Title:

Performance of a Conical Jellyfish Exclusion Device Installed in a Trawl Net

Running Title:

A conical jellyfish exclusion device

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Abstract

Recently, the increasing population of giant jellyfish *Nemopilema nomurai* has negatively affected coastal fisheries in Korea. As a result, the fishing industry has begun developing devices to prevent jellyfish capture. In this study, we assessed the performance of a conical jellyfish exclusion device in the coastal areas of Yokji Island in southern Korea during 2009. After hauling, we measured the length, diameter, and weight of the jellyfish and fish that were captured by the cod end and cover net. We found that the captured species included *N. nomurai*, silver croakers *Pennahia argentata*, yellow croakers *Larimichthys polyactics*, shotted halibut *Eopsetta grigorjewi*, largehead hairtails *Trichiurus lepturus*, and melon seeds *Psenopsis anomala*. The catch ratios of the giant jellyfish that entered the cod end in terms of the weight ranged from 0.005 to 0.027. In contrast, the catch ratios of total fish in terms of the weight and number were 0.793 and 0.835, respectively. From the selectivity analysis of a conical separator for individual fish species, their exclusion ratios were independent of their length, and were similar to their observed exclusion ratios in terms of number. These results indicated that a conical jellyfish exclusion device performs well; however, some improvements are needed to minimize the escape of fish from the net.

KEY WORDS: Jellyfish, *Nemopilema nomurai*, Jellyfish Exclusion Device, Selectivity, Separator, Trawl

INTRODUCTION

The recent increase in the population of jellyfish, especially giant jellyfish *Nemopilema nomurai* and moon jellyfish *Aurelia aurita*, in the coastal waters of Korea and Japan has negatively affected the fishing industry. Jellyfish are undesirable catches because they have poison-filled nematocysts on their tentacles, which they use to sting potential predators, and they are relatively heavy since they are approximately 95% water [1, 2].

In general, jellyfish move both horizontally and vertically within the water column, and they tend to move upward during the day and downward during night. For example, giant jellyfish *Nemopilema nomurai* can move from the water surface to depths up to 176 m [3, 4]. However, this species is most often found at a depth of 40 m in a warm, low-salinity water column [5]. The average swimming speed of giant jellyfish is 0.11 $m \cdot s^{-1}$, and most of them grow until their bell diameter and weight are 2 m and 200 kg, respectively [6, 7]. Due to these characteristics of jellyfish, their unwanted capture causes many negative effects, including damage to fishing nets due to their weight, increased water resistance and exclusion of the desired fish due to their large size, reduction of the commercial value of captured fish due to their toxin, and increased work for and health and safety risks to fishery laborers who have contact with jellyfish to sort them from other fish [8, 9]. Furthermore, jellyfish damage affects almost all fishing equipments, including trawls, Danish seines, set nets, pair trawls, stow nets, shrimp beam trawls, and gillnets [10].

Because of the high cost and risk associated with jellyfish damage, the operations of many fisheries in Korea are limited by jellyfish conditions. To overcome this problem, the fisheries industry has begun developing devices that effectively prevent jellyfish capture by separating and releasing them from fishing nets. Several recent studies have recommended using a combination of an exclusion device that is attached to the trawl nets and an interception net at the entrance of the set net [10–13]. Jellyfish exclusion devices use a sloping panel, which consists of square mesh netting or diamond mesh netting or a metal grid panel, in front of the cod end to separate jellyfish from trawl nets. The efficacy of these devices to exclude jellyfish and limit fish escape depends on their shapes and material compositions. Although jellyfish exclusion devices have a higher exclusion rate and a lower fish escape rate than many other exclusion devices, further improvement is needed to increase their efficacy and ease of use in commercial fisheries.

Recently, fishermen that use stow net fishery (FAO Home: http://www.fao.org/fishery/geartype/227/en) on the western coast of Korea have developed and adopted a jellyfish exclusion device that uses a conical separator, which is formed from an isosceles triangular or trapezoidal piece of netting. This cone-shaped separator works similar to sieve nets that are inserted in shrimp trawls to direct unwanted bycatch to an escape hole under the body of the trawl net [14, 15]. Although the stow net is one of the fixed gears using tidal current, it appears to have almost the same characteristics as the trawl net in the hydrodynamic aspect. In this study, we assessed the performance of a jellyfish exclusion device that uses a conical separator in a trawl net.

MATERIALS AND METHODS

Experimental net

Our jellyfish exclusion device (0.86 m depth × 1.42 m width × 8.50 m length), which consisted of extension and conical separator with the outlet, was attached between the body and cod end of the experimental trawl net, which was 43.12 m long (Fig. 1). The cone-shaped separator was connected to the inside of the cylindrical extension (Fig. 1). When the jellyfish is in contact with the net panel, it is more likely for jellyfish to be cut due to its weight and momentum as the twine diameter becomes thinner or the mesh size becomes larger. To decrease the entering of the fragments of jellyfish, which were cut by the netting of the separator, to cod end, we used thick twine with the diameter of 8 or 5.5 mm for the netting of the separator and designed the length of the separator to be as long as possible to minimize the slope angle of the upper line (5.8°).

We constructed the separator by rolling up netting that was shaped like an isosceles triangle, which was composed of a 400 mm mesh front panel (twine diameter, 8 mm; mesh opening, 360mm) and a 200 mm mesh rear panel (twine diameter, 5.5 mm; mesh opening, 188mm) near the outlet (Fig. 1). We used this combination of mesh sizes to allow fish to easily pass through the larger mesh, but hold jellyfish in the smaller mesh without being damaged. In addition, this combination of mesh sizes facilitated the weaving and construction of the net.

In addition, the 2 m long outlet was placed parallel to the water flow on the bottom panel of the extension similar to that of a conventional stow net (Fig. 2), so that jellyfish would naturally move toward the outlet due to water resistance. The distance between the outlet and the sea bed was designed to be approximately 0.7 m. For the experiment, we attached a cover net [14, 15], which had a 50 mm mesh opening as the same opening as the cod end, to the outside of the outlet to collect any jellyfish or fish that escaped through the outlet (Fig. 2). Several sinkers were also attached to the bottom side of the cover net to prevent the masking effect caused by overlap of the cover net with the outlet during towing [16, 17, 18].

Sea trials and measurements

We investigated the performance of this conical jellyfish exclusion device on the *R/V* Tamgu 3rd (GT369) near Yokji Island in Korea for 7 d in September 2009. We trawled for approximately 30 minutes at a speed of 4 knots and a depth of approximately 40 m to maximize the exposure of our device to giant jellyfish.

After hauling, we measured the length and weight of the fish as well as the bell diameter and weight of the jellyfish that were caught by the cod end and cover net with a tapeline and a spring type balance. However, we only measured the weight of the fragments of jellyfish that entered the cod end.

Catch ratio

We calculated the catch ratio (Eq. 1) of jellyfish as the ratio of the catch weight in the cod end to the total catch weight of the cod end and the cover net combined.

$$Rc = \text{catch in cod end} / (\text{catch in cover net} + \text{catch in cod end}) \quad (1)$$

In addition, we calculated the catch ratio for fish in terms of both the catch weight and the number of fish.

Selectivity analysis

In general, a meshed fishing gear allows selective capture of a specific species or a certain range of fish sizes. When the target fish encounter the separator net, some of them pass through the separator net into the cod end, while the rest escape through the outlet which plays a role of exclusion vent. In this study, we defined the selectivity of the separator net (Eq. 2) as the exclusion ratio of fish with body length *l* through the outlet [14].

$$Re = 1 - Rc = \text{catch in cover net} / (\text{catch in cover net} + \text{catch in cod end}) \quad (2)$$

We modeled selectivity as a logistic function (Eq. 3), such that the exclusion ratio increases with fish length *l*, or a constant function (Eq. 4), which is independent of fish length *l*.

$$\text{Logistic function: } Re(l) = \exp(a + bl) / [1+\exp(a + bl)] \quad (3)$$

$$\text{Constant function: } Re(l) = c \quad (4)$$

where a and b are logistic function parameters, and c is a constant.

The parameters were estimated by using the maximum likelihood method [16, 19–21], and Akaike's Information Criterion (AIC) values (Eq. 5) were used to choose the best fit model [22–24]:

$$AIC = -2MLL + 2q \quad (5)$$

where MLL is the maximum log-likelihood and q is the number of parameters. Smaller AIC value indicates better fit model.

Since giant jellyfish in the cod end were mostly fragmented, the bell diameter of the original jellyfish could not be measured, so we could not quantify the selectivity of separator for jellyfish in this study.

Statistical analysis

We used the Kolmogorov-Smirnov test to determine statistically significant differences in distributions of lengths of the fish that were captured in the cod end with those that were caught in the cover net. The level of significance (α) was defined to be 0.05.

RESULTS

Catch composition and ratios

As shown in Tables 1 and 2, we caught giant jellyfish and various fish species by using our experimental fishing gear with the conical jellyfish exclusion device. As expected, giant jellyfish were the predominant species of jellyfish. The low marketable fish species such as Kammal thryssa *Thryssa kammalensis* were included in others of Table 2.

The catch ratios of the fish and giant jellyfish that were caught in the cod end and cover net are summarized in Tables 1 and 2. The catch ratios of giant jellyfish that entered into the cod end in terms of weight ranged from 0.005 to 0.027, whereas the value for the total was 0.010. As a result, the jellyfish exclusion device separated and excluded 99% of the giant jellyfish that entered the trawl net. However, we found some differences in the catch ratio of the individual fish species that were caught in the cod end; the catch ratios that were based on the number or weight of fish were 0.0–1.0, whereas the catch ratios that were based on the total number or weight were 0.835 and 0.793, respectively.

Size distribution

The bell diameter and weight of the giant jellyfish that were caught in the cover net and cod end ranged from 25 to 95 cm and the maximum wet weight was 31 kg (Figs. 3 and 4). The weight of giant jellyfish of which bell diameter was measured corresponds to 42.8% of its total weight caught in the experimental net. When the giant jellyfish grows up to be 2 m of bell diameter, the calculation is done by using the regression equation given in Fig. 4 to give its weight, 230 kg approximately.

The length distributions of fish species that had more than 50 individuals in the cod end are shown in Fig. 5. A little difference was observed between the length ranges of fish that were caught in the cover net and the cod end (Fig. 5). However, it should be noted that we could not compare the length distributions of yellow croakers in the cover and cod end because we did not catch any yellow croakers in the cover net. The Kolmogorov-Smirnov test was used to compare the catch length distributions for each fish species in the cod end and the cover net (Kolmogorov-Smirnov test, $\alpha = 0.05$) [24]. When the yellow croaker data were excluded, the differences in the length distributions of the fish that were caught in the cover net and the cod end were not statistically significant (Table 3).

Relationship between length and girth

The maximum total lengths (TLs) of silver croaker and yellow croaker were 37.0 and 25.0 cm, respectively. By using regression analysis [25] of the maximum length and girth (*G*) of fish, we determined that the girths applicable to the maximum TLs of these fish were 24.4 and 13.9 cm, respectively. Similarly, the maximum anal length (AL) of largehead hairtail and the maximum fork length (FL) of melon seed were 28.0 and 21.0 cm, respectively, which corresponded to girths of 11.4 and 20.1 cm, respectively [25].

From the other fishing results carried out in the same ground and season using trawl net, their regression equations and coefficients of determination for redwing sea robin, marbled sole, shotted halibut were G (cm) = $0.3982TL - 4.533$ ($R^2 = 0.8025$), Bd (cm) = $0.3837TL - 0.184$ ($R^2 = 0.9171$), Bd (cm) = $0.435TL - 1.064$ ($R^2 = 0.9978$), respectively. Here Bd is body depth of the flat fish. For these fish, their maximum TLs were 35.0, 39.0, and 23.0 cm, respectively, which corresponded to a girth of 18.5 cm and body depths (Bds) of 15.1 and 8.9 cm, respectively.

The standardized relative girth (G/P) which is the ratio of body girth (G) to the mesh perimeter (twice the mesh ~~size~~ opening, P) is a primary factor of contact selection [21, 25, 27]. When the fish encountered the 400 mm mesh front panel (mesh opening, 360 mm) of separator, the relative girths with the maximum lengths of silver croaker, yellow croaker, redwing sea robin, largehead hairtail, melon seed were 0.340, 0.193, 0.257, 0.159, and 0.280, respectively. For flat fish, such as marbled sole and shotted halibut, the corresponding ratios of body depth to mesh size opening, which is similar to the relative girth, were 0.421 and 0.248, respectively. When the fish encountered the rear panel (mesh opening, 188 mm) of the separator, the relative girths with the maximum lengths of fish were slightly less than twice the mesh opening of the front panel because the mesh opening of rear panel was larger than half of that of the front panel.

Parameter estimates and model selection

The parameter estimates of the models for the fish species that were relatively much caught in the cover net (silver croaker, largehead hairtail, melon seed, redwing sea robin, and Japanese Spanish mackerel) are shown in Table 4. The length classes with zero catch were eliminated in the calculation of selection curves. In addition, the selection curve, which was calculated from both the observed values and the estimated parameters, is shown in Fig. 6. The likelihood ratio statistics values, which are twice the log of the likelihood ratio between the full and current models, were calculated to test goodness of fit for each model (Table 4) [20, 24]. There was no evidence of a lack of fit in two models. The AIC value of the constant selectivity model tended to be slightly less than that of the logistic selectivity model. Therefore, we chose the constant function as the best fit model of the selectivity of the separator net for each fish species. In this model, the selectivity of separator for silver croaker, largehead hairtail, melon seed, redwing searobin, and Japanese Spanish mackerel were 0.185, 0.058, 0.292, 0.247, and 0.238, respectively (Table 4). These values were similar to the observed exclusion ratios of individual number for fish species (Table 2).

DISCUSSION

Our results showed that the exclusion ratio of our conical jellyfish exclusion device for giant jellyfish in terms of weight (0.99) is higher than that of any other previously reported device. For example, Matsushita *et al.* [11] reported that a grid jellyfish excluder device (grid spacing, 0.18 m; fragment size of jellyfish $\geq 28 \times 26 \times 5$ cm), which was designed for towed fishing gear, had an exclusion ratio of 0.89 for giant jellyfish, in terms of weight. Similarly, Okino *et al.* [12] showed that the exclusion ratio for a jellyfish excluder device with an intercepting net (mesh size, 400 mm; jellyfish bell diameter, 70–90 cm) ranged from 0.40 to 0.74, in terms of weight. These results suggested that a conical jellyfish exclusion device effectively excludes giant jellyfish.

The results of Kim *et al.* [10] examined in the same ground in July, 2004 showed that by increasing the tilt angle of the square mesh separator panel by 10°, 15°, or 20°, the escape ratios of fish in terms of weight were 0.49, 0.51, and 0.56, respectively, whereas the jellyfish exclusion ratios in terms of weight were 0.66, 0.41, and 0.44, respectively. Thus, a smaller tilt angle tends to increase the jellyfish exclusion ratio but decreases the exclusion ratio of fish. As a result, we used a relatively small slope angle in this study (5.8°). We believe that this small slope angle, which was smaller than any angle previously reported for a separating net or grid panel, also contributed to the high performance of our conical jellyfish exclusion device.

In the present study, the exclusion ratios that were based on the number for Japanese jack mackerel, melon seeds, yellow croakers, largehead hairtails, and shotted halibut were 0.043, 0.282, 0.000, 0.052, and 0.047, respectively. These values tended to be less than those reported by Kim *et al*. [10], which were 0.94, 0.91, 0.89, 0.74, and 0.00, respectively. In addition, Okino *et al.* [12] showed that the exclusion ratio of shotted halibut in terms of number was 0.123, which is higher than the value that we determined in our study. However, these differences might have been due to differences in the position of the outlet in the jellyfish exclusion devices in our study compared with those in other studies; the outlet of our conical jellyfish exclusion device was located on the bottom panel of the net, while the outlet of other exclusion devices were located on the top panel [10−12]. The different effects of the position of the outlet on the exclusion ratio may have been influenced by the fish swimming behavior in different parts of the net [26] because fish swimming near an outlet may escape from it easier than from a more distant outlet. A comparison of our exclusion ratios with those of Kim *et al.* (2008) suggested that Japanese jack mackerel, melon seeds, yellow croakers, and largehead hairtails swim near the top panel of the net. On the other hand, our exclusion ratios of ocellate spot skate and olive flounder suggested that these species usually swim near the seabed.

Although a 100% catch ratio of fish in the trawl net would be ideal, it is not possible with the exclusion device because both fish and jellyfish can escape from the exclusion device. Initially, we thought that the fish that escaped from the outlet were larger than the fish that were caught in the cod end net, because the fish had to pass through the separator, which may limit the size of the fish that are captured in the cod end. However, the absence of any statistically significant differences in the distribution of lengths of fish between the cod end and cover nets suggested that the separator used in the experiment did not limit the size of the fish that were captured in the cod end or escaped from the exclusion device.

The mesh size selectivity for fishing gear is usually expressed as a function of the fish girth [20, 21, 25, 27]. The selectivity of fishing gears starts at the range that the relative girth, the ratio of girth to mesh perimeter is greater than 0.5 [20, 25, 27]. In the case of fish with cylindrical body such as conger or hagfish the selection probability appears near one in the relative girth [20]. Except for Japanese Spanish mackerel without girth data, the relative girths applicable to the maximum lengths of the most fish in this study were less than 0.5, when the fish encountered the 400 mm mesh front panel of separator. In the case of 200 mm mesh rear panel of separator, the relative girths applicable to the maximum lengths of silver croaker and melon seed were slightly greater than 0.5. Also, the ratio of body depth to mesh opening for marbled sole was greater than 0.5. It indicates that the most of fish entered through the separator to the cod end because the contact selection probability based on the relative girth is 0 when they encountered the 400 mm mesh front panel of separator. When the silver croaker, melon seed, and marbled sole encountered the 200 mm mesh rear panel of separator, some large-sized individuals could have possibility not to pass the separator by its contact selection. However, our results represented that some portion of each fish species except for yellow croaker were excluded through the outlet (Table 2). Moreover, the difference in the length distribution of silver croaker and melon seed that were caught in the cover net and the cod end was not statistically significant. It means the fish were excluded through the outlet not only by the contact selection of separator but also by its available selection including their avoidance behavior [21, 28].

In conclusion, our results showed that a constant function is the best fit model of the selectivity of the separator net for individual fish species because their exclusion ratio was independent of their length. In addition, the exclusion ratios which represent selectivity of separator differed among fish species, which suggested that the escape behavior of fish is species-specific. However, when giant jellyfish encountered the conical separator in the jellyfish exclusion device, it was considered to be excluded by contact selection of the separator because of no expectation of its escape behavior. Further research is needed to elucidate the species-specific behavior of fish shoals with respect to the mesh size of the separator net in the jellyfish exclusion device. We anticipate that optimized conical jellyfish exclusion devices will significantly reduce the negative impact of jellyfish on the fishing industry.

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Figure legends and Tables

Fig. 1. Schematic diagram of the conical jellyfish exclusion device that was inserted between the cod end and aft body of the experimental trawl net

Fig. 2. Placement of the cover net below the outlet of the jellyfish exclusion device

Fig. 3. Distribution of the bell diameters of the giant jellyfish that were caught in the cover net of the experimental trawl net

Fig. 4. Relationship of body weight and bell diameter of giant jellyfish

Fig. 5. Distribution of lengths and cumulative proportions of various fish species that were caught in the experimental trawl net

Fig. 6. Selection curves of the separator net for each fish species

Table 1 Catch and exclusion ratios of giant jellyfish that were caught in the experimental fishing gear with the conical jellyfish exclusion device

Haul	Weight (kg)		Ratio	
No.	Cod end	Cover net	Catch ratio*1	Exclusion ratio*2
1	3.0	205.0	0.014	0.986
2	3.0	554.9	0.005	0.995
3	2.4	304.0	0.008	0.992
4	5.0	352.0	0.014	0.986
5	10.0	1153.2	0.009	0.991
6	2.0	293.2	0.007	0.993
7	6.2	291.6	0.021	0.979
8	9.5	1777.4	0.005	0.995
9	15.0	533.8	0.027	0.973
Total	56.1	5465.1	0.010	0.990

*1, Catch ratio means the ratio of catch weight in the cod end to the total catch

*2, Exclusion ratio = 1 - Catch ratio

Table 2 Catch and exclusion ratios of jellyfish and fish caught in the experimental fishing gear with the conical jellyfish exclusion device

Species		Cod end		Cover net		Catch ratio*1		Exclusion ratio*2	
Common name	Scientific name	Individuals	Weight (kg)	Individuals	Weight (kg)	Individuals	Weight	Individuals	Weight
Giant jellyfish	*Nemopilema nomurai*		56.1		5465.1		0.010		0.990
Silver croaker	*Pennahia argentata*	1,654	294.7	373	70.8	0.816	0.806	0.184	0.194
Largehead hairtail	*Trichiurus lepturus*	423	27.0	23	2.1	0.948	0.928	0.052	0.072
Melon seed	*Psenopsis anomala*	158	16.1	62	6.7	0.718	0.708	0.282	0.292
Shotted halibut	*Eopsetta grigorjewi*	102	5.6	5	0.3	0.953	0.948	0.047	0.052
Japanese Spanish mackerel	*Scomberomorusrus niphonius*	83	11.8	28	5.0	0.748	0.703	0.252	0.297
Yellow croaker	*Larimichthys polyactics*	72	6.5	0	0.0	1.000	1.000	0.000	0.000
Redwing searobin	*Lepidotrigla microptera*	64	16.7	25	5.8	0.719	0.742	0.281	0.258
Finespotted flounder	*Pleuronichthys cornutus*	47	4.0	8	1.1	0.855	0.779	0.145	0.221
Japanese jack mackerel	*Trachurus japonicus*	44	1.6	2	0.1	0.957	0.942	0.043	0.058
Japanese stargazer	*Uranoscopus japonicus*	41	10.0	18	5.1	0.695	0.662	0.305	0.338
Japanese barracuda	*Sphyraena japonica*	29	4.3	1	0.2	0.967	0.957	0.033	0.043
Marbled sole	*Pleuronectes yokohamae*	28	6.2	12	4.3	0.700	0.592	0.300	0.408
Korean pomfret	*Pampus echinogaster*	18	4.9	16	4.9	0.529	0.496	0.471	0.504
Ocellate spot skate	*Okamejei kenojei*	11	3.5	6	2.4	0.647	0.593	0.353	0.407
Olive flounder	*Paralichthys olivaceus*	1	1.2	2	1.6	0.333	0.425	0.667	0.575
Blackmouth angler	*Lophiomus setigerus*	0	0.0	1	0.2	0.000	0.000	1.000	1.000
Tiger puffer	*Takifugu rubripes*	1	0.8	0	0.0	1.000	1.000	0.000	0.000
Daggertooth pike conger	*Muraenesox cinereus*	3	1.5	0	0.0	1.000	1.000	0.000	0.000
Others		370	18.8	41	3.0				
Total of fish		3,149	435.1	623	113.5	0.835	0.793	0.165	0.207

*1, Catch ratio means the ratio of catch in the cod end to the total catch

*2, Exclusion ratio = 1 - Catch ratio

Table 3 The results of the Kolmogorov-Smirnov test used to compare the catch length distributions in the cod end and cover net

Species	*m*	*n*	*D*	Critical values of $D_{0.05}$ *1	
Pennahia argentata	1,654	373	0.0364	0.0778	(H0 not rejected)
Trichiurus lepturus	423	23	0.0284	0.2908	(H0 not rejected)
Psenopsis anomala	158	62	0.0798	0.2035	(H0 not rejected)
Eopsetta grigorjewi	102	5	0.2824	0.6221	(H0 not rejected)
Scomberomorusrus niphonius	83	28	0.1618	0.2968	(H0 not rejected)
Lepidotrigla microptera	64	25	0.2244	0.3203	(H0 not rejected)

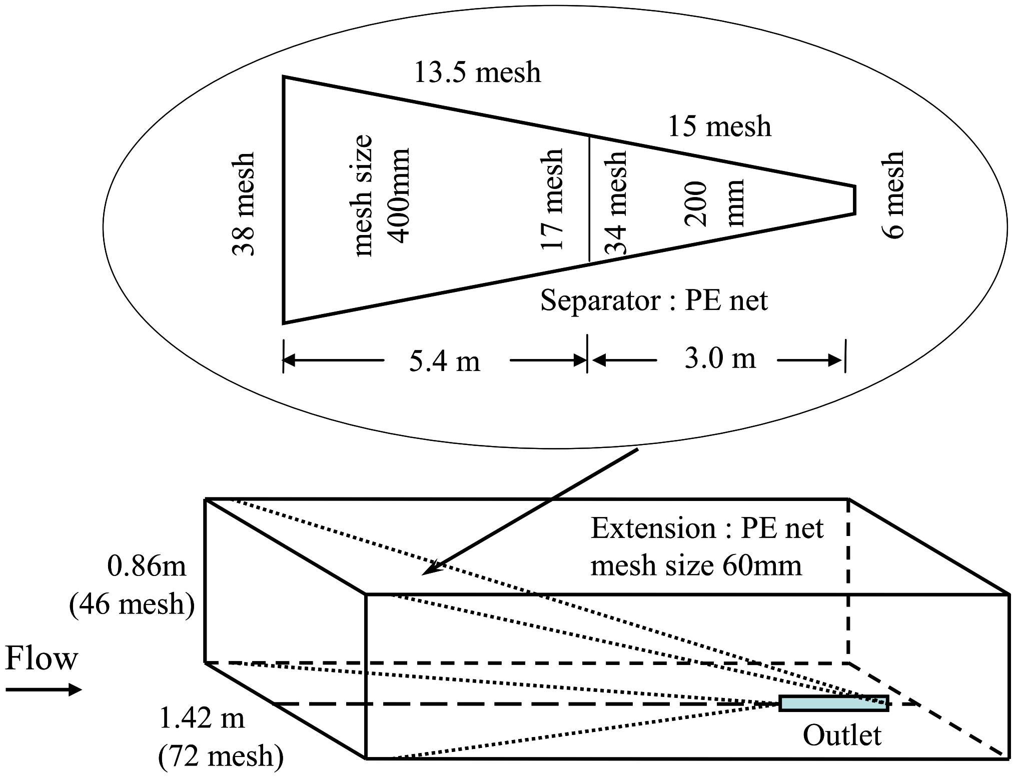
* The null hypothesis is that the length distributions of catch in cod end and cover net are the same.

*1 Level of significance = 0.05.

Table 4 Parameter estimates of the SELECT model of the conical exclusion device for individual fish species

Parameter and MLL	Species									
	Pennahia argentata		*Trichiurus lepturus*		*Psenopsis anomala*		*Lepidotrigla microptera*		*Scomberomorusrus niphonius*	
	Logistic	Constant	Logistic	Constant	Logistic	Constant	Logistic	Constant	Logistic	Constant
Length	Total length (cm)		Anal length (cm)		Fork length (cm)		Total length (cm)		Total length (cm)	
Logistic Re(l)=exp(a + bl) / [1+exp(a + bl)]										
Constant Re(l)=constant										
a	-2.2910		-2.7888		-0.8855		-1.1199		-3.2329	
b	0.0325		0.0001		0.00001		0.0001		0.0709	
c		0.1845		0.0580		0.2921		0.2466		0.2376
L 50 (cm) *1	70.5		27888.2		88546.2		11199.3		45.6	
S.R. (cm) *2	67.6		21972.2		219722.5		21972.2		31.0	
MLL*3	-963.06	-964.02	-80.17	-80.17	-122.01	-122.01	-40.77	-40.77	-55.15	-55.38
MLL(full)*4	-956.94		-79.61		-119.69		-37.55		-52.41	
AIC*5	1930.12	1930.04	164.34	162.34	248.02	246.02	85.55	83.55	114.31	112.76
H0:Model fit										
Model deviance	12.247	14.165	1.108	1.108	4.630	4.630	6.451	6.451	5.492	5.948
degrees of freedom	14	15	5	6	2	3	5	6	3	4
P value	0.586	0.513	0.953	0.981	0.099	0.201	0.265	0.375	0.139	0.203

*1, length of 50% retention probability. *2, Selection range defined as l_{75}(length of 75% retention) - l_{25}(length of 25% retention).
*3, Maximum log-likelihood. *4, Maximum log-likelihood of full model. *5, Akaike's Information Criterion.



Lacing line PP rope dia. 24 mm, Total length 8.5 m, Outlet length 2 m

Figure 1

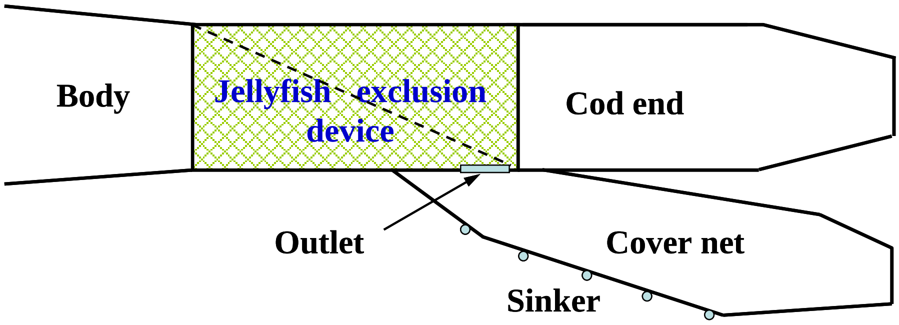


Figure 2

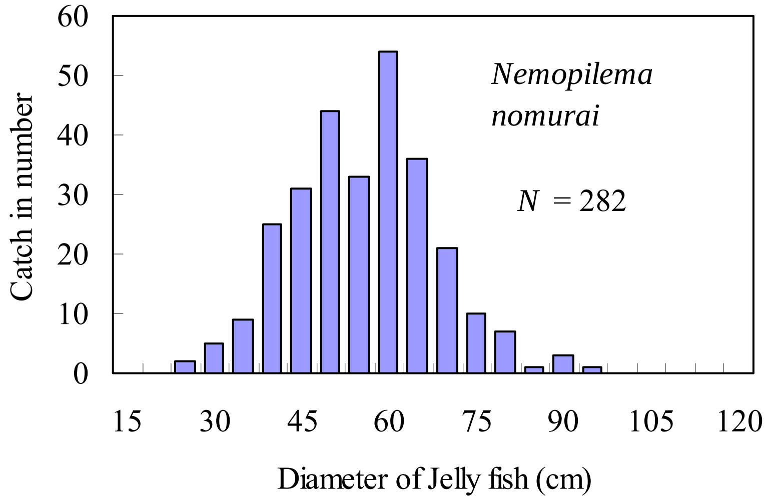


Figure 3

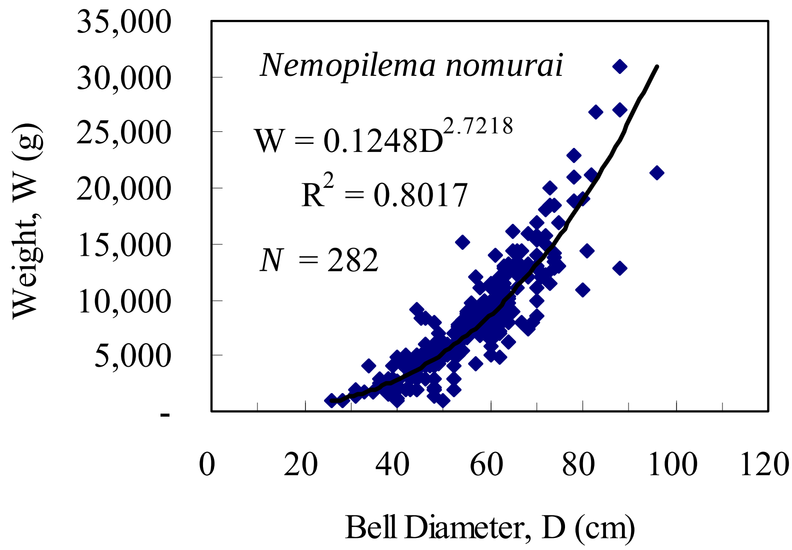


Figure 4

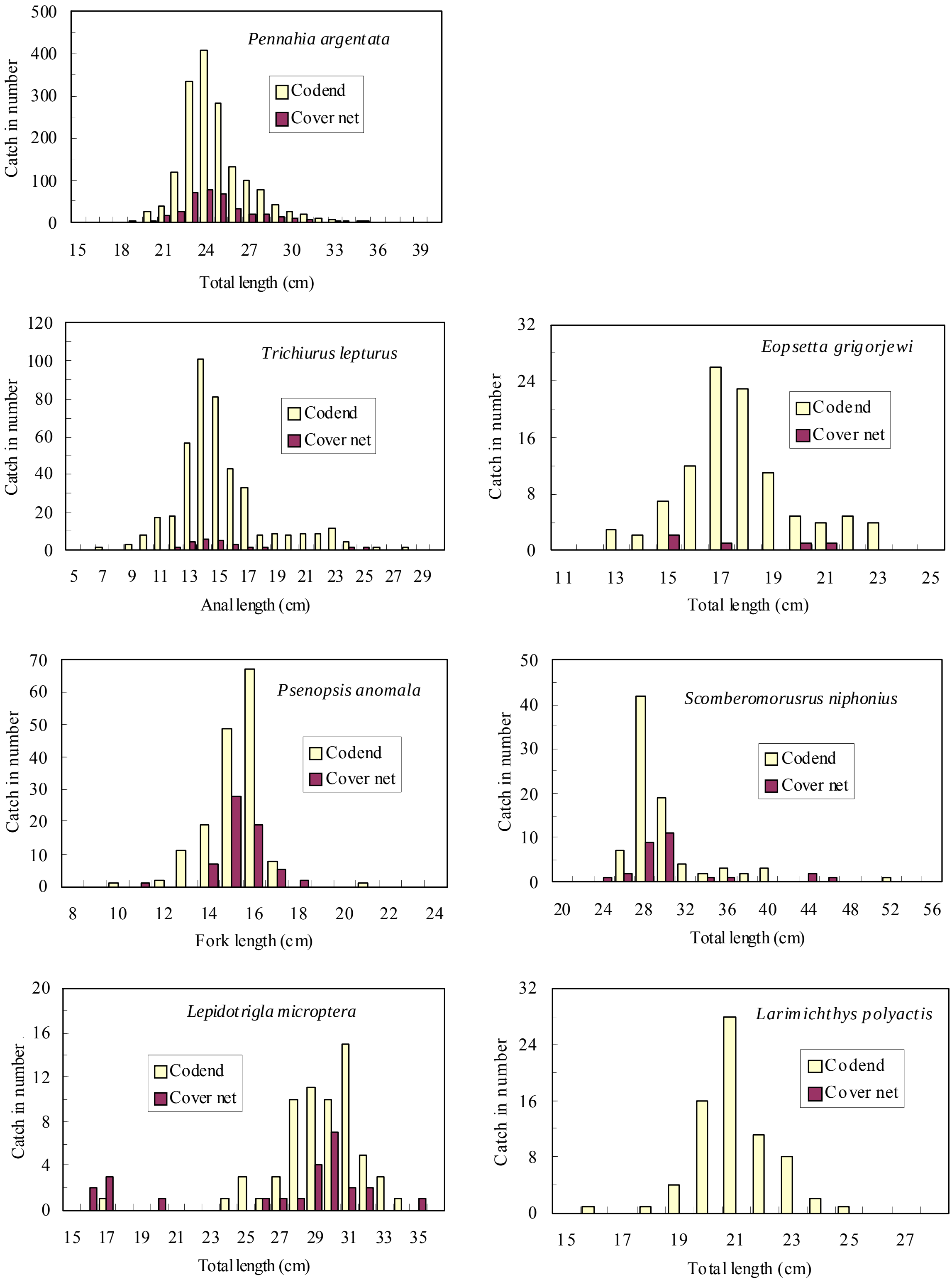

Pennahia argentata
Codend
Cover net
Catch in number
Total length (cm)
Trichiurus lepturus
Codend
Cover net
Catch in number
Anal length (cm)
Eopsetta grigorjewi
Codend
Cover net
Catch in number
Total length (cm)
Psenopsis anomala
Codend
Cover net
Catch in number
Fork length (cm)
Scomberomorusrus niphonius
Codend
Cover net
Catch in number
Total length (cm)
Lepidotrigla microptera
Codend
Cover net
Catch in number
Total length (cm)
Larimichthys polyactis
Codend
Cover net
Catch in number
Total length (cm)

Figure 5

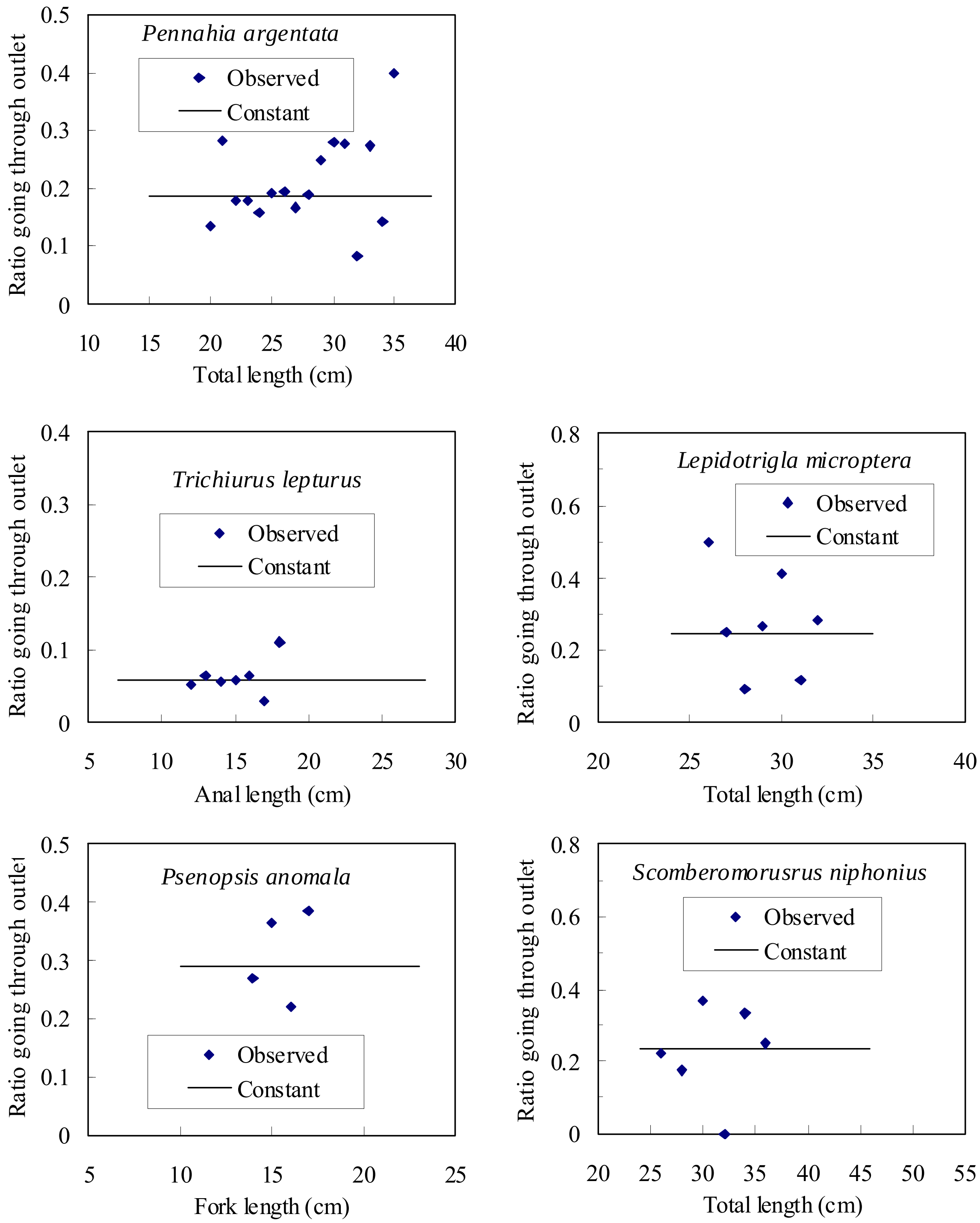

Pennahia argentata
Observed
Constant
Ratio going through outlet
Total length (cm)
Trichiurus lepturus
Observed
Constant
Ratio going through outlet
Anal length (cm)
Lepidotrigla microptera
Observed
Constant
Ratio going through outlet
Total length (cm)
Psenopsis anomala
Observed
Constant
Observed
Constant
Ratio going through outlet
Fork length (cm)
Scomberomorusrus niphonius
Observed
Constant
Ratio going through outlet
Total length (cm)

Figure 6.