Testing of Two Selective Flatfish Sorting Grid Bycatch Reduction Devices in the U.S. West Coast Groundfish Bottom Trawl Fishery

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Abstract

In the U.S. West Coast limited entry (LE) groundfish bottom trawl fishery, catches of stocks with restrictive harvest limits (e.g., Darkblotched Rockfish, Sablefish, and Pacific Halibut) continue to hinder many fishermen's ability to fully utilize their quota shares of more abundant flatfish stocks (e.g., Dover Sole, and Petrale Sole). We examined the size-selection characteristics of two selective flatfish sorting grid bycatch reduction devices (BRDs), designed to reduce catches of Pacific Halibut and non-flatfish species while retaining target flatfishes, using a recapture net. The two devices were identical in materials and design with only the sorting grid dimensions differing between the two designs (BRD-1 = 6.4 cm x 25.4 cm grid size vs. BRD-2 = 6.4 cm x 30.5 cm grid size). The size selectivity parameters for rockfishes, other roundfishes, Pacific Halibut, English Sole, and Rex Sole did not differ significantly between the two designs. However, for Arrowtooth Flounder 53-58 cm in total length (TL), Dover Sole 39-53 cm TL, and Petrale Sole 36-49 cm TL, BRD-1 retained significantly more fish of these length classes than BRD-2. Combined, the mean flatfish retention by weight (not including Pacific Halibut) was 89.3% for BRD-1 and 81.7% for BRD-2. Compared to previous flatfish sorting grid selectivity work conducted in the LE bottom trawl fishery, BRD-1 showed the ability to improve the overall retention of flatfishes while reducing catches of non-target and constraining species.

Introduction

Implementing practices that enhance utilization of fishery quotas, and provide for an economically sustainable fishery are objectives of the U.S. West Coast limited entry (LE) groundfish bottom trawl fishery catch shares program (PFMC and NMFS 2011, 2015). In this fishery, participants are held fully accountable for catches of all individual fishing quota (IFQ)

species catches and bycatch of Pacific Halibut *Hippoglossus stenolepis* (a prohibited species). Catch accountability has encouraged fishermen to fish more selectively to improve the utilization of their catches of IFQ species, however, constraints on stocks with restrictive harvest limits continue to impact fishermen's ability to fully utilize their quota shares of healthier groundfish stocks.

In the LE bottom trawl fishery, fishermen trawling shoreward of 183 m bottom depth and north of 40°10'N latitude are currently mandated to use a two-seam low-rise selective flatfish trawl (Hannah et al. 2005; King et al. 2004; NOAA 2014). This regulation was implemented in efforts to minimize catches of overfished and rebuilding rockfish *Sebastes* spp. stocks when trawling for flatfishes (i.e., English Sole *Parophrys vetulus*, Dover Sole *Microstomus pacificus,* and Petrale Sole *Eopsetta jordani*) over the continental shelf. This trawl has been shown to be successful at reducing catches of some benthopelagic rockfishes (notably Canary Rockfish *S. pinniger*, a previously overfished stock recently rebuilt). However, catches of Darkblotched Rockfish *S. crameri*, Sablefish *Anoplopoma fimbria*, and Pacific Halibut often occur that restrict many fishermen from fully utilizing their flatfish IFQs as relatively limited quota is available. Consequently, developing techniques that minimize catches of constraining species and provide fishermen with more opportunities to fully utilize their catch share quota of healthier fish stocks would be beneficial to fishermen, coastal communities, management, and the resource.

Selectivity studies evaluating sorting grid bycatch reduction devices (BRDs) (Lomeli and Wakefield 2013, 2015, 2016), cod end mesh sizes and configurations (Lomeli et al. 2017; Perez-Comas et al. 1998; Wallace et al. 1996), and trawl designs (Hannah et al. 2005; King et al. 2004) have occurred in the LE bottom trawl fishery in efforts to enhance trawl selectivity and catch utilization. For bottom trawl fishermen targeting flatfishes, a sorting grid BRD was developed to

reduce catches of rockfishes, other roundfishes, and Pacific Halibut (Lomeli and Wakefield 2015, 2016). The design consisted of long rectangular slots (4.4 cm high x 21.6 cm long) to allow flatfishes to pass through and move aft towards the cod end, whereas non-target species unable to pass though the slots are released out of the trawl. During gear trials, the BRD demonstrated the ability to significantly reduce catches of rockfishes, Sablefish, and Pacific Halibut. The mean catch of flatfishes (five species evaluated) ranged from 68.1 to 92.3% by weight, with an overall mean of 85.6%. While encouraging results were achieved, the authors noted that improvements in the gears ability to retain flatfishes (particularly larger-sized fish with higher economical value) were desired to enhance the gears effectiveness in the fishery.

The objective of the current study was to examine the size-selection characteristics of two alternative sorting grid sizes, and evaluate their ability to further improve flatfish retention from previous studies while reducing non-target species catches.

Methods

Trawl design

The trawl used for this study was a two-seam Eastern 400 low-rise selective flatfish trawl with a cutback headrope. The headrope was 40.3 m in length and the chain footrope was 31.2 m in length. The chain footrope was covered with rubber discs 20.3 cm in diameter and outfitted with rubber rockhopper discs 35.6 cm in diameter placed approximately every 58.4 cm over the footrope length. This trawl lacks floats along the central portion of the headrope to reduce fish diving reactions to floats. Refer to Hannah et al. (2005) and King et al. (2004) for the trawl net plan.

Gear designs

We followed the BRD design of Lomeli and Wakefield (2015, 2016), but tested two different grid dimensions. The BRDs were built within four-seam tubes of 116 mm diamond netting (Table 1) and inserted between the intermediate section of the trawl and the codend. A 50 mesh deep two-seam to four-seam transitional tube of netting attach each BRD to the trawl. The two grids tested consisted of elongated slots that were 6.4 cm high x 25.4 cm long (BRD-1) and 6.4 cm high x 30.5 cm long (BRD-2). Each BRD utilized two vertical panels that extended longitudinally down the tube of netting (Fig. 1). The concept of the design was that fish smaller than the grid openings pass through the grid and move aft towards the codend, whereas fish larger than the grid openings such as roundfishes and most adult Pacific halibut are excluded. Fish that do not pass through the grid openings were guided by the exit ramp and exit out the top of the trawl. Between the two vertical sorting panels, ropes with chafing material wedged through them were positioned to create partial obstructions to fish moving aft to stimulate fish to move towards the sorting grids. At the aft end of each BRD, the top portion of the vertical panels angled outward to allow for integration of the exit ramp and its associated escape opening. The trawl codend was a four-seam tube of 116 mm diamond netting. For further design detail refer to Lomeli and Wakefield (2016).

We used a recapture net to quantify fish escapement for the two BRD designs. The recapture net was a four-seam tube of 116 mm diamond netting that was 100 meshes deep and 70 meshes in circumference (25 meshes on the top and bottom panel; 10 meshes on the side panels), excluding meshes in each selvedge (Table 1). Because a codend cover was not used to capture fish passing through the meshes of the trawl codend, the mesh of the recapture net needed to be the same size as the trawl for a direct catch comparison. The recapture net was attached to the

BRD just forward of the escape opening to allow excluded fish to be captured. To keep the recapture net from masking the escape opening, two 20.3 cm center-hole floats were placed on each top ribline of the recapture net, above the escape area of the BRD, while two 27.9 cm ear-floats were placed on the top panel webbing in the middle (between the top riblines) of the recapture net.

Gear trials and fish sampling

We conducted our sea trials aboard the F/V *Miss Sue* (24.7 m long, 640 horsepower trawler), off central Oregon between 44°30' and 45°32 N and between 124°17' and 124°48' W in April 2016. Towing occurred over the continental shelf and shelf break during daylight hours, between 0600 and 1800 Pacific daylight time, at bottom fishing depths from 146 to 402 m. The average bottom fishing depth was 249 m. Towing speed over ground ranged from 2.2 to 2.6 knots. Tow durations were set to 1 h. The BRDs were fished in an alternate tow randomized block design. After each tow, all fish were identified to species and weighed using a motion compensated platform scale. Flatfishes, Shortspine Thornyhead *Sebastolobus alascanus*, and Lingcod *Ophiodon elongatus* were measured to the nearest cm total length (TL), while Sablefish and rockfishes were measured to the nearest cm fork length.

Selectivity analysis

The *Clogit* model function in the statistical analysis software SELNET (SELection in trawl NETting) was used to analyze the data (Sistiaga et al. 2010; Herrmann et al. 2012). This model estimates the likelihood that fish of length class l entering the grid area will contact the grid system and is denoted as C_{grid}:

$$r_{average}(l) = Clogit(l, L50_{\text{grid}}, SR_{\text{grid}}, C_{\text{grid}}) \equiv 1 - C_{\text{grid}} \times (1 - Logit(l, L50_{\text{grid}}, SR_{\text{grid}}))$$

Values range from $0 \leq C_{\text{grid}} \leq 1$, with $C_{\text{grid}} = 1$ meaning all fish contacted the grid and attempted to pass through. Fit statistics to determine if the model adequately describes the experimental data are p-values >0.05, and deviance not to exceed degrees of freedom by approximately two times (Wileman et al. 1996; Notti et al. 2016).

Mean size-selection curves were estimated by pooling length data across tows for each BRD tested. All tows and length classes caught were used in the analysis. $L25_{\text{grid}}$, $L50_{\text{grid}}$, and $L75_{\text{grid}}$ values are defined as the length where 25%, 50%, and 75% of fish, respectively, have the probability of contacting and passing through the grid system. SR_{grid} is the difference between $L25_{\text{grid}}$ and $L75_{\text{grid}}$. Efron percentile 95% confidence intervals (CIs) (Efron, 1982) for $L25_{\text{grid}}$, $L50_{\text{grid}}$, $L75_{\text{grid}}$, SR_{grid}, and C_{grid} were estimated from 1,000 bootstrap repetitions using a double bootstrapping method implemented in SELNET to account for both within- and between-haul variation. This method is used to avoid underestimating CI limits for selectivity curves when pooling haul data (Sistiaga et al. 2010; Herrmann et al. 2012). See Sistiaga et al. (2010), Herrmann et al. (2013), and Grimaldo et al. (2015) for complete *Clogit* model details. Table 2 presents the data that were used to obtain the selectivity results for each BRD design.

Results

We completed 30 tows (15 tows for each BRD design). Combined, flatfishes comprised 62.9% of the total catch by weight, with Pacific Halibut, English Sole, Rex Sole *Glyptocephalus zachirus*, Arrowtooth Flounder *Atheresthes stomias*, Dover Sole, and Petrale Sole comprising 98.3% of flatfish catches. The remaining 37.1% of the total catch, 36 species, included

rockfishes (predominantly Darkblotched and Greenstriped *S. elongatus* rockfishes), other roundfishes (mainly Shortspine Thornyhead, Sablefish, and Lingcod), and elasmobranchs (primarily longnose skate *Raja rhina*). Size selectivity characteristics for elasmobranchs were not evaluated due to limited sample sizes.

Flatfishes

Mean cod end retention rates (by weight) were substantially higher in BRD-1 for English Sole, Arrowtooth Flounder, Dover Sole, and Petrale Sole than BRD-2. The largest difference in mean retention between the two BRDs was observed in Dover Sole and Petrale Sole with BRD-1 retaining 9.9% and 7.6% more than BRD-2, respectively (Table 3). For BRD-1, Petrale Sole (91.4%) and Dover Sole (89.9%) displayed the highest mean retention. Rex Sole (86.5%) and Petrale Sole (83.8%) showed the highest mean retention for BRD-2. Mean retention of Pacific Halibut and Rex Sole were similar between the two BRDs. Combined, the mean retention by weight of target flatfishes was 89.3% for BRD-1 and 81.7% for BRD-2.

Model fit statistics for English Sole in BRD-1 and Pacific Halibut, Arrowtooth Flounder, and Dover Sole in BRD-2 had p-values <0.05 and required further assessment to determine if the models were adequately describing the experimental data for these species (Table 4). Inspecting the fit between the experimental catch comparison data and the modeled mean curve for these species indicated the p-values <0.05 were due to overdispersion of the data rather than the model's inability to adequately describe the data.

Mean C_{grid} values ranging from 0.89 to 0.99 for BRD-1 and 0.82 to 0.99 for BRD-2 showed target flatfishes displayed a high probability of contacting the grid system. While the general selectivity trend shows BRD-1 retaining more fish than BRD-2, the size selectivity

parameters for Pacific Halibut, English Sole, and Rex Sole did not differ significantly between the BRDs as indicated by their selectivity curves overlapping 95% CIs (Table 4, Fig. 2). However, for Arrowtooth Flounder 53-58 cm TL, Dover Sole 39-53 cm TL, and Petrale Sole 36-49 cm TL, BRD-1 retained significantly more fish of these length classes than BRD-2 (Fig. 2). The size selectivity characteristics for BRD-1 and -2 for the six flatfish species evaluated are depicted in figures 3-5.

Rockfishes and other roundfishes

Both BRDs tested were effective at minimizing catches of rockfishes and other roundfishes (Table 5). For the five species evaluated, mean $L50_{\text{grid}}$ values did not differ significantly between the two BRDs as indicated by their selectivity curves overlapping 95% CIs (Table 6, Fig. 6). For Darkblotched and Greenstriped rockfishes, and Shortspine Thornyhead, mean $L50_{\text{grid}}$ values were 29.9, 29.9, and 33.5 cm in BRD-1 and 27.6, 30.2, and 31.4 cm in BRD-2, respectively (Table 6, Fig. 7). Sablefish and Lingcod, species that are more elongated and round in shape than rockfishes and Shortspine Thornyhead, displayed slightly higher mean $L50_{\text{grid}}$ values. For BRD-1, mean $L50_{\text{grid}}$ value for Sablefish and Lingcod were 44.6 and 42.2 cm, respectively. Their mean $L50_{\text{grid}}$ values for BRD-2 were 45.5 and 44.4 cm, respectively. For both BRDs tested, relatively steep selectivity curves were observed (Figs. 7-8).

With the exception of Lingcod, the *Clogit* model adequately described the data for BRD-1 and -2 as depicted by the model fit statistics (Table 6). Examination of the model output for Lingcod suggested the p-value<0.05 was the result of overdispersion of the data rather than the inability of the model to adequately describe the experimental data.

C_{grid} mean values were relatively high in both BRDs indicating that the species evaluated

have a high likelihood of contacting the grid system. While the mean values were not significantly different, higher C_{grid} values were observed for Darkblotched Rockfish, Shortspine Thornyhead, and Sablefish in BRD-1 than BRD-2 (Table 6). The opposite was noted for Greenstriped Rockfish. For Lingcod, mean C_{grid} values were the same between the two BRDs.

Discussion

The two BRDs tested substantially reduced catches of rockfishes, other roundfishes, and Pacific Halibut that otherwise would have been retained if the BRDs were not used. For target flatfishes, the size-selection characteristics between the two BRDs did not differ significantly for English Sole or Rex Sole. However, there were differences for Arrowtooth Flounder, Dover Sole, and Petrale Sole with significantly more fish of larger size classes caught in BRD-1 than BRD-2. This result was not anticipated as flatfish retention was expected to be higher in BRD-2 with the larger grid size. These unexpected results could be due to a relatively low sample size, or to a true gear effect of the larger grid size; for example, after fish pass through a grid opening, and begin moving back toward the cod end, the larger grid dimensions increase their probability of passing back through the grid and then releasing out the trawl. Further work using video camera or imaging sonar could reveal if the latter is happening.

In the LE bottom trawl fishery, the shoreside trawl ACL for Dover Sole has been ca. 45,980 mt (NOAA 2015). However, recent catches of Dover Sole have been ca. 6,250 mt (PacFIN 2015), which represents only 13.6% attainment of the shoreside trawl allocation, with constraining species such as Darkblotched Rockfish, Sablefish, and Pacific Halibut limiting full attainment. In this study, BRD-1 was effective at retaining Dover Sole across all size classes (89.9% retained by weight overall), while substantially minimizing catches of non-target and

constraining species. For fishermen seeking more opportunities to capitalize on the Dover Sole allocation and increase their net economic benefits, the BRD-1 evaluated in this study could provide fishermen further opportunities to access this resource.

Results from Lomeli and Wakefield's (2015, 2016) prior work examining a 4.4 cm x 21.6 cm grid size showed similar mean flatfish retention rates between their two studies, 84.6% vs. 85.6% by weight, respectively. Due to limited vessel time, sampling logistics, and previous results, the 4.4 cm x 21.6 cm grid size was not incorporated into the current study. Compared to the prior research, the larger grid dimension of BRD-1 (6.4 cm x 25.4 cm) increased the overall retention of flatfishes by up to 4.7% (by weight) while still substantially lowering catches of rockfishes, other roundfishes, and Pacific Halibut. Overall, BRD-1 retained 89.3% of the flatfishes encountered. The most notable improvement in the gears performance (compared to the earlier work) was the overall retention of Arrowtooth Flounder. For BRD-1, the mean retention of Arrowtooth Flounder was 85.7% by weight, whereas their mean retention in the previous research was 68.1%. Catch improvements for larger-sized Dover Sole and Petrale Sole (e.g., fish larger than 39 cm in length) were also noted for BRD-1. In the Gulf of Alaska, where bycatch of Pacific Halibut at times has impacted fishermen's ability to fully utilize the available resource of Rex Sole, Arrowtooth Flounder, Dover Sole, and Flathead Sole *Hippoglossoides elassodon* (Rose and Gauvin 2000), use of the BRD design evaluated in the current study may prove useful for improving catch utilization in that flatfish fishery.

For selective fishing devices such as sorting grids, mesh panels, or modified cod ends (e.g., T90, Bacoma, square mesh, etc.) to be effective, the probability of fish contacting the selective gear needs to be high. Methods to increase contact probabilities have included deflector/guiding devices (Santos et al. 2016), lifting panels (Sistiaga et al. 2010), and reduced

number of meshes in cod end circumferences (Herrmann et al. 2007, 2013). In this study, flatfishes and roundfishes exhibited a high probability of contacting the grid systems as indicated by the high C_{grid} mean values observed for each BRD design. These findings demonstrate that the general BRD design of using two elongated vertical sorting panels to crowd and sort fish, was effective at getting fish to interact with the sorting grids.

In summary, the size-selection characteristics of two flexible sorting grid BRDs designed to retain flatfishes while reducing catches of rockfishes, other roundfishes, and Pacific Halibut in the LE groundfish bottom trawl fishery were evaluated. The size selectivity parameters for rockfishes, other roundfishes, Pacific Halibut, English Sole, and Rex Sole did not differ significantly between the two designs. However, there were differences for Arrowtooth Flounder, Dover Sole, and Petrale Sole with significantly more fish of larger size classes caught in BRD-1 than BRD-2. Compared to previous flatfish sorting grid selectivity work conducted in the fishery (Lomeli and Wakefield 2015, 2016), BRD-1 tested in this study showed the ability to improve the overall retention of flatfishes while reducing catches of non-target and constraining species.

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Table 1. Specifications of the two BRDs tested. Mesh sizes (mm) are stretched measurements between-knots. DM = diamond mesh; sngl. = single; dbl. = double; LL = long link. * = does not account for meshes gored in each selvedge.

	BRD-1	BRD-2	Recapture net	Trawl cod end
Grid dimensions (H x L)	6.4 cm x 25.4 cm	6.4 cm x 30.5 cm	-	-
Netting	116 mm DM	116 mm DM	116 mm DM	116 mm DM
Twine	4 mm sngl. (top and side panels); 5 mm dbl. (bottom panel)	4 mm sngl. (top and side panels); 5 mm dbl. (bottom panel)	6 mm dbl.	6 mm dbl.
Circumference*	100	100	70	88
Meshes deep	80	80	100	75
Top riblines	32 mm Blue Steel™ Poly rope, hung at 6%	32 mm Blue Steel™ Poly rope, hung at 6%	12.7 mm Blue Steel™ Poly rope, hung at 6%	32 mm Blue Steel™ Poly rope, hung at 6%
Bottom riblines	12.7 mm LL chain, hung at 6%	12.7 mm LL chain, hung at 6%	12.7 mm Blue Steel™ Poly rope, hung at 6%	32 mm Blue Steel™ Poly rope, hung at 6%

Table 2. Length data used to *Clogit* model the size-selectivity for each BRD design. Values in parentheses are the subsample ratio.

Species	No. of tows	No. measured in cod end	No. measured in recapture net	Length range (cm)
BRD-1 grid size 6.4 cm x 25.4 cm				
Pacific Halibut	10	5 (1.0)	21 (1.0)	55 – 81
English Sole	13	401 (0.59)	86 (1.0)	23 – 40
Rex Sole	15	1,170 (0.70)	196 (1.0)	21 – 52
Arrowtooth Flounder	15	1,028 (0.78)	155 (1.0)	24 – 66
Dover Sole	15	2,477 (0.43)	451 (1.0)	28 – 61
Petrale Sole	13	1,492 (0.72)	168 (1.0)	26 – 56
Darkblotched Rockfish	11	339 (1.0)	176 (1.0)	19 – 40
Greenstriped Rockfish	12	503 (0.59)	318 (0.55)	19 – 38
Shortspine Thornyhead	7	298 (0.62)	75 (1.0)	17 – 44
Sablefish	14	249 (1.0)	556 (1.0)	34 – 92
Lingcod	13	8 (1.0)	93 (1.0)	45 – 92
BRD-2 grid size 6.4 cm x 30.5 cm				
Pacific Halibut	10	5 (1.0)	13 (1.0)	55 – 91
English Sole	15	261 (0.71)	71 (1.0)	25 – 42
Rex Sole	15	1,015 (0.68)	191 (1.0)	23 – 47
Arrowtooth Flounder	15	562 (1.0)	169 (1.0)	26 – 68
Dover Sole	15	1,919 (0.65)	523 (1.0)	29 – 61
Petrale Sole	15	1,683 (0.57)	361 (1.0)	26 – 57
Darkblotched Rockfish	10	171 (1.0)	296 (0.69)	19 – 45
Greenstriped Rockfish	13	217 (1.0)	183 (1.0)	21 – 38
Shortspine Thornyhead	6	131 (1.0)	68 (1.0)	19 – 44
Sablefish	14	102 (1.0)	193 (1.0)	37 – 77
Lingcod	11	131 (1.0)	207 (0.40)	41 – 86

Table 3. Catch data by weight (kg) from the 30 tows conducted for six flatfishes. BRD-1 = grid size 6.4 cm x 25.4 cm; BRD-2 = grid size 6.4 cm x 30.5 cm; RN = recapture net; * = month/day/year.

			Pacific Halibut		English Sole		Rex Sole		Arrowtooth Flounder		Dover Sole		Petrale Sole	
Tow	Date*	BRD-	RN	Codend	RN	Codend	RN	Codend	RN	Codend	RN	Codend	RN	Codend
1	4/20/16	2	0	0	0.3	0.4	1.5	10.1	15.1	38.1	20.5	72.8	2.4	28.3
2	4/21/16	1	5.0	0	0	1.6	1.4	12.7	3.2	21.5	21.6	101.3	19.0	283.1
3	4/21/16	1	0	0	0.4	4.2	2.0	14.5	6.0	15.6	10.8	77.2	11.6	123.1
4	4/21/16	1	2.8	13.1	7.6	34.6	4.6	10.8	3.4	10.3	10.5	59.3	12.4	94.1
5	4/21/16	1	11.4	0	2.5	24.5	1.5	27.8	6.8	49.5	12.8	65.8	9.4	74.9
6	4/21/16	1	34.9	0	5.5	37.1	1.9	18.1	24.8	107	25.8	159.4	0.6	76.6
7	4/22/16	2	5.6	0	1.9	15.4	3.3	13.0	11.0	50.4	18.1	102.1	0.9	26.1
8	4/22/16	2	5.3	8.8	0.3	4.2	3.6	11.7	12.8	42.2	50.5	164.2	7.2	24.1
9	4/22/16	2	3.8	0	7.7	28.4	0.5	10.8	0	4.4	9.1	50.2	33.1	58.7
10	4/22/16	2	13.3	0	0.3	2.5	0.5	10.3	5.1	24.3	24.9	95.2	6.0	22.0
11	4/22/16	2	4.8	2.9	0.8	2.3	1.5	9.3	13.0	37.1	31.2	82.4	55.4	242.1
12	4/23/16	1	0	3.1	0	0	2.9	8.6	9.5	62.7	75.9	806.4	0	0
13	4/23/16	1	0	0	0	0	0.9	2.4	8.1	23.0	1.4	16.7	0	0
14	4/23/16	1	0	0	0.3	2.4	1.6	19.2	15.6	114.9	23.6	279.1	3.8	59.5
15	4/23/16	1	0	0	5.7	24.1	0	6.3	0.8	5.7	3.4	20.8	0.8	8.7
16	4/23/16	1	7.9	0	0	8.2	2.1	18.1	26.2	140.6	9.7	119.2	6.9	118.8
17	4/24/16	1	0	0	0	3.0	3.7	30.2	30.7	124.2	76.2	720.0	0	9.0
18	4/24/16	1	14.9	3.4	0	3.8	3.1	51.9	1.6	116.9	28.4	377.0	5.2	60.5
19	4/24/16	1	15.0	0	0.6	1.9	2.3	22.1	11.2	84.8	22.8	200.5	0.7	14.1
20	4/26/16	2	3.7	5.1	4.2	12.1	0.6	15.1	0	3.6	38.4	44.5	31.2	173.3
21	4/26/16	2	4.8	4.0	2.0	2.6	3.2	18.1	1.2	4.3	14.8	49.3	0	62.7
22	4/26/16	2	5.6	2.8	0.3	1.8	7.2	30.9	1.3	6.8	28.5	139.1	23.9	139.8
23	4/26/16	2	10.8	0	0	1.4	1.2	6.7	1.9	42.1	10.9	42.1	7.3	23.3
24	4/26/16	2	0	0	1.5	4.8	1.3	10.5	1.7	4.5	26.1	51.8	44.3	353.7
25	4/27/16	2	0	0	0	0.7	2.3	18.5	11.9	42.4	46.1	167.8	13.1	19.7
26	4/27/16	2	0	0	0	1.8	6.1	26.5	26.4	109.9	37.8	198.0	7.1	0
27	4/27/16	2	0	0	0	0.3	1.5	11.5	4.4	9.2	15.2	51.5	0	1.2
28	4/27/16	2	15.9	0	0.7	7.8	6.4	58.6	6.8	34.1	42.4	342.8	16.3	108.8
29	4/28/16	1	11.8	0	0.3	2.0	9.3	28.0	0.5	4.6	27.6	129.6	22.1	96.7
30	4/28/16	1	4.1	9.9	0.3	1.6	3.3	16.9	0	5.2	6.0	42.9	19.4	169.8
Total – BRD-1			107.8	29.5	23.2	149.0	40.6	287.6	148.4	886.5	356.5	3,175.2	111.9	1,188.9
Codend retention			21.5%		86.5%		87.6%		85.7%		89.9%		91.4%	
Total – BRD-2			73.6	23.6	20.0	86.5	40.7	261.6	112.6	453.4	414.5	1,653.8	248.2	1,283.4
Codend retention			24.3%		81.2%		86.5%		80.1%		80.0%		83.8%	

Table 4. *Clogit* model mean selectivity results for flatfishes for the two BRD designs tested. Values in parentheses are Efron percentile bootstrap 95% confidence limits. *df* = degrees of freedom; * = value not defined.

Species	$L25_{grid}$	$L50_{grid}$	$L75_{grid}$	SR_{grid}	C_{grid}	p-value	Deviance	*df*
BRD-1 grid size 6.4 cm x 25.4 cm								
Pacific Halibut	* (*-58.8)	* (*-60.8)	* (*-199.9)	* (*-45.8)	0.20 (0.07-0.99)	0.1159	12.9	8
English Sole	40.5 (35.7-194.2)	46.5 (38.0-195.0)	51.5 (39.9-200.0)	11.1 (0.6-107.1)	0.89 (0.84-0.99)	0.0049	32.9	15
Rex Sole	48.0 (36.3-190.2)	67.2 (40.0-192.7)	85.6 (42.0-201.3)	37.6 (0.1-106.0)	0.97 (0.84-0.99)	0.5715	21.2	23
Arrowtooth Flounder	60.9 (53.6-78.4)	82.5 (62.8-127.8)	104.1 (69.4-178.0)	43.2 (12.6-100.0)	0.99 (0.90-0.99)	0.1096	46.7	36
Dover Sole	67.6 (54.4-161.0)	80.6 (56.7-192.2)	92.0 (58.7-234.0)	24.4 (2.3-108.3)	0.92 (0.89-0.99)	0.4307	29.7	29
Petrale Sole	189.7 (54.4-198.0)	190.6 (56.1-199.4)	191.4 (57.6-245.4)	1.6 (0.3-109.7)	0.91 (0.89-0.99)	0.0807	37.8	27
BRD-2 grid size 6.4 cm x 30.5 cm								
Pacific Halibut	35.8 (*-62.9)	51.3 (*-63.0)	66.8 (*-199.9)	30.9 (*-70.4)	0.99 (0.17-0.99)	0.0354	16.5	8
English Sole	39.8 (34.4-193.2)	45.8 (37.4-196.8)	49.9 (38.0-200.2)	10.0 (0.1-109.4)	0.82 (0.78-0.99)	0.6941	10.9	14
Rex Sole	48.7 (36.4-193.2)	73.2 (41.5-195.1)	97.7 (41.9-203.6)	49.1 (0.1-112.4)	0.99 (0.85-.099)	0.6961	17.3	21
Arrowtooth Flounder	48.0 (46.5-53.3)	60.4 (55.3-69.4)	72.8 (58.3-88.8)	24.8 (5.8-38.8)	0.99 (0.86-0.99)	0.0369	51.3	35
Dover Sole	48.5 (42.7-56.9)	68.2 (56.4-90.9)	88.0 (59.5-130.8)	39.5 (1.4-77.1)	0.99 (0.81-0.99)	0.0245	45.8	29
Petrale Sole	55.9 (46.3-101.3)	84.5 (51.1-157.6)	113.1 (52.1-189.4)	57.2 (0.1-106.6)	0.99 (0.84-.099)	0.3200	32.0	29

Table 5. Catch data by weight (kg) from the 30 tows conducted for Darkblotched Rockfish, Greenstriped Rockfish, Shortspine Thornyhead, Sablefish, and Lingcod. BRD-1 = grid size 6.4 cm x 25.4 cm; BRD-2 = grid size 6.4 cm x 30.5 cm; RN = recapture net; * = month/day/year.

			Darkblotchd Rockfish		Greenstriped Rockfish		Shortspine Thornyhead		Sablefish		Lingcod	
Tow	Date*	BRD-	RN	Codend	RN	Codend	RN	Codend	RN	Codend	RN	Codend
1	4/20/16	2	5.7	4.1	4.6	3.2	0.4	1.3	37.4	20.1	2.6	0
2	4/21/16	1	0.8	3.9	17.5	13.4	0	0	1.2	0	4.1	1.3
3	4/21/16	1	1.0	8.7	117.6	91.7	0	0	1.2	0	11.7	0
4	4/21/16	1	0	0.2	20.1	12.3	0	0	2.4	0.8	20.2	5.4
5	4/21/16	1	5.4	36.5	7.0	3.4	0	0	13.8	4.9	11.0	1.4
6	4/21/16	1	0	23.4	6.9	8.3	0	0	148.2	31.7	103.0	0
7	4/22/16	2	11.5	8.2	1.6	3.2	0	0.5	22.4	9.5	67.8	10.2
8	4/22/16	2	4.9	3.4	3.6	2.1	0	0	28.9	21.7	22.1	0
9	4/22/16	2	0	0	56.8	26.6	0	0	2.7	1.1	496.9	196.8
10	4/22/16	2	5.3	12.4	2.4	2.1	0	0.2	4.9	7.4	14.4	0
11	4/22/16	2	0.4	0.4	1.7	2.9	0	0	12.1	5.7	0	0.7
12	4/23/16	1	0	0	0	0	7.1	9.7	87.9	26.3	0	0
13	4/23/16	1	0	0	0	0	7.2	5.1	24.0	0	0	0
14	4/23/16	1	1.8	1.0	0.9	1.2	3.1	8.8	84.9	51.7	41.9	0
15	4/23/16	1	0	0	0	0.3	0	0	1.2	0	6.2	1.0
16	4/23/16	1	0	1.0	2.0	1.4	1.8	3.1	9.4	10.8	13.2	0
17	4/24/16	1	73.2	25.5	0	0	14.1	44.7	119.0	26.2	9.3	0
18	4/24/16	1	2.0	0	2.5	12.2	1.3	0.6	100.3	48.7	19.1	1.0
19	4/24/16	1	1.5	3.4	0.7	0.5	1.4	10.4	147.8	58.2	28.4	3.2
20	4/26/16	2	0	0	4.8	8.6	0	0	0	0	0	0
21	4/26/16	2	0.2	0.6	2.7	1.6	0	0	0	0.5	0	0
22	4/26/16	2	0	1.0	6.8	3.2	0	0	2.1	0.9	0	0
23	4/26/16	2	0.3	0.7	0.4	2.7	0	0	11.3	5.6	1.2	0
24	4/26/16	2	0	0	2.2	6.8	0	0	13.6	11.6	10.1	2.1
25	4/27/16	2	1.2	0.2	0.6	0.2	2	4.3	22.0	4.5	2.7	0
26	4/27/16	2	281.6	36.5	0	0	4.9	13.2	62.7	3.6	0	0
27	4/27/16	2	0	0	0	0	20.2	11.7	21.1	2.4	0	0
28	4/27/16	2	0	0	0	7.4	0	0	12.6	6.2	32.9	3.7
29	4/28/16	1	0.5	2.3	13.0	22.7	0	0	1.4	0	11.7	0
30	4/28/16	1	0	0	2.0	2.8	0	0	0	0	2.1	0
Total – BRD-1			86.2	105.9	190.2	170.2	36.0	82.4	742.7	259.3	281.9	13.3
Codend retention			55.1%		47.2 %		69.6%		25.9%		4.5%	
Total – BRD-2			311.1	67.5	88.2	70.6	27.5	31.2	253.8	100.8	650.7	213.5
Codend retention			17.8%		44.4%		53.2%		28.4%		24.7%	

Table 6. *Clogit* model mean selectivity results for roundfishes for the two BRD designs tested. Values in parentheses are Efron percentile bootstrap 95% confidence limits. *df* = degrees of freedom; * = value not defined.

Species	$L25_{grid}$	$L50_{grid}$	$L75_{grid}$	SR_{grid}	C_{grid}	p-value	Deviance	*df*
BRD-1 grid size 6.4 cm x 25.4 cm								
Darkblotched Rockfish	26.9 (23.3-32.8)	29.9 (27.6-32.8)	32.3 (28.1-34.6)	5.4 (0.1-8.9)	0.87 (0.80-0.99)	0.6009	16.8	19
Greenstriped Rockfish	27.2 (25.5-28.8)	29.9 (28.9-31.3)	32.2 (31.4-33.9)	5.1 (3.9-7.2)	0.89 (0.81-0.99)	0.5104	16.2	17
Shortspine Thornyhead	30.4 (23.4-34.2)	33.5 (31.4-38.5)	36.4 (33.6-39.6)	6.0 (0.1-10.8)	0.95 (0.76-0.99)	0.6511	19.9	23
Sablefish	38.0 (*-41.0)	44.6 (41.3-46.1)	51.3 (49.4-53.8)	13.3 (*-21.6)	0.99 (0.54-0.99)	0.6990	30.2	35
Lingcod	33.6 (*-49.9)	42.2 (*-51.5)	50.7 (*-61.9)	17.2 (*-35.4)	0.99 (0.91-.099)	0.6117	33.0	36
BRD-2 grid size 6.4 cm x 30.5 cm								
Darkblotched Rockfish	21.5 (*-28.4)	27.6 (25.7-31.3)	31.7 (29.5-33.2)	10.2 (*-14.6)	0.82 (0.56-0.99)	0.9782	11.4	23
Greenstriped Rockfish	26.9 (23.7-28.9)	30.2 (29.1-32.1)	33.5 (31.7-35.4)	6.6 (3.3-9.0)	0.99 (0.79-0.99)	0.6957	11.8	15
Shortspine Thornyhead	26.6 (*-33.9)	31.4 (29.8-37.1)	34.7 (32.3-48.1)	8.1 (*-19.6)	0.83 (0.74-0.99)	0.9953	8.0	21
Sablefish	* (*-41.7)	45.5 (*-48.0)	51.5 (49.7-55.5)	* (*-17.8)	0.71 (0.36-0.99)	0.9771	16.6	30
Lingcod	33.0 (*-46.2)	44.4 (*-54.7)	55.9 (54.3-82.5)	23.0 (*-51.8)	0.99 (0.26-0.99)	0.0032	66.0	38

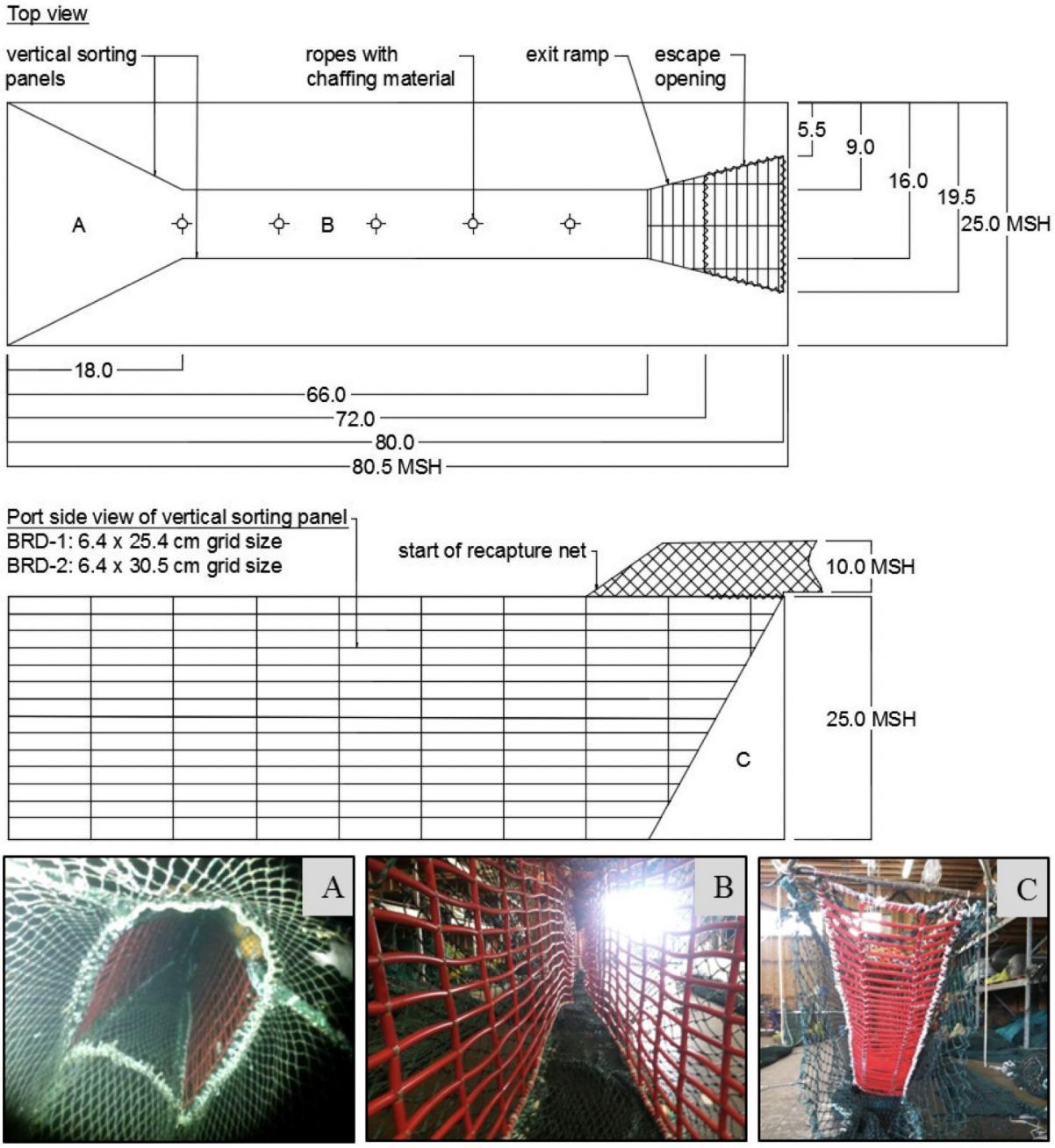

Figure 1. Schematic diagram (not to scale) of the flexible sorting grid general design tested (top). The only design difference between BRD-1 and -2 are the grid sizes. Aft view of the forward portion of the gear where fish enter and encounter the BRD (image A); aft view of the area between the two vertical sorting panels (image B); fore view of the upward-angled exit ramp (image C). MSH = meshes.

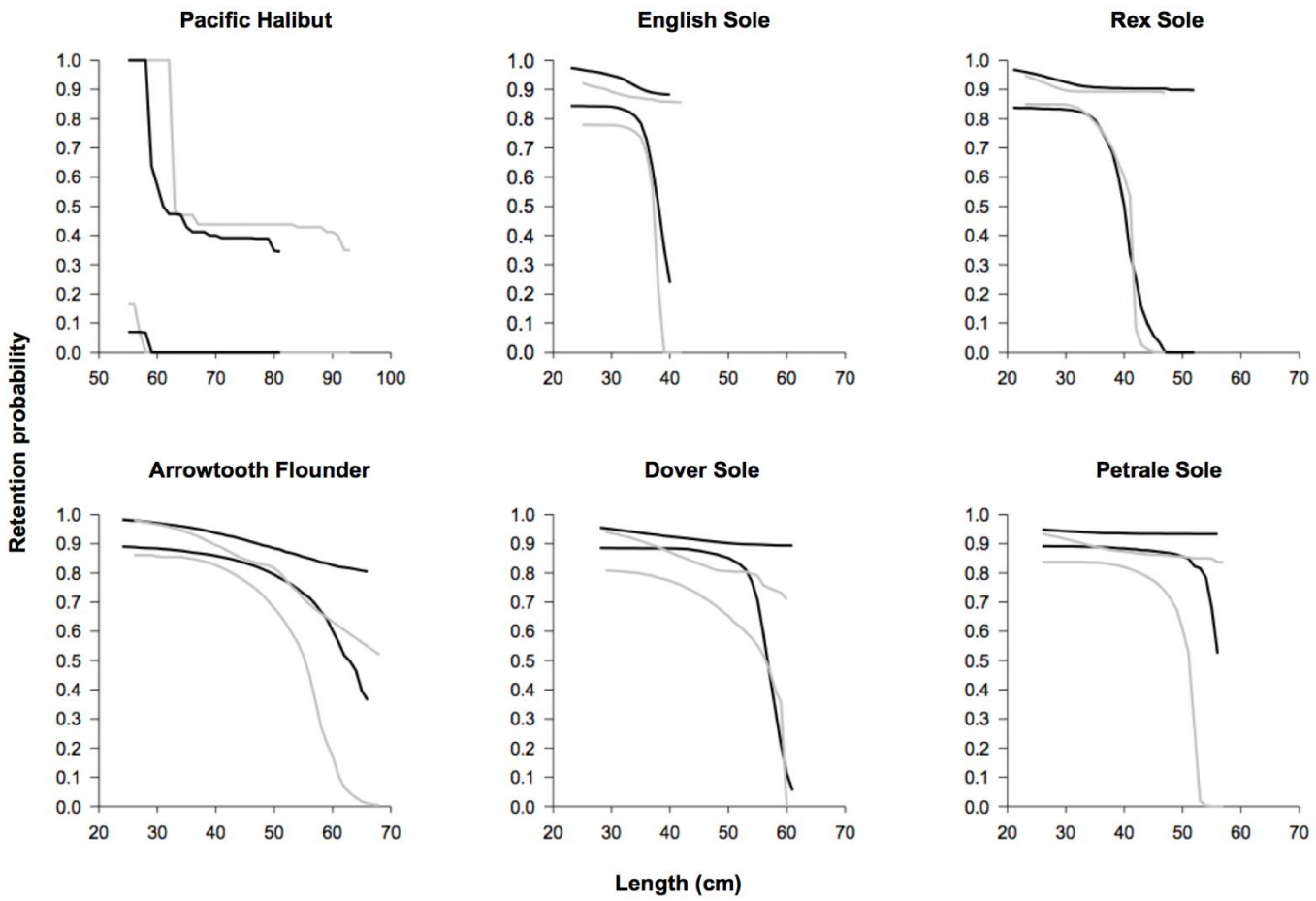

Figure 2. Comparison of the 95% confidence interval limits for the size-selection curves estimated for the six flatfishes evaluated for the two BRD designs. Solid black lines represent BRD-1 (6.4 cm x 25.4 cm grid size); solid grey lines represent BRD-2 (6.4 cm x 30.5 cm grid size).

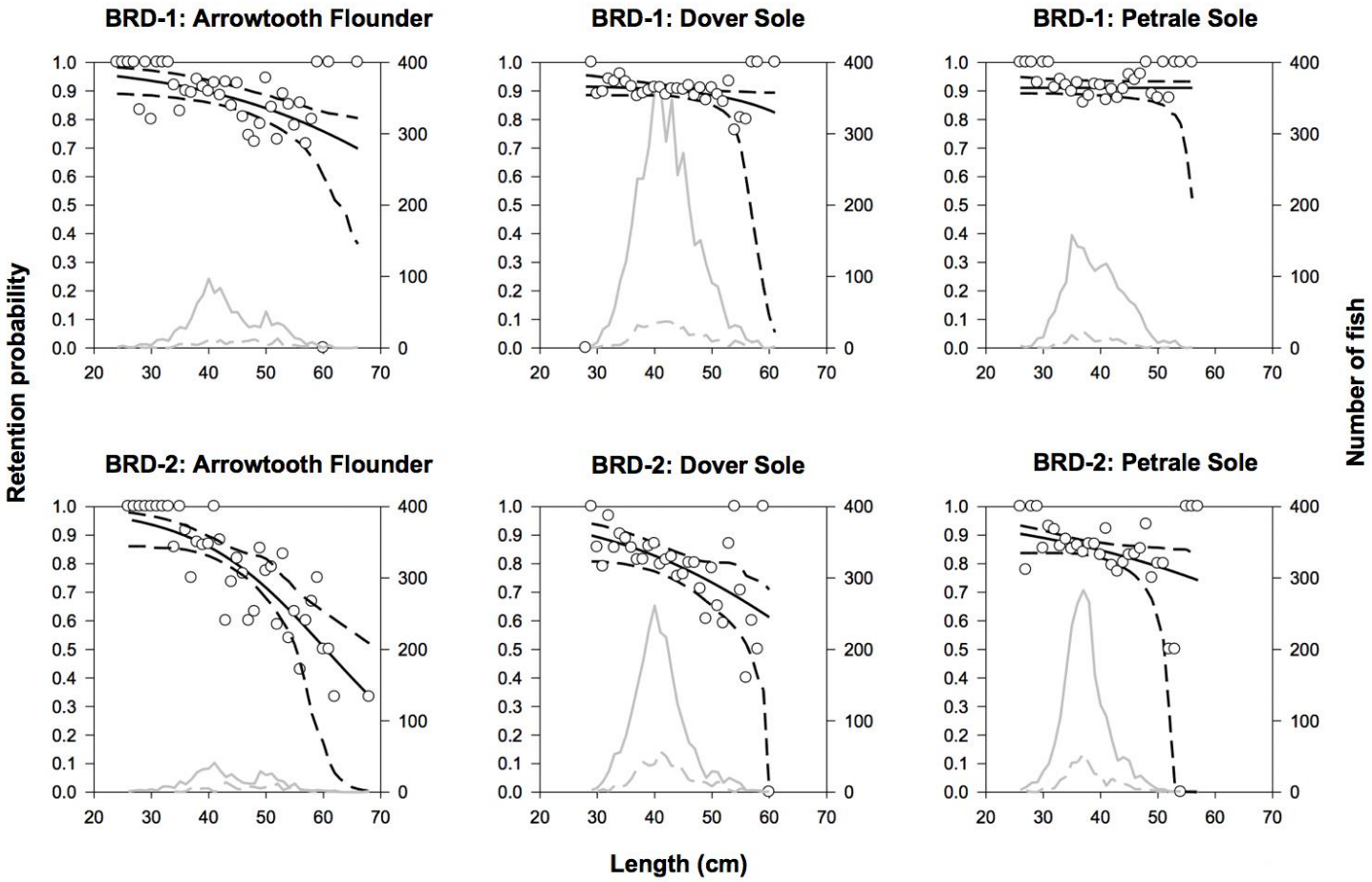

Figure 3. Mean selectivity curves modeled for Arrowtooth Flounder, Dover Sole, and Petrale Sole for BRD-1 and -2. Black solid lines are the modeled value; black dashed lines are the 95% confidence interval limits; open circles are the experimental data; grey solid lines are the number of fish caught in the trawl cod end; grey dashed lines are the number of fish caught in the recapture net.

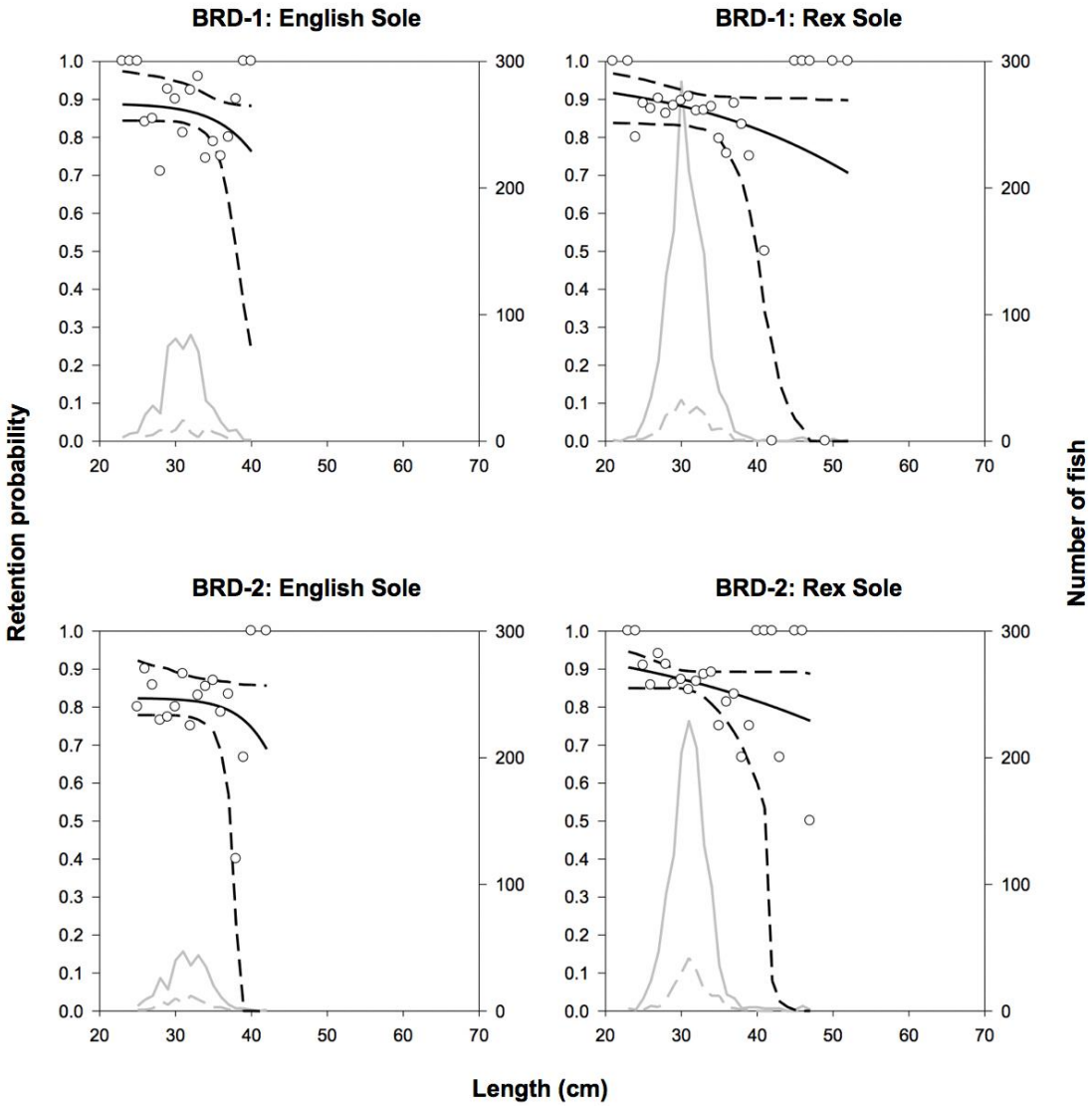

Figure 4. Mean selectivity curves modeled for English Sole, and Rex Sole for BRD-1 and -2. Black solid lines are the modeled value; black dashed lines are the 95% confidence interval limits; open circles are the experimental data; grey solid lines are the number of fish caught in the trawl cod end; grey dashed lines are the number of fish caught in the recapture net.

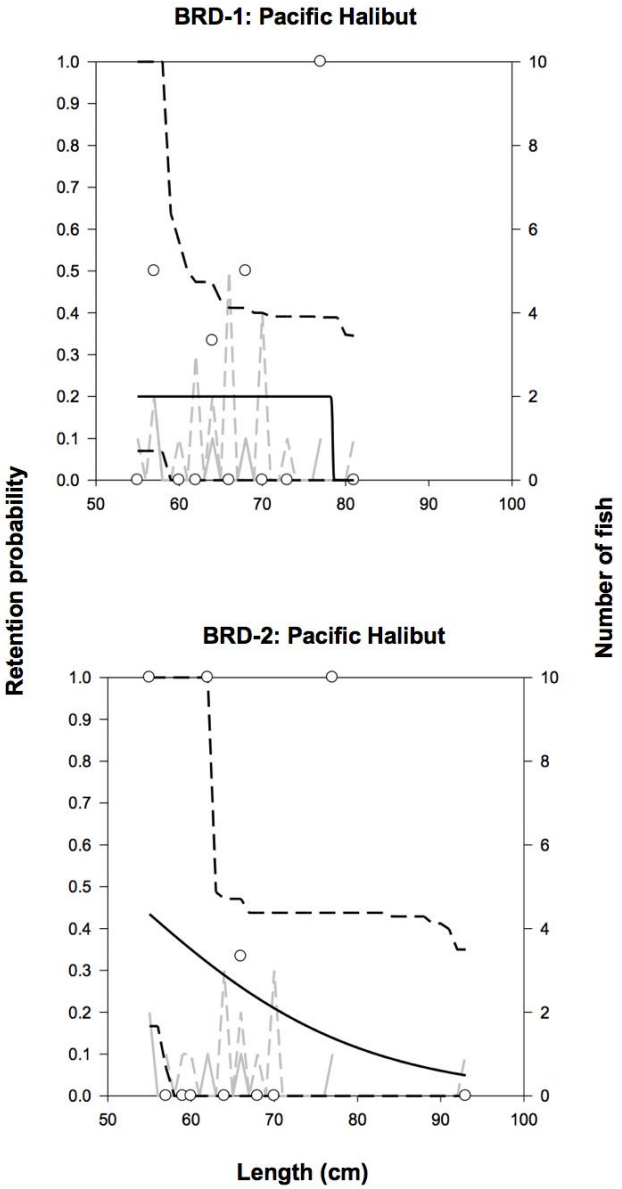

Figure 5. Mean selectivity curves modeled for Pacific Halibut for BRD-1 and -2. Black solid lines are the modeled value; black dashed lines are the 95% confidence interval limits; open circles are the experimental data; grey solid lines are the number of fish caught in the trawl cod end; grey dashed lines are the number of fish caught in the recapture net.

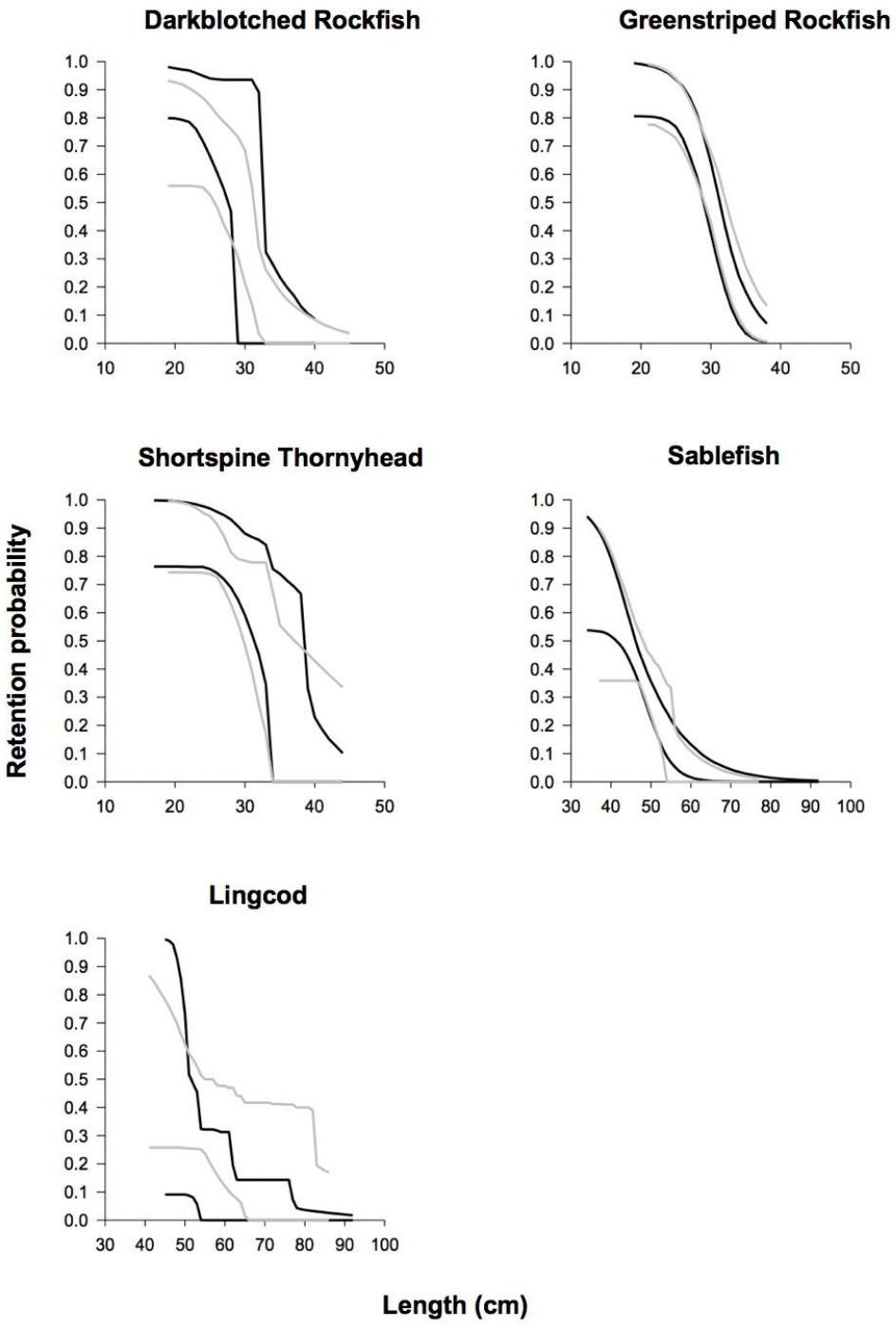

Figure 6. Comparison of the 95% confidence interval limits for the size-selection curves estimated for the five roundfishes evaluated for the two BRD designs. Solid black lines represent BRD-1 (6.4 cm x 25.4 cm grid size); solid grey lines represent BRD-2 (6.4 cm X 30.5 cm grid size).

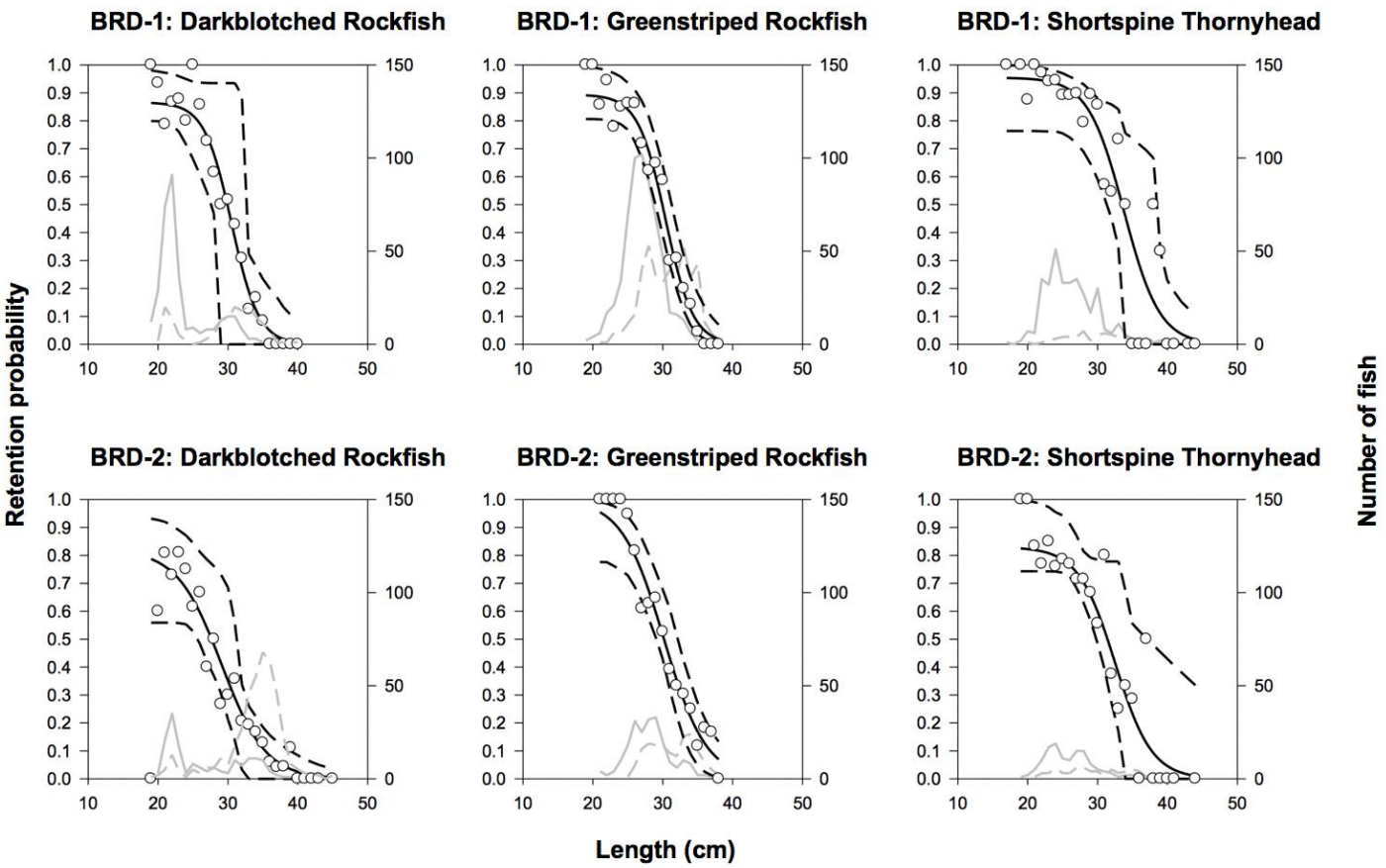

Figure 7. Mean selectivity curves modeled for Darkblotched Rockfish, Greenstriped Rockfish, and Shortspine Thornyhead for BRD-1 and -2. Black solid lines are the modeled value; black dashed lines are the 95% confidence interval limits; open circles are the experimental data; grey solid lines are the number of fish caught in the trawl cod end; grey dashed lines are the number of fish caught in the recapture net.

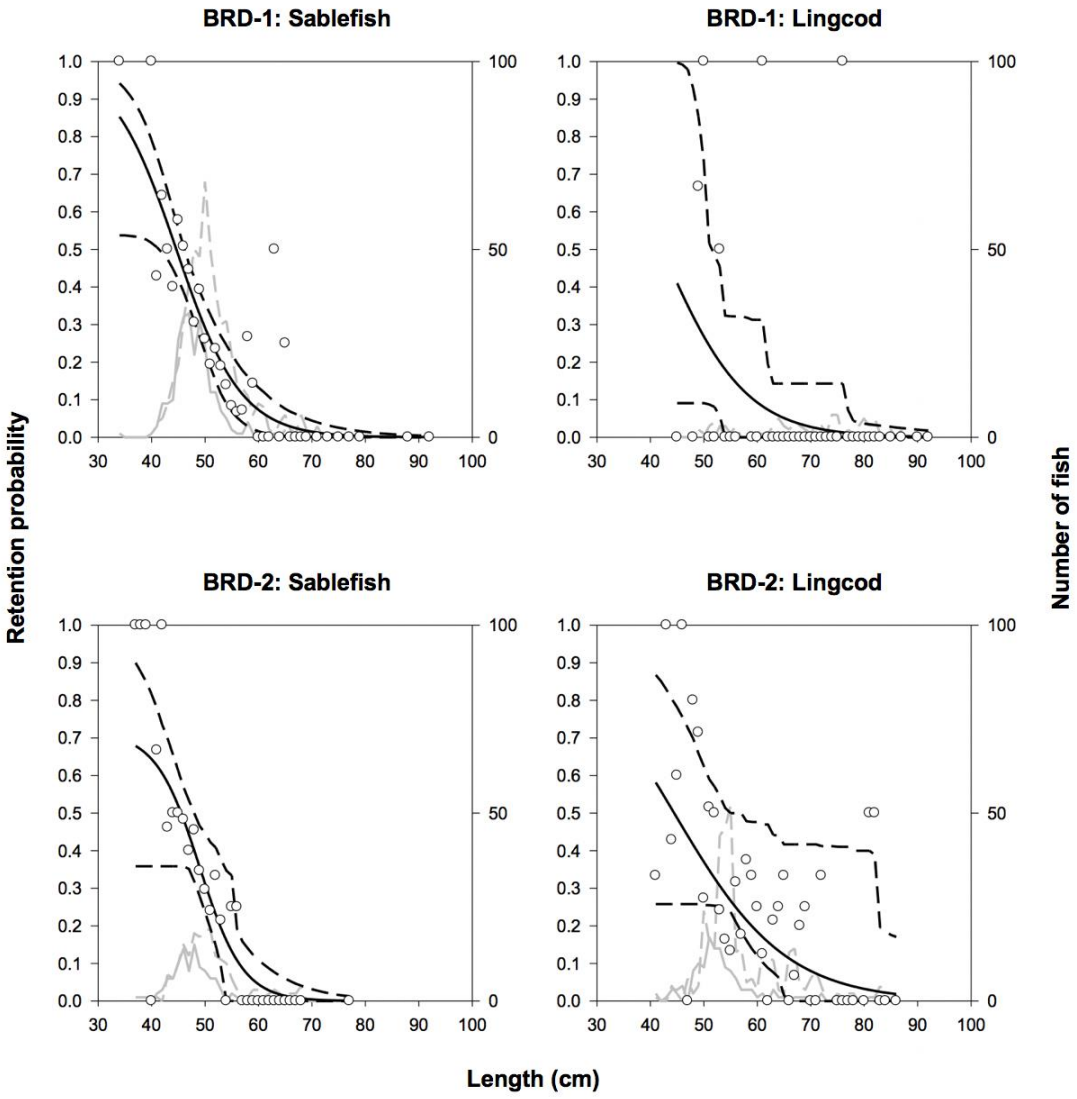

Figure 8. Mean selectivity curves modeled for Sablefish, and Lingcod for BRD-1 and -2. Black solid lines are the modeled value; black dashed lines are the 95% confidence interval limits; open circles are the experimental data; grey solid lines are the number of fish caught in the trawl cod end; grey dashed lines are the number of fish caught in the recapture net.