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〈Original Article〉

Analysis of body size selectivity of by-catch using the cover net method for a shrimp beam trawl

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Selectivity and by-catch are the main features used to define fish catch for fisheries management or to determine fishing gear efficiency. A fish girth distribution analysis was carried out to determine the retention rate of juveniles discarded and to establish common selectivity for a multispecies catch. Total body length, body weight, and girth of juvenile fish retained in the cod-end and cover net separately were collected using an 18-mm mesh cover net during 12 fishing trials with a 41-mm cod-end beam trawl. The by-catch weight ratio in the cod-end was twice that of the by-catch ratio in number. The 50% selectivity of body length and 50% girth of redfin velvet fish were not significantly different between the cod-end and cover net, whereas those of other fish species were significantly different between the cod-end and cover net. The difference in 50% selectivity girth of other fish between the cod-end and cover net was similar between cod-end mesh size and cover net mesh size. Furthermore, the difference in 50% body length selectivity of other fish between the cod-end and cover net was almost double the difference in girth. Girth selectivity in a multispecies catch using towed fishing gear was effectively used to determine fish and net mesh size.

Keywords: Cover net, By-catch ratio, Selection body length, Selection girth, Multi-species

Introduction

By-catch is one of the main issues in fisheries management, and juvenile by-catch is particularly important for conservation and survival after fish escape the net. By-catch and selectivity of targeted fish have been investigated and reported for several decades (MacLennan 1993; Tokai et al., 1994; Chopin and Suuronen, 2009; Sea Grant, 2014). However, smaller discarded fish and escaping fish sampled using a cover net and analyzed with respect to selectivity of the juvenile by-catch rate have not been investigated thoroughly (O'Neill and Kynoch, 1996; Tokac et al., 2004; Deval et al., 2006). For example, fish with a girth smaller than the mesh circumference are frequently caught in towed fishing gear with a larger mesh size. This tendency is the so-called "masking effect", which is quantitatively expressed as the by-catch ratio or the weight of juvenile by-catch fish (non-targeted fish by permit) per weight of total fish caught according to the Fisheries Law of the South Korea. However, video observations show that most fish remain in the cod-end and almost none of the fish approach the mesh, as an optomotor response, whereas the other fish penetrate the mesh and escape (Wardle, 1993; Ryer, 2008). Therefore, the retention rate of juvenile or undersize fish in the cod-end could be related mostly to fish shape (Kurkilahti et al., 2002;

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Ingólfsson. 2011), and fish behavior is an additional factor involved in the masking effect (Herrmann, 2005).

The selection of body size by trawl gear is traditionally expressed by body length curves but some trawl selectivity studies have reported a girth-body length relationship (Tokai et al., 1994; Matsushita and Ali, 1997). However, no study has evaluated the girth selection curve for trawl catch, except using a gillnet (Reis and Pawson, 1999; Kurkilahti et al., 2002; Scholten and Bettoli, 2007). The purposes of this study were to conduct a preliminary experiment to analyze retention and escape rates of undersized fish in the cod-end using a cover net and a shrimp beam trawl. We also assessed girth selectivity methods for multispecies catch fisheries. Fish number and size data were collected during 12 fishing trials using a 41-mm mesh cod-end attached around an 18-mm mesh cover net, which is a little different from a commercial shrimp beam trawl. The retention ratio was analyzed as the number and weight of undersized fish with a girth equal or smaller than the mesh circumference. Furthermore, the girth selectivity method was evaluated for whole by-catch species using cumulative selective curves or by each species to compare mesh circumference with fish size.

Materials and methods

The shrimp beam trawl used is shown in Fig. 1. The net was modified from the Southern type used by the fishing boat "Kumpo-ho" (2.99 G/T) in Tongyoung. Total net length was 20 m, beam length was 7.5 m, and the cod-end length was 4 m with a 41-mm nominal mesh size (referring to the Turkish beam trawl by Deval et al., 2006) which is larger than a normal shrimp beam trawl (Kim and Whang, 2014). The attached 18-mm mesh size cover net to collect fish from the cod-end was more than 1 m wider and longer than those of a normal shrimp beam trawl referring to the cover net method (O'Neill and Kynoch, 1996; Mituhasi et al., 2000; Deval et al., 2006).

Towing speed was measured with a Doppler log (201D, Marsh-McBirney Inc. Frederick, MD, USA) and a ship-built GPS. The fishing experiments were conducted at depths of 40–60 m between Yondaedo and Sojido in the South Sea of Tongyoung, as shown in Kim and Whang (2014). Three tows per day were performed from 22 to 25 April 2014 (Table 1). The length of the tow line was about 500 m, and the towing direction was almost identical to the tidal direction. The actual towing time was 1 hour from the time the fishing net touched the seabed until they were pulled off the seabed.

The catch in the cod-end after each haul was sorted and measured as marketable catch (mainly fish and octopus) and by-catch (fish and other garbage) using a balance (30-kg scale; accuracy, 0.1 kg). The main by-catch species were

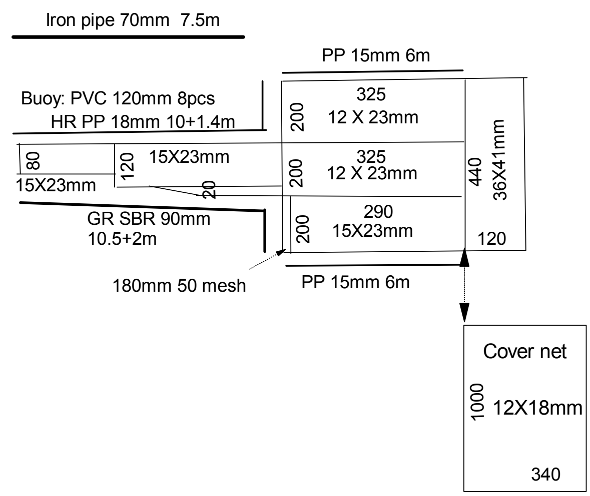

Fig. 1. Design of the experimental beam trawl attached with a cover net over the cod-end.

Table 1. Fishing trial conditions using a cod-end cover net on a shrimp beam trawl during April 2014

Trial	Date	Shot-Haul (Hr:Min)	Co (deg)	Speed (kt)	Tide	Wave (m)
F1	22	5:40-6:40	120	1.8	Ebb	0.5
F2	22	7:22-8:22	130	1.9	Ebb	0.5
F3	22	8:55-9:55	305	1.7	Flood	0.5
F4	23	5:15-6:15	130	1.9	Ebb	0.5
F5	23	6:57-7:57	130	1.9	Ebb	0.5
F6	23	8:50-9:50	310	2.0	Flood	0.5
F7	24	5:50-6:50	120	1.9	Ebb	1.0
F8	24	7:40-8:40	150	1.9	Ebb	1.0
F9	24	9:30-10:30	170	1.8	Ebb	1.0
F10	25	5:30-6:30	130	1.8	Ebb	0.5
F11	25	7:25-8:25	140	1.8	Ebb	0.5
F12	25	9:10-10:10	160	1.9	Ebb	0.5

greenling, *Hexagrammos agrammus* (suffix f); redfin velvetfish, *Hypodytes rubripinnis*; juvenile cod, *Gadus macrocephalus*; shotted halibut, *Eopsetta grigorjewi*; and reduling sea robin, *Lepidotrigla microptera*. The by-catch in a haul was sorted and measured for total body length and girth as maximum body circumference using a 1-mm flexible scale and for body weight using a digital balance (accuracy, 0.01 g; EB-4000HU, Shimadzu, Tokyo, Japan). Shrimp body length was measured as total length from the orbit to the end of the telson and from the snout to the end of the caudal fin for fish. The *t*-test was used to determine differences in the by-catch ratio or selection ratio.

Results and discussion

The cod-end and cover net catch during the 12 fishing trials using a beam trawl are shown in Table 1 by weight. The main marketable catch in the cod-end was octopus, flounder, red robin, and shrimp, with about 40% total retention in the cod-end and about 60% total retention of garbage. However, the fish catch in the cover net was greater than garbage. The garbage rate in the 41-mm mesh cod-end was greater than that of a smaller mesh normal shrimp beam trawl (Kim and Whang, 2014). Whole fish to total fish in the cover net was about 30%, whereas garbage to total garbage in the cover net was 20% by weight. The fish and garbage composition rates in the cover net were represented by the weight ratio of the cover net to total weight (Rc; %) in the cod-end and cover net (Fig. 2). The fish weight ratio (Rf;%) and garbage ratio (Rg;%) in the cover net increased significantly with Rc, as follows:

$$Rf = 1.53Rc - 6.3 \qquad (n = 12,\ r = 0.93) \qquad (1)$$

$$Rg = 0.733Rc + 1.54 \qquad (n = 12,\ r = 0.88) \qquad (2)$$

The ratio of total weight and garbage weight in the cover net was not different from the total fish ratio and garbage ratio, respectively ($p>0.05$).

The numbers and weights of by-catch measured for each haul are shown in Table 3. The ratio of fish numbers in the cod-end to the total number of discarded fish (cod-end and cover net) was about 20%, whereas the weight ratio in the cod-end to all discarded fish was about 40%, which was double the fish number ratio. This finding resulted from bigger fish being caught in the larger mesh cod-end than in the smaller mesh cover net, as shown by the body size and body weight analyses later. The ratio of by-catch fish in the cod-end was 40% by weight, which was similar to that of coastal trawls conducted in Malaysia (Matsushita and Ali, 1997). The discarded fish ratio was 20% in the cod-end,

Table 2. Catch weight in the cod-end and cover net during the beam trawl fishing trials

Trial	Codend (kg)			Cover net (kg)		
	Fishes	Garbage	Total	Fishes (%*)	Garbage (%**)	Total (%***)
F1	18.7	20.5	39.2	4.4 (19.0)	2.3 (10.1)	6.7 (14.6)
F2	12.1	20.1	32.2	3.7 (23.4)	2.8 (12.2)	6.5 (16.8)
F3	10.0	14.0	24.0	2.8 (21.9)	3.7 (16.7)	6.5 (21.3)
F4	8.3	19.5	27.8	6.8 (45.0)	7.5 (27.8)	14.3 (34.0)
F5	11.1	10.0	21.1	3.5 (24.0)	3.0 (23.1)	6.5 (23.6)
F6	12.6	24.0	36.6	5.4 (30.0)	4.8 (16.7)	10.2 (21.8)
F7	15.5	20.3	35.8	4.7 (23.3)	4.0 (16.5)	8.7 (19.6)
F8	10.5	16.0	26.5	2.9 (21.6)	3.7 (18.7)	6.6 (19.9)
F9	15.0	19.3	34.3	4.3 (22.8)	4.7 (19.6)	9.0 (20.8)
F10	10.8	20.3	31.1	5.5 (33.7)	4.1 (16.8)	9.6 (23.6)
F11	8.6	19.7	28.3	8.2 (48.8)	6.2 (23.9)	14.4 (33.7)
F12	11.6	20.0	31.6	6.3 (35.2)	4.4 (18.0)	10.7 (25.3)
Mean	12.1	18.6	30.7	4.9 (29.1)	4.3 (18.3)	9.1 (22.9)
SD	3.0	3.7	5.4	1.6 (9.7)	1.4 (4.9)	2.9 (5.9)

*Fish in cover net/ Total fish
** Garbage in cover net/ Total garbage
** Total in cover net / Total retention in codend and cover

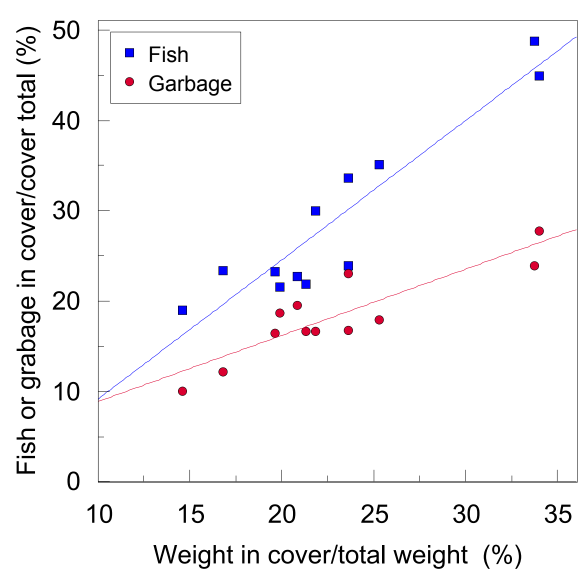

Fig. 2. Relationship between fish weight and garbage weight rates in the cover net and the weight ratio of the cover net to total weight.

Table 3. The numbers (N), weights (W; kg) of by-catch and their ratios to total catch (t) in the cod-end (c) and cover net (v) of an experimental beam trawl

Trial	Codend		Cover		Sum		Retention ratio	
	Nc	Wc	Nv	Wv	Nt	Wt	Nc/Nt	Wc/Wt
F1	155	2.75	682	3.63	837	6.38	0.185	0.468
F2	73	1.26	614	2.74	687	4.00	0.106	0.315
F3	122	1.68	704	2.45	826	4.13	0.148	0.400
F4	120	1.22	425	4.12	545	5.34	0.220	0.228
F5	40	1.02	198	0.63	238	1.65	0.168	0.618
F6	107	1.88	387	2.97	494	4.85	0.217	0.388
F7	88	1.75	507	3.25	595	4.00	0.148	0.350
F8	48	1.19	246	0.75	294	1.94	0.163	0.613
F9	77	1.56	410	4.58	487	6.14	0.158	0.254
F10	98	1.86	224	0.81	322	2.67	0.304	0.697
F11	132	1.35	580	4.86	712	6.21	0.185	0.217
F12	120	2.19	444	4.15	564	6.34	0.213	0.345
Mean	98	1.64	452	2.91	550	4.47	0.185	0.408
SD	34	0.49	173	1.50	197	1.71	0.050	0.160

which was similar with that obtained with a Turkish rose shrimp beam trawl using 40-mm cod-end mesh with 28-mm cover net mesh, although no by-catch weight data were provided (Deval et al., 2006).

The relationships between total body length and weight and body girth of by-catch fish species in the cod-end and cover net, respectively, are shown in Table 3 and Fig. 3; and those for redfin velvet fish and the other fish species, such as greenling, shotted halibut, and reduling sea robin are shown in Fig. 4 with girth selectivity. The relationships between body length (L; cm) and weight (W; g) or girth (G; cm) were expressed as follows:

$$W = a\ L^{b} \tag{3}$$

$$G = c + dL \tag{4}$$

The coefficients for Eqs. 3 and 4 are presented in Table 4. The body length-girth relationship for perch in a gillnet has been expressed previously as a first-order equation (Kurkilahti et al., 2002) and for several fish species in the Aegean Sea (Stergiou and Karpouzi, 2003). In contrast, Tokai et al. (1994) calculated girth from body width and body depth to measure body size.

Table 4. Eq. 2 coefficients for fish body weight and Eq. 3 coefficients for fish girth in the cod-end and cover net as sampled number of data, *n*, with correlation coefficients, r

Fish	Part	Weight				Girth			
		a	b	n	r	c	d	n	r
Redfin velvet	Codend	0.0512	2.51	305	0.89	1.53	0.497	120	0.76
	Cover	0.0391	2.61	1,181	0.90	0.99	0.557	746	0.81
Other fish	Codend	0.0033	3.41	399	0.98	1.43	0.425	112	0.75
	Cover	0.0137	2.81	782	0.85	2.41	0.27	166	0.74

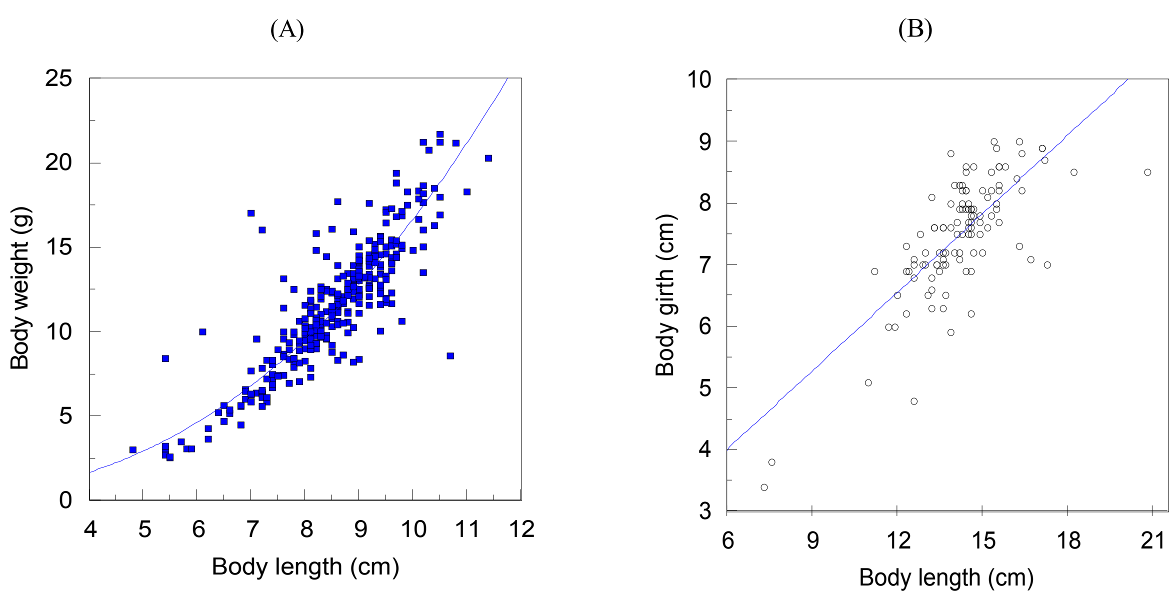

Fig. 3. Relationships between redfin velvetfish body length and weight (A) and girth (B) in the cod-end.

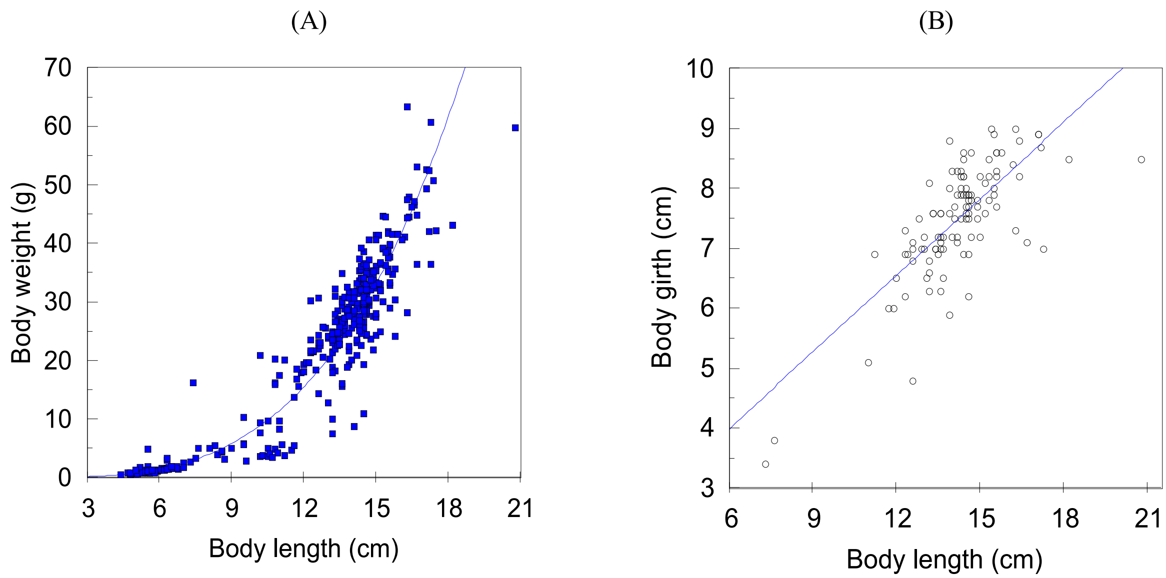

Fig. 4. Relationships between body length and weight (A) and girth (B) of the other fish species in the cod-end.

Based on the data in Table 4, fish with a body girth < 8.5 cm, which is nearly equal to the cod-end mesh circumference, were selected and shown as selective curves in Fig. 5 for the redfin velvet fish and in Fig. 6 for greenling, shotted halibut, and reduling sea robin. Body length and girth of the 50% selection for redfin velvet fish and the other fish are shown in Table 5. The 50% selection body length and girth of redfin velvet fish were similar between the cod-end and cover net, whereas the 50% selection body length and girth of the other fish were significantly different between the cod-end (41-mm) and cover net (18-mm) or the smaller mesh cod-end (18-mm) ($p < 0.05$). The spikes on the redfin velvet fish may have caused a difference in mesh size selection due to easier tangling with mesh or garbage. The difference in the 50% selection body length for the other fish between the cod-end and cover net was about 4 cm or double the mesh difference of 2.3 cm due to the wide body length distribution. However, the difference in 50% selection girth between the cod-end and cover net was about 1.9 cm, which was similar to the 2.3-cm mesh size difference.

From the re-calculated body length selectivity for red mullet (Tokac et al., 2004), the difference in 50% body length selectivity between a 40-mm cod-end and a 24-mm cover net was 2 cm, which was similar to the 1.6-cm mesh difference. Using a similar estimate of total length selectivity for rose shrimp (Deval et al., 2006), the difference in 50% total length selectivity between the 40-mm cod-end and the 24-mm cover net was 0.8 cm or half the 1.6-cm mesh size difference. The girth selection range between 4 and 11 cm seems to be a large difference by fish species based on the girth data in the cod-end without a cover net (Matsushita and Ali, 1997) due to body width and depth differences. These results and those of previous reports clearly show that 50% selection was closely related to fish body shape and morphology.

Table 5. The 50% selection of body length and girth for redfin velvet fish and other fish species caught in the cod-end and cover net, respectively

Fish	Part	Body length (cm)	Girth (cm)
Redfin Velvet	Codend (41mm)	8.6	5.5
	Codend (18mm)*	7.4	5.7
	Cover (18mm)	8.4	5.6
Other fish	Codend (41mm)	12.1	7.6
	Codend (18mm)*	9.3	6.0
	Cover (18mm)	8.1	5.7

*Estimated from the data by Kim and Whang (2014)

The retention ratio of by-catch frequency in the cod-end to total by-catch number based on each girth step for the several fishing trials is shown in Fig. 7. The retention ratio by girth in the cod-end was irregular for a smaller girth due to fewer data; however, the retention ratio converged steadily after passing the 50% selection girth until the maximum girth reached the mesh circumference. The cumulative girth selection curves in the cod-end and cover net for each fishing trial are shown in Fig. 8. The difference in 50% girth selection between hauls or between the cod-end and cover net was < 1 cm smaller than that of the 50% selection girth from Table 4 ($p < 0.05$). The reason is that Fig. 8 considers main fish species including as redfin velvet fish, which was not different in 50% selection girth between the cod-end and cover net and other fish, which had a different 50% selection girth. However, these data cannot be compared directly with other results due to the lack of studies on girth selectivity in towed fish gear as author known.

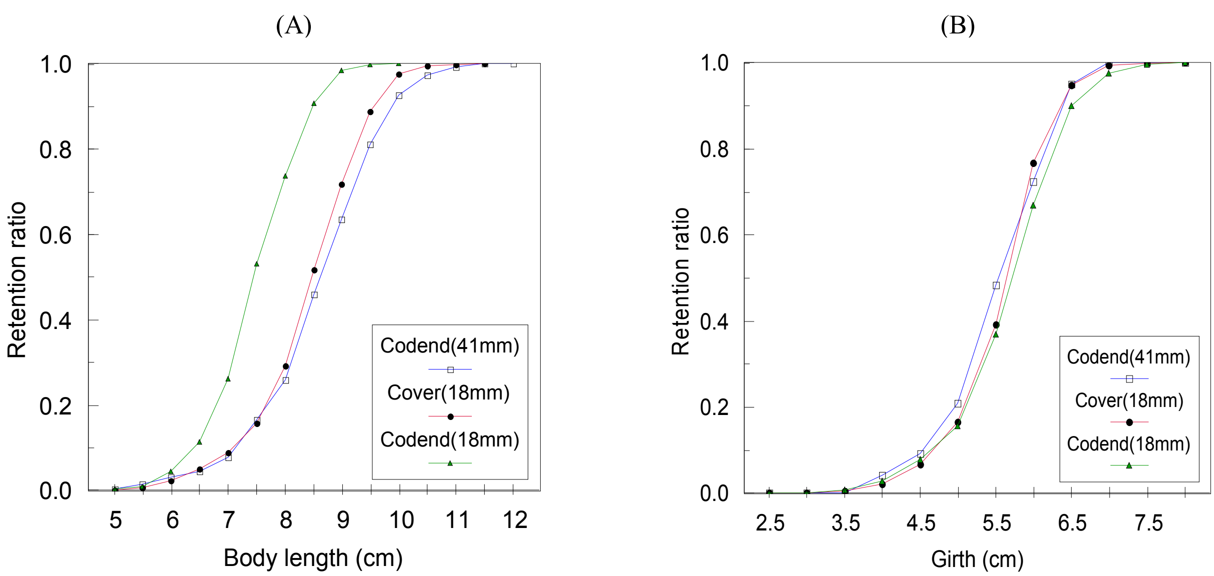

Fig. 5. Selection curves for redfin velvet fish body length (A) and body girth (B) in the cod-end and cover net.

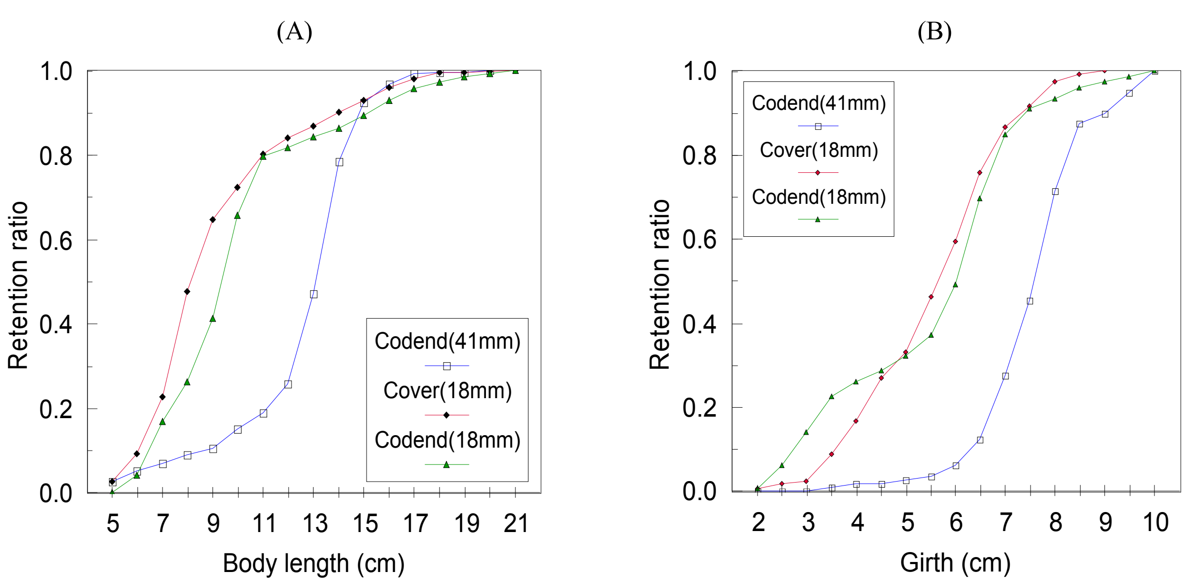

Fig. 6. Selection curves for body length (A) and body girth (B) for the other fish species in the cod-end and cover net.

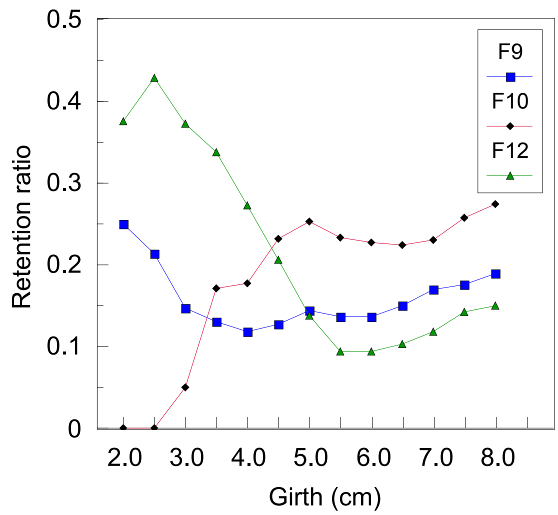

Fig. 7. Variation in the retention ratio by girth steps for whole by-catch frequency in the cod-end for three haul.

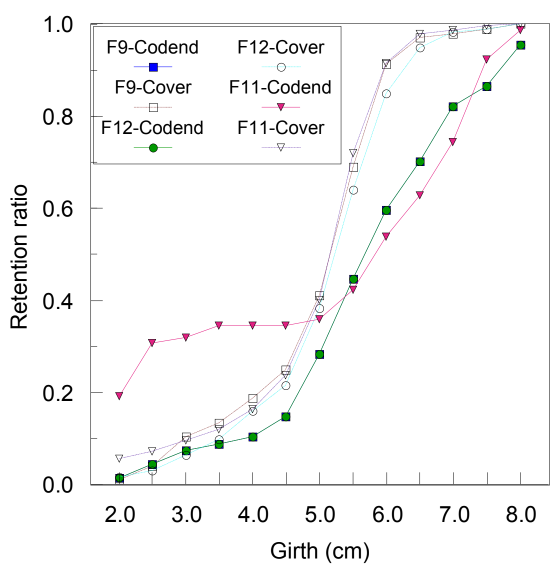

Fig. 8. Cumulative retention ratio of girth for whole by-catch in the cod-end and cover net for three haul.

Our results show that the by-catch ratio of undersized fish smaller than the cod-end mesh circumference was about 40% in weight and about 20% in number. However, by-catch in the cod-end as the weight ratio of by-catch to total catch in terms of the Fisheries Law was about 15%, which appears to be a smaller by-catch but represents a large number of undersized fish retained in the cod-end. Therefore, juvenile by-catch in the cod-end should be investigated considering the numbers and weights of undersized fish penetrating the net.

The girth selection method using a beam trawl was adapted first in this study to analyze by-catch in the cod-end and cover net. Girth selectivity can be applied to several fish in one curve and the penetrating fish size can be determined easily using mesh circumference. Then, the 50% selection girth can be converted using the girth-length relationship (Stergiou and Karpouzi, 2003; Santos et al., 2006) for regulatory purposes as an example. However, further investigations using other towed fishing gear and more-stable fish data considering relevant selectivity factors are necessary to establish the validity of the girth selectivity method.

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