April 2014

Initial Tests of a Bycatch Reduction Device Designed to Improve Trawl Selectivity in the West Coast Limited Entry Groundfish Bottom Trawl Directed Flatfish Fishery

Mark J M Lomeli & W Waldo Wakefield

NOAA FISHERIES

Initial Tests of a Bycatch Reduction Device Designed to Improve Trawl Selectivity in the West Coast Limited Entry Groundfish Bottom Trawl Directed Flatfish Fishery

Mark J.M. Lomeli[a*]

W. Waldo Wakefield[b]

[a]Pacific States Marine Fisheries Commission

2032 SE OSU Drive

Newport, Oregon 97365, U.S.A.

[b]Fishery Resource Analysis and Monitoring Division

Northwest Fisheries Science Center

National Marine Fisheries Service

National Oceanic and Atmospheric Administration

2032 SE OSU Drive

Newport, Oregon 97365, U.S.A.

*Corresponding author: email: mlomeli@psmfc.org, Tel.: 541 867-0544

April 2014

This document should be cited as follows:

Lomeli, M.J.M. and W.W. Wakefield. 2014. Initial tests of a bycatch reduction device designed to improve trawl selectivity in the west coast limited entry groundfish bottom trawl directed flatfish fishery. NMFS Northwest Fisheries Science Center Report, 23 pp.

Abstract

In 2011, the U.S. west coast limited entry (LE) groundfish trawl fishery began management under a catch share program. This program established annual catch limits and individual fishing quotas along with individual bycatch quotas for prohibited species. For many fishermen engaged in the bottom trawl fishery targeting flatfishes, and participating in this program, catches of sablefish, Pacific halibut, and overfished and rebuilding rockfishes are a concern because quota is limited relative to flatfish quotas. Individual fishermen could reach their quota for one of these species before reaching their catch share quota of more abundant and productive flatfishes, thereby ending their fishing season or forcing them to purchase limited and expensive quota. In this study, we tested a flexible sorting grid bycatch reduction device (BRD) designed to reduce catches of rockfishes, sablefish, and Pacific halibut, while retaining the targeted flatfish species. Fish retention and escapement was quantified using a recapture net. The retention (by weight) of marketable-sized flatfishes ranged from 74.8% to 93.3% with retention being highest for petrale sole (93.3%), Dover sole (89.4%), and English sole (87.9%). Arrowtooth flounder, the lowest valued flatfish, displayed the lowest percent retention, 74.8%. The escapement of rockfishes was greatest for fish measuring 36 cm or greater, 94.6%. Lingcod and sablefish measuring over 38 cm exhibited escapement rates over 92%. Overall, 85.1% of the marketable-sized flatfishes encountered were retained, whereas 72.1% of rockfishes, 96.5% of roundfishes, and 93.7% of Pacific halibut encountered were excluded from the trawl. Results demonstrated the capability of a flexible sorting grid BRD to reduce catches of rockfishes, roundfishes, and Pacific halibut while retaining a relatively high proportion of the targeted flatfish species. As efforts to improve trawl selectivity in the west coast LE groundfish bottom trawl fishery continue, findings from this study provide important information to 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. A mixture of flatfishes, rockfishes, roundfishes, and skates are targeted with arrowtooth flounder, Dover sole, petrale sole, sablefish, thornyheads, and longnose skate accounting for a significant portion of annual landed-catches by weight (PacFIN, 2011, 2012).

In 2011, the west coast LE groundfish trawl fishery began management under a catch share program, hereafter referred to as the Individual Fishing Quota (IFQ) program (PFMC and NMFS, 2010). This program established annual catch limits (ACLs) and individual fishing quotas along with individual bycatch quotas (IBQs) for prohibited species. The IFQ program also provides the option of catching quota using trawl or fixed gear (termed “gear switching”). Some in the IFQ program have enabled this option and switched to fixed gear, but the majority of program participants continue to fish with bottom trawl (especially when targeting flatfish species). For many fishermen engaged in the bottom trawl fishery and targeting flatfishes, catches of overfished and rebuilding rockfishes (i.e. Pacific ocean perch [POP], darkblotched rockfish, bocaccio, canary rockfish), species that have exceeded their acceptable biological catches (ABC’s) and overfishing limits (OLFs) in recent years (i.e. minor slope complex stocks such as shortraker rockfish, rougheye rockfish, and blackgill rockfish), sablefish (a precautionary zone groundfish stock[1]), and Pacific halibut (a prohibited species) are a concern because limited quota is available due to low spawning stock biomass for these species relative to the more abundant and productive flatfishes (i.e. English sole, arrowtooth flounder, Dover sole, petrale sole). Individual fishermen could reach their quota for one of these “lower-quota” species before reaching their catch share quota of more abundant flatfish stocks, thereby ending their fishing season with allowable harvest still left in the ocean unless additional 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. species needing quota coverage, amount of extra quota needed, time of year). Developing techniques that improve trawl selectivity and provide fishermen with more opportunities to fully utilize their catch share quota of healthy groundfish stocks are increasingly important to fishermen and the west coast groundfish trawl catch share program.

Since 2008, the National Marine Fisheries Service-Northwest Fisheries Science Center, Pacific States Marine Fisheries Commission, and fishing industry have conducted collaborative trawl selectivity studies in west coast groundfish trawl fisheries (BREP, 2009-2012; Lomeli and Wakefield, 2012, 2013ab, 2014). Recently this group examined the efficacy of flexible sorting grid bycatch reduction devices (BRDs) to reduce rockfish bycatch in the Pacific hake fishery (Lomeli and Wakefield, 2013a), and Pacific halibut bycatch in the groundfish bottom trawl fishery (Lomeli and Wakefield, 2013b, 2014). Findings from these recent projects have demonstrated that flexible sorting grid BRDs can be effective at reducing bycatch while retaining a relatively high proportion of the targeted groundfish species. Because the body shape and size of rockfishes (large, fusiform shape) and sablefish (large elongated body, round shape) are distinctly different from the targeted flatfishes (depressed, flattened body) in this fishery, fishermen and gear researchers hypothesized that a flexible sorting grid BRD with narrow rectangular slots can be effective at reducing catches of rockfishes and sablefish while retaining the targeted flatfish species. It is also believed that this design would be beneficial at reducing the incidental catch of Pacific halibut as the majority of Pacific halibut caught in the fishery are greater than 65 cm in length (Jannot et al., 2011; Wallace and Hastie, 2008; 2009) and much larger in size than the targeted flatfish species (Hannah et al., 2005; King et al., 2004; Lomeli and Wakefield, 2013b, 2014).

The objective of this study was to evaluate the efficacy of a flexible sorting grid BRD designed to reduce catches of overfished and rebuilding rockfishes, sablefish, and Pacific halibut in the west coast LE groundfish bottom trawl directed flatfish 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 LE groundfish bottom trawl 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 (Fig. 1).

The concept to the BRD tested is that fish smaller than the grid openings will pass through and move aft towards the codend, whereas fish larger than the grid openings will be excluded. The BRD was constructed within a four-seam tube of netting that was 80 meshes deep (fore to aft) and 100 meshes in circumference (25 meshes per seam), excluding meshes in each selvedge (Table 1, Fig. 2). The BRD was designed to be inserted between the intermediate section of a bottom trawl and the codend. The design utilizes two vertical panels (grids) of 1.75 x 8.5" [4.4 x 21.6 cm] (H X L) rectangular slot openings to crowd fish and direct large fish towards an upward-angled exit ramp. 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 Spectra® line placed through AQUAPEX® tubing. The vertical panels stand approximately 36" [0.9 m] in height and extend longitudinally down the tube of netting 66 meshes deep before connecting to the exit ramp. Over this distance, the two panels gradually angle inward over 18 meshes deep (1-point, 2-bar taper) then straighten to create a narrow "hallway" that extends aft 48 meshes deep (Fig. 2). Within the "hallway" section of the excluder, ropes with chaffing material wedged through them (Fig. 3) 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 approximately every 10 meshes deep within the "hallway" section of the excluder. At the end of the "hallway", the top portion of the vertical panels gradually angle outward, to become 14 meshes apart, to allow for integration of the exit ramp and the associated "escape" tube of netting. Fish that do not pass through the panel openings are guided by the exit ramp and exit out the top of the trawl through a 4-seam "escape" tube of netting that is 12 meshes deep and 70 meshes in circumference, excluding meshes in each selvedge. To offset the weight created by the sorting panels, 8" [20.3 cm] center-hole floats were placed above the vertical panels along the outside of the net.

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 15 tows were completed off central Oregon between 44^{o}19′ and 44^{o}52′N and between 124^{o}23′ and 124^{o}49′W during June 2013. Towing occurred over the continental shelf between 119 and 188 m water depth. Average bottom fishing depth was 159 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. A JT Electric Ltd. Lowlux camera system equipped with a black and white video camera and LED light was used on tows 2 and 7 to gather information on fish behavior and confirm that the BRD was configured correctly.

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.

3. Results

Catch per tow ranged from 17 to 232 kg for the trawl codend and 14 to 439 kg for the recapture net. Flatfishes, not including Pacific halibut, comprised 53.1% of the total catch composition with arrowtooth flounder, Dover sole, and petrale sole accounting for 85.7% of the total flatfish catch. Rockfishes (12 species), roundfishes (7 species), skates (3 species), and Pacific halibut (34 fish) made up the remaining 46.9% of the total catch composition. Catch data from the 15 tows are summarized in Table 2.

Pacific halibut encountered during this study ranged from 2.6 to 19.8 kg (mean 6.8 kg, SE ±0.8 kg) in weight and 62 to 111 cm (mean 80 cm, SE ±2.3 cm) in length. Over this size range, bycatch was reduced 93.7% by weight and 88.2% by numbers. Pacific halibut over 75 cm were caught exclusively in the recapture net (Fig. 4). Overall, the retention (by weight) of marketable-sized flatfishes (Table 3) ranged from 74.8% to 93.3% with retention being highest for petrale sole (93.3%), Dover sole (89.4%), and English sole (87.9%). Arrowtooth flounder, the lowest valued flatfish, displayed the lowest percent retention, 74.8%. The escapement of rockfishes was greatest for fish measuring 36 cm or greater. Of the rockfishes encountered measuring 36 cm or greater, 94.6% were caught in the recapture net, whereas only 46.5% of rockfishes measuring less than 36 cm were caught in the recapture net. Lingcod and sablefish measuring over 38 cm exhibited escapement rates over 92% (Table 3). Nearly all skates encountered were caught in the recapture net. Overall, 85.1% of the marketable-sized flatfishes encountered were retained, whereas only 27.9% of rockfishes, 3.5% of roundfishes, and 6.3% of Pacific halibut encountered were retained by the trawl (Tables 2 and 3).

With the exception of Pacific halibut, no large differences in mean length were found for flatfishes caught in the trawl versus the recapture net (Table 4). For most rockfishes and roundfishes, however, comparisons of mean lengths showed larger-sized fish were excluded from the trawl with only the smaller-sized individuals retained. For all species caught, the largest mean length differences noted were in Pacific halibut (13 cm), chilipepper (8 cm), lingcod (6 cm), and sablefish (5 cm).

All Pacific halibut caught in the trawl and recapture net were assigned to the viability category "excellent". While viability was not assessed on other fish species, 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.

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

Developing techniques that improve trawl selectivity and provide fishermen with more opportunities to fully utilize their catch share quota of healthy flatfish stocks and increase their net economic benefits are increasingly important to fishermen and management. Additional tools, such as improved selectivity, are also needed to reduce fishing mortality on overfished stocks to augment their recovery and on stocks that are experiencing overfishing under status quo management measures (i.e., some slope and shelf rockfish species). In this study, a BRD was examined that demonstrated the ability to reduce catches of overfished and rebuilding rockfishes, sablefish, and Pacific halibut while retaining a relatively high proportion of the targeted flatfish species. As efforts to improve trawl selectivity in the west coast LE groundfish bottom trawl fishery continue, findings from this study provide important information to industry and management.

Dover sole and petrale sole are two economically important flatfish species harvested in the west coast LE groundfish bottom trawl flatfish fishery. Dover sole are significant as they account for over 62% by weight of all flatfish landings (annual) and exhibit an ex-vessel value of approximately $0.45/lb. In 2012, over 7,000 mt of Dover sole was landed (PacFIN, 2012). Petrale sole, on the other hand, account for 8% to 10% of all flatfish landings (PacFIN, 2011, 2012), but can have an ex-vessel value of up to $1.50/lb. Among all flatfishes, petrale sole exhibit the highest ex-vessel price/lb. In the current study, the BRD was most effective at retaining Dover sole and petrale sole. Combined, 91.3% of the marketable-sized Dover sole and petrale sole were caught in the trawl with no significant difference in mean length occurring between fish caught in the trawl and recapture net. These findings suggest that the BRD examined may prove useful for allowing fishermen to harvest Dover sole and petrale sole on fishing grounds where larger-sized rockfishes, sablefish, and/or Pacific halibut co-occur.

Overall, 83% of the roundfish species encountered, including rockfishes, were excluded from the trawl. The 17% that were retained consisted primarily of smaller-sized fish (mean 28 cm, SE ±0.2). A simple technique that could be used to further reduce this catch of juvenile roundfishes, while retaining flatfishes, would be through the use of a T90 mesh codend. T90 mesh is conventional diamond mesh turned 90^{o} in orientation. This unique configuration allows the meshes over the entire codend to remain open during towing (which does not occur in the traditional diamond codend), thereby improving the size selectivity of the codend and allowing juvenile fishes increased opportunities to escape. This novel mesh configuration, originally designed for use in the Baltic cod trawl fishery (Moderhak, 1997, 2000) and now recently examined in the Norway Lobster trawl fishery (Madesn et al., 2012), has introduced a new level of selectivity. A selective flatfish trawl, with a cutback headrope and low total rise, designed to allow fish that have a tendency to rise when encountering the footrope to escape, could be used to separate some species of roundfishes and flatfishes before trawl entrainment (Hannah et al., 2005; King et al., 2004).

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. 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.

Current management tools available to reduce catches of species with low ACLs relative to encounter rates include depth-area closures (i.e., rockfish conservation areas) along with the implementation of the IFQ program which requires 100% observer coverage and full accountability of catch (PFMC and NMFS, 2010). Landings exceeding ABCs and OFLs have recently been documented for some species and species groups caught by the trawl fishery (Hicks et al., 2014; NMFS, 2013). Unless more selective trawl gear is used, as described herein, management may be forced to restrict fishing over a broader range of depths/areas or implement lower harvest guidelines and ACLs to ensure that commercial fisheries do not exceed the OFLs for certain species. Providing fishermen with an option of using a more selective trawl that will provide access to highly productive flatfishes while reducing the catch of those species with relative low ACLs or harvest guidelines would be beneficial to the fishery, coastal communities, management, and the resource.

In summary, this research examined a flexible sorting grid excluder that demonstrated the ability to reduce catches of overfished and rebuilding rockfishes, sablefish, and Pacific halibut while retaining a relatively high proportion of the targeted flatfish 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. In 2014, further testing of this BRD will be conducted.

Acknowledgements

We would like to thank the captain and crew of the *F/V Miss Sue* for their assistance with this research. Funding for this study was provided by NOAA National Marine Fisheries Service Bycatch Reduction Engineering Program.

References

Casey, J.M., Myers, R.A., 1998. Diel variation in trawl catchability: is it as clear as day and night? Can. J. Fish. Aquat. Sci. 55, 2329-2340.

Clark, W.G., Hoag, S.H., Trumble, R.J., Williams, G.H., 1992. Re-estimation of survival for trawl caught halibut released in different condition factors. International Pacific Halibut Commission, Report of Assessment and Research Activities 1992: 197-206.

Hannah, R.W., Parker, S.J., Buell, T.V., 2005. Evaluation of a selective flatfish trawl and diel variation in the rockfish catchability as bycatch reduction tools in the deepwater complex fishery off the U.S. west coast. N. Am. J. Fish. Manage. 25, 581-593.

Hart, T.D., Clemons, J.E.R., Wakefield, W.W., Heppell, S.S., 2010. Day and night abundance, distribution, and activity patterns of demersal fishes on Heceta Bank, Oregon. Fish. Bull. 108, 466-477.

Hicks, A.C., Wetzel, C., Harms, J., 2014. The status of rougheye (*Sebastes aleutianus*) and blackspotted rockfish (*S. melanostictus*) as a complex along the U.S. West Coast in 2013. Pacific Fishery Management Council, Portland, OR. 269 pp.

Hoag, S. H., 1975. Survival of Halibut Released After Capture By Trawls. International Pacific Halibut Commission, Scientific Report No. 57, 18 p.

Jannot, J.E., M. A. Bellman and J. Majewski. 2011. Pacific halibut bycatch in the U.S. west coast groundfish fishery from 2002 through 2010. West Coast Groundfish Observer Program. NWFSC, 2725 Montlake Blvd E., Seattle, WA 98112.

King, S.E., Hannah, R.W., Parker, S.J., Matteson, K.M., Berkeley, S.A., 2004. Protecting rockfish through gear design: development of a selective flatfish trawl for the U.S. west coast bottom trawl fishery. Can. J. Fish. Aquat. Sci. 61, 487-496.

Lomeli, M.J.M., Wakefield, W.W. 2012. Efforts to reduce Chinook salmon (*Oncorhynchus tshawytscha*) and rockfish (*Sebastes* spp.) bycatch in the U.S. west coast Pacific hake (*Merluccius productus*) fishery. Fish. Res. 119-120: 128-132.

Lomeli, M.J.M. and W.W. Wakefield. 2013a. A pilot study testing the efficacy of a flexible sorting grid rockfish excluder in the U.S. Pacific hake fishery: outcome of a collaborative workshop. NMFS Northwest Fisheries Science Center Report, 25 pp.

Lomeli, M.J.M., Wakefield, W.W. 2013b. A flexible sorting grid to reduce Pacific halibut (*Hippoglossus stenolepis*) bycatch in the U.S. west coast groundfish bottom trawl fishery. Fish. Res. 143, 102-108.

Lomeli, M.J.M. and W.W. Wakefield. 2014. Testing of an industry-designed bycatch reduction device to reduce the incidental catch of Pacific halibut in a groundfish bottom trawl fishery. NMFS Northwest Fisheries Science Center Report, 23 pp.

Madesn, N., Herrmann, B., Frandsen, R.P., Krag, L.A., 2012. Comparing selectivity of a standard and turned mesh T90 codend during towing and haul-back. Aquatic Living Resources. 25, 231-240.

Moderhak, W., 1997. Determination of selectivity of cod codends made of netting turned through 90 degree. Bull Sea Fish Inst 140:3–14.

Moderhak, W., 2000. Selective properties of polyamide (PA) cod trawl codends made of meshes turned 90. In: Scientific papers presented at the Polish-Swedish symposium on "selectivity research in the Baltic Sea area", Gdynia, Poland March 23–25, 1999. Meddelande Fran Havsfiskelaboratoriet, Lysekil, No. 329,

NMFS., 2013. Minor slope complex stocks with consistent overfishing limit contribution overages; council consideration of reorganization of blackgill, rougheye, and shortraker rockfish for additional analysis. Supplemental NMFS Report, Agenda Item H.4.b., Pacific Fishery Management Council, Portland, OR, November 2013.

NMFS-BREP Report. 2009, 2010, 2011, and 2012. Annual Report to Congress on the Bycatch Reduction Engineering Program. (http://www.nmfs.noaa.gov/by_catch/bycatch_BREP.htm).

Northwest Fisheries Science Center (NWFSC). 2010. West Coast Groundfish Observer Training Manual. West Coast Groundfish Observer Program. NWFSC, 2725 Montlake Blvd E., Seattle, Washington, 98112.

PacFIN (Pacific Fisheries Information Network) report # 010Wtwl. 2011. Pacific States Marine Fisheries Commission, Portland, Oregon. http://pacfin.psmfc.org/ (accessed 30.10.13).

PacFIN (Pacific Fisheries Information Network) report # 010Wtwl. 2012. Pacific States Marine Fisheries Commission, Portland, Oregon. http://pacfin.psmfc.org/ (accessed 30.10.13).

Petrakis, G., MacLennan, D.N., Newton, A.W., 2001. Day–night and depth effects on catch rates during trawl surveys in the North Sea. ICES J. Mar. Sci. 58, 50–60.

PFMC (Pacific Fishery Management Council) and NMFS (National Marine Fisheries Service). 2010. Rationalization of the Pacific coast groundfish limited entry trawl fishery; final environmental impact statement including regulatory impact review and initial regulatory flexibility analysis. Pacific Fishery Management Council, Portland, OR. June 2010.

Ressler, P.H., Fleischer, G.W., Wespestad, V.G., Harms, J., 2009. Developing a commercial-vessel-based stock assessment survey methodology for monitoring the U.S. west coast widow rockfish (*Sebastes entomelas*) stock. Fish. Res. 99, 63-73.

Ryer, C.H., Rose, C.S., Iseri, P.J., 2010. Flatfish herding behavior in response to trawl sweeps: a comparison of diel responses to conventional sweeps and elevated sweeps. Fish. Bull. 108, 145-154.

Suuronen, P., Perez-Comas, J.A., Lehtonen, E., Tschernij, V., 1996. Size-related mortality of herring (*Clupea harengus* L.) escaping through a rigid sorting grid and trawl codend meshes. ICES J. Mar. Sci. 53, 691-700.

Wallace, J., Hastie, J., 2008. Pacific halibut bycatch in IPHC Area 2A in the 2007 groundfish bottom trawl fishery. NOAA Fisheries Northwest Fisheries Science Center. November 2008. pp. 20.

Wallace, J., Hastie, J., 2009. Pacific halibut bycatch in IPHC Area 2A in the 2008 groundfish bottom trawl fishery. NOAA Fisheries Northwest Fisheries Science Center. November 2009. pp. 20.

Walsh, S.J., Hickey, W.M., 1993. Behavioural reactions of demersal fish to bottom trawls at various light conditions. ICES J. Mar. Sci. Symp. 196, 68-76.

Williams, G. H. and D. Chen. 2004. Pacific halibut discard mortality rates in the 1990-2002 Alaskan groundfish fisheries, with recommendations for monitoring in 2004. International Pacific Halibut Commission. Report of Assessment and Research Activities 2003: 227-244.

Footnote

[1]A precautionary zone groundfish stock is identified by the Pacific Fishery Management Council (PFMC) under the groundfish Fishery Management Plan as "*Stocks estimated to be above the depletion threshold, yet below an abundance level that supports MSY*" (PFMC, 2008).

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.

	Flexible sorting grid 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)	100* (25/panel)	70* (25/top and bottom panels; 10/side panels)	100* (25/panel)
Meshes deep	80	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. Catch by weight (kg) for Pacific halibut, flatfishes, rockfishes, roundfishes, and skates from the 15 tows conducted. TR = trawl; RN = recapture net; %R = percent retention.

	Pacific halibut			Flatfishes			Rockfishes			Roundfishes			Skates		
Tow	TR	RN	%R	TR	RN	%R	TR	RN	%R	TR	RN	%R	TR	RN	%R
1	0	33.60	0.0	90.25	16.40	84.6	1.25	5.50	18.5	0.90	13.15	6.4	0	40.05	0.0
2	0	25.00	0.0	88.45	24.80	78.1	0	2.00	0.0	0	22.85	0.0	0	8.10	0.0
3	0	0	-	51.40	19.85	72.1	0	2.55	0.0	0	58.45	0.0	0	19.25	0.0
4	0	0	-	78.90	16.30	82.9	0	0.25	0.0	0.15	33.05	0.5	0	19.10	0.0
5	0	0	-	226.25	57.75	79.7	0.50	2.00	20.0	3.55	43.30	7.6	1.25	32.55	3.7
6	8.35	18.50	31.1	68.25	6.60	91.2	37.75	28.35	57.1	2.50	25.65	8.9	0	28.55	0.0
7	0	16.90	0.0	45.00	5.55	89.0	25.05	29.15	46.2	0.70	34.15	2.0	1.15	3.55	24.5
8	0	0	-	39.40	4.80	89.1	1.35	4.20	24.3	0.30	6.85	4.2	0	14.10	0.0
9	0	30.70	0.0	72.20	10.75	87.0	78.80	277.05	22.1	4.15	106.65	3.8	0	13.05	0.0
10	0	13.55	0.0	37.15	3.80	90.7	7.35	5.60	56.8	0	42.90	0.0	0	5.10	0.0
11	0	4.50	0.0	188.35	9.10	95.4	5.90	37.10	13.7	1.50	27.25	5.2	0	0	-
12	0	0	-	89.20	17.30	83.8	0.15	12.55	1.2	1.05	3.30	24.1	0	5.00	0.0
13	0	4.75	0.0	40.15	12.60	76.1	1.15	3.70	23.7	1.10	10.15	9.8	0	4.70	0.0
14	0	6.55	0.0	16.25	4.60	77.9	0	2.15	0.0	0	0	-	0	0	-
15	6.15	62.75	8.9	49.80	4.75	91.3	0	0	-	0	16.95	0.0	0	4.55	0.0
Total	14.50	216.80	6.3	1,181.00	214.95	84.6	159.25	412.15	27.9	15.90	444.65	3.5	2.40	197.65	1.2
Mean	0.97	14.45		78.73	14.33		10.62	27.48		1.06	29.64		0.16	13.18	
SE	0.67	4.8		14.75	3.53		1.64	1.38		0.15	1.46		0.11	3.20	

Table 3. Percent retention of Pacific halibut and selected groundfishes by total weight (kg) and total weight of marketable-sized fish caught. The minimum market size at the processing plant that fish were delivered to when this study was conducted was 33 cm for flatfishes, 28 cm for rockfishes, 27 cm for lingcod, and over 6.6 lbs (round weight) for skates. Sablefish did not have a minimum market size. POP = Pacific ocean perch.

	Total weight			Total weight of marketable-sized fish		
Species	recapture net	trawl	% retention	recapture net	trawl	% retention
			Prohibited species			
Pacific halibut	216.80	14.50	6.3	n/a	n/a	n/a
			Flatfishes			
English sole	15.00	109.10	87.9	15.00	108.77	87.9
Arrowtooth flounder	116.25	341.65	74.6	111.02	330.38	74.8
Dover sole	40.35	339.35	89.4	39.10	328.83	89.4
Petrale sole	28.65	345.70	92.3	22.78	318.39	93.3
Other (5 species)[1]	14.70	45.20	75.5	5.99	22.72	79.1
Total	214.95	1,181.00	84.6	193.89	1,109.09	85.1
			Rockfishes			
POP*	0	0.85	100.0	0	0.57	100.0
Darkblotched rockfish*	0.30	0.80	72.7	0	0	-
Greenstriped rockfish	65.00	53.15	45.0	62.34	39.07	38.5
Widow rockfish	28.95	0	0.0	28.95	0	0.0
Chilipepper	243.20	92.15	27.5	208.18	54.00	20.6
Bocaccio*	5.5	0	0.0	5.5	0	0.0
Canary rockfish*	38.9	1.7	4.2	38.9	1.7	4.2
Other rockfishes (5 species)[2]	30.3	10.6	25.9	3.2	1.3	28.9
Total	412.15	159.25	27.9	347.07	96.54	21.8
			Roundfishes			
Sablefish	41.50	3.30	7.4	41.50	3.30	7.4
Lingcod	387.05	3.95	1.0	73.54	0.0	0.0
Other (5 species)[3]	16.10	8.65	34.9	0.0	0.0	-
Total	444.65	15.90	3.5	115.04	3.30	2.8
			Skates			
Sandpaper skate, big skate, longnose skate,	197.65	2.40	1.2	194.09	0.0	0.0
Total	197.65	2.40	1.2	194.09	0.0	0.0

* = identified as an overfished and rebuilding rockfish stock.

[1] = species included rock sole, Pacific sanddab, rex sole, slender sole, and flathead sole.

[2] = species included silvergray, widow, yellowtail, shortbelly, stripetail, and sharpchin rockfish.

[3] = species include spiny dogfish, spotted ratfish, Pacific hake, shortspine thornyhead, and threadfin sculpin.

Table 4. Statistical comparison of mean fork lengths (cm) for Pacific halibut and selected flatfishes, rockfishes, and roundfishes caught in the recapture net and the trawl. $_1$ = 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_t = refers to the number of fish that were measured from the trawl. POP = Pacific ocean perch.

Species	Recapture net mean fork length (SE)	N_r	Trawl mean fork length (SE)	N_t	P-value
			Prohibited species		
Pacific halibut	81 (2.4)	30	68 (2.7)	4	0.0282_2
			Flatfishes		
English sole	33 (0.5)	49	33 (0.1)	351	0.5288_1
Arrowtooth flounder	45 (0.7)	132	43 (0.3)	397	0.0252_3
Dover sole	41 (0.8)	64	42 (0.3)	327	0.2271_2
Petrale sole	38 (1.0)	44	39 (0.3)	315	0.2264_2
Other (5 species)$_4$	28 (0.3)	78	30 (0.3)	212	0.0012_1
			Rockfishes		
POP*	0 (-)	0	28 (1.0)	3	n/a
Silvergray rockfish	0 (-)	0	44 (-)	1	n/a
Darkblotched rockfish*	26 (-)	1	23 (0.4)	4	0.4000_3
Greenstriped rockfish	30 (0.2)	148	30 (0.2)	166	$<0.0001_1$
Widow rockfish	45 (0.5)	21	0 (-)	0	n/a
Yellowtail rockfish	51 (0.3)	4	41 (-)	1	0.4000_3
Chilipepper	36 (0.6)	146	28 (0.2)	198	$<0.0001_3$
Shortbelly rockfish	0 (-)	0	21 (0.4)	5	n/a
Bocaccio*	80 (-)	1	0 (-)	0	n/a
Canary rockfish*	49 (1.2)	19	46 (-)	1	0.8000_3
Stripetail rockfish	22 (0.4)	105	23 (0.7)	40	0.4618_2
Sharpchin rockfish	24 (0.8)	22	26 (0.6)	3	0.1782_2
			Roundfishes		
Sablefish	49 (0.6)	40	44 (1.3)	5	0.0152_2
Lingcod	61 (0.6)	184	55 (4.5)	3	0.2651_2

* = identified as an overfished and rebuilding rockfish stock.

$_4$ = species included rock sole, Pacific sanddab, rex sole, slender sole, and flathead sole.

Figure 1. *F/V Miss Sue* chartered for the research project.

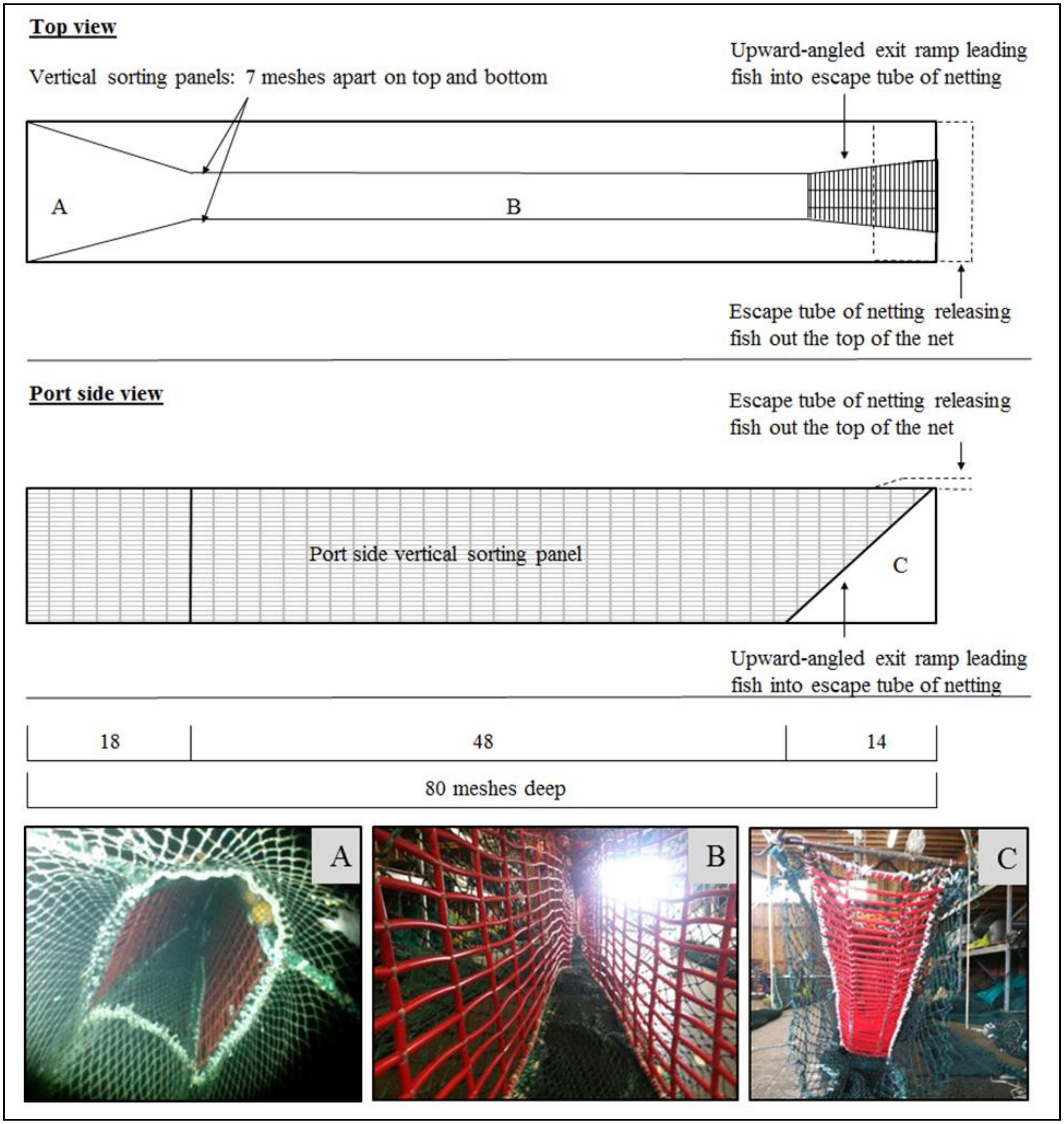

Figure 2. Schematic diagram of the flexible sorting grid bycatch reduction device (BRD) tested (top); aft view of the forward portion of the BRD where fish enter and encounter the device (image A); aft view of the "hallway" section of the BRD being built (image B); forward view of the upward-angled exit ramp (image C). Note: the schematic diagram is not drawn to scale.

Figure 3. Image of one of the ropes with chaffing gear wedged through it used within the “hallway” section of the excluder in an attempt to stimulate fish to interact with the vertical sorting panels.

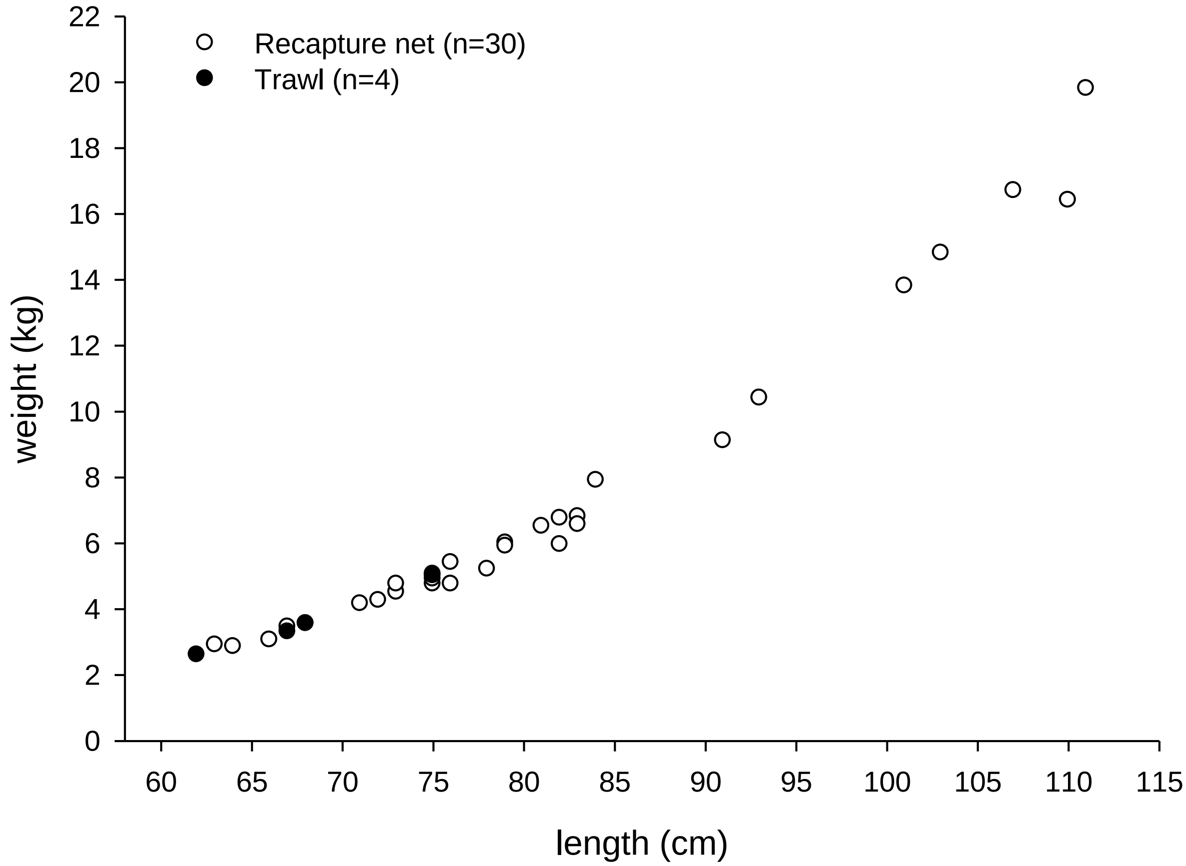

Figure 4. Length-weight scatter plot of Pacific halibut caught during this project.