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〈Original Article〉

Escape response of juvenile seabream with rockfish from the separating model codend in tank experiments

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Most grid sorting has been used to sort out flatfish in shrimp fisheries, while double grid systems have been tested to separate smaller shrimp. The escape of juvenile red seabream through separating panels made with steel grids or large mesh tested for masking effects in a two-species system. Fish behavior was observed in a circulating water tank. The escape rate was 20% greater with the separating codends than with the normal codend in the single-species experiments. The rates in the two-species experiments were 30% or 20% greater than the single-species rates for the normal or separating codends, respectively. The seabream retention rates in the grid separator codend decreased as rockfish retention increased, possibly due to a threat effect. Conversely, the retention rate of both species increased concurrently in the net separator, possibly due to a masking effect. The escape rates of juvenile red seabream varied by compartment in the mesh separating codend. These results suggest that grid separating codends can be used in the field as towed fishing gear to reduce juvenile catch.

Keywords : Model codend, Grid and mesh separator, Juvenile fish, Retention rate

Introduction

Optimizing catch size while minimizing discarded bycatch in towed fisheries is both economically and environmentally desirable. Bycatch reduction devices (BRDs) such as square mesh windows, sorting grid systems, and separator panels have been tested and adapted for various species, gear, and regions (Broadhurst, 2000; Matsushita, 2000; Madsen and Valentinsson, 2010). The most effective and simplest way to reduce bycatch in passive static fishing gear is to use a larger mesh size. However, in towed fishing gear, optomotor and panic responses (Kim et al., 2008) of fish exhausted by the towing speed are the main escape behaviors from the codend, which may be complicated by masking effects as catch accumulates (Hannah and Jones, 2012). Many BRDs have been adapted to different species, gear, and regions in accordance with local regulations. However, each BRD has shortcomings for reaching optimum catch while minimizing discard (Madsen and Valentinsson, 2010). Furthermore, international guidelines for bycatch reduction are difficult to agree upon (Chopin and Suuronen, 2009; Sea Grant. 2014).

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Recently, active stimulating devices (ASDs) have been tested as BRDs in tank experiments, including a fluttering net panel inside the codend (Kim and Whang, 2010; Kim, 2011) and a shaking codend (Kim, 2015). Pulsing codends (O'Neil et al., 2003) and fluttering windows (Grimaldo et al., 2007) have also been shown to reduce bycatch. Observational studies have revealed that fish near codends may behave erratically (Kim et al., 2008) or are behaviorally impaired as they try to escape the codend (Hannah and Jones, 2012). Therefore, an alternative method to decrease bycatch may be an active stimulating BRD using flow around and in the codend to create a filtering or sieving effect on juvenile fish.

The grid sorting method has been tested in trawl nets (Issksen et al., 1992), followed by many improvements in materials, such as rope grids (He and Balzano, 2011) or flexible synthesis grids (Massutí et al., 2009), and design changes such as horizontal bars (Ohata et al., 2008). Generally, most grid sorting has been used to separate flatfish from shrimp catches. The double grid system uses a front grid to sort flatfish while the rear grid sorts out small shrimps like in a typical grid BRD (He and Balzano, 2007). However, sorting grids have not yet been used to separate smaller fish from a target fish catch.

The escape of juvenile fish through both grid and mesh separating panels investigated the effectiveness of these BRDs in multi-species catches. In addition, the separating codends were compared to a normal codend without a BRD. Then the codend retention rates were compared by codend type, compartment, and species.

Materials and Methods

The experimental fish were juvenile red seabream, Pagrus major, which are common in Korean waters. Approximately 5,000 juvenile red seabream with a mean total length of 6.1 ± 0.7 cm, mean girth of 3.9 ± 0.6 cm, and mean body weight of 3.7 ± 1.0 g (Fig. 1) were purchased from a fish hatchery in Tongyoung, Korea, on May 25, 2015. The relationships between total body length (BL, in cm) and girth (G, in cm)/weight (W, in g) from a sample of 300 red seabream were as follows:

$G = 0.67BL - 0.21$ (n = 300, r = 0.82)

$W = 0.094BL^{2.02}$ (n = 300, r = 0.83)

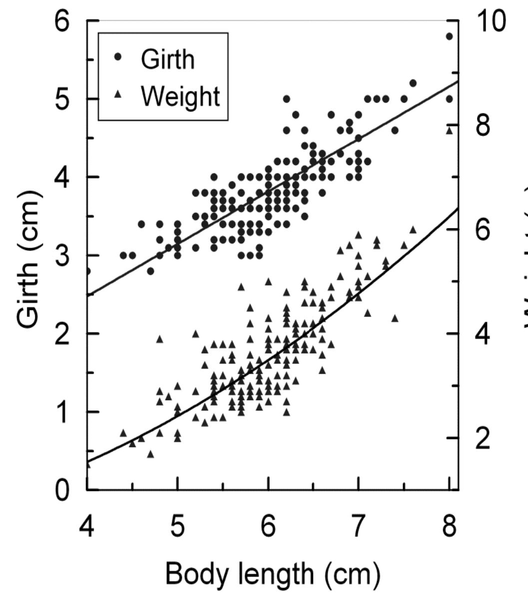

Fig. 1. Relationship between total body length and girth/weight from a sample of 300 red seabream.

To observe the escape behavior of juvenile fish when bigger fish were present in the codend, 160 rockfish Sebastiscus marmoratus were purchased from a live fish shop in Tongyoung, Korea, after they were caught on the inshore seabed of the southern Sea of Korea. They had a mean total length of 15.7 ± 2.7 cm, mean girth of 10.6 ± 1.5 cm, and mean body weight of 68.2 ± 26.7 g. The relationships between total body length (BL, in cm) and girth (G, in cm)/weight (W, in g) from a sample of 138 rockfish are shown in Fig. 2.

$G = 0.612BL + 1.3$ (n = 138, r = 0.81)

$W = 0.124BL^{2.28}$ (n = 138, r = 0.85)

The fish were reared in a 3 m diameter water tank that formed the central part of a 5 m diameter blue FRP circular tank (Kim and Whang, 2010) located at the

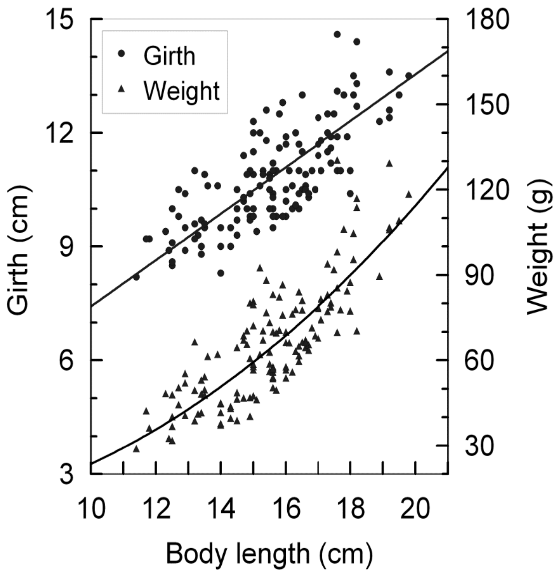

Fig. 2. Relationships between total body length and girth/weight from a sample of 138 rockfish.

College of Marine Science, Tongyoung, South Korea. The fish were fed aquaculture pellets in the morning and the evening. Seawater in the tank was filtered through a 500 L filter system with underwater pumps (PS-225, 220V, 1 hp, Hanil Electronics). Water temperature was maintained at 20 ± 0.5°C using a seawater chiller (220V, 3 hp). The salinity was 34 psu during all experiments, as measured by a handheld meter (85FT: YSI, Inc., Yellow Springs, OH., USA).

Fig. 3 shows the designs of the normal cylinder codend and the grid separator codend.

The normal cylinder codend (Kim and Whang, 2010) was 150 cm long with a diameter of 45 cm made from 0.5 mm dark brown PE netting with a 43 mm nominal mesh size to allow juvenile red seabream to pass through while blocking all rockfish (Fig. 3A). The codend had a circumference of 60 meshes and was 35 meshes long

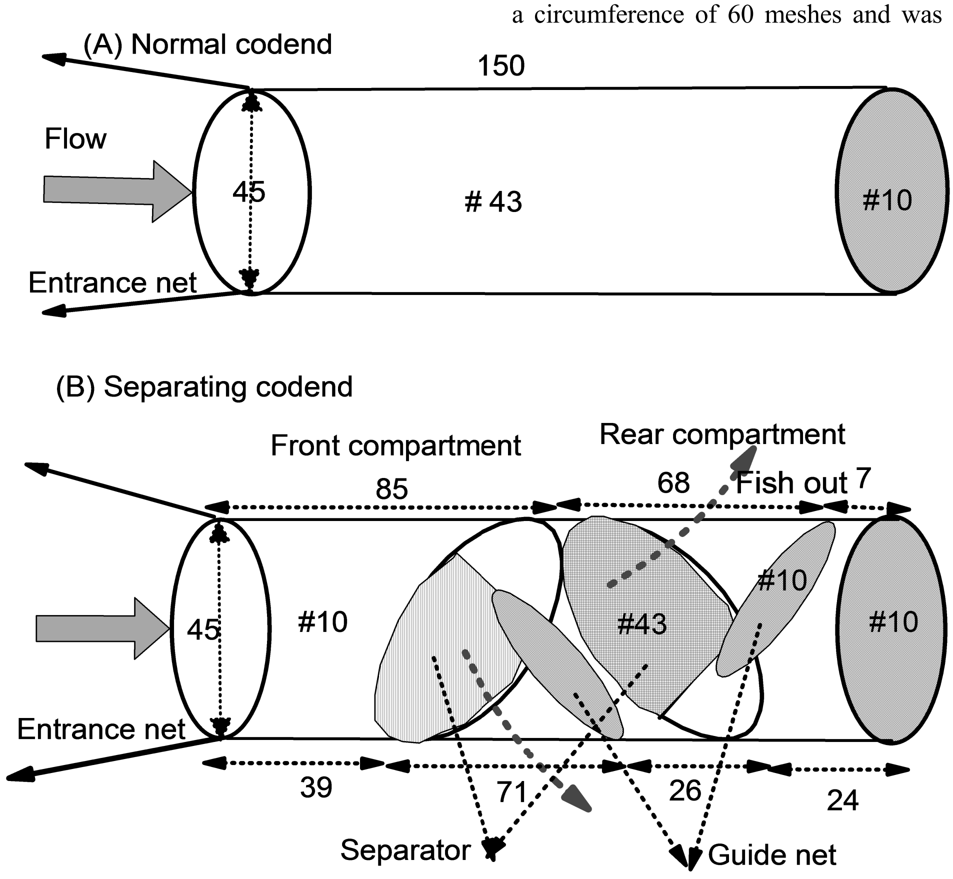

Fig. 3. Experimental codends. (A) A normal cylinder codend and (B) a grid separator codend (units in cm except mesh size # in mm).

(Fig. 3A). The normal codend hung on four rings made of stainless steel wires (5.0 mm diameter). The front entrance bagnet (length 70 cm) and rear round panels had 10 mm nominal mesh made of white PA Raschel netting (multifilament, 0.5 mm diameter), which did not allow juvenile fish to pass through.

The separating codends were 160 cm long with a diameter of 45 cm, framed by 5 rings with 4 horizontal bars made from 5 mm stainless steel wire, and covered with 10 mm nominal mesh made from white PA Raschel netting (multifilament, 0.5 mm diameter) (Figs. 3B and 4). Two grids were positioned diagonally at 45° to guide small fish upwards in the front grid (downward escaping) and then downwards (upward escaping) in the rear grid. These directions were the opposite of those used in shrimp size sorting grids (He and Balzano, 2007). Mesh was removed around the sloping panels to create a downward lateral escape exit between the grid and guide net panel in the front section and a lateral upward escape exit in the rear section (Figs. 3B and 4). Two separating codend designs were used: one with panels composed of stainless steel wire (5 mm diameter) and another with panels composed of mesh separators (0.5 mm dark brown PE netting with 43 mm nominal mesh size). The openings of the escape exits were 11.3 ± 1.4 mm in the front section and 11.6 ± 1.1 mm in the rear section, which allowed most of the juvenile red seabream to pass while blocking all rockfish.

The codends were set up in the outer channel of the circular tank, following the experimental design of Kim and Whang (2010). Water flow was generated using seven underwater pumps (IPV-835, 220V, 1 hp: Hanil Electronics,), which produced a mean water flow of 0.6 m/s in the middle of the tank, as measured by a 201D Flowmeter (Marsh McBirne, Loveland, CO., USA). The ceiling was covered by four squares of blue canvas to provide approximately 10 lx illumination, as measured laterally by an underwater illumination meter (IM-5: Topcon, Japan) in the middle of the tank.

In the single-species experiments, 200 red seabream were released from the extended entrance of the bagnet (white 0.5 mm diameter PA Raschel netting with a 10 mm nominal mesh size) into the water flow at the front of the codend. In the two-species experiments, 20 rockfish were first released from the entrance of the bagnet, followed by 200 red seabream. Fish behavior and codend motion were observed for 30 min using underwater video cameras (OE 1210, Simrad; OE1358, DeepSea Power & Light; UWC-150VH-N, Huhu) and VTRs (WR-1000; SV-DVR300, Samsung). The fish retained in the codends at the end of the experiments were transferred to a resting tank for counting. The red seabream escape (retention) rate was calculated as the number of escaped fish/200 (retained fish/200). In the separating codend, the retained fish were separately counted in the front compartment (from entrance to the end of front separator) and rear compartment (from the end of front separator to the end of the codend) for each fish species. Each experiment was repeated 10 times at a minimum interval of 2 days for randomly selected groups of 200 fish until all of the fish were used. Table 1 shows the dates, fish, codend type, codend motion, and

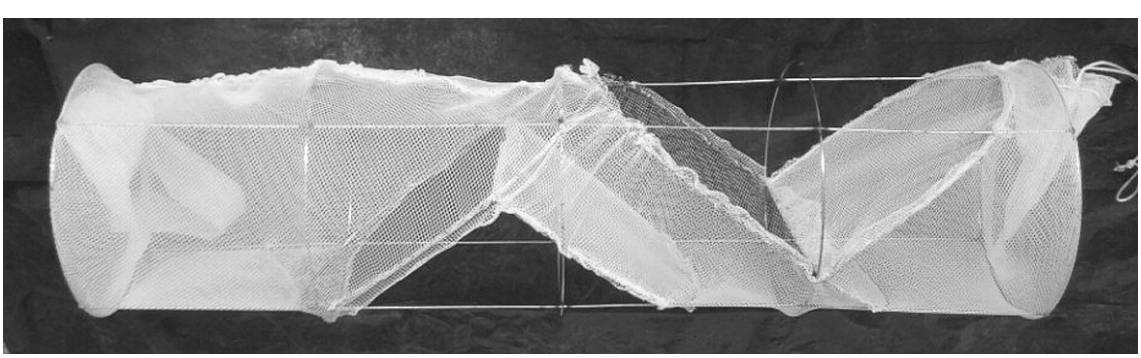

Fig. 4. The lateral view of the separating codend with a mesh separator. Flow is from left to right.

Table 1. Dates and conditions for each experimental run

Codend	Type	Trial Nos (month,date)	
		Seabream	Seabream+Rockfish
Normal	Mesh	10(5.28)	7(6.6), 1(6.10), 2(6.11)
Separating	Grid	10(5.31)	8(6.5), 2(6.6)
	Mesh	6(6.2), 3(6.8), 1(6.10)	8(6.8), 2(6.11)

flow velocity for each experimental run.

Student's t-test was used to compare the retained fish rates between fish species, types of codend, and separators (Table 1). In addition, two-factor ANOVA was conducted between fish species and type of separator.

Results

Most of the fish retained in the codends displayed an optomotor response in the front section and then fell back into the rear section as time elapsed. Table 2 shows the retention rates for each codend type after 30 min and Fig. 5 shows their means and SDs. The seabream retention rate was significantly lower in two-species experiments than in one-species experiments (P < 0.001) for the normal codend. However, there were no differences in total retention rates of juvenile seabream between grid and net separators or between one-species and two-species experiments for the separating codends. Although the codend designs and sizes were different, the retention rates of juvenile seabream in the separating codends were significantly lower than in the normal codend in the single-species experiment. However, the retention rate in the normal codend was significantly lower than in the grid separator (P < 0.03) or mesh separator (P < 0.006) in the two-species experiments.

Table 2. Total retention rate of juvenile seabream by codend type and separating type

Codend	Type	Species*	n	Retention rate (%)			
				Mean	SD	Min.	Max.
Normal	Mesh	1	10	90	4	84	96
	Mesh	2	10	60	9	46	72
Separating	Mesh	1	10	71	12	45	89
	Grid	1	10	71	14	53	97
	Mesh	2	10	72	10	58	89
	Grid	2	10	74	4	71	79

** 1 denotes seabream only and 2 denotes seabream and rockfish

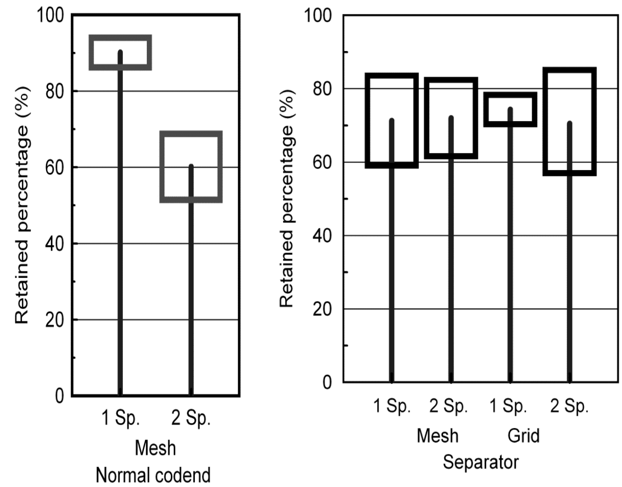

Fig. 5. Comparison of the juvenile seabream retention rates between each type of codend showing mean values and SDs.

Table 3 shows the retention rates by compartment of the separating codends. The retention rate was significantly higher in the rear compartment than in the front compartment for both separator types and species experiments (P < 0.001). The rockfish retention rate in the front compartment of the mesh separator was significantly higher than that of the grid separator (P < 0.04), whereas the rear retention rates did not differ. This may have been due to the increased friction caused by the mesh compared to the gliding stainless steel grid.

Table 3. Retention rates of juvenile seabream and rockfish in the compartments of the separating codends

Separator	Species	Compartment	n	Retention rate (%)			
				Mean	SD	Min.	Max.
Grid	Seabream	Front	10	6	4	3	13
		Rear	10	66	13	38	79
Mesh	Seabream	Front	10	10	5	7	12
		Rear	10	62	12	51	79
Grid	Seabream	Front	10	8	11	2	41
		Rear	10	62	13	39	83
	Rockfish	Front	10	28	13	5	45
		Rear	10	72	13	55	95
Mesh	Seabream	Front	10	9	4	3	17
		Rear	10	65	12	41	79
	Rockfish	Front	10	38	13	20	65
		Rear	10	64	13	35	80

Table 4 combines the results of the ANOVA with the data shown in Table 3 in order to check up the interaction of two factors. The rockfish retention rate was influenced

Table 4. Results of two-factor ANOVA for retention rate between the front and rear compartments of the separating codends in the two-species experiments from Table 3

Condition	Factors	p
Seabream	Front : Rear	0.00001*
	Grid : Mesh	0.98
	Interaction	0.402
Rockfish	Front : Rear	0.00001*
	Grid : Mesh	0.76
	Interaction	0.0225*
Grid	Front : Rear	0.00001*
	Seabream : Rockfish	0.0011*
	Interaction	0.387
Mesh	Front : Rear	0.00001*
	Seabream : Rockfish	0.00013*
	Interaction	0.00005*

*Significant probability p<0.05

by the separating materials (grid or mesh) and ompartment section, while seabream retention was not influenced by those factors. Retention rate interacted with compartment section and species in the mesh separating codend but not in the grid codend.

Fig. 6 plots the retention rates of seabream and rockfish by separator types and compartments for each trial to examine the effects of bigger fish on juvenile fish. Table 5 summarizes the results of linear and power regressions between the retention rates of rockfish and seabream. Most of the correlation coefficients were ≥0.5, except for the front compartment of the mesh separator. Most of the correlation coefficients were weakly ($P < 0.1$) or strongly ($P < 0.05$) significant, except for the front compartment of the mesh separator. The seabream retention rate in the grid separator decreased as the rockfish retention rate increased, perhaps due to a threat effect. Conversely, the seabream and rockfish retention rates increased simultaneously in the mesh separator, which may reflect a masking effect. These results indicate that multi-species and/or multi-size catches in codends may affect catch selectivity and the escape behavior of juvenile fish.

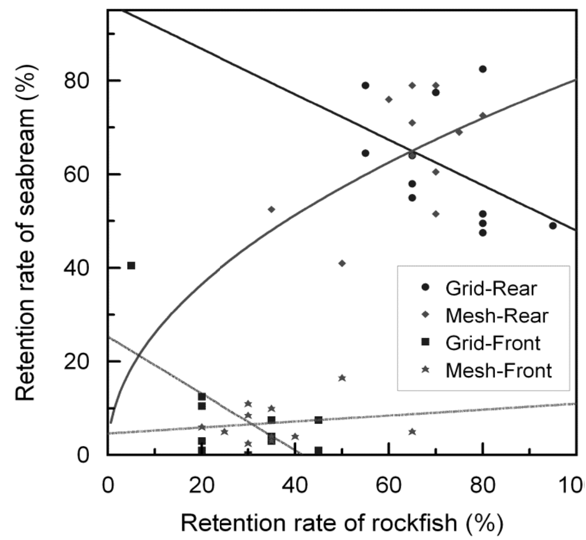

Fig. 6. Relationship between the retention rates of seabream and rockfish by separator type and compartment (lines represent power regression).

Table 5. Correlation coefficients (r) of regressions between retention rates of rockfish and seabream and their P-values from Fig. 6

Separator	Compartment	Linear regression		Power regression	
Seabream		r	p	r	p
Grid	Front	-0.65	0.031	-0.54	0.06
	Rear	-0.46	0.152	-0.51	0.098
Mesh	Front	0.10	0.77	0.13	0.70
	Rear	0.53	0.097	0.59	0.05

Discussion

The first trial of separating codend for escape of juvenile red seabream was showed about 20% increase than normal codend although the construction and size of the codends were different. The escape rates from the separating codends were generally lower in this study than those from a fluttering net panel codend (Kim and Whang, 2010) but were similar to those from a shaking model codend (Kim, 2015) under similar flow conditions but different ASD. Bycatch reduction was similar to those of shrimp fishing operations using shrimp sorting grids (He and Balzano, 2007), which can reduce smaller shrimp catch by 16% of catch without a funnel and by 24% or 39% by number or catch, respectively, with a funnel.

The grid spaces used in this study (10~12 mm) were greater than the mean girth of the juvenile seabream.

In addition, the mesh size of the mesh separator was large enough to allow juvenile seabream to pass through. Grid spaces for sorting in shrimp trawls have been shown to be proportional to the size of shrimp caught (He and Balzano, 2012). Fish of similar size have also been observed getting stuck between grids (Matsushita et al., 2004). However, the juvenile seabream in this observation did not swim actively to pass through the grid or mesh separators, instead mostly displaying optomotor responses (Kim and Whang, 2010; Wardle, 1993). Fish became exhausted over time and floated passively through or diagonally along the surface of the separators.

The presence of the bigger fish in the codends may have been threatening to the juvenile seabream during their optomotor response, resulting in a masking effect once the fish were exhausted (Kim and Wardle, 2008). However, the different relationships between the retention rates of seabream and rockfish (Fig. 6) in the grid and mesh separators are difficult to explain. They were possibly due to fewer trials or high variability in retention rate (Table 3). Therefore, the next test should be conducted using a separating codend with the same frame dimensions and same outer mesh size except for the separator. In addition, a test using juvenile and adult fish of a single species for the mixed catch trial would be useful to test threat effects or blocking in the codend.

Fish responses to codends can be affected by the contrast of fishing gear (Kim and Whang, 2011) and by netting materials (Tokaç et al., 2004). The contrast or frictional coefficient of silver stainless steel in the grid separator was higher than and the dark brown net in the mesh separator. The total rockfish retention rates in the compartments of the mesh separator were different than in the grid separator, while the seabream retention rates were similar between the grid and mesh separators.

Fish density in the codend (Jones et al., 2008) in relation to the codend circumference (Graham et al., 2009) can also affect fish escape responses. This study considered the relative ratios between fish length and school formation, but not blocking of the mesh as fish accumulated. Future studies with full-sized grid separator codends should be conducted in the field, with consideration for scale effects such as codend circumference and relative space (O'Neill et al., 2008; Broadhurst and Miller, 2009).

Conclusion

The total escape rate of juvenile seabream in the separating codends was 20% greater than in the normal codend in the single-species experiments. The escape rates in the two-species experiments were 20~30% greater than in the single-species experiment for all codends. The juvenile seabream retention rates in the mesh separating codend were affected by compartment section and species, while retention rate in the grid codend was not affected by these factors. These results suggest that grid separating codends can be used in the field for towed fishing gear to reduce juvenile catch. Future studies with full-sized grid separator codends should be conducted in the field, with consideration for scale effects such as codend circumference and relative space.

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