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Abstract

In 2011, the U.S. west coast limited entry groundfish trawl fishery started to be managed under a catch share program. This program established annual catch limits and individual fishing quotas along with individual bycatch quotas (IBQs) for prohibited species. For many fishermen participating in the bottom trawl component of this fishery, a major bycatch species of concern is Pacific halibut because limited IBQ is available. Individual fishermen could reach their Pacific halibut IBQ before reaching their catch share quotas, thereby ending their fishing season or forcing them to purchase limited and expensive quota. In this study, we tested an industry-designed flexible sorting grid bycatch reduction device (BRD) that many fishermen felt showed promise in reducing Pacific halibut bycatch, while maintaining catch levels for several target species. Fish retention and escapement was quantified using a recapture net. Pacific halibut bycatch was reduced 83.7% by weight and 74.3% by numbers. Exclusion was highest for Pacific halibut longer than 80 cm. Retention of marketable-sized arrowtooth flounder, Dover sole, and petrale sole was 93.3%, 99.0%, and 96.9%, respectively. The percentage retained of marketable-sized shortspine thornyhead, and sablefish was 96.9% and 90.0%, respectively. Sablefish longer than 79 cm were caught in the recapture net in a higher proportion than in the trawl and accounted for nearly 50% of the 10.0% loss observed. Results demonstrated the capability of a flexible sorting grid BRD to reduce Pacific halibut bycatch, while maintaining catch levels for several target species. The scientific evaluation of this BRD will provide valuable information to the fishing industry and management.

1. Introduction

The U.S. west coast limited entry (LE) groundfish bottom trawl fishery ranges from southern California to northern Washington and seaward to depths up to 1,280 m. Along the shelf break of the outer continental shelf (250-500 m) generally larger vessels target primarily shortspine thornyhead (*Sebastolobus alascanus*), longspine thornyhead (*Sebastolobus altivelis*), sablefish (*Anoplopoma fimbria*), and Dover sole (*Microstomus pacificus*), whereas typically smaller vessels operate over the continental shelf and target a variety of flatfishes, rockfishes (*Sebastes* spp.), roundfishes, and skates (Rajidae).

In 2011, the west coast LE groundfish trawl fishery started to be managed under a catch share program (PFMC and NMFS, 2010). This program established annual catch limits (ACLs) and individual fishing quotas (allocated by weight) along with individual bycatch quotas (IBQs) for prohibited species. For many fishermen participating in the bottom trawl component of this fishery, a major bycatch species of concern is Pacific halibut (*Hippoglossus stenolepis*), because limited IBQ is available. Individual fishermen could reach their Pacific halibut IBQ before reaching their groundfish catch share quotas, thereby ending their fishing season with allowable harvest still left in the ocean unless additional Pacific halibut bycatch quota can be leased or purchased from another quota share/permit holder. Acquiring additional quota, however, can be costly and/or difficult to obtain given certain circumstances (i.e. amount of quota needed, time of year). This scenario did occur both in 2011 and 2012. Reducing Pacific halibut bycatch would allow fishermen to more effectively utilize their catch share quotas and increase their net economic benefits. Under mandate of the International Pacific Halibut Commission (IPHC) trawl-caught Pacific halibut must be discarded at sea. Prior to the catch share program fishermen were not held individually accountable for discarding Pacific halibut. The implementation of a catch share program has created increased demand among fishermen to reduce bycatch and improve trawl selectivity. Since 2011, many fishermen have begun using BRDs to improve trawl selectivity; however, limited scientific evaluation of the devices being used is available to industry or management.

Depending on fish behavior, sorting grids can be effective at reducing bycatch in trawl fisheries when morphological differences occur between the target and bycatch species (Hannah et al., 2011; Lomeli and Wakefield, 2013ab, 2014; Rose and Gauvin, 2000). In the west coast LE groundfish bottom trawl fishery, the majority of Pacific halibut caught are greater than 65 cm in length (Jannot et al., 2011; Wallace and Hastie, 2009) and larger in size than the primary target species (Hannah et al., 2005; King et al., 2004; Lomeli and Wakefield, 2013a, 2014). While studies examining sorting grids have often found the most successful results when rigid grids are used (Broadhurst and Kenney, 1996; Broadhurst et al., 1997; Hannah and Jones, 2003), rigid grids are known to provide handling difficulties on vessels with restricted deck space or that use net drums for setting and hauling. Because most vessels in the west coast LE groundfish bottom trawl fishery are less than 26 m in overall length, have limited deck space, and use net drums the

use of flexible sorting grids are more acceptable in this fishery. This study tested an industry-designed flexible sorting grid to reduce Pacific halibut bycatch and evaluated its efficacy in the U.S. west coast LE groundfish bottom trawl fishery.

2. Materials and methods

For this project, the chartered *F/V Miss Sue* provided a four-seam Aberdeen trawl; a typical design used in the west coast groundfish fishery. The headrope was 26.8 m in length and utilized 27.9-cm deep-water floats for lift. The footrope length (section attached to the trawl) was 20.7 m and covered with rubber disks 15.2 cm in diameter with 40.6 cm rockhopper discs placed approximately every 61.0 cm over this distance. The port and starboard footrope extensions were each 6.1 m in length and covered with 15.2-cm rubber discs. The *F/V Miss Sue* is a 24.7m long, 640 horsepower trawler out of Newport, Oregon, USA.

The BRD examined in this study was developed by the fishing industry in 2011 and is one of a number of BRDs being used to address Pacific halibut bycatch in the U.S. west coast LE groundfish bottom trawl fishery. The BRD was constructed within a four-seam tube of netting that was 50 meshes deep (fore to aft) by 88 meshes in circumference (22 meshes per seam), excluding meshes in each selvedge (Table 1, Fig. 1). The BRD was designed to be inserted between the intermediate section of a bottom trawl and the codend. The design utilizes an oblique sorting panel (grid) that tapers downward (1-mesh, 3-bar taper) over the distance of 12 meshes deep to connect to a horizontal sorting panel that crowds fish and directs large fish towards an escape opening out the bottom of the trawl (Fig. 1). The sorting panels of this design are rectangular openings 14.0 x 15.2 cm (width x height) in dimension. The panels were built of 9.5 mm diameter Spectra® line placed through 15.5 mm inside diameter (21.3 mm outside diameter) PVC schedule 40 pipe to create a semi-rigid grid system. The concept of this design is that fish smaller than the panel openings can pass through and move aft towards the codend, whereas fish larger than the panel openings will be excluded. Fish that do not pass through the panel openings are released out the bottom of the trawl through a four-seam "escape" tube of netting that is 12 meshes deep by 70 meshes in circumference, excluding meshes in each selvedge. Where fish transition from the BRD to the escape tube of netting, they pass through an

opening that is 0.5 meshes deep by 22 meshes long. Foulweather Trawl, LLC, manufactured the BRD examined in this study.

To prevent large debris (i.e. rocks, logs, crab pots, fish traps, etc.) from contacting the BRD and potentially clogging or damaging the device, a "debris panel" built of diamond netting (40.6 cm between-knots, single 5 mm twine) that was 5 meshes deep by 5 meshes long was rotated into a square mesh configuration and inserted forward of the BRD. The debris panel was laced to the trawl in a downward angle (all bar taper) along the lower seven meshes of the trawl side panels and across the entire bottom panel (Fig. 1). To access debris caught by the panel a zipper line running port to starboard along the bottom of the trawl was placed just forward of where the panel attached to the bottom of the trawl.

A recapture net was used to quantify fish escapement and retention. The recapture net was a four-seam tube of netting that was 50 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. The recapture net was attached to the "escape" tube of netting to capture fish excluded from the trawl.

A total of 23 tows were completed off central Oregon between 44°20′ and 45°02′N and between 124°53′ and 125°20′W during June 2013. Towing primarily occurred over the upper continental slope between 191 and 440 m. Average bottom fishing depth was 301 m. Towing speed ranged from 2.2 to 2.6 knots. To avoid large catches that could not be completely sampled or that might limit the numbers of tows to be conducted during the project, tow durations were set to 45 min.

After each tow, all fish caught in the trawl and recapture net were identified to species and weighed using a motion compensating platform scale. Calibration of the scale occurred before each tow. To examine size selectivity, subsamples of commercial importance species were randomly selected for individual measurements. Up to 100 fish per the trawl and recapture net were selected per tow and measured to the nearest cm fork length. All Pacific halibut caught were weighed, measured, and assigned to a viability category (excellent, poor, or dead) following Williams and Chen (2004) and the West Coast Groundfish Observer Program protocol (NWFSC, 2010). The IPHC has estimated mortality rates for trawl-caught Pacific halibut

discarded at sea in excellent, poor, and dead condition at 20%, 55%, and 90%, respectively (Clark et al. 1992; Hoag, 1975).

Percent retention by weight (trawl / (trawl + recapture net)) in kg was calculated for all species. To determine if mean lengths differed significantly between fish caught in the recapture net and trawl, we used either an equal variance two-sample t-test, Mann-Whitney U test, or a Kolmogorov-Smirnov test depending on the variance and normality test results for the species being analyzed. A JT Electric Ltd. Lowlux camera system equipped with a black and white video camera and LED light was used on tows 10 and 12 to gather information on fish behavior and confirm that the BRD was configured correctly.

3. Results

Catch per tow ranged from 120 to 3,270 kg for the trawl codend and 11 to 392 kg for the recapture net. Shortspine thornyhead, sablefish, arrowtooth flounder (*Atheresthes stomias*), and Dover sole comprised 77% of the total catch composition. The remaining 23% of the catch consisted of 31 species and included marketable species (such as rockfishes, lingcod [*Ophiodon elongatus*], rex sole [*Glyptocephalus zachirus*], petrale sole [*Eopsetta jordani*], and skates), juvenile and unmarketable-sized groundfishes, non-commercial species, and Pacific halibut bycatch.

Bycatch of Pacific halibut was reduced 83.7% by weight (74.3% by numbers) while retaining 93.5% of the marketable-sized flatfishes and roundfishes targeted (Table 2). Retention of marketable-sized arrowtooth flounder, Dover sole, and petrale sole was 93.3%, 99.0%, and 96.9%, respectively. The percentage retained of marketable-sized shortspine thornyhead, and sablefish was 96.9% and 90.0%, respectively. Sablefish larger than 79 cm were caught in the recapture net in a higher proportion than in the trawl and accounted for nearly 50% of the 10.0% total loss observed (Fig. 2). Big skate and longnose skate, secondary target species, were retained in low numbers. Total catch and retention rates of Pacific halibut and target species are summarized in Table 3.

Pacific halibut encountered during this study ranged from 2.75 to 32.5 kg (mean 8.31 kg, SE ±0.6 kg) in weight and 64 to 141 cm (mean 87 cm, SE ±1.6 cm) in length. Exclusion was highest

for Pacific halibut longer than 80 cm. Of the fish encountered over 80 cm, 87.2% were caught in the recapture net, whereas only 47.8% of the fish less than 80 cm were caught in the recapture net. Pacific halibut over 89 cm (27 fish) were caught exclusively in the recapture net (Fig. 3).

With the exception of one fish, all Pacific halibut caught in the recapture net were assigned to the viability category "excellent" (Table 4). For Pacific halibut caught in the trawl, the majority of fish were categorized as "excellent" with only a few fish being categorized as "poor" or "dead". One Pacific halibut (73 cm, 6.5 kg) was caught wedged in a sorting grid opening of the BRD. This was the only incident observed. Although viability was only assessed for Pacific halibut, most fish caught in the recapture net (with the exception of rockfishes, which suffered from barotrauma) appeared lively and in good condition when brought on deck.

A difference in the mean length between Pacific halibut caught in the trawl and the recapture net was found with significantly ($P<0.0001$) larger-sized fish occurring in the recapture net (Table 5). This result was also found for sablefish ($P<0.0001$). The mean length difference for Pacific halibut and sablefish caught between the trawl and recapture net was 14 cm and 16 cm, respectively. Though significant in value ($P<0.05$), no meaningful differences in mean length were shown for shortspine thornyhead, rougheye rockfish (*S. aleutianus*), or arrowtooth flounder between retained and excluded individuals.

The debris panel positioned forward of the BRD was effective at preventing debris from contacting the excluder. This panel caught debris on six of the 23 tows conducted and included small logs, a television set, a hagfish (*Eptatretus* spp.) pot, and a sablefish fish trap. Occasionally this panel would retain a skate.

On the two tows that the video camera system was used, viewable footage was only obtained during gear deployment and haulback because light attenuation from the mud cloud created by the trawl gear during the tow process prevented the camera system from being able to produce a useable image. While the video confirmed that the BRD was configured correctly, information on fish behavior in response to the BRD was not obtained. These tows were not excluded from the analysis as they did not appear to differ from the other tows conducted (Table 2).

4. Discussion

Reducing Pacific halibut bycatch and providing opportunities to fully utilize catch share quota of healthier fish stocks are increasingly important to fishermen and the west coast groundfish trawl catch share program. In the present study an industry-designed BRD was tested and shown to be effective at reducing the bycatch of larger-sized Pacific halibut while maintaining catch levels for several targeted flatfish and roundfish species. Prior to this research, fishermen and manufacturers of fishing gear were skeptical on the BRD's ability to reduce Pacific halibut bycatch while maintaining catch levels. The scientific evaluation of this BRD will provide valuable information to the fishing industry and management.

The majority of Pacific halibut incidentally caught in the U.S. west coast LE groundfish bottom trawl fishery occurs between 65 and 95 cm in length (Jannot et al., 2011; Wallace and Hastie, 2009). In the current study, a noticeable difference in the BRD performance was noted across this size range with the gear selecting towards larger-sized Pacific halibut (>80 cm). For Pacific halibut between 65 and 80 cm a 45.5% reduction (by weight) in bycatch was observed, whereas fish between 80 and 95 cm, an 82.9% reduction occurred. In prior work by Lomeli and Wakefield (2013), where a flexible sorting grid with 19.1 x 19.1 cm square openings was examined (a design originally developed by industry for use off Alaska), their results were similar with 55.4% and 86.6% of the Pacific halibut encountered being excluded between the size range of 65 and 80 cm, and 80 and 95 cm, respectively. Though it may not be as advantageous to conservation, developing techniques that significantly reduce the incidental catch of larger-sized Pacific halibut while maintaining catch levels of target species is important to industry in a fishery where management allocates IBQ by weight rather than numbers of fish.

Mortality rates for trawl-caught Pacific halibut discarded at sea have been estimated (Clark et al., 1992; Hoag, 1975; Williams and Chen, 2004). However, information is lacking on the condition of Pacific halibut that escape out BRDs and are not observed in the catch. In the present study, Pacific halibut excluded from the trawl were categorized as being in "excellent" viable condition, with the exception of one fish. Although Pacific halibut escaping out the BRD were recaptured, as opposed to being released during the tow process as would occur under a normal fishing operation, this work provides some insight on the potential effect the BRD may have on the condition of Pacific halibut that escape. Had trawling occurred over harder substrates, the camera

work may have provided further information on the behavior and condition of Pacific halibut interacting with the BRD. While this could provide data on potential short-term survival rates, research using holding cages (Suuronen et al., 1996) or tags (Hoag, 1975) could be used to monitor the longer-term survival rates of Pacific halibut excluded from trawls.

While skates are considered a secondary target species by most fishermen in this fishery, skate catches can contribute substantially to the ex-vessel value of a fishing trip as they draw approximately $0.88/kg (ex-vessel value when this project was conducted). In this study, the BRD was not effective at retaining skates. This result, however, was anticipated for skates of a marketable size (>3 kg) as only a small percentage pass through the sorting grids. To address this issue, some fishermen using this BRD place a large mesh skate recapture bag (38.1 to 45.7 cm knot to knot) over the escape hole to allow skates to be retained. While this technique improves the retaining of larger-sized skates it increases the likelihood of retaining large-sized Pacific halibut, which can significantly affect a fishermen's Pacific halibut IBQ. In 2013, this scenario was reported to occur (personally communicated to Lomeli and Wakefield by a regional commercial fisherman). Currently, fishermen and gear researchers are collaborating on developing alternative techniques to address this issue.

Sorting grids are effective at reducing bycatch in trawl fisheries. However, the effectiveness of this gear design is susceptible to clogging by debris, large fish (i.e. skates), or high fish volumes. In the present study, the debris panel (positioned forward of the BRD) was effective at catching debris and likely contributed to the positive results noted for this BRD as 26% of the tows conducted encountered debris capable of clogging the excluder and affecting its sorting ability. The panel was not effective at retaining larger-sized skates, though its primary purpose was designed to catch debris. Extending the debris panel further up the side panels of trawl would likely increase skate retention if limiting skates from encountering the gear were an objective. However, this alteration may increase the probability of retaining larger-sized Pacific halibut.

In summary, this research examined an industry-designed BRD that demonstrated the ability to reduce Pacific halibut bycatch while maintaining catch levels for several target species. Because research has demonstrated that fish behavior and activity (Hart et al., 2010; Ressler et al., 2009; Ryer et al., 2010), and catchability can differ between day and night (Petrakis et al., 2001; Walsh

and Hickey, 1993), by depth (Casey and Myers, 1998; Hannah et al., 2005), and with differences in trawl design (Hannah et al., 2005; King et al., 2004), it is important that further testing occur over various fishing operations to better determine this gears effectiveness.

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

	Pacific halibut excluder	Recapture net	Trawl codend
Netting	Olivine DM 116 mm	Olivine DM 116 mm	Olivine DM 116 mm
Twine size	4 mm single (top and side panels); 5 mm dbl. (bottom panel)	6 mm dbl.	5 mm dbl.
Circumference (four-seam net)	88* (22/panel)	70* (25/top and bottom panels; 10/side panels)	100* (25/panel)
Meshes deep	50	50	75
Top riblines	32 mm Blue Steel™ Poly rope, hung at 6%	None, selvedges sufficed as riblines	32 mm Blue Steel™ Poly rope, hung at 6%
Bottom riblines	12.7 mm LL chain (grade 80), hung at 6%	None, selvedges sufficed as riblines	32 mm Blue Steel™ Poly rope, hung at 6%

Table 2. Percent retention of Pacific halibut and target species by total weight (kg) and total weigh of marketable-sized fish caught. Values in parentheses represent the number of Pacific halibut captured. Numbers were rounded for inclusion in the table.

	Total weight			Total weight of marketable-sized fish		
Species	recapture net	trawl	retention (%)	recapture net	trawl	retention (%)
			Flatfishes			
Pacific halibut	486.65 (52)	95.00 (18)	16.3 (25.7)	n/a*	n/a*	n/a*
Rex sole	14.95	405.85	96.4	7.48	251.16	97.1
Arrowtooth flounder	239.15	3,345.55	93.3	237.71	3,318.90	93.3
Dover sole	22.85	2,450.45	99.1	22.22	2,304.65	99.0
Petrale sole	12.90	419.50	96.9	11.73	365.34	96.9
			Rockfishes			
Rougheye rockfish	22.40	163.10	87.9	22.40	163.10	87.9
			Roundfishes			
Shortspine thornyhead	27.10	784.15	96.7	24.13	753.24	96.9
Sablefish	747.60	6,707.55	90.0	747.60	6,707.55	90.0
Lingcod	22.05	242.05	91.7	22.05	201.71	90.1
			Skates			
Big skate	134.30	0.00	0.00	134	0.00	0.00
Longnose skate	541.10	67.30	11.1	539.70	64.20	10.6

n/a* = prohibited species.

Table 3. Catch data by weight (kg) from the 23 tows conducted. # = numbers of Pacific halibut; TR = trawl; RN = recapture net; %R = percent retention.

	Pacific halibut (#)			Pacific halibut			Rex sole			Arrowtooth flounder			Dover sole			Petrale sole		
Tow	TR	RN	%R	TR	RN	%R	TR	RN	%R	TR	RN	%R	TR	RN	%R	TR	RN	%R
1	0	1	0.0	0	32.50	0.0	22.55	1.40	94.2	27.00	2.30	92.2	24.95	0	100.0	0	0	-
2	2	5	28.6	14.00	36.45	27.8	28.50	1.05	96.5	267.25	21.55	92.5	54.45	1.45	97.4	0	0	-
3	2	5	28.6	12.40	49.70	20.0	38.30	2.15	94.7	203.75	16.65	92.5	64.65	0.55	99.2	1.10	0	100.0
4	0	2	0.0	0	12.80	0.0	14.90	0.40	97.4	189.55	8.75	95.60	36.30	0.65	98.2	1.25	0	100.0
5	1	4	20.0	4.70	38.35	10.9	15.0	0.25	98.4	209.45	8.70	96.0	28.45	0	100.0	0	0	-
6	0	1	0.0	0	10.95	0.0	9.75	0	100.0	72.70	2.55	96.6	85.45	0.60	99.3	0	0	-
7	0	0	-	0	0	-	43.50	0	100.0	66.20	2.70	96.1	93.60	0.75	99.2	0	0	-
8	1	1	50.0	3.15	15.65	16.8	24.90	0.45	98.2	100.00	8.85	91.9	283.90	7.05	97.6	0	0	-
9	0	1	0.0	0	7.80	0.0	6.00	0	100.0	96.30	12.05	88.9	307.15	0.65	99.80	0	0	-
10	1	1	50.0	4.85	10.00	32.7	19.15	0.70	96.5	162.30	16.40	90.8	114.05	0.60	99.5	0.90	0	100.0
11	0	0	-	0	0	-	6.95	0.95	88.0	66.90	19.90	77.1	488.65	2.40	99.5	0	0	-
12	0	2	0.0	0	29.20	0.0	67.50	2.95	95.8	241.40	20.95	92.0	226.25	4.30	98.1	0	0	-
13	0	0	-	0	0	-	44.90	2.45	94.8	145.55	20.60	87.6	218.95	1.95	99.1	0	0	-
14	0	1	0.0	0	8.65	0.0	3.15	0	100.0	24.05	0	100.0	57.85	0	100.0	0	0	-
15	0	3	0.0	0	34.20	0.0	6.05	0.30	95.3	132.35	5.15	96.3	31.40	0	100.0	0	0	-
16	3	5	37.5	14.70	50.60	22.5	32.60	0.85	97.5	989.50	63.85	93.9	63.40	1.80	97.2	0	0	-
17	3	5	37.5	15.75	40.45	28.0	6.55	0.45	93.6	98.10	4.65	95.5	3.65	0	100.0	69.30	2.15	97.0
18	2	4	33.3	11.80	27.05	30.4	0.50	0.10	83.3	35.95	0.80	97.8	27.40	0	100.0	81.40	2.30	97.3
19	0	4	0.0	0	30.65	0.0	2.25	0	100.0	45.80	0.60	98.7	50.50	0	100.0	28.25	2.10	93.1
20	2	4	33.3	9.55	28.20	25.3	4.35	0.50	89.70	55.00	2.05	96.4	40.95	0	100.0	27.35	0	100.0
21	0	1	0.0	0	9.10	0.0	6.65	0	100.0	83.55	0.10	99.9	59.65	0.10	99.8	14.90	0	100.0
22	0	1	0.0	0	9.30	0.0	0.95	0	100.0	7.70	0	100.0	56.70	0	100.0	111.75	1.95	98.3
23	1	1	50.0	4.1	5.05	44.8	0.90	0	100.0	25.20	0	100.0	32.15	0	100.0	83.30	4.40	95.0
Total	18	52	25.7	95.00	486.65	16.3	405.85	14.95	96.4	3,345.55	239.15	93.3	2,450.45	22.85	99.1	419.50	12.90	97.0
Mean	0.78	2.26		4.13	21.16		17.65	0.65		145.46	10.40		106.54	0.99		18.24	0.56	
SE	0.22	0.38		1.20	3.35		3.70	.018		41.39	2.92		24.83	0.35		7.03	0.24	

Table 3. Continued.

	Shortspine thornyhead			Rougheye rockfish			Sablefish			Lingcod			Big skate			Longnose skate		
Tow	TR	RN	%R	TR	RN	%R	TR	RN	%R	TR	RN	%R	TR	RN	%R	TR	RN	%R
1	29.15	0.80	97.3	82.25	6.50	92.7	155.30	8.85	94.6	0	0	-	0	0	-	21.40	20.35	51.3
2	54.40	1.85	96.7	5.80	5.95	49.4	173.55	10.15	94.5	0	0	-	0	0	-	0	37.55	0.0
3	101.60	1.10	98.9	0	0	-	42.45	6.25	87.2	9.20	0	100.0	0	0	-	0	22.20	0.0
4	20.35	0.35	98.3	0	0	-	17.50	0	100.0	4.15	0	100.0	0	11.60	0.0	0	41.00	0.0
5	37.00	2.05	94.8	25.75	0	100.0	197.30	3.55	98.2	0	0	-	0	0	-	10.10	29.55	25.5
6	59.55	2.55	95.9	3.80	0	100.0	124.35	20.35	85.9	0	0	-	0	0	-	30.55	28.45	51.8
7	80.40	4.45	94.8	0	0	-	155.80	0	100.0	0	0	-	0	0	-	0	0	-
8	104.60	3.95	96.4	0	0	-	779.95	92.30	89.4	0	0	-	0	0	-	0	5.20	0.0
9	76.50	0.30	99.6	0	0	-	2,777.05	372.45	88.2	0	0	-	0	0	-	1.00	6.45	13.4
10	46.40	3.45	93.1	0	0	-	23.60	0	100.0	5.20	0	100.0	0	0	-	0	1.40	0.0
11	37.00	2.20	94.4	0	0	-	1,662.40	199.40	89.3	0	0	-	0	0	-	0.85	16.30	5.0
12	2.05	0	100.0	0	0	-	138.75	4.70	96.7	0	0	-	0	0	-	0	103.35	0.0
13	10.50	0	100.0	1.85	0	100.0	154.55	17.60	89.8	0	0	-	0	0	-	0	70.60	0.0
14	20.30	0.60	97.1	0	0	-	7.35	0	100.0	0	0	-	0	0	-	0	9.45	0.0
15	34.45	1.90	94.8	31.70	9.95	76.1	154.25	10.45	93.7	0	0	-	0	0	-	3.40	23.75	12.5
16	69.55	1.55	97.8	11.95	0	100.0	143.40	1.55	98.9	2.40	0	100.0	0	0	-	0	41.75	0.0
17	0	0	-	0	0	-	0	0	-	23.30	0	100.0	0	37.95	0.0	0	39.55	0.0
18	0	0	-	0	0	-	0	0	-	17.70	2.55	87.4	0	77.40	0.0	0	10.30	0.0
19	0	0	-	0	0	-	0	0	-	5.75	0	100.0	0	0	-	0	5.35	0.0
20	0	0	-	0	0	-	0	0	-	6.65	0	100.0	0	0	-	0	0	-
21	0.35	0	100.0	0	0	-	0	0	-	3.65	12.30	22.9	0	0	-	0	15.05	0.0
22	0	0	-	0	0	-	0	0	-	112.15	2.95	97.4	0	0	-	0	7.10	0.0
23	0	0	-	0	0	-	0	0	-	51.90	4.25	92.4	0	7.35	0.0	0	6.40	
Total	784.15	27.10	96.7	163.1	22.40	87.9	6,707.55	747.60	90.0	242.05	22.05	91.7	0	134.30	0.00	67.30	541.10	11.1
Mean	34.10	1.18		7.10	0.97		291.63	32.50		10.52	0.96		0	5.84		2.93	23.53	
SE	7.18	0.29		3.84	0.55		135.94	17.99		5.22	0.57		0	3.68		1.61	5.14	

Table 4. Viability category assigned to Pacific halibut caught between the trawl and recapture net.

	Viability category			% excellent condition
	excellent	poor	dead	
Trawl	13	1	4	72.2
Recapture net	51	0	1	98.0
Total	64	1	5	91.4

Table 5. Comparison of mean lengths (cm) between target species and Pacific halibut caught in the recapture net and the trawl. N_r = refers to the number of fish that were measured from the recapture net; N_t = refers to the number of fish that were measured from the trawl. $_1$ = equal variance two-sample t-test; $_2$ = Mann-Whitney U test; $_3$ = Kolmogorov-Smirnov test; N_r = refers to the number of fish that were measured from the recapture net; N_c = refers to the number of fish that were measured from the codend. * = subsample lengths taken from a larger species catch.

Species	Recapture net mean total length (SE)	N_r	Trawl mean total length (SE)	N_t	P-value
			Flatfishes		
Pacific halibut	90 (1.9)	52	76 (1.6)	18	$<0.0001_2$
Rex sole	31 (0.4)	67	32 (0.0)	976*	0.1760_2
Arrowtooth flounder	52 (0.7)	166	49 (0.2)	1,130*	$<0.0001_1$
Dover sole	40 (0.8)	36	40 (0.2)	1,042*	0.9978_2
Petrale sole	40 (2.1)	11	38 (0.2)	426*	0.3605_3
			Rockfishes		
Darkblotched rockfish	30 (-)	1	33 (0.3)	305	0.8758_3
Rougheye rockfish	57 (0.9)	7	50 (0.8)	69	0.0008_3
			Roundfishes		
Shortspine thornyhead	27 (0.8)	82	28 (0.2)	1,091*	$<0.0165_3$
Sablefish	77 (0.9)	133	61 (0.3)	807*	$<0.0001_2$
Lingcod	72 (0.7)	5	61 (0.8)	96*	0.3323_3

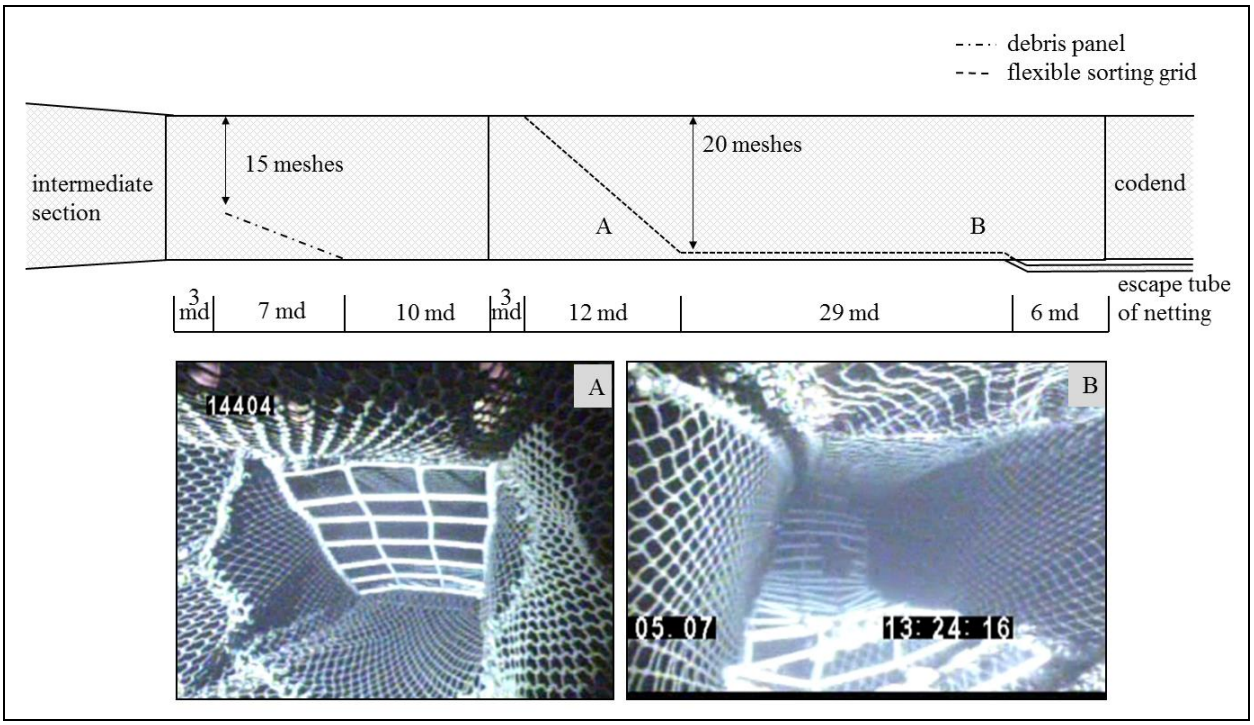

Figure 1. Top: schematic diagram of the debris panel and Pacific halibut flexible sorting grid bycatch reduction device (BRD) tested; bottom: aft view of the BRD showing the oblique sorting grid (image A); forward view of the BRD showing the oblique and horizontal sections of the sorting grid (image B). Note: images A and B are not from BRD tested in this study. These images were provided by a groundfish bottom trawl vessel examining the same BRD design examined in this work, but with a 25.4 x 25.4 cm grid size. The schematic diagram is not drawn to scale. md = meshes deep.

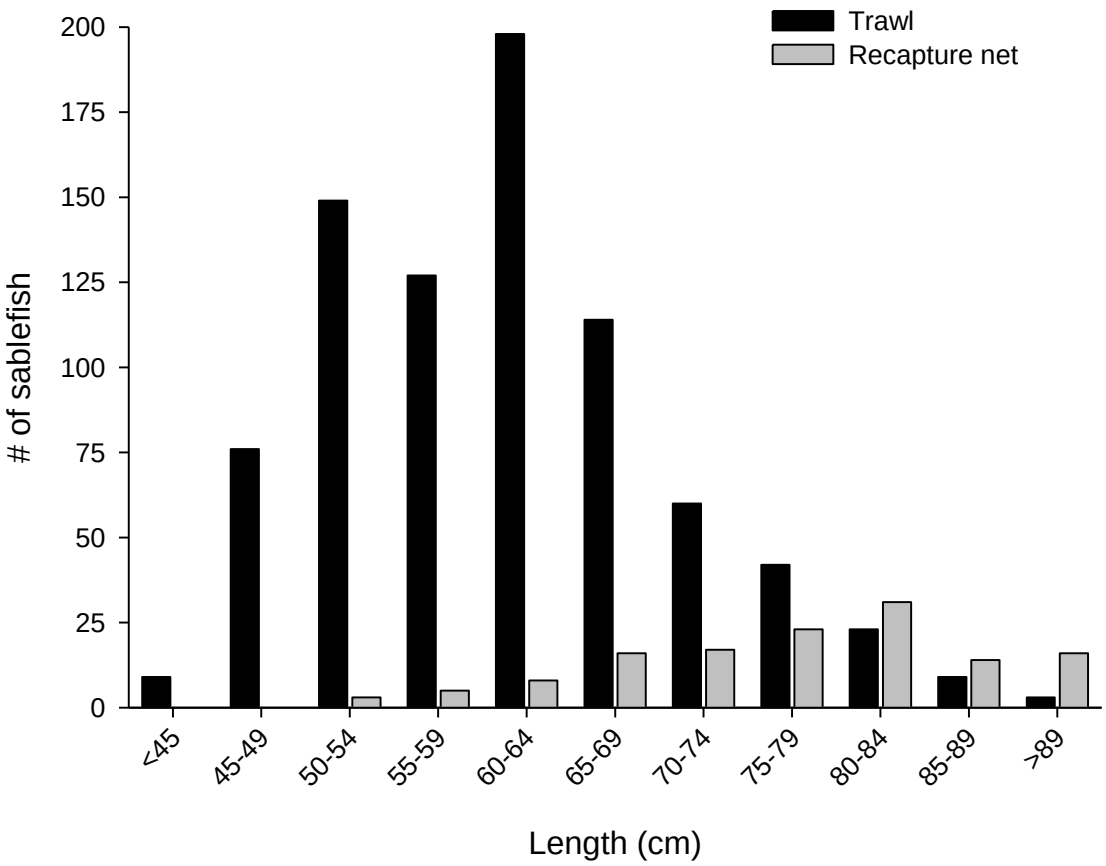

Figure 2. Comparison of sablefish caught between the trawl and recapture net by size class.

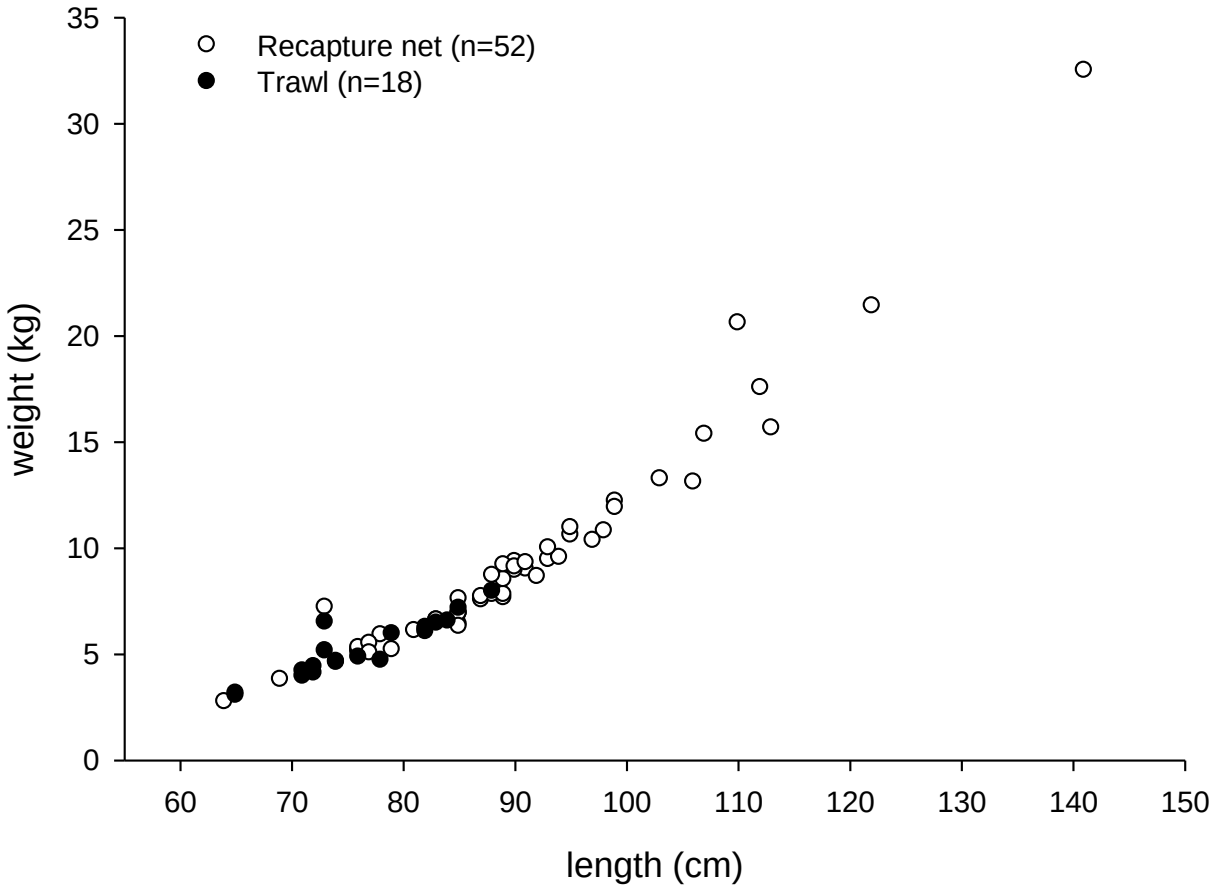

Figure 3. Length-weight scatter plot of Pacific halibut caught during this project.