Model Experiments on Small Trawls
Feasibility Study on the Double Rigged Versus Single Rigged Type

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Abstract

This paper provides a general feasibility study on double rigged versus single rigged trawls. This study used model experimental nets tested in a circulating water tank. Three kinds of trawls were tested, i. e. the Mexican semi ballon double rigged shrimp trawl designed by Nichimo*** (hereafter called net A), the traditional two seam single rigged Malaysian shrimp trawl (net B) and the four seam trawl modified from the above Malaysian trawl (net C). The head rope length of net A is about half that of net B and net C. Primary objectives are to determine physical characteristics, working performance and to estimate the main engine output necessary to pull these nets.

To provide a double rigged shrimp trawl in the Malaysian shrimp fisheries, results of experiments are summarised as follows:

1) At 2 knots, which is a normal towing speed of a Malaysian shrimp trawler, net mouth height of net A is 1.2 meter, net B is 2 meter and net C is 1.8 meter. In accordance to the behaviour of shrimp, these net mouth height are sufficient.

2) In order to ensure the security of the catch, the most efficient average mesh opening was determined to be five vertical cross-sections. The mesh opening is bigger at the square panel and becomes smaller towards the cod end. The opening is about 3 centimeter for 5.7 centimeter mesh size.

3) The wing tip spread of net A is 11 meter, which is 80% of its head rope length. Net B is 14 meter (55%) and net C is 14.4 meter (60%).

4) The working performance of a shrimp trawl is determined by its sweeping area. The obtained experimental equations of the sweeping area of the three net are slimplified as follows:

$$2 \text{ net A}: \quad A'_s = 2.18\,V$$
$$\text{net B}: \quad A''_s = 1.57\,V$$
$$\text{net C}: \quad A'''_s = 1.58\,V$$

5) The estimation of suitable main engine output necessary to pull the net is calculated from the conversion of total gear drag force values to horse power values. Equations of the above power of the three nets are:

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2 net A : $EHP' = 12.19\,V^{2.79}$
net B : $EHP'' = 11.01\,V^{2.68}$
net C : $EHP''' = 10.89\,V^{2.61}$

Introduction

The coastal shrimp resources off the west coast of the Malaysian Peninsular in the Straits of Malacca sustain a very important fishery in Malaysia. In terms of commercial value, shrimp accounted for more than half of the total export earnings of fish, crustacean, and mollusk.

In Malaysia, the used of the double rigged shrimp trawl is not universal because of a lack of knowledge among fishermen regarding its use and advantages.

In actual practise, the shirmp trawl should have a wide net mouth so as to achieve a large sweeping area. There are two factors to be considered for this purpose, the general trawl construction and the correct dimensions of the otter board. Preferably an otter board should have a large shear force for a large spread (attack angle) and a small drag force to reduce resistance. The otter board also help to keep both wings touching the ground as well as to wing ends vertically against the lift force. At the same time the sinking force of the ground rope should be sufficient to touch the ground. This is necessary in order to catch the shrimp which embed themselves in the ground.

Materials and methods

Particulars of full scale nets adopted in this study are given in Table 1. The plans of the three nets are as illustrated in Figures 1-a, 1-b and 1-c. The full scale net plans

Table 1. Particulars of full scale nets adopted in the study.

Particulars \ Net type	A	B	C
Total length (m)	19.00	38.00	33.00
Head rope length (m)	13.72	25.00	24.00
Ground rope length (m)	17.06	26.00	28.00
Buoyant force (kg)	5.68	18.50	18.50
Sinking force (kg)	6.81	22.70	22.70
Rope diameter (cm)	1.90	1.90	1.90
Rope material	compound rope (CPR)	kurehalon	kurehalon
Body mesh size (cm)	5.70	4.45	4.45
Body twine diameter (mm)	1.91	1.35	1.35
Cod end mesh size (cm)	4.45	2.54	2.54
Cod end twine diameter (mm)	2.63	1.48	1.48
Twine material	polyethelene is used for all nets.		

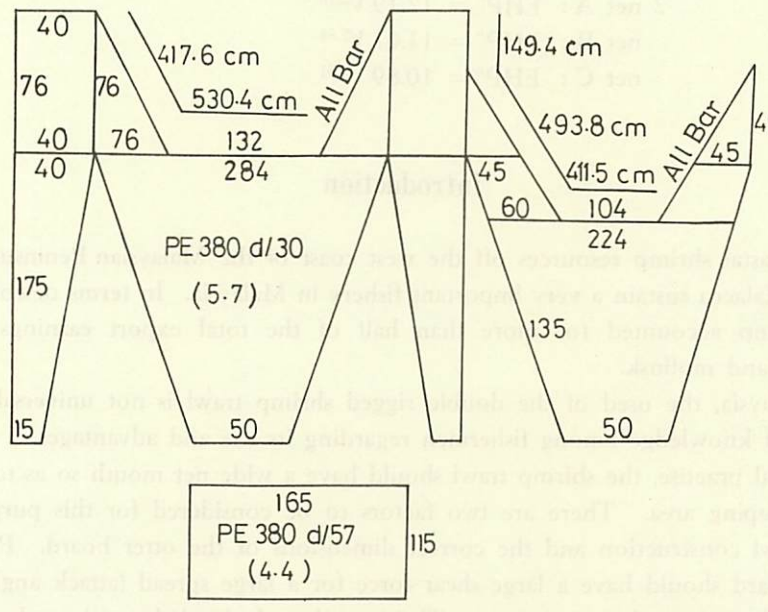


Figure 1-a. The net plan of net A. Numbers in the figure show mesh numbers and bracketed numbers are mesh sizes (cm).

were transformed into model scale based on Tauti's Comparative Method (M. TAUTI, 1934)[4], as follows:

a) Reducing scale ratio

$$\frac{\lambda'}{\lambda''} \quad \cdots\cdots (1)$$

b) Ratio of the twine diameter D and the mesh size L

$$\frac{D'}{D''} = \frac{L'}{L''} = K \quad \cdots\cdots (2)$$

c) Velocity ratio

$$\frac{V'}{V''} = \sqrt{\frac{D'}{D''}(\rho'-1)(\rho''-1)} \quad \cdots\cdots (3)$$

d) Ratio of rope diameter

$$\frac{D_1'}{D_2''} = \sqrt{\frac{\lambda'}{\lambda''}(\rho'-1)(\rho''-1)\ \frac{V'}{V''}} \quad \cdots\cdots (4)$$

e) Ratio of the sinking and floating power F, and the force acting on the net R

$$\frac{F'}{F''} = \frac{R'}{R''} = \frac{\lambda'^2}{\lambda''^2}\cdot\frac{V'^2}{V''^2} \quad \cdots\cdots (5)$$

where:

λ : Scale
$'$: Item for model
$''$: Item for full scale
ρ : Specific gravity of material

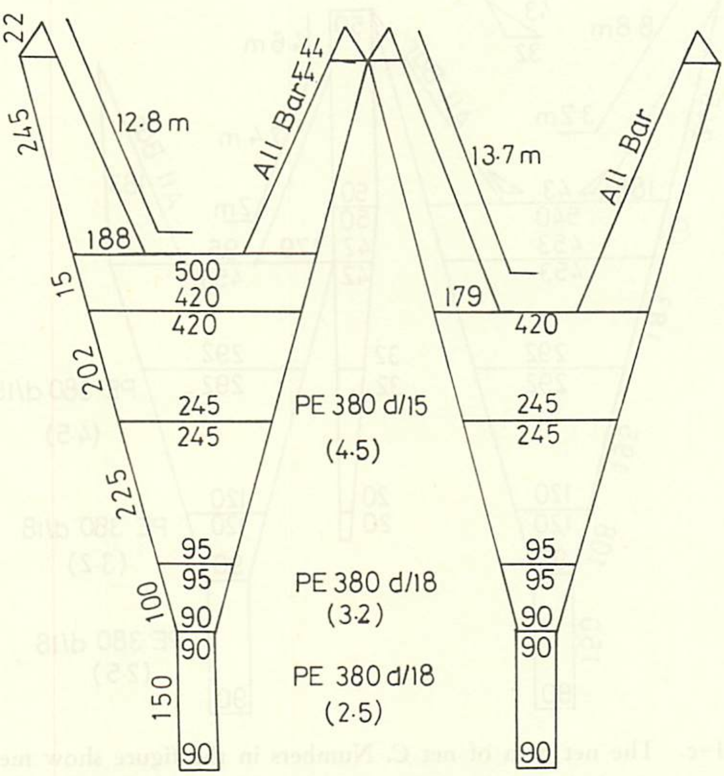


Figure 1-b. The net plan of net B. Numbers in the figure show mesh numbers and bracketed numbers are mesh sizes (cm).

K : Constant

In order to limit the circulating power of the tank, the scale ratio λ was chosen so as to fit the model in the tank and to match to the constant value K. Dimension of the experimental model nets is given in Table 2.

The model experiments were carried out in the circulating water tank belonging to the Faculty of Fisheries, Kagoshima University. In order to eliminate the boundary layer, a 20 centimeter board elevated with 5 centimeter scale marks was placed in the observing channel of the tank. Before the experiment proceeded, the flow uniformity was checked and adjusted. The net was placed on the board. Each trawl warp was connected to a tension meter system through a movable pulley. The tension meter system consisted of a UT-gauge (600 gf), a strain amplifier (Y. E. W. 3458-10) and a flat bed pen recorder (Y. E. W. 3502) to detect and record the tension of the trawl during the experiment.

Two phases of experiment were carried out; in the first phase, only the trawl was tested. A stick was used to hold the wing tip vertically. K. WADA (1973)[5] estimated that in practice, the wing spread of a shrimp trawl when it is towed was in the range of 60% to 80% of the head rope length. J. W. WATSON (1976)[6], also observed the same phenomena. In this experiment therefore, the wing spread were set fixed at 50%,

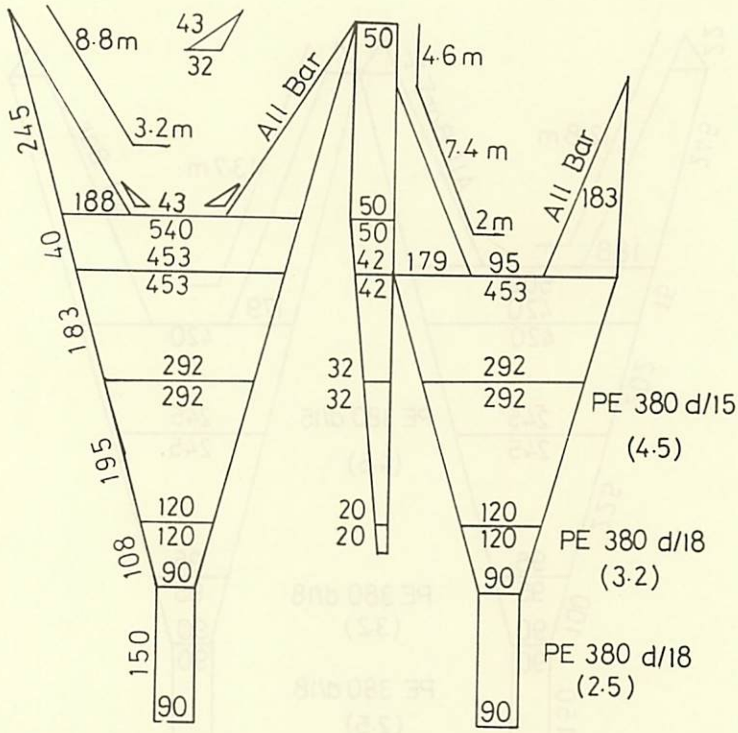
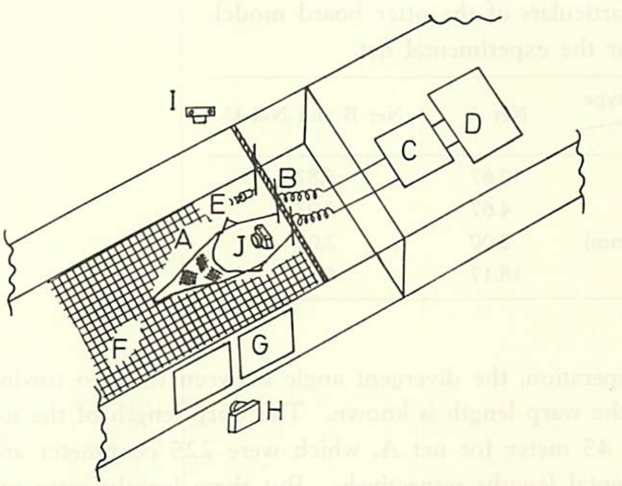


Figure 1-c. The net plan of net C. Numbers in the figure show mesh numbers and bracketed numbers are mesh sizes (cm).

Table 2. Dimension of the reducing ratio of the experimental condition of model nets.

Items / Net type	λ'/λ''	D'/D''	V'/V''	D_1'/D_1''	F'/F''
A	$\frac{1}{20}$	0.29	0.54	0.06	7.2×10^{-4}
B & C	$\frac{1}{40}$	0.27	0.52	0.03	1.7×10^{-4}

60%, 70%, and 80% of the head rope length. For each wing tip spread, the trawl was tested at six levels of towing velocities, 0.5 knots, 1 knot, 1.5 knots, 2 knots, 2.5 knots, 3 knots. The water flow velocity was measured by a Toho Dentan CM-10S current meter. The net shape, net height and position of the trawl on the board was determined by eye using X-Y-Z coordinate system. To read these coordinates, the trawl was marked at 10 points on each side and at the corresponding centerline. The X and Y coordinates were read from the scale surface of the board. The Z coordinate was the trawl elevation and was measured by means of a scaled stick placed at the



A : Model net with otter board rigged
B : Supporting bar, UT gauge and bridge head
C : Strain amplifier
D : Pen recorder
E : Current meter
F : Scaled board
G : Observing window
H : Camera (side view)
I : Camera (top view)
J : Camera (front view)

Figure 2. Schematic drawing of the whole set up of second phase experiment in the observing channel of the circulating water tank.

marked points of the trawl. The plane view, side view and the front view were also photographed for each towing velocity and wing tip spread.

From this experiment, it was possible to determine the area of the otter board using :

$$S = \frac{2 F_l}{C_l \rho V^2} \quad \text{..............} (6)$$

where
- S : Area of the otter board
- F_l : Shear force of the trawl
- C_l : Shear coefficient for a flat rectangular type of otter board (0.9)
- ρ : Density of water ($102\,\mathrm{kg.sec^2/m^4}$)
- V : Normal towing velocity ($2\,\mathrm{knots} = 1.029\,\mathrm{m/sec}$)

Here, F_l was calculated at 2 knots towing velocity and at 70% wing tip spread because in this situation the trawl was uniformly tapered.

$$F_l = T \sin \beta \quad \text{..............} (7)$$

where
- T : Tension
- β : Angle between direction of flow and warp

The otter board was made from a 2 millimeter polyvinyl chloride plate. Lead foil attached to the bottom edge to represent the iron shoe and to account for the weight. The weight was determined from the specific gravity of a real otter board. By using aspect ratio of 0.5, the dimension of the otter board for net B and net C were determined and constructed. The dimensions of the otter board for net A was reduced from full scale one. Particulars of the otter board model are given in Table 3.

In the second phase, an experiment similar to the first was conducted, except that the trawls were rigged with otter boards. The wing spread varied dependent upon the water velocity. Figure 2 shows the general set up of the experiment in the observing channel of the tank. It only differs from the first phase in the presence of the otter

Table 3. Particulars of the otter board model for the experimental net.

O. B. type / Particulars	Net A	Net B and Net C
Length (cm)	10.67	5.82
Height (cm)	4.67	2.97
Thickness (mm)	2.00	2.00
Weight (g)	18.17	6.40

board. In the actual trawling operation, the divergent angle between the two towing warps is about 10° to 12°, and the warp length is known. The warp length of the net B and net C is 100 meter and 45 meter for net A, which were 225 centimeter and 250 centimeter for the experimental lengths respectively. But these lengths were too long for the tank, and were therefore geometrically reduced. From the calculations the distance between supporting bars which hold the warps was determined to be 22 centimeter for nets B and C, and 16 centimeter for net A. As in the first phase, each trawl was tested under six towing velocities.

Results

Emphasis is placed on results concerning actual operation, i. e. on the second phase. For convenience of discussion and better understanding, all empirical values are converted to full scale values unless otherwise indicated. All lines and curves are derived from empirical equations.

1) The wing tip spread D_w

As the velocity increased the freely towed otter board and wing tip gradually spread out. The initial wing tip spread, when towed at 0.5 knots was 8.3 meter, 12 meter, and 12 meter for nets A, B, and C; respectively. In the case of nets B and C, the wing tips continued to spread as the towing velocity increased to 3 knots. After 2 knots there was no significant change in the spread of net A which was about 11 meter. Between wing tip spread and velocity can be described a liner equation. The equation and regression line of the above relationship for the three nets were obtained using a linear regression and are presented in Figure 3.

2) The net mouth height H_n

As the towing velocity increased from 0.5 knots to 3 knots, the net mouth height decreased, in all nets a rapid decrease was noticed from 0.5 to 1.5 knots. It is assumed that for towing velocities exceeding 3 knots, the net mouth height would remain constant. This was because the height at the wing tip was maintained by the otter board height.

The relationship between the net mouth height H_n and the towing velocity V is assumed to be negative exponential function. The experimental expressions of the three nets are displayed in Figure 4.

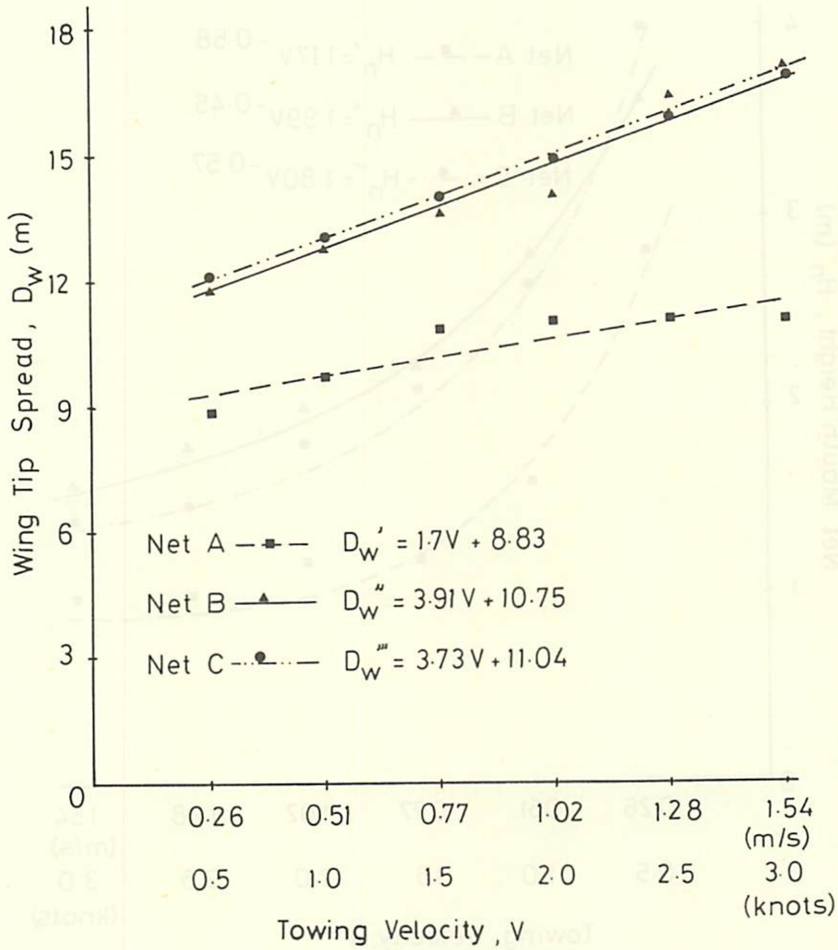


Figure 3. Relationship between the wing tip spread D_w and the towing velocity V of the three model nets.

3) The sweeping area A_s

The sweeping area is the area covered between wing end as it is moved through the ground, that means it is equal to the product the wing tip spread D_w and the towing velocity V.

$$A_s = D_w V \quad \cdots\cdots (8)$$

Up to the 3 knots towing velocity, the sweeping area can best be described as being directly proportional to the towing velocity and the relationship can be expressed as a linear regression. The equations of the sweeping area of the three nets obtained by multiple regression are shown in Figure 5.

4) The total gear drag force R_t

The total gear drag force included the fluid dynamical force imposed on the trawl and the otter board. It is impossible to simulate the bottom friction because the experiment was conducted in circulating water tank.

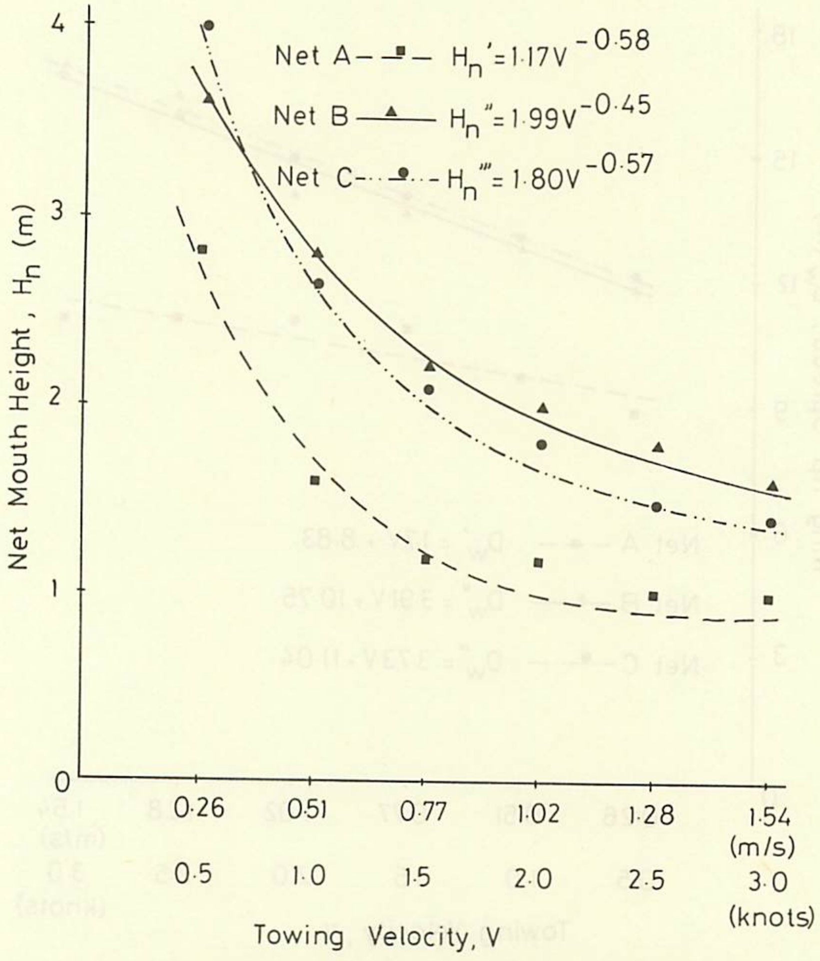


Figure 4. Relationship between the net mouth height H_n and the towing velocity V of the three model nets.

The drag force increased as towing velocity increased. When the data were plotted on a logarithm graph (Figure 6), it is nearly linear. Therefore, it is possible to express the equation as:

$$R_t = xV^y \quad \text{.. (9)}$$

where V : Towing velocity
x : Coefficient
y : Exponent

This means that the gear drag force increases exponentially with the towing velocity. The equations of the total gear drag force of the three nets are presented in Figure 6.

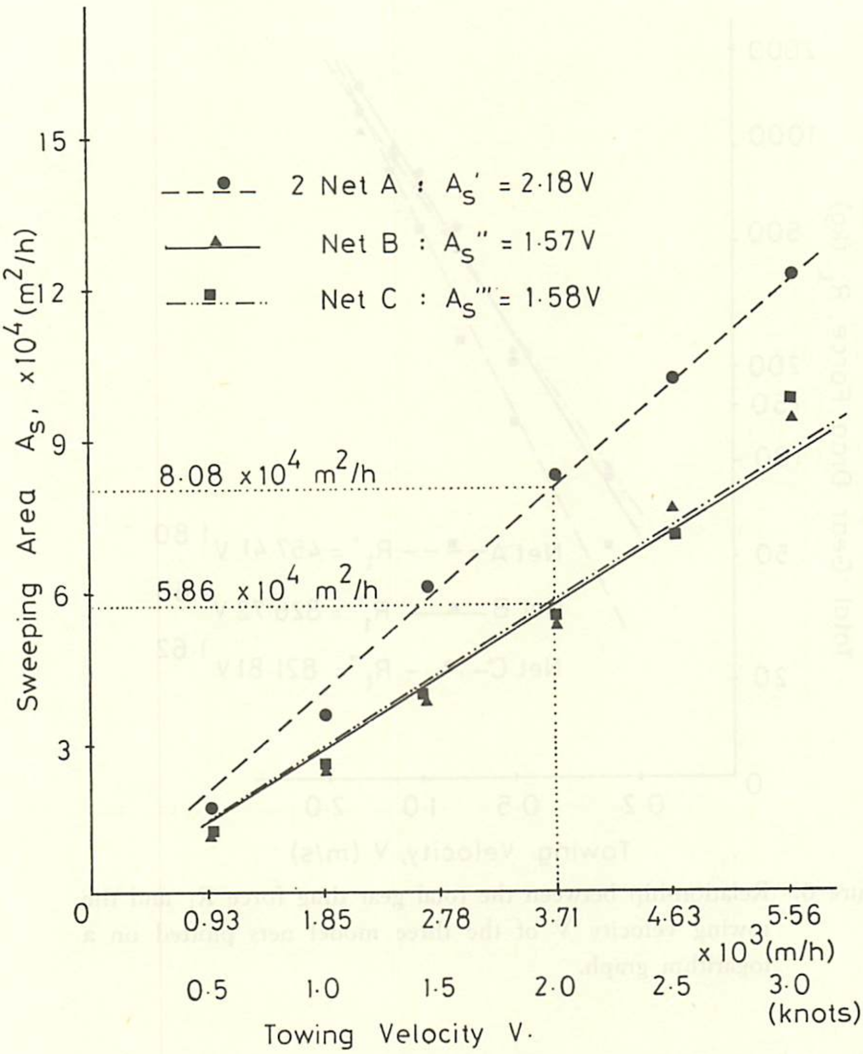


Figure 5. Relationship between the sweeping area A_s and the towing velocity V. Dotted lines denote the value of sweeping area at 2 knots towing velocity.

Discussion

For the purpose of catching shrimp, which are not actively mobile organisms, a 2 knot towing speed is sufficient. On the basis of shrimp behaviour, a shrimp trawl should have a wide and flat with a low net mouth, H. MIYAMOTO (1968)[3], B. ELDERED et al. (1968)[1]. The low net mouth height reduces the water column swept above the trawl. Thus slow swimming fish fry and other protected species on top of the trawl will not get trapped. In this experiment, at 2 knots, the net mouth heights were 1.2 meter, 2 meter, 1.8 meter for net A, net B and net C respectively.

The working performance of a shrimp trawl comments on the catch ability and is

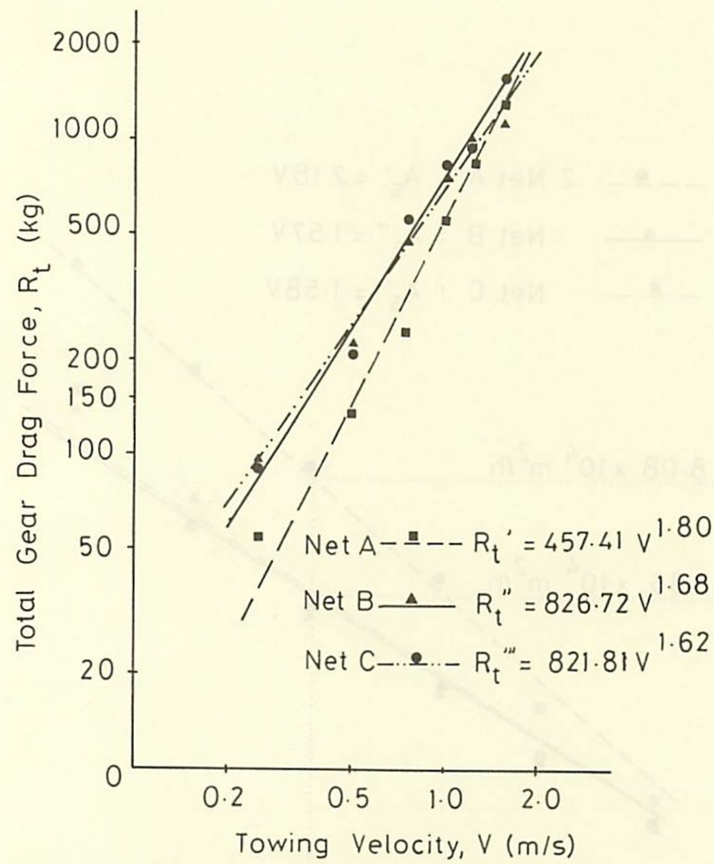


Figure 6. Relationship between the total gear drag force R_t and the towing velocity V of the three model nets plotted on a logarithm graph.

concerned with the sweeping area. Looking at equation (8), increasing the sweeping area can be achieved either by increasing the wing tip spread or increasing the speed of trawler. If the two types of rigs are compared, the double rigged type provides 28% more sweeping area than the single rigged type (Figure 5).

The average mesh opening at five vertical cross-section of the trawl was determined at 2 knots towing velocity using the following equation:

$$\theta_p = 2\ sin^{-1}\left(\frac{J_p}{N_p\ L_p}\right) \quad \cdots\cdots (10)$$

where θ_p : Mesh opening angle at cross-section p

J_p : Circumference at cross-section p

N_p : Number of meshes at cross-section p

L_p : Length of a mesh at cross-section p

These section are shown in Figure 7. From Figure 8, it can be seen that the angle is biggest at the square region and becomes smaller toward the cod end. In the case of the four seam types, nets A and C, the angle at section S is bigger than its

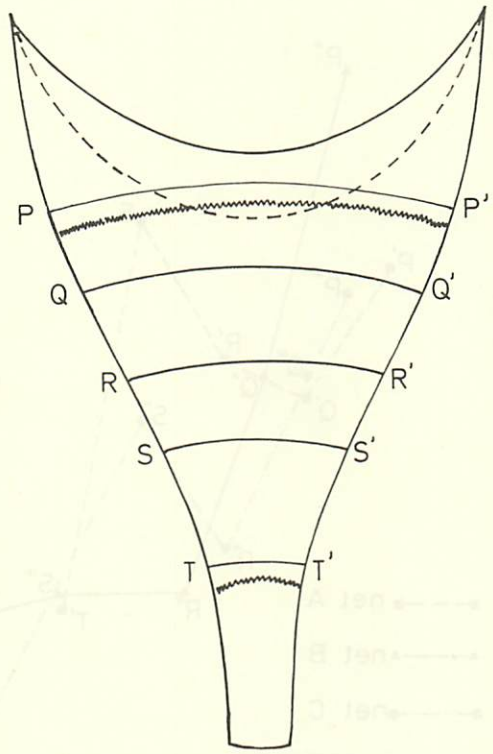


Figure 7. Schematic drawing of the experimental trawl at 2 knots towing velocity, showing the selected vertical cross sections where the average mesh opening angle are determined.

adjacent sections. Generally, at this mesh opening angle, a 5.5 centimeter mesh size netting, the mesh becomes to 3 centimeter in width which could secure the big shrimp and yet allow the small shrimp and fry escape.

The main engine output necessary to pull these nets was estimated from the conversion of total gear drag force value R_t to a horse power value EHP using, T. KOYAMA (1976)[2]:

$$EHP = \frac{R_t \ V}{75} (PS) \quad \cdots\cdots\cdots\cdots (11)$$

Since net A is designed to be pulled a pair, the R_t value is doubled. From Figure 9, it is apparent that there is little difference in the output power necessary to pull a single rigged trawl and a double rigged trawl, each half the size of the single. At 2 knots the double requires 12 PS. About 20% of that is necessary to compensate for the ground and other frictions.

Any Malaysian trawler that is able to pull the above single rigged trawl should also be able to pull the above double rigged trawl. Thus on the same fishing ground and on the same trawler, the double rigged type has an advantage over the single rigged type in term of catch ability. With a simultaneous trawling operation of two trawls,

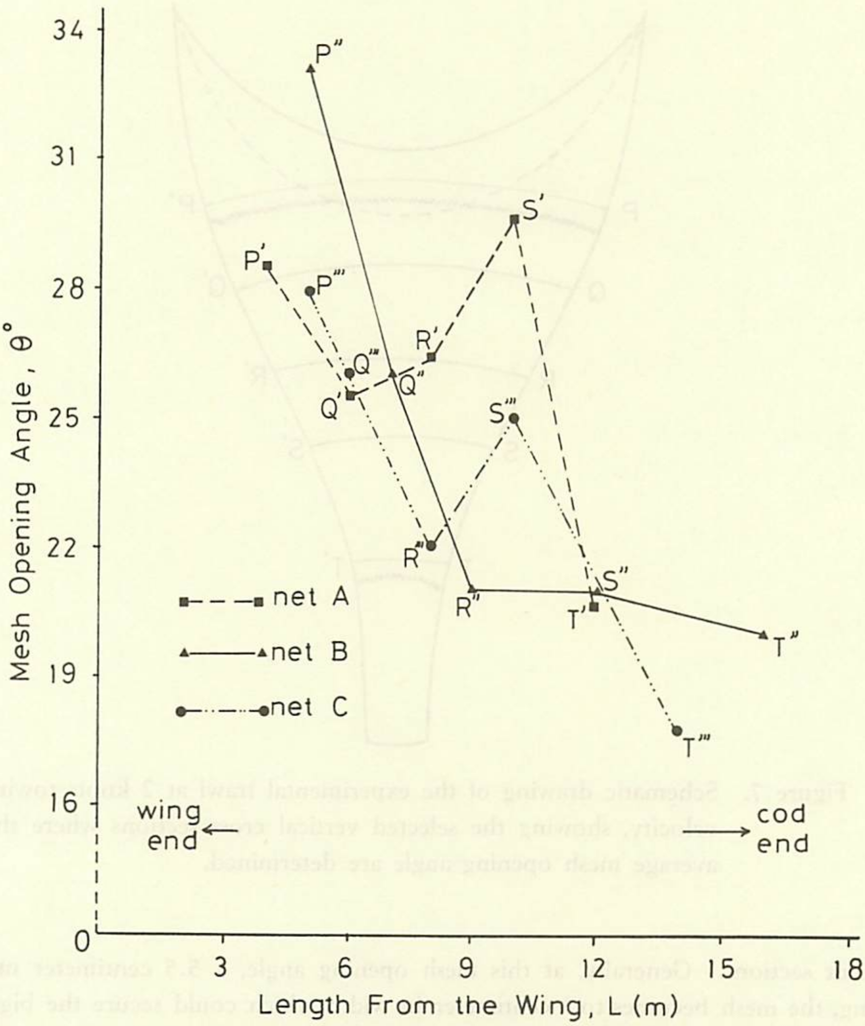


Figure 8. Relationship between the mesh opening angle and various vertical cross sections of the trawl ′, ″ and ‴ indicate selected cross sections of net A, net B and net C respectively.

it saves energy and labour.

In respect to the conservation of fish fry and other immobile species, these shrimp trawls comply to the rule for being pulled at a low speed, with a low net mouth height and a suitable mesh opening.

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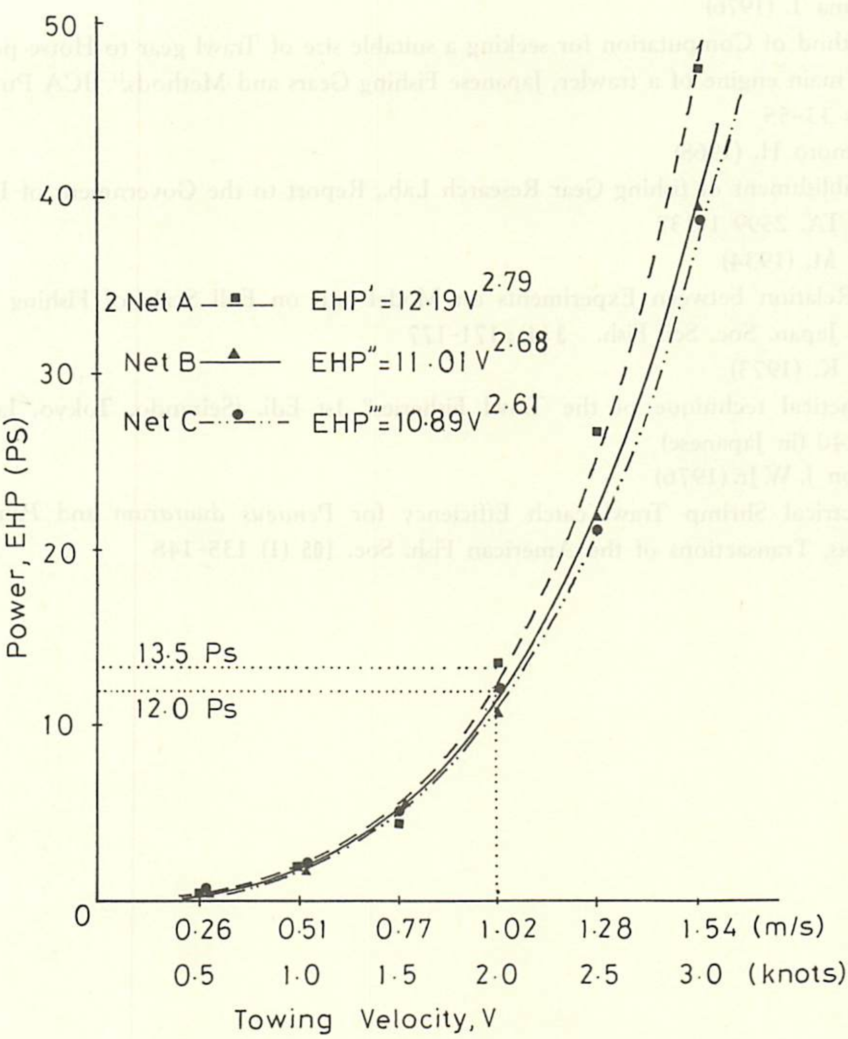

Figure 9. Relationship between the output power necessary to pull a net EHP and a towing velocity V. Dotted lines denote the necessary output at 2 knots towing velocity.

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