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Original Article

A flume test of a model net with varying wing-end widths to characterize the performance of shrimp trawl in Kotabaru, Indonesia

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Abstract
Shrimp trawl net is the prominent fishing gear that beneficially supports shrimp industries in Kotabaru, Indonesia. However, concurrently local fishermen have no idea how trawl works under towing condition. For this reason, a flume test of a 1/8 scale model net with varying wing-end widths was undertaken. The flow speeds of model were 48, 56, 64, 72, and 80 cm s^{-1}. Meanwhile wing tips distance was set at 46–66% of head-rope length. At a towing speed of 64 cm s^{-1} (2-knot in full scale), the net height was 12 cm, the projective area of net mouth was 9.16×10^2 cm^2, water filtering volume was 58.44×10^3 cm^3 s^{-1} and total net resistance was 6.34×10^2 g. The ratios of net height to net circumference ranged of 0.04–0.08. The net height was 5.5% of net circumference and getting lower at higher towing speeds. The exponent value of 1.40 was smaller than the suggested value (2.0) indicating the shape of net body should be refined by inserting triangle nets between the side net and baiting. Moreover, the length of nets should be afforded to the lacing lines to increase the height of net opening by better distributing the towing forces.

Keywords: Model scale; flume tank; net circumference; shrimp trawl; Kotabaru

1 | INTRODUCTION

Varieties of fishing methods and gears are being used worldwide to collect shellfishes from aquatic habitats. Some of these methods and gears include baited traps (e.g. Mejia-Ortiz *et al.* 2001), electrofishing (e.g. Alonso 2001), sex-pheromone-baited traps (e.g. Stebbing *et al.* 2004), trammel nets (e.g. Boutson *et al.* 2007), gillnet (e.g. Pravin and Ravindran 2011), light traps (e.g. Ahmadi 2012), cast nets (e.g. Lawal-Are and Akinjogunla 2012), fyke-nets (e.g. Deniz *et al.* 2010), tangle nets (Ahmadi *et al.* 2015), liftnet (e.g. Puspito *et al.* 2015), trawl nets (e.g. Wong *et al.* 2015; Broadhurst *et al.* 2017), and underwater hand fishing (Parvez et al. 2017).

The gear efficiencies and physical characteristics of fishing gears (e.g. Galib *et al.* 2009; Singh and Agarwal 2014; Das *et al.* 2015; Olopade *et al.* 2017) including trawls (e.g. Higo 1971; Broadhurst *et al.* 2017) have long been studied. Higo (1971) reported that the four-seam trawl has a better gear efficiency than the two-seam trawl in term of net mouth performance. The net height opening was influenced by the distance between wing ends, towing speed and buoyancy. Muchtar *et al.* (1973) undertaken the experimental model and mechanical comparison of four-seam trawl net and six-seam trawl net based on Japanese bull trawl “Teguri ami”. The difference of the nets used in these experiments only on its constructions. The result showed that the net height of six-seam trawl net was higher than that of four-seam trawl net.

Mangunsukarto (1979) carried out model and field experiments to obtain some fundamental suggestions on gear efficiency of three types of trawl nets in different sizes. He found that the four-seam trawl net had a better net height opening than other nets in the same wing tips distance of 40%. Miyamoto (1968) suggested that the net mouth height of 60 to 100 cm would be sufficient to catch shrimp actually. Shahardin (1983) reported that the feasibility of employing the double rigged type shrimp trawl at the same fishing ground and the same trawler had advantages over the single rigged in terms of the sweeping area and catchability. Fuwa *et al.* (2013) stated that fish catching efficiency of knotless trawl was superior to that of knotted trawl. Ebata *et al.* (2013) demonstrated that the use of "Dyneema" (ultra-high strength polyethylene fibre) was able to reduce up to 24.7% the hydrodynamic resistance of a bottom trawl net to save fuel consumption of operation, while the shape of the net did not change. Khaled *et al.* (2012) optimized cable length for trawl fuel consumption reduction. Broadhurst *et al.* (2013) measured the drag of single-, twin-, triple- and quad-rigs in the field and demonstrated fuel savings of up to 26% from using the high-order, multiple-net rigs. Other studies focused on the size selectivity in the codends (Tokac *et al.* 2009; Sala and Lucchetti 2011; Dereli *et al.* 2016), energy-efficient in trawling operation, bycatch reduction by using grid size-sorting system (Madsen and Hansen 2001; He and Balzano 2012, bridles floatation (He *et al.* 2014) or by configuring the mesh sizes, side taper and wing depth of trawls (Broadhurst *et al.* 2014), as well as numerical model application for improved trawling systems (Chin *et al.* 2000; Suzuki *et al.* 2003; Khaled *et al.* 2012). Lastly, fish behaviour during trawling operations was also observed (Hannah *et al.* 1996; He *et al.* 2008; Özbilgin *et al.* 2013; Bayse *et al.* 2016).

Shrimp trawls in Kotabaru, Indonesia are very important fishing gear for commercial shrimp harvesting. In general, it was categorized in small size groups but it commons in 2-seam shrimp trawls (Figure 1A–1B). A total of 4079 bottom-trawls are being operated in this region (BPS-Statistic of Kotabaru Regency 2015). It is quite reasonable because the shrimp industries in Kotabaru required more raw materials for domestic and export products. Thus, the annual production of shrimp in Kotabaru increases proportionally with increasing the number of trawl nets (Table 1). In practice, local fishermen have no idea how shrimp trawl works during its operation due to lack of information of what full scale trawl (prototype) look like under trawling condition. To acquire new knowledge in this area of study, we carried out an experimental model of the net in the flume tank to provide some fundamental suggestions on the gear efficiency based on the physical characteristic and performance of trawls under towing conditions. From the standpoint of fishing gear, the results of experiments could become valuable information for improving the current shrimp trawl construction.

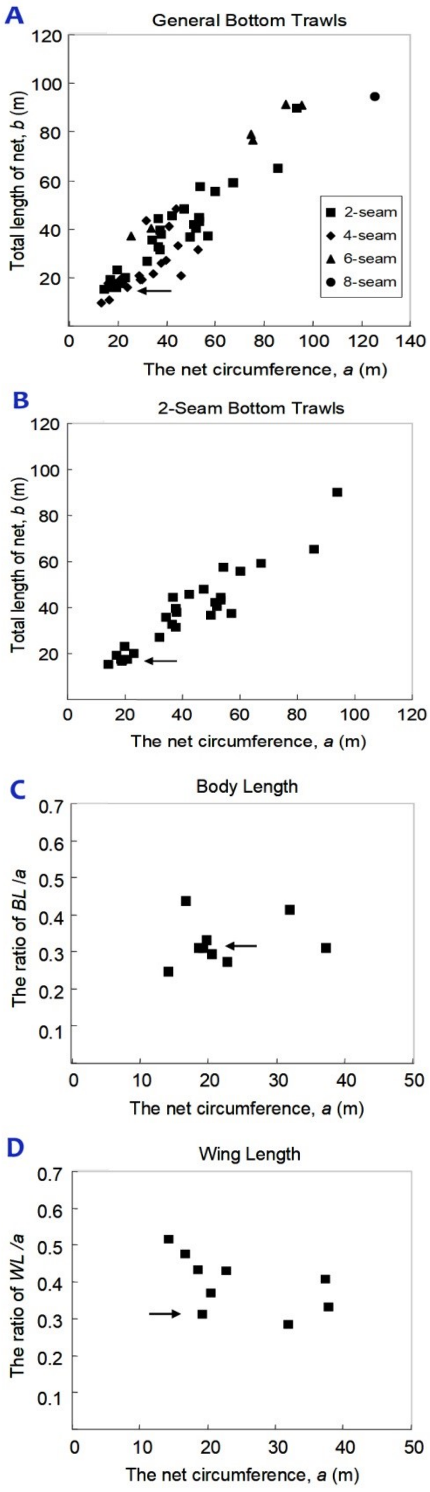

FIGURE 1 (A) the position of shrimp trawl from Kotabaru in general bottom trawls, **(B)** Its position among other 2-Seam bottom trawls, **(C)** Comparative ratio of body length to the net circumference (*BL/a*) among 2-seam shrimp trawls, and **(D)** Comparative ratio of wing length to the net circumference (*WL/a*) among the trawls. The arrows pointed to the position of the current shrimp trawl net.

TABLE 1 The trend status of shrimp fishing in Kotabaru Regency during 2011–2015

Variables	***Year***				
	2011	***2012***	***2013***	***2014***	***2015***
Annual production (ton)	192.9	337.6	590.9	709	4930
Capture fishery households	5492	5495	5945	4591	11836
Fishing boats (<5 GT)	4966	4970	4790	3892	6749
Number of trawl nets	589	589	589	4079	4079

Source: BPS-Statistic of Kotabaru Regency (2015)

2 | METHODOLOGY

2.1 | Gear Characteristics

Kotabaru District is one of the potential fishing ground for shrimp in South Kalimantan Province. Sample of traditional shrimp trawl net was taken from Pulau Laut Utara of Kotabaru (3°21'S and 116°11'E; Figure 2) during 2004, and the current status of trawl net fishery was updated. It was a typically bottom trawl with a low engine power of 20 HP at a towing speed of 2-knot, which has commonly been adopted by fisherman for catching black tiger prawn, banana prawn, endeavour shrimp, barramundi and red snapper. According to fisherman information, fishing season for shrimps is from August to January and for fish is from September to November. The net type was composed of 2-seam (top and bottom panels) with the specification as described in Table 2. The net was constructed without using the lacing lines. Lacing twine used for joining to both selvedges of belly-baiting and side nets. Actually, the lacing lines were originally meant to strengthen the netting for hauling. The function of the lacing lines has been extended to increase the height of net opening by better distributing the towing forces which had previously been concentrated on the head rope and ground rope. In the construction of a trawl, the ratio of head rope (HR) to ground rope (GR) is important factor for having a good performance of the net mouth. The suggested ratio of this is 0.87 for two-seam trawl and 0.83 for four-seam trawl (Nomura *et al.* 1977). In case of shrimp trawl in Kotabaru, the HR/GR ratio was 0.88 instead of the suggested ratio. The otter boards were used to spread the wing tips horizontally, and simultaneously to keep it in contact with the seabed. It made of wood (70×45 cm), the lower part fulfilled with cement mixed with leads to have touch connection power to the sea bottom and the upper part put two plastic floats with diameter 100 mm to hold it stands vertically and total weight was 20 kg per unit. The hand rope 2 m long of Polyethylene diameter 8 mm, attached together with otter boards.

The original full scale net plans were transformed into experimental model scale based on the Tauti's comparative method (Tauti 1934). The ratio between experimental model scale (') and full scale (") were described as follows:

1. Reducing scale is λ' / λ''
2. Ratio of twine diameter, D and mesh size, L is $D' / D'' = L' / L''$
3. Ratio of velocity, V is $V' / V'' = \sqrt{D'/D''.(\rho'-1)(\rho''-1)}$
4. Ratio of rope diameter, D_1 is $D_1' / D_1'' = \sqrt{\lambda'/\lambda''.(\rho_1''-1)(\rho_1'-1).V'^2/V''^2}$
5. Ratio of sinking and floating power, F and that of the force acting on the net, R *is* $F' / F'' = R' / R'' = (\lambda'^2 / \lambda''^2)(V'^2 / V''^2)$

Where ρ is the specific gravity of netting cord, and ρ_1 is the specific gravity of the rope.

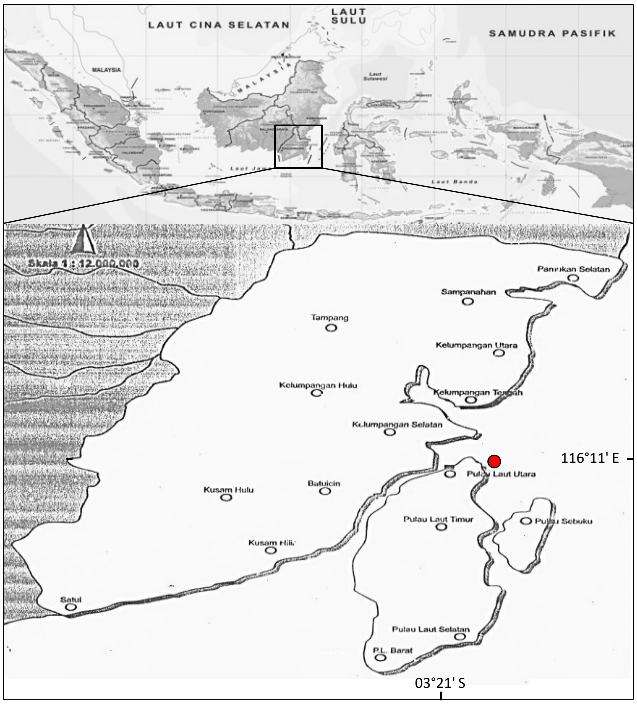

Figure 2 Map showing the location where a sample of shrimp trawl net was taken in Pulau Laut Utara of Kotabaru, South Kalimantan

2.2 | Main dimensions of the model net

The main dimensions of the experimental model scale are as follows: the reducing ratio was 1/8, the ratio of twine diameter and the ratio of the bar lengths of the mesh size were 0.028 and the ratio of flow speed were 0.62. The comparative values of full scale and experimental model scale are described in Table 3. The model nets were constructed with polyamide twine of 210 denier 9 ply, 15 mm stretched mesh with twine diameter 0.42 mm. Model net was built and rigged with a 1.75 m head rope and a 2 m ground rope of Polyethylene with rope diameter 1.125 mm (Figure 3). The ratio of the head rope to the ground rope equals 0.88. Total buoyancy of floats was 22.82 g, composed of 26 floats along the head rope hold the net open vertically. Total sinkers weight in air was 72.01 g, consisted of 160 small leads were attached to the ground rope in each 2.5 cm long with 80 intervals.

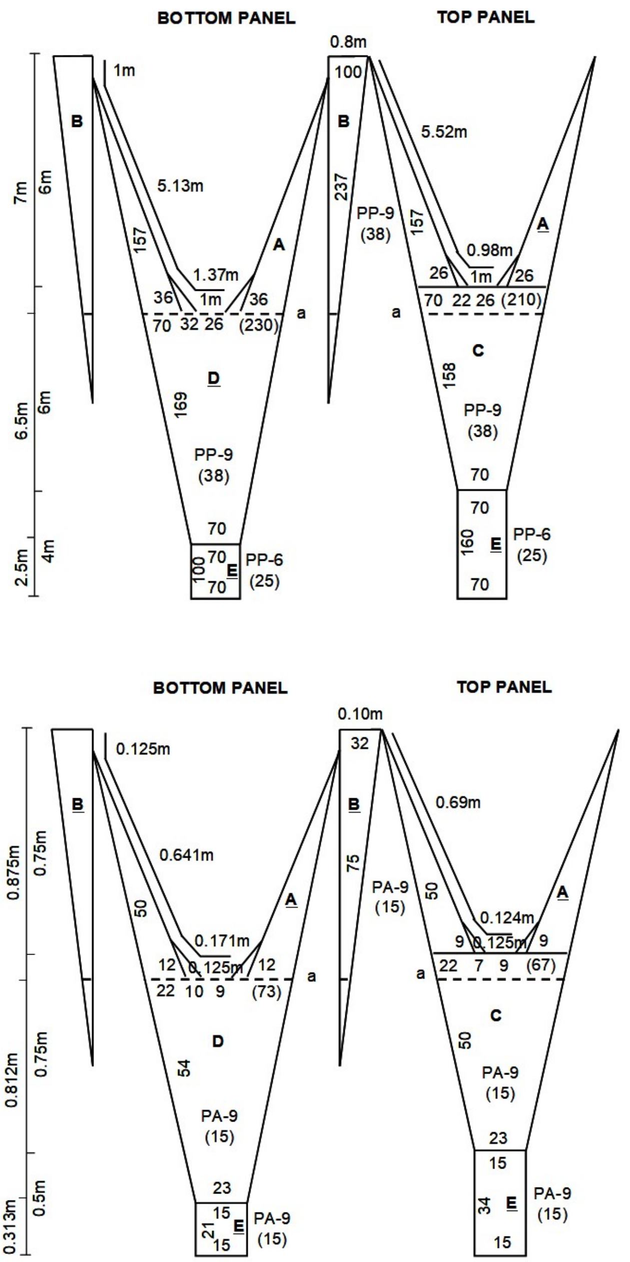

FIGURE 3 Full scale net of shrimp trawl from Kotabaru (top) and model scale net plan at 1/8 scale (bottom). The bracketed numbers are mesh sizes (mm). Panel of elements: A, upper and lower wings; B, side net; C, baiting; D, belly; E, Codends; and a- net circumference

TABLE 2 The specification of traditional shrimp trawl operated in Kotabaru, Indonesia

Variable elements	*Description*		
Frontal shape at net mouth	Bottom shape is different from top shape. The bottom portion is shorter than the top one.		
Wing construction	Upper and lower wings are different in position, which lower wing put backward 1 m from the front edge. The lower wing is longer than upper wing.		
Square part	Available square part on the top body in lateral line with the bottom body. Net circumference is showed in dashed lines.		
Body size	Bottom body (belly) is longer and wider than top one (baiting)		
Codend size	The bottom portion is shorter than the top one.		
Head rope (*l*)	14 m, PE, ∅ 9 mm	*l/m*	0.88
Ground rope (*m*)	16 m, PE, ∅ 10 mm	*l/b*	0.88
Total length of net (*b*)	16 m	*m/b*	1.00
Stretched net circumference (*a*)	17.54 m, PP-170D/9, 38 mm, ∅ 1.08 mm	*b/a*	0.91
Upper wing (*c*)	6 m, PP-170D/9, 38 mm, ∅ 1.08 mm	*c/a*	0.34
Lower wing (*d*)	7 m, PP-170D/9, 38 mm, ∅ 1.08 mm	*d/a*	0.41
Square (*d-c*)	1 m, PP-170D/9, 38 mm, ∅ 1.08 mm	*(d-c)/a*	0.06
Side net (*e*)	9 m, PP-170D/9, 38 mm, ∅ 1.08 mm	*e/a*	0.51
Baiting/belly (*f*)	6.5 m, PP-170D/9, 38 mm, ∅ 1.08 mm	*f/a*	0.37
Cod-end (*g*)	2.5 m, PP-170D/6, 25 mm, ∅ 0.98 mm	*g/a*	0.14
Float	Plastic, dia. 70–100 mm, 13 pcs, total buoyancy 3.8 kg		
Sinker	Lead, 720 pcs, total weight 12 kg		
Otter board	Wooden, 70 × 45 cm, 2 pcs, total weight 40 kg		
Warp	30 m, PE, ∅ 8 mm		
Hand rope	2 m, PE, ∅ 8 mm		
Boat dimension	L.B.D (9 × 1.5 × 1 m), wooden, 1 GT		
Engine power	20 HP		
Trawling speed	2 knots (1.03 ms^{-1})		
Depth	6–10 m		
Warp length	30 m		
Trawling time	2 hours (4 times a daytime)		
Hauling	by hand		
Number of crew	1		
Fishing day	20 $month^{-1}$		
Seabed	Mud-sandy		

PE, polyethylene; ∅, diameter; LBD, length, beam, depth

2.3 | Experimental conditions

A shrimp trawl model was tested experimentally in water circular tank belongs to the Faculty of Fishery, Kagoshima University, Japan. The tank consists of 2 impellers type vertical circulating water channel with 2 sets drive motor D.C. 22 kilowatt. The main body dimension: 14.8 m long, 2.0 m wide and 5.9 m high, and measuring section: 6 m long, 2 m wide and 1 m deep, it constructed of reinforced concrete with approximately 80,000 litres freshwater in capacity. The central observation channel is 2 m wide and the right and the left water ways are each 1 m wide. The water flows symmetrically into the central section forming a straight water channel for experimental works. The flow is made by two sets of rotating propeller driven by an alternating current motor.

TABLE 3 The comparative values of full scale and experimental model scale of shrimp trawl

Type of net	***Full scale***	***Model scale***
Total length of net (m)	16	2
Stretched net circumference (m)	17.54	2.19
HR length (m)	14	1.75
GR length (m)	16	2
Total buoyancy of floats (kg)	3.8	22.82×10^{-3}
Total weight of sinkers (kg)	12	72.01×10^{-3}

The flow speed of 0–2.2 m s^{-1} can be accurately controlled and adjusted by an ultrasonic current meter. Both side walls of observing channel which are made of glass, a window situated at the centre of the channel make it possible to take measurements and photographs. The experimental conditions can also be observed from the top and side views. The experimental model net was placed on the floor of observation channel under ordinary current. The floor whose diagram used to set up wing tips distance position properly and symmetrically, and also to measure coordinate of measured points from top view by using a glass boat. Flow speeds used in these experiments including towing speed used in the actual fishing *i.e.* 2-knot (64 cm s^{-1} in model scale). In this study, the flow speeds of model were 48, 56, 64, 72, and 80 cm s^{-1} (corresponding to the full-scale range of 1.5, 1.75, 2.0, 2.25, and 2.5 -knot). Wing tips distance was set at 46–66%. It was fixed to be 46% (80 cm), 51% (90 cm), 57% (100 cm), 60% (105 cm) and 66% (115 cm) of HR length respectively (corresponding to full-scale wing-end spreads of 6.4, 7.2, 8.0, 8.4 and 9.2 m). Actually measurements of wing tips distance have also been tried during trawling operation in Kotabaru, but unsatisfied due to inappropriate instrument used.

In a flume tank, wing tips distance was adjusted to a desired distance by simply placing the supporting rod on the iron board which holds the towing line (warp) through the moveable pulley which connected to the hand ropes of wing tips and load cell. The height of net mouth was measured directly by using a laser point (laser beam sight level 230) and millimetre bar through the observation window. To measure it easily, 7 marked floats along the head rope were fixed to be the measured points of the net mouth height. The distances of each marked float were also measured (represented by the X and Y coordinates). The results of measurements on the net heights and distances later will be used to calculate the projective area of net mouth and then water filtering volume. Tension of line was measured indirectly by using three components such as load cell, DC strain amplifier and Analog Digital Converter, which connected and recorded into the personal computer (PC) and also through the instrumental calibration, later it will be used to calculate the total net resistance. The ratio of net height to the net circumference will be calculated in relation to the gear construction and performance of trawl at various wing tips distances and towing speed condition.

For statistical analysis, the Mann-Whitney test was employed to compare the values between two variables tested (e.g. difference in the net height at the slowest and the highest towing speeds). Kruskal-Wallis test was used to examine differences in the height of net mouth, projective are of net mouth, total net resistance or the H/a ratio among the five wing-ends spreads. Multiple comparison tests were conducted to see which values differed among them. All tests were analysed at the 95% level of significance using SPSS-16.0 software. In addition, the values of constant (a) and exponent (b) obtained from the linear regression of the estimated parameters were also presented.

3 | RESULTS

The output results (Table 4) show that there were no significant differences in wing-end spreads when applied for determining the height of net mouth, projective are of net mouth, total net resistance and the H/a ratio ($P > 0.05$).

3.1 | Height of net mouth

From the results of experiments, the net height opening is understood as being very important for the design of the net. The height of net mouth is defined as vertical distance from the head rope to the ground rope at the central point of head rope. The results showed that the height of net mouth decreased gradually with increasing the towing speed and distance between both wing tips. There was no statistically significant difference in the height of net among the five wing-end spreads ($P > 0.05$). Data analysis also showed no statistically significant difference in the height of net at the slowest towing speed and the highest one ($P > 0.05$). At towing speed 64 cm s^{-1} (2-knot), the net height at different wing tips distances varied from 10.2 to 12.6 cm (from 0.82 to 1.01 m in full scale). The highest net mouth opening was 16.5 cm (1.32 m) with wing tips distance 80 cm (6.4 m, 46% of HR length) at towing speed of 48 cm s^{-1} (1.5-knot), and the lowest one was 8.5 cm (0.68 m) with wing tips distance 115 cm (9.2 m) at towing speed of 80 cm s^{-1} (2.5 knots).

TABLE 4 Descriptive parameters and measurement results of a shrimp trawl model scale (*n* = 7 $trial^{-1}$)

Experiment and parameters	*Values of parameters based on measured empirical data*				
Experiment 1: Wing tips distance 80 cm (46% of HR length)					
Towing speed (cm s^{-1})	48	56	64	72	80
Height of net mouth (cm)	16.5	14.3	12.6	11.2	10.3
Ratio of net height/circumference (H/a)	0.08	0.07	0.06	0.05	0.05
Projective area of net mouth (10^2 cm^2)	10.58	8.94	8.10	7.34	6.75
Water filtering volume (10^3 m^3)	29.32	28.96	30.02	30.64	31.33
Total net resistance (10^2 gf)	4.30	5.11	5.94	7.12	8.40
Attack angle at head rope (°)	16	18	20	18	18
Experiment 2: Wing tips distance 90 cm (51% of HR length)					
Towing speed (cm s^{-1})	48	56	64	72	80
Height of net mouth (cm)	15.6	13.3	12.0	10.8	10.3
Ratio of net height/circumference (H/a)	0.07	0.06	0.05	0.05	0.05
Projective area of net mouth (10^2 cm^2)	11.33	10.02	9.16	8.28	7.83
Water filtering volume (10^3 m^3)	31.40	32.45	33.97	34.59	36.37
Total net resistance (10^2 gf)	4.44	5.54	6.34	7.42	8.73
Attack angle at head rope (°)	20	18	20	20	20
Experiment 3: Wing tips distance 100 cm (57% of HR length)					
Towing speed (cm s^{-1})	48	56	64	72	80
Height of net mouth (cm)	14.2	12.7	11.1	9.8	9.3
Ratio of net height/circumference (H/a)	0.06	0.06	0.05	0.04	0.04
Projective area of net mouth (10^2 cm^2)	11.75	10.42	9.35	8.53	7.99
Water filtering volume (10^3 m^3)	32.56	33.77	34.68	35.62	37.09
Total net resistance (10^2 gf)	4.26	5.14	6.33	7.28	8.62
Attack angle at head rope (°)	22	24	22	24	24
Experiment 4: Wing tips distance: 105 cm (60% of HR length)					
Towing speed (cm s^{-1})	48	56	64	72	80
Height of net mouth (cm)	14.5	12.6	11.2	10.0	9.5
Ratio of net height/circumference (H/a)	0.07	0.06	0.05	0.05	0.04
Projective area of net mouth (10^2 cm^2)	12.90	11.56	10.43	9.21	9.20
Water filtering volume (10^3 m^3)	35.76	37.44	38.67	39.10	42.72
Total net resistance (10^2 gf)	5.41	6.74	8.05	9.62	11.36
Attack angle at head rope (°)	27	24	27	24	24
Experiment 5: Wing tips distance 115 cm (66% of HR length)					
Towing speed (cm s^{-1})	48	56	64	72	80
Height of net mouth (cm)	12.8	11.8	10.2	9.2	8.5
Ratio of net height/circumference (H/a)	0.06	0.05	0.05	0.04	0.04
Projective area of net mouth (10^2 cm^2)	11.72	10.94	9.59	8.76	8.30
Water filtering volume (10^3 m^3)	32.49	35.43	35.56	36.58	38.53
Total net resistance (10^2 gf)	4.33	5.65	7.03	8.38	10.05
Attack angle at head rope (°)	31	29	27	29	29

3.2 | Projective area of net mouth

Projective area of net mouth is area of net mouth when trawl net is being towed by ship on trawling operation. From the standpoint of experimental model, the projective area of net mouth is defined as the area between both wing ends of trawl net under towing condition. The largest projective area was 12.9×10^2 cm^2 (1.03 m^2 in full scale) at the distance 105 cm (8.4 m, 60% of HR length) and the smallest one was 6.75×10^2 cm^2 (0.54 m^2) at the distance 80 cm (6.4 m, 46%). However, there was no significantly difference in projective area of net mouth among the five wing-end spreads (P > 0.05). The result also revealed that no significantly difference in projective area of net mouth at the slowest towing speed and the highest one (P > 0.05). At towing speed of 64 cm s^{-1} (2-knot), the projective areas of net mouth ranged from 8.10×10^2 to 10.43×10^2 cm^2 (from 0.65 to 0.83 m^2). The projective area of net mouth decreases when towing speed increases.

3.3 | Water filtering volume

The calculated data showed that there was statistically significant difference in water filtering volume among the five wing-end spreads (P < 0.001). Water filtering volume at the highest towing speed was considerably higher than that of at the slowest towing speed (P < 0.001). This is relatively proportional to the increasing of projective area of net mouth and the intensity of towing speeds. Water filtering volume at a towing speed of 64 cm s^{-1} (2-knot) was ranged from 30.02×10^3 to 38.67×10^3 m^3. The changeover wing tips distances from 90 cm (7.2 m, 51%) to 115 cm (9.2 m, 66%) have produced more water filtering volume. The largest water filtering volume was 50.26×10^3 m^3 with wing tips distance 105 cm (8.4 m, 60%) and the smallest one was 28.96×10^3 m^3 with wing tips distance 80 cm (6.4 m, 46%). Trawl net with large water filtering volume is more efficient than small one because it is assumed that in one unit time of towing operation, the net will filter more fish and shrimp.

3.4 | Total net resistance

There was no significantly difference in total net resistance among the five wing-end spreads (P > 0.05). At the same way, no statistical difference in total net resistance observed at the slowest towing speed and the highest one (P > 0.05). At a towing speed of 64 cm s^{-1} (2-knot), total net resistances ranged from 5.94×10^2 to 8.05×10^2 g (from 4.75 to 6.44 kg in full scale). The highest total net resistance was 11.36×10^2 g (9.09 kg) with wing tips distance 105 cm (8.4 m, 60%), and the lowest one was 4.26×10^2 g (3.41 kg) at the distance 100 cm (8.0 m, 57%). Total net resistance increases proportionally to towing speeds. When the towing speed increases intensively, it will bring a big volume of water entering into the net, the resistance of net increases remarkably, and in consequence, the force to make the net wide increases. Total net resistance is parallel to the flow in line with the cod end, but tension is not parallel, it more corresponds to the towing line and attack angle of warp. Total net resistance, which measured on the head rope, was larger than the ground rope. During experiments, wing tips distances slightly expanded from its initial position *i.e.* about 2.0–4.2 cm because of a large towing resistance toward the net.

It can be understood that trawl net when exerted by water forces, distribution of the towing forces more concentrated on the head rope, so that the upper part of net has tendency to lessen its room and in consequence, the angle of incidence becomes smaller than the lower one. The attack angle was much influenced by wing tips distances; the wider wing tips distance the bigger the attack angle of warp (see Table 3). Dealing with the increasing of towing speed, it can be generally said that some the attack angles tend to have its own values constantly at various wing tips distances.

3.5 | The gear efficiency of the net

We already obtained the results of measurement on the net height in the flume tank; however, the gear efficiency cannot be determined directly by this value. Occasionally the difference of net height showed by the trend line of curve is relatively similar each other, but they are actually difference in actual. Thus, we applied non dimension number of the ratio of net height (H) to the net circumference (a) to determine the gear efficiency of the net, since this factor is closely related to the gear construction and performance of trawl net. In the present study, the *H/a* ratio were ranged from 0.04 to 0.08 (Table 4). There was no significantly difference in the H/a ratio among the five wing-ends spreads (P > 0.05). Similarly, there was no significantly difference in the *H/a* ratio applied for the slowest towing speed and the highest one (P > 0.05). At a towing speed of 64 cm s^{-1} (2 knots), the *H/a* ratio was 0.055±0.004 or 5.5% of net circumference and getting lower at higher towing speeds. Nomura (1989) reported that normally, according to the kinds of trawl the net height opening will be a certain percentage of the a value, for example: 5% for two-seam trawl net, 10% for big stern trawl, 4–8 seam, and 15% for two-boat type trawl. The highest *H/a* ratio were 0.08 with wing tips distance 80 cm (6.4 m, 46%) and the lowest one was 0.04 with wing tips distance 115 cm (9.2 m, 66%). The ratio of the net was considerably high because of having a square part of net body in its construction. The square is a rectangular sheet of netting. The section of netting fitted between the top body (baiting) and the two top wings so that it partially overhangs the ground rope. It is really this part of the trawl net which is most important, for it does to a great degree govern the way the rest of the net can be shaped. In the same buoyancy of floats, the bigger net circumference the higher net opening. Considering reducing ratio of *H/a* in relation to the increasing of towing speed, it shows the tendency that the reducing ratio becomes zero and the value of ratio becomes stable also when the towing speed reaches definite speed. Each net has peculiar speed and it may be slower when a distance between both wing tips is wide. This tendency is considered that net webbing near net mouth expanded to sideways, a little expansive power from net webbing itself will be raised by increasing towing speed. It will be balanced to the buoyancy of float function and maintain some heights of net mouth.

4 | DISCUSSION

A flume test of a model net with varying wing-end widths was performed. In the present study, the exponent values obtained ranging from 1.36 to 1.44 (1.40±0.03) indicating the shape of net body under towing condition should be refined (Table 5). Tauti (1934) confirmed that indication of the best condition of net shape deformation if the value of exponent is 2.

In trawling operation, the work function of trawl was also influenced by the projective area of net mouth and water filtering volume. The larger projective area of net mouth and water filtering volume the more efficient trawl net used. Khaled *et al.* (2012) reported that the mass of catch encountering the gear is proportional with net mouth area of the trawl and that the amount of fish caught by trawl is the intersection of mouth trawl area and fish distribution. For the purpose of catching shrimp, Nomura *et al.* (1977) suggested that the trawl net should have a wide but flat net mouth, and it is not necessary to have a long body. For catching swimming fish, the trawl net should have a long head rope in order to take in a big volume of water caused by a high opening of net mouth. A long net body is also necessary to prevent the trapped fish from escaping in spite of the low towing speed. The net circumference was determined as a main basic of comparison for other trawl dimensions. The difference can be compared by the non-dimension number of the ratio of total length of net to the net circumference (*TL/a*). The comparative study showed that *TL* and *TL/a* of the current shrimp trawl net are much smaller than bottom trawls from other geographical areas (Figure 1A–1B). The ratio of body length to the net circumference (*BL/a*) was observed in the middle-level, and at lower level for the ratio of wing length to the net circumference (*WL/a*; Figure 1C–1D. Nomura (1989) reported that for the purpose of increasing the net height opening, the maximum stretched circumference of net should have a big value; in particular the first essential is to increase the width of the side net. In the present study, the *TL/a* ratio calculated were 0.91. However, due to the side net was constructed with a 100 meshes in 0.8 m wide (see Figure 3), so it might cause an effect on the net shape and the net height opening. The hanging ratios obtained were 0.98 stretched lengths in depth and 0.02 stretched lengths in breadth. Even though for the purpose of catching shrimp, the net height is not necessary, however, in this area of study, the height of net mouth is still considered to be important thing because of having correlation to the shape of gear constructions and performance of shrimp trawl net under different trawling conditions.

TABLE 5 Descriptive statistics of constant (*a*) and exponent (*b*) obtained from the linear regression of the estimated parameters (n = 5 trial^{-1})

Estimated parameters	***Linear regression equations***	***Wing tips distance (% of head rope length)***									
		80 cm (46%)		***90 cm (51%)***		***100 cm (57%)***		***105 cm (60%)***		***115 cm (66%)***	
		a	***b***	***a***	***b***	***a***	***b***	***a***	***b***	***a***	***b***
Net height	$H = aV^b$	381.1	–0.82	219.6	–0.70	216.9	–0.71	224.2	–0.72	241.3	–0.76
Projective area	$P = aV^b$	199.4	–0.77	106.4	–0.59	139.7	–0.65	113.0	–0.57	144.5	–0.65
Filtering volume	$FV = aV^b$	31.4	0.40	33.7	0.41	34.8	0.35	38.8	0.43	35.7	0.35
Total net resistance	$R = aV^b$	0.02	1.36	0.02	1.38	0.02	1.44	0.2	1.41	0.01	1.43
Ratio of net height to circumference	$H/a = aV^b$	1.7	–0.82	1.0	–0.70	1.0	–0.71	1.0	–0.72	1.1	–0.76

It is also necessary to understand that before constructing the model scale of net, a decision on a reducing scale should be determined carefully in order that the size of net can be accommodated in the water circular tank and the whole net body can be seen through the observation window without any difficulties. In making the model scale, a similar construction as the original full scale has to be adopted in all parts. In other words, designing and constructing a scale model is to get some indications of what the full scale trawl or prototype will look like prior to construction based on available room.

The twine material should be carefully chosen in order to have a flexibility of netting structure for ascertaining dynamic similarity on trawl net model (Hu *et al.* 2001). Stiff netting would not give a smooth net shape. In present study, polypropylene (PP) twine was used for making full scale trawl, but it was not suitable for making model scale. For this reason, nylon polyamide (PA) is preferable. In the full scale, the net body was constructed with 38 mm stretched mesh with twine diameter 1.08 mm (PP 170D/9) and 25 mm stretched mesh with twine diameter 0.98 mm (PP 170D/6) for the cod end. Meanwhile in the model scale, the nets all were constructed with 15 mm stretched mesh with twine diameter 0.42 mm (PA 210D/9). Dealing with research and development in the net materials, Balash and Sterling (2012) suggested using Ultracross Dyneema, Euroline Premium Plus or Hampidjan Dynex in commercial trawl practices rather than polyethylene (PE) because of less drag, thinner and high breaking strength.

One of the most important factors to enhance the performance of a trawl net is the effect of floats and sinkers (ground chain) during towing operation. The buoyancy force work on the head rope will hold the net open vertically while the sinking force of the ground rope must be having good touch connection power to the sea bottom. Excess of sinking force will make the ground rope to dig in the ground. As consequently, this could lead to have a bigger towing resistance. Otherwise, if the net excess of buoyancy force, the horizontal spreads of net will decrease and the capacity of ground rope pressing the bottom will be diminished. The rope for managing net and that for holding the buoys and sinkers have two kinds of influences upon the form of net, one is due to that they have the unchangeable length and the other due to that they have the apparent weight in water and that they are under the resistance of water. Furthermore, once the bottom trawl shape has been calculated, Khaled *et al.* (2012) suggested that for catching swimming fish the foot-rope should be at least 3.5 m behind headline in order to avoid fish escapement above headline. For shrimp trawl in the present study the foot-rope is 2 m behind headline, and this is sufficient for catching shrimp with the height of net ranged of 0.68–1.32 m. In the case of *Nephrops norvegicus*, Main and Sangster (1985) determined that the *N. norvegicus* during trawling do not swim higher than 1 m from seabed and enter the net only through the width of the bosom ground-line. When the *N. norvegicus* are in the sweep path, most of them are overrun by the sweeps and the bridles. Bridles do not have any effect on herding neither on catch. Same applies to sweeps. Another issue related to this work is the ratio of wing-end spread and warp length. Based on the measurement results of model scale, we converted wing-end spreads in full scale approximately ranged from 6.4 to 9.2 m.

In case of Italian bottom trawls, Fiorentini *et al.* (2004) reported that the wing-end spread was strongly affected by the warp and sweep length. During the hauls made where the warp length was 150 m and sweep was 203 m, the wing-end spread reached value less than 13 m, in contrast with approximately 18 m measured when the warp paid out was 350 m and sweep was 81 m. On the other words, the longer warp length the wider wing-end spread. The longer sweep length the smaller wing-end spread. In the flume tank, at lower towing speeds, the net shape is relatively changeable corresponding to the flow speed given and tends to hold own shape constantly at higher towing speeds. Such visual observation was consistently done with the same procedure at various wing tips distances.

The net mouth opening during experiment was fixed at the distance of 80–115 cm or 46–66% of head rope length. The height of net mouth opening various depends on towing speed, distance between both wing tips and angle of attack. This phenomenon can be seen clearly when towing speed and wing tips distance increased, the height of net became decreased. In the field, the change in ship direction is not only affected to the wing-end spread and otter board position but also will increase the netting drag force. Sterling (2009) stated that when a trawler is exposed to side currents and/or wind, the effective resistance to forward motion is increased; rudder drag increases due to the application of rudder to produce the necessary angle of leeway and angled flow onto the hull to resist the side loads, hull drag is increased because it is travelling at an angle of attack (leeway) and lastly, because of the misalignment of the flow into the propeller, the thrust force is slightly reduced.

In perspective of the fundamental suggestions on the gear efficiency, the side net of shrimp trawl should first be properly reconstructed to have better net shape and increase the net height opening with the appropriate hanging ratio, for example, by inserting triangle nets between the side net and baiting (Figure 4). The length of nets will be afforded to the lacing lines to increase the height of net opening by better distributing the towing forces which had previously been concentrated on the head rope and ground rope. Improvement of net height opening is also expected to increase the catches production of both shrimp and fish especially in the same months of fishing seasons. The local fishermen are more likely to use new techniques if they perceive realized benefits.

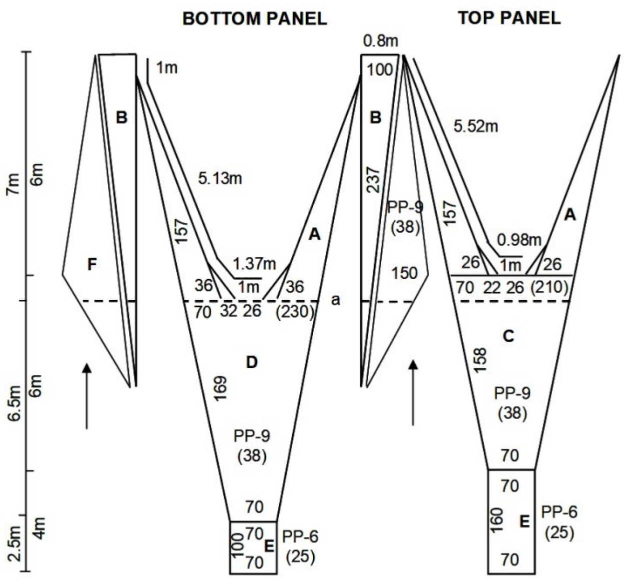

FIGURE 4 Modification of full scale shrimp trawl net design where the triangle nets (**F**) would be inserted between the side nets (**B**) and baiting (**C**) to improve the gear efficiency of the net.

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