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Abstract

This study examined two versions of a flexible sorting grid rockfish excluder in the U.S. Pacific hake fishery. The designs tested (design-A and design-B) were developed following a collaborative workshop held between gear researchers and Pacific hake fishing industry participants. Tests occurred off Oregon and Washington during 2012 aboard the *F/V Perseverance*. A recapture net was used to quantify the escapement of Pacific hake and non-target species. Both designs retained a relatively high proportion of Pacific hake (>93%). However, the two designs did not perform equally with design-B being much more effective at reducing bycatch. Results showed rockfish bycatch was reduced by 70.2% under design-B and only 15.4% under design-A. For both designs, the mean lengths of Pacific hake caught between the codend and the recapture net did not differ significantly. A reduction in the catch of Pacific halibut and Chinook salmon, which are prohibited take species, was also noted. Unfortunately, both designs tested were only effective under slow-to-moderate fish volumes. Under heavy fish volumes both designs tended to clog. Results of this research suggest there is potential for reducing rockfish bycatch in the Pacific hake fishery using a flexible sorting grid excluder.

Introduction

The Pacific hake fishery represents the largest groundfish fishery by volume off the U.S. west coast with landings exceeding 267,000 mt in some years (NOAA Fisheries Service-NWR 2008, PacFIN 2011). Pacific hake are caught using midwater trawls, by catcher boats delivering to shore-based processing plants and to at-sea mothership processors, and by large catcher-processor vessels. Spatially this fishery ranges from northern California to northern Washington and seaward to bottom depths exceeding 500 m. Although landed catches consist of mostly Pacific hake, bycatch is an issue affecting the fishery (PFMC and NMFS 2010, 2012).

Starting in 2011, the U.S. west coast groundfish trawl fishery began management under a catch share program (PFMC and NMFS 2010). The West Coast Groundfish Trawl Catch Share Program, or trawl rationalization, established annual catch limits and individual fishing quotas (IFQs) along with individual bycatch quotas (IBQs). For many Pacific hake fishermen participating in this program, bycatch of rockfishes is a concern because limited bycatch quota is available for selected species. Individual fishermen could reach a rockfish IBQ for a given rockfish before reaching their Pacific hake IFQ, thereby ending their fishing season. This scenario occurred in 2011 for some fishermen. Developing techniques that reduce rockfish bycatch while retaining a high proportion of targeted Pacific hake have become increasingly important.

Since 2009, the NMFS-Northwest Fisheries Science Center (NWFSC)-Habitat and Conservation Engineering (H&CE) group, Pacific States Marine Fisheries Commission (PSMFC), and fishing industry have collaborated on developing an open escape window bycatch reduction device (BRD) designed to reduce Chinook salmon bycatch in the Pacific hake fishery (BREP 2012, Lomeli and Wakefield 2012). While reducing Chinook salmon bycatch was the focus of research, valuable data on rockfish behavior and size, and escapement was also gained. Because the body size and shape of rockfishes (large, deep bodied, and fusiform shape) taken in the fishery typically differ from that of Pacific hake (small thin body, elongated shape) fishermen and gear researchers believe a sorting grid excluder can be effective at reducing rockfish bycatch while maintaining Pacific hake catch levels. In trawl fisheries around the world, sorting grid excluders have shown to be effective devices for reducing bycatch while maintaining target catches (Kvalsvik et al. 2002, Sistiaga et al. 2008, Chosid et al. 2012, Lomeli and Wakefield 2013). These findings suggest a sorting grid excluder could be effective at reducing rockfish bycatch in the Pacific hake fishery.

Although 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 their net. Because vessels in the Pacific hake fishery are typically less than 30 m in overall length and have limited deck space, and use net drums, the use of flexible sorting grids are more acceptable to the industry. The objective of this study was to design a flexible sorting grid rockfish excluder and evaluate its efficacy in the Pacific hake fishery.

Methods

Collaborative Workshop and Gear Design

On 03 May 2012 the NWFSC-H&CE group and PSMFC conducted a collaborative workshop to develop a rockfish excluder for testing in the Pacific hake fishery. A total of 29 attendees including vessel owners, captains and crewmen, seafood company operators, regional net manufacturers, and gear researchers participated. At the workshop, gear researchers and representatives from the fishing industry shared data and insights on the escapement and behavior of rockfishes and Pacific hake in relation to BRDs and trawl gear. After an exchange of information and considerable discussion, the group came to a consensus that a flexible sorting grid excluder showed merit for reducing rockfish bycatch. Following the workshop, the information exchanged was used to develop an excluder for testing.

The concept of the excluder design tested is that fish smaller than the sorting grid openings (i.e., Pacific hake) will pass through and be retained, whereas fish greater than the sorting grid openings (i.e., rockfishes) will be excluded. Fish that do not pass through the panel openings are guided by an upward-angled ramp and exit out the top of the trawl. Two versions of a flexible sorting grid BRD were examined in this study (designs A and B), where the differences between the two designs were the grid openings and the angle and distance between the vertical panels (Figure 1). The BRD was constructed within a four-seam tube of netting that was 200.5 meshes deep and 168 meshes in circumference, excluding meshes in each selvedge. The BRD was designed to be inserted between the intermediate section of the trawl and the packer/stuffing tube forward of the codend. The basic design utilizes two vertical panels (grids) and an upward-angled exit ramp that sort fish by size as they move aft towards the codend. The vertical panels were built of 3/8" [0.95 cm] Spectra® line (running vertically) and 5/16" [0.79 cm] (7 x 19 strand core) galvanized steel cable (running horizontally) placed through 1/2" [1.27 cm] (inside diameter) AQUAPEX® tubing to create a semi-rigid grid. The exit ramp was constructed of only Spectra® line placed through AQUAPEX® tubing. The vertical panels of both designs stand 48" [1.22 m] in height and extend longitudinally down the tube of netting 175 meshes deep before connecting to the exit ramp. Over this distance the two panels gradually angle inward then straighten to create a narrow "hallway" that extends aft (Figure 1). Within the "hallway" section of the excluder ropes with chaffing material wedged through them (Figure 2) were installed to stimulate fish to interact with the vertical panels by creating a partial obstruction to fish moving aft. These ropes were positioned vertically (attached to the bottom and top panel of the tube of netting) and placed every 15 meshes deep within the "hallway" section of the excluder.

The grid openings of design-A were 3.5 x 5.5" [8.89 x 13.97 cm] (H x L), whereas for design-B the grid openings were 3.0 x 3.5" [7.62 x 8.89 cm] (H x L). Testing was first conducted using design-A. However, after reviewing the rockfish escapement data from four trips/offloads, design-B was developed in an attempt to increase rockfish escapement. For the remainder of the study design-B was tested. Escapement of Pacific hake and non-target species was quantified using a recapture net. The excluder and recapture net used in this study was manufactured by Foulweather Trawl, LLC.

Sea Trials

A total of 18 valid tows were conducted off Oregon and Washington between 42°53′ and 47°59′N and between 124°22′ and 125°30′W during June and July 2012 aboard the chartered *F/V Perseverance* (Figure 3); a 26.5-m length overall, 1,000 horsepower midwater trawler. Tow speeds ranged from 3.0 to 3.4 knots with headrope fishing depths occurring primarily between 128 and 201 m (70 and 110 ftm).

Autonomous, high-resolution, low-light, color video camera systems were used throughout the study to gather information on fish behavior and gear performance (Figure 4). However, several tows occurred without the use of cameras and artificial lights to observe gear performance under "normal" fishing conditions. After each tow, all fish caught in the recapture net were dumped on deck and identified to species, measured (nearest cm fork length), and weighed (nearest kg) using a Marel M1100 platform scale. Fish retained in the codend were dumped into the vessel's fish holds then delivered to a shore-side processing plant where data on catch compositions, lengths, and weights were collected.

Percent escapement by weight (kg) of Pacific hake and bycatch was calculated using the following formula: (recapture net / (recapture net + codend)). To determine if mean fork lengths differed significantly between fish caught in the recapture net and codend, we used either an equal variance two-sample t-test, or a Mann-Whitney U test depending on the variance and normality test results for the species being analyzed. Total catch and catch rates of Pacific hake per tow were estimated using the logbook data. Refer to Appendix 1 for the scientific names of species mentioned in this report.

Results

Five rockfish species were noted to encounter both gear designs, with yellowtail rockfish being the dominant species (Table 1). Both designs retained a relatively high proportion of Pacific hake (> 93%). However, the two designs did not perform equally with design-B being much more effective at reducing bycatch (Figures 5 and 6). Results showed rockfish bycatch was reduced by 70.2% under design-B and only 15.4% under design-A (Table 1). Design-B was highly effective at reducing widow rockfish and rougheye rockfish bycatch, reducing their take by 82.5% and 95.3%, respectively. Interestingly, widow rockfish exhibited a 13% higher escapement rate than yellowtail rockfish, though being significantly smaller than yellowtail rockfish in length ($P<0.05$,

Table 2). Overall, rockfishes larger than 49 cm were primarily retained in the recapture net for both designs.

Relatively small Pacific hake were encountered during this study with mean forks lengths ranging from 36.4 to 40.0 cm, approximately 300 gram fish (Table 2). For both designs, the mean lengths of Pacific hake caught between the codend and the recapture net did not differ significantly (P>0.05, Table 3). Estimated total catch of Pacific hake per tow ranged from 8 to 84 mt for design-A and 16 to 52 mt for design-B. The estimated catch rate per tow ranged from 0.13 to 0.76 mt/min for design-A and 0.07 to 0.57 mt/min for design-B. Unfortunately, both designs tested were only effective under slow-to-moderate fish volumes. Under heavy fish volumes both designs tended to clog, resulting in the vessel having to haulback before completing its tow. Estimated catch rates when clogging occurred ranged from 1.22 to 1.24 mt/min.

Although a small sample size was caught, a reduction in the catch of Pacific halibut and Chinook salmon was noted. Here, design-B excluded both Pacific halibut encountered while design-A excluded 3 of the 5 (60.0%) Chinook salmon encountered (Table 1). While the catch ratio of Chinook salmon caught is typically <0.04 fish per metric ton of Pacific hake (Jesse 2008), there are concerns about bycatch because of the high volume of the fishery and the incidental capture of Endangered Species Act (ESA) listed Chinook salmon that occurs at times. Genetic samples were collected on all Chinook salmon caught during this study and provided to the Oregon State University-Hatfield Marine Science Center-Collaborative Research on Oregon Ocean Salmon (CROOS) program. This program analyzes DNA samples collected by commercial fishermen to gather information and insights on the fine-scale distribution of Chinook salmon in commercial ocean fisheries off the U.S. west coast. CROOS informed us that two of the Chinook salmon retained in the recapture net, were ESA listed species. One fish was identified with 100% probability as a California Coastal Evolutionarily Significant Unit (ESU) species, whereas the other was identified with 99.99% probability as a Lower Columbia River ESU species. No ESA salmon were caught in the codend.

To obtain a short video compilation of design-A and B please contact the project authors.

Discussion

Results from this pilot study suggest the potential for reducing rockfish bycatch in the Pacific hake fishery using a flexible sorting grid excluder. This design also shows promise at reducing the incidental catch of Chinook salmon and Pacific halibut, which are prohibited take species. Off the U.S. west coast this project is the first to test a flexible sorting grid and evaluate its effectiveness in a high volume midwater trawl fishery. While both designs tested retained a relatively high proportion of Pacific hake (> 93%), design-B was the only design able to reduce rockfish bycatch to a level desired by Pacific hake fishermen. However, under its current configuration design-B would only serve as a useful BRD under slow-to-moderate fish volumes.

Since implementation of the catch shares program the use and experimentation of excluders in the Pacific hake fishery have increased. However, the high volume nature of the fishery has made the development of excluders that can effectively reduce rockfish bycatch, while limiting the loss of Pacific hake, challenging to gear researchers and industry. In this fishery, catch volumes exceeding 75 mt in tow durations less than 30 minutes can occur at times. Under these levels of fishing it is unlikely that any excluder design would be effective at reducing bycatch while maintaining catch levels of the target species. Although the Pacific hake fishery is a high-volume fishery, there are times when fishing becomes slow-to-moderate and vessels have to tow for extended durations to fill their fish holds. Under these conditions design-B would serve as an effective rockfish BRD and allow fishermen more opportunities to harvest their catch shares quota.

Video observations showed the few Chinook salmon encountered remaining forward of the "hallway" section of the excluder for a significant portion of the duration of the tow. On several occasions, they were observed drifting back and then bursting forward once contacting the first rope with chaffing gear (located at the beginning of the "hallway", Figure 1). It was not until the trawl neared the surface during haulback that most Chinook salmon were observed to turn and move aft through the excluder towards the exit ramp. For the single Chinook salmon caught under design-B, it was caught in the intermediate section of the trawl forward of the excluder. These observations suggest that an escape opening positioned forward of the excluder might be an effective location for providing an escape opportunity for Chinook salmon.

Following the conclusion of this project, Foulweather Trawl and two fishing vessels continued to experiment with design-B to improve the gears performance. One modification tested consisted of lengthening the distance that the vertical panels taper inward to 100 meshed deep, and increasing the width inside the "hallway" section of the excluder to 16 meshes apart. While clogging was not observed, video footage collected by one of the vessels showed a high loss of Pacific hake, possibly over 40-50% of the total catch. This estimation was based on the vessels codend catch and what was observed on video escaping out the exit ramp. This observation provides valuable information for further developing design-B as this change in gear configuration significantly affected the excluder's ability to retain Pacific hake.

In summary, a collaborative workshop facilitated the design and testing of a flexible sorting grid excluder that was able to reduce rockfish bycatch while maintaining catch levels of Pacific hake. During slow-to-moderate fishing conditions this gear could immediately assist Pacific hake fishermen in reducing rockfish bycatch. However, further refinement of the excluder is needed for the gear to function under heavy fish volumes. Insights and lessons learned during this project and from fishermen's use of the excluder are currently being exchanged in a collaborative effort to modify design-B for further testing in the 2013 Pacific hake fishery.

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Table 1. Percent escapement by weight of target and non-target species between excluder design-A and B.

	Design-A (3.5 x 5.5" [8.89 x 13.97 cm] grid)		Design-B (3.0 x 3.5" [7.62 x 8.89 cm] grid)	
Species	Weight - kg (codend/recapture net)	% escapement	Weight - kg (codend/recapture net)	% escapement
Pacific hake	175,096 / 5,933	3.3	137,768 / 8,915	6.1
Yellowtail rockfish	2,836 / 379	11.8	1,478 / 3,340	69.3
Widow rockfish	45 / 5	10.0	22 / 104	82.5
Canary rockfish	493 / 220	30.9	0 / 3	100.0
Rougheye rockfish	2 / 0	0.0	5 / 101	95.3
Darkblotched rockfish	1 / 0	0.0	1 / 5	83.3
Bocaccio	0 / 13	100.0	0 / 0	-
Silvergray rockfish	2 / 0	0.0	0 / 0	-
Pacific Ocean perch	1 / 0	0.0	0 / 0	-
Splitnose rockfish	1 / 0	0.0	0 / 0	-
Total – Rockfish	3,381 / 617	15.4	1,506 / 3,553	70.2
		Prohibited take species		
Chinook salmon*	2 / 3	60.0	1 / 0	0.0
Pacific halibut*	1 / 0	0.0	0 / 2	100.0

* = numbers of fish.

Table 2. Mean fork lengths (cm) of Pacific hake and non-target species encountered while testing excluder designs-A and B. *N* = refers to the number of fish measured.

	Design-A (3.5 x 5.5" [8.89 x 13.97 cm] grid)		Design-B (3.0 x 3.5" [7.62 x 8.89 cm] grid)	
Species	Mean fork length (SE)	*N*	Mean fork length (SE)	*N*
Pacific hake	36 (0.1)	1,115	40 (0.1)	629
Yellowtail rockfish	46 (0.6)	35	48 (0.2)	149
Widow rockfish	38 (0.8)	18	45 (0.4)	75
Rougheye rockfish	0 (-)	0	50 (1.0)	50
Canary rockfish	51 (1.1)	26	55 (-)	1
Darkblotched rockfish	33 (-)	1	40 (2.2)	4
Bocaccio	68 (0.6)	3	0 (-)	0
Silvergray rockfish	56 (-)	1	0 (-)	0
Splitnose rockfish	26 (1.2)	3	0 (-)	0
Pacific Ocean perch	34 (-)	1	0 (-)	0
	Prohibited take species			
Chinook salmon	75 (6.2)	5	61 (-)	1
Pacific halibut	86 (-)	1	80 (1.0)	2

Table 3. Mann-Whitney U test comparison of mean fork lengths (cm) between Pacific hake caught in the recapture net and the codend between excluder design-A and B. *N* = refers to the number of fish measured.

	Mean fork length				
Design	Codend (SE)	*N*	Recapture net (SE)	*N*	p-value
A (3.5 x 5.5” [8.89 x 13.97 cm] grid)	36 (0.2)	504	37 (0.2)	611	0.2302
B (3.0 x 3.5” [7.62 x 8.89 cm] grid)	40 (0.1)	309	40 (0.2)	320	0.1293

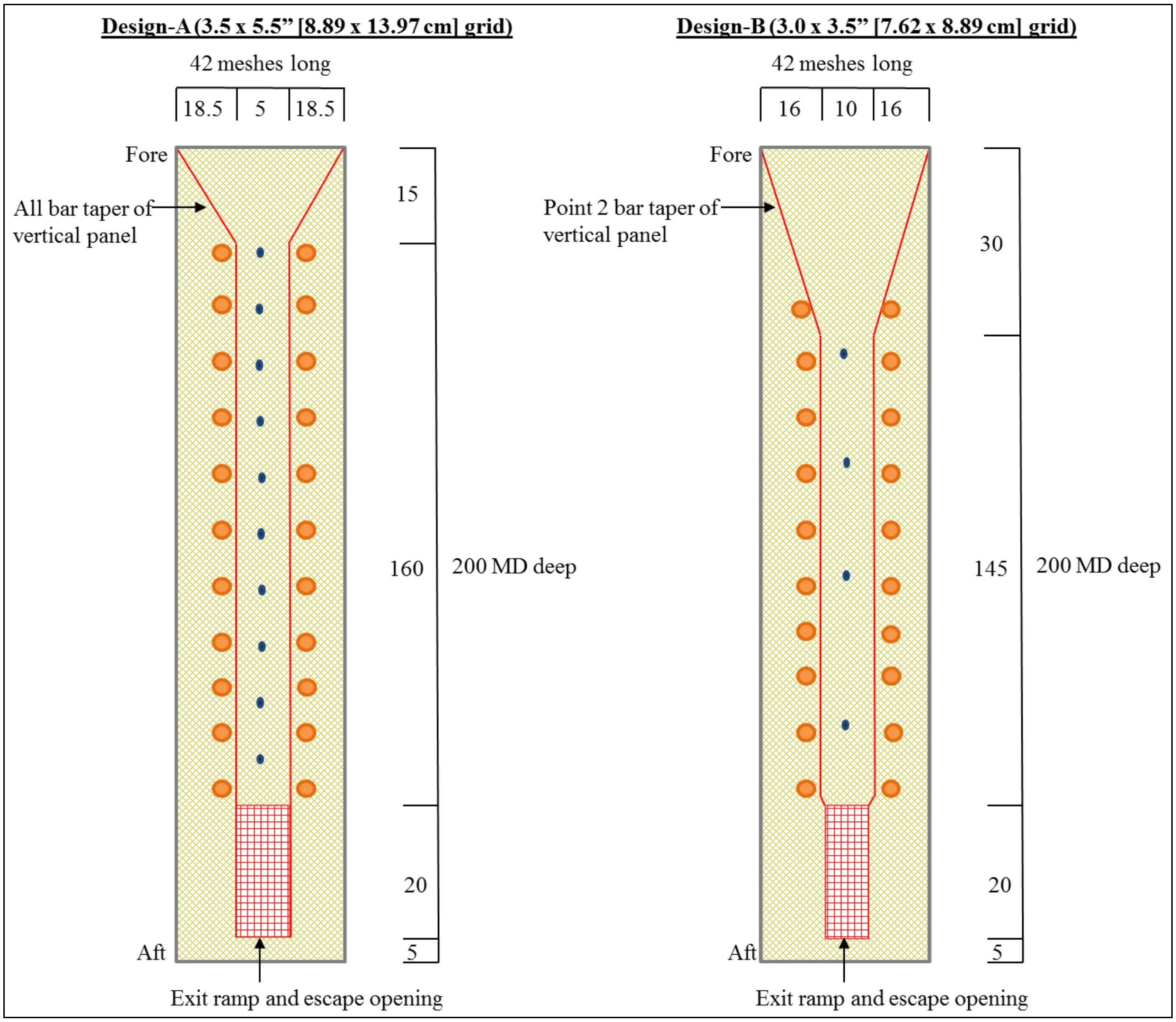

Figure 1. Top view diagram depicting the differences between design-A and B. Solid red lines represent the vertical sorting panels, whereas the red grids represent the exit ramp. The orange circles represent 8” [20.32 cm] centerhole floats. The blue oval shapes represent the ropes with chaffing gear wedged through them. MD = diamond mesh. Note: this diagram is not drawn to scale.

Figure 2. Image of one of the ropes with chaffing gear wedged through it that was used within the “hallway” section of the excluder in an attempt to stimulate fish to interact with the vertical sorting panels.

Figure 3. *F/V Perseverance* chartered for the research project. Photo courtesy *F/V Perseverance*.

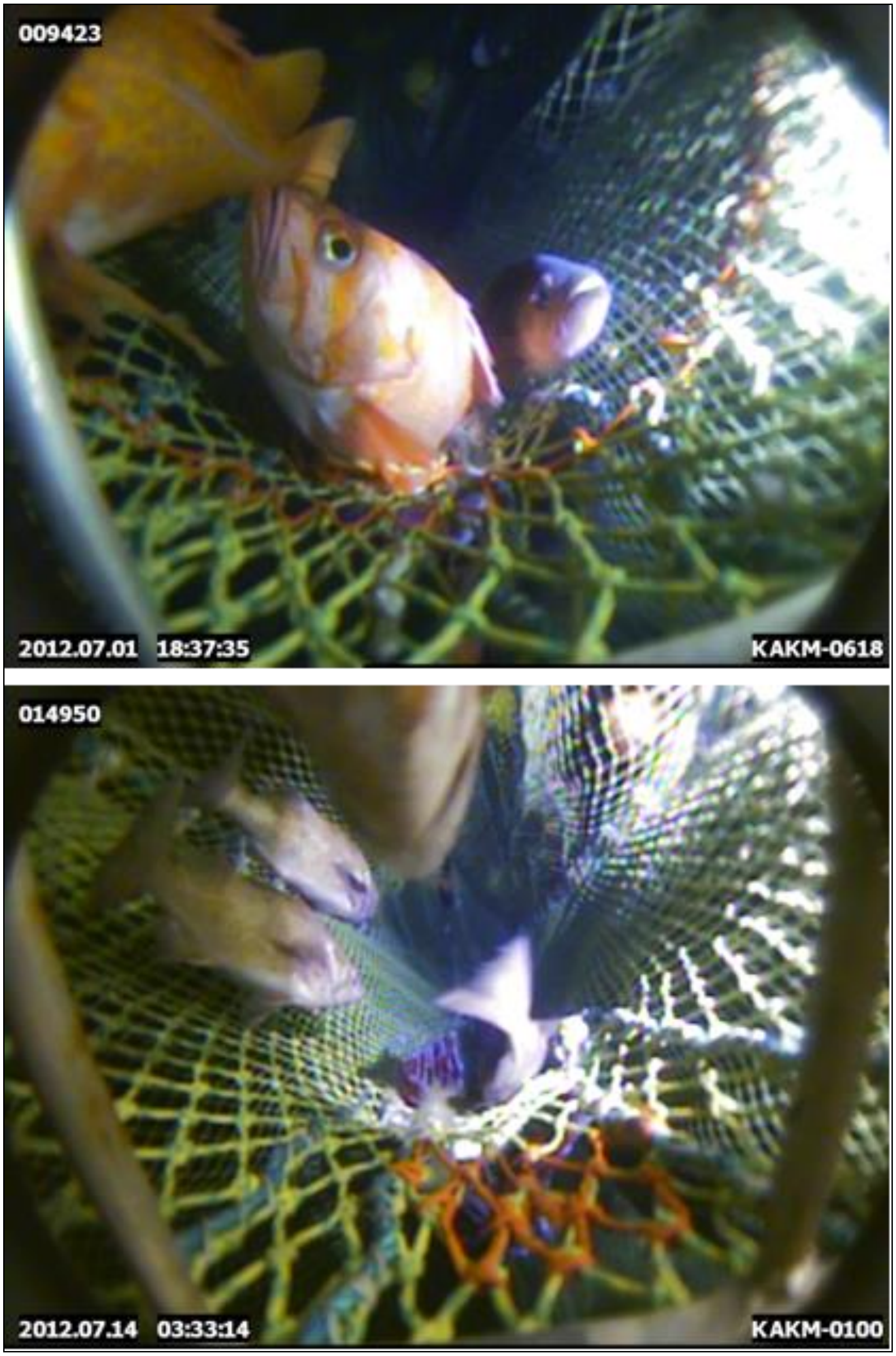

Figure 4. Video frame grabs showing canary rockfish and yellowtail rockfish (above, design-A) and widow rockfish (below, design-B) swimming inside the recapture net surrounding the exit ramp of the rockfish excluder tested.

Figure 5. Photos illustrating results from a tow when testing design-B. Left image shows a portion of the codend catch (mostly Pacific hake), whereas the right top image shows the entire recapture net catch (mixture of rockfishes and Pacific hake). The bottom right image shows baskets of rockfishes sorted (mixture of yellowtail rockfish, widow rockfish, and rougheye rockfish) from the recapture net catch. For this tow the retention of hake was 95.1% while the escapement of rockfishes was 71.1%.

Figure 6. Rougheye rockfish and darkblotched rockfish caught in the recapture net during a tow when testing design-B. For this tow rougheye rockfish bycatch was reduced by 91.9%.

Appendix 1. Common and scientific names of species mentioned in this report.

Common name	Scientific name
Chinook salmon	*Oncorhynchus tshawytscha*
Pacific hake	*Merluccius productus*
Rougheye rockfish	*Sebastes aleutianus*
Pacific Ocean perch	*S. alutus*
Silvergray rockfish	*S. brevispinis*
Darkblotched rockfish	*S. crameri*
Splitnose rockfish	*S. diploproa*
Widow rockfish	*S. entomelas*
Yellowtail rockfish	*S. flavidus*
Bocaccio	*S. paucispinis*
Canary rockfish	*S. pinniger*
Pacific halibut	*Hippoglossus stenolepis*

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