamic drag coefficient value of netted semi-cylinder at 0 a degree was caused by a significantly different plan form area between 0 and other attack angles. The differences observed in maximum and minimum hydrodynamic drag coefficient of the traps were due to variation in material used in construction.

The values of $C_D$ in semi-cylinder-shaped traps (netted and wire) at a 0 degree are higher than other shapes as indicated (about 5.8–4.5, respectively). The values of $C_D$ in semi-cylinder shapes at attack angles of 15–90 degrees were almost constant with values 3.53–2.7. The value of $C_D$ for heart, box, and cylinder-shaped traps showed similar values in attack angles of 30–90 degrees. Suggesting that the shape and construction of the trap affected the semi-cylinder-shaped traps hydrodynamic drag coefficient.

The relationship found between the drag coefficient, the twin area, and angle of attack, confirm previous research on the net features that affect the magnitude of the hydrodynamic drag coefficient. An increase in the attack angle of the webbing resulted in a significant increase in the hydrodynamic drag coefficient. The difference in the hydrodynamic drag force between the net features and traps can be explained by the combination of the walls of the trap ($S_0$ and $S_90$).

The hydrodynamic lift coefficient ($C_L$) varied with attack angle (Fig. 5). The netted semi-cylinder and heart-shaped traps gave a parabolic pattern against the attack angles of the hydrodynamic lift coefficient. However, for the wire semi-cylinder, box, and cylinder-shaped traps, they showed almost constant values against the attack angles. In contrast, the results of the hydrodynamic lift coefficient were relatively different compared to that of the hydrodynamic drag coefficient. Since the netted semi-cylinder and heart-shaped traps were constructed of bamboo frame and strips they were affected by hydrodynamic lift coefficient.

Two categories have been observed in the actual relationship between the hydrodynamic drag force of the five trap shapes. First, there was a significant effect on the hydrodynamic drag force in the range of attack angles and flow speeds tested, such as netted semi-cylinder and heart-shaped traps. Second, there was no significant increase in the

Fig. 5 Relationship between the hydrodynamic force coefficient and the attack angles of the traps.
hydrodynamic drag force through the range of attack angles tested. The drag force was slightly smaller, but a systematic increase in drag force with increase in water speed tested was observed in the wire semi-cylinder, box, and cylinder-shaped traps. The actual cause for these observed differences were due to the use of the bamboo strips for the heart-shaped trap and the large bamboo frame for the netted semi-cylinder-shaped trap.

**Frictional force**

The measured maximum static frictional force of traps at the seabed were as follows: 8.40 kgw for the netted semi-cylinder, 4.75 kgw for the wire semi-cylinder, 4.10 kgw for heart shape, 3.55 kgw for the box shape, and 3.58 kgw for cylinder-shaped traps, respectively.

The traps were affected not only by hydrodynamics forces acting on the trap but also by forces arising from the physical contact of the gear with the seabed. If the resultant hydrodynamic forces acting on the trap were smaller than the frictional force on the trap, the traps remained on the seabed. In contrast, if the resultant force was larger than the frictional force, the trap moved (Fig. 6). Based on the data from the field study, it can be seen also in Fig. 7 from the comparison between the frictional force (F) among the different attack angles and resultant force. The flow speed (0.5 m/s) was effective for setting the netted semi-cylinder, wire semi-cylinder, box and cylinder-shaped traps. However, for the heart-shaped trap, the flow speed was effective only a 30 degree attack angles and below.

Once the actual relationship between the hydrodynamic resistances of the net have been defined, a predictive range for the velocity gradient of fishing ground within the five traps, based on the twine area and frame measurement, can be generated.

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