Final Report to the NOAA Fisheries Bycatch Reduction Engineering Program & Deep Sea Coral Research and Technology Program

NOAA Award #NA20NMF4720274

Evaluating the efficacy of semi-pelagic trawl gear to harvest demersal fishes in the U.S. West Coast groundfish bottom trawl fishery

Mark J.M. Lomeli[1,2] and W. Waldo Wakefield[2,3]

[1] Pacific States Marine Fisheries Commission, 2032 SE OSU Drive, Newport, OR 97365, USA

[2] Oregon State University, Marine Resource Management Program, 318 Strand Hall, Corvallis, OR 97331, USA

[3] Oregon State University, Cooperative Institute for Marine Ecosystems and Resources Studies, 2030 SE Marine Science Drive, Newport, OR 97365, USA

Abstract

This study involved catch comparison sampling and analyses to determine how changing from a conventional trawl rigged with bottom tending doors to a semi-pelagic trawl rigged with midwater doors affect the catch efficiency of demersal fishes in the West Coast groundfish bottom trawl fishery. For both trawl designs, the most abundant species caught by weight were sablefish, Dover sole, shortspine thornyhead, petrale sole, and lingcod. Mean CPUE values for Dover sole, lingcod, and petrale sole were slightly higher in the semi-pelagic trawl, whereas the conventional trawl showed a slightly higher mean CPUE effort value for shortspine thornyhead. However, these results were only trends and not significant. For sablefish, a significant catch result was observed with the semi-pelagic trawl catching significantly more sablefish (a mean CPUE increase of 169.8% [95% CLs: 38.9-327.9]) than the conventional trawl. Trawl door sensors showed the semi-pelagic trawl exhibited a 42.1 m increase in door spread compared to the conventional trawl, while bottom contact sensors showed the midwater trawl doors outfitted on the semi-pelagic trawl fished on average a minimum of 0.8 m above the seafloor; Thus, providing sufficient height for lower-profile epifaunal and infaunal organisms to pass under the door without contact or disturbance. Our research demonstrates that semi-pelagic trawl gear can effectively harvest demersal groundfishes in the West Coast groundfish bottom trawl fishery while significantly reducing trawl-seafloor interactions.

1. Introduction

In the West Coast groundfish bottom trawl fishery, fishers use bottom trawl gear to harvest groundfishes (e.g., sablefish, lingcod, rockfishes, Dover sole, petrale sole) over low-relief trawlable habitats consisting of a range of indurations (e.g., mud, sand, gravel, cobble, boulder, and rock). Conventional bottom trawl gear is outfitted with low-aspect-ratio doors and lengthy sweeps designed to maintain seafloor contact and herd groundfishes towards the trawl mouth. While this conventional gear configuration is highly effective at herding groundfishes, its bottom-tending characteristics can have potential impacts (e.g., injury and unobserved mortality) on structure-forming invertebrates, Dungeness crab (a species supporting the West Coast's most valuable fishery [PacFIN, 2022]), other bottom-dwelling organisms, and the physical habitat. The predominant megafaunal invertebrates inhabiting sedimentary trawl fishing grounds are crustaceans (e.g., Dungeness crab, brown box crab), echinoderms (e.g., sea stars, urchins), annelids (e.g., polychaetes, sponges), and cnidarians (e.g., anemones, sea whips and sea pens [flexible structure-forming invertebrates]) (Hixon and Tissot, 2007; Hannah et al., 2014; Henkel et al., 2020). *Note: scientific classification of the species listed in this final report is provided following the *References* section.

The potential impact of bottom trawling on seafloor habitats, benthic communities, sediment resuspension and biogeochemical cycling has received Worldwide attention (Jennings and Kaiser, 1998; Kaiser et al., 2002; van de Velde et al., 2018; Sciberras et al., 2018; Bradshaw et al., 2021). Along the U.S. West Coast, the Pacific Fishery Management Council prioritized "minimize fishing impacts on habitat by adopting gear modifications to trawls to reduce the area of direct seafloor contact" in its "Research and Data Needs" (PFMC, 2018). Thus, gear modifications designed to reduce trawl-seafloor interactions such as bottom trawling using semi-pelagic trawl technology, have been developed (He and Winger, 2010; ICES, 2014, 2016; Grimaldo et al., 2015). Semi-pelagic trawling technology consists of using high-aspect-ratio midwater trawl doors and sweeps with sections elevated off bottom across their length. This novel technique originated in Scandinavia and was designed to reduce trawl-seafloor contact and drag forces associated with conventional bottom trawl gear. Off Alaska and in many international fisheries, use of semi-pelagic trawls to harvest demersal groundfishes is common. The advantages to semi-pelagic trawling include: 1) significant reductions in trawl-seafloor-habitat interactions, 2) increased catch efficiencies, and 3) reduced fuel consumption and emissions (as drag forces are reduced). The effectiveness of semi-pelagic trawl technology in the West Coast groundfish bottom trawl fishery has not been evaluated. Examining the efficacy of semi-pelagic trawl technology in the West Coast groundfish bottom trawl fishery would provide managers and industry new data for assessing gear modifications that can minimize trawl-seafloor interactions and disturbances to structure forming invertebrates, mobile benthic organisms, and groundfish habitats.

The objective of this study was to compare the catch efficiency for target groundfishes between semi-pelagic and conventional trawl gear, and measure the degree that semi-pelagic trawling reduces trawl-seafloor interactions.

2. Methods

2.1. Sea trials and trawl designs

Sea trials were conducted off the central Oregon coast during September 2022 onboard the chartered *F/V Last Straw*, a 23.2 m long, 540-hp trawler. Towing occurred between sunrise and sunset using the vessel's net. The trawl had a fishing mouth circumference of 180 meshes wide (24.1 cm mesh size) that tapers down over 77.5 meshes to a codend circumference opening that is 88 meshes wide (11.4 cm mesh size). The footrope was 24.7 m in length and incorporated 20.3 cm diameter rubber disks, with 45.7 cm rockhopper discs placed approximately every 73.7 cm across the length of the footrope. A T90 mesh codend (127 mm nominal mesh size, 6.0 mm double twine, 88 meshes in circumference and 75 meshes in length) was used. After each tow, the codend catch was sorted to species, and weighed. Tow duration was 60 minutes, however, some tows of 30 and 45 minutes occurred due to anticipated large catches.

The conventional trawl employed Thyborøn type-11 low-aspect-ratio demersal doors (size = 4.8 m^2; weight = 995 kg) (Fig. 1). The semi-pelagic trawl employed NET Systems Series 2000 high-aspect-ratio midwater trawl doors (size = 4.5 m^2; weight = 568 kg) (Fig. 1). Sweeps 91.4 m in length consisting of 4.8 cm combination wire with 25.4 cm steel bobbins placed every 30.5 m (to elevate sections of the sweeps off bottom) were used on both trawls as research has demonstrated that conventional bottom tending sweeps and elevated sweeps show similar catches (Rose et al. 2010; Lomeli et al. 2019). The only experimental change to the fishing gear was the door type (Fig. 2). Due to limited space on the vessel, the conventional and midwater trawl doors could not be stored on the vessel at the same time. This required returning to port to change between bottom and midwater doors. The sampling order across three four-day fishing trips for the conventional and semi-pelagic trawl designs is shown in Table 1. Bottom contact sensors were placed on the bottom of each midwater door to measure the door's height off bottom (Fig. 3). The calibration function used to convert the bottom contact sensor's relative units to height was:

$$y = 1804.3*x^{-0.949} \quad (1)$$

where x is the bottom contact sensor relative unit. Sensors were used on both door types to measure spread.

Following the successful methods performed by Lomeli et al. (2019), a bottom-tending sled outfitted with a Sound Metrics Dual-frequency IDentification SONar (DIDSON, operating at 1.8 MHz) and an HD video camera system (equipped with spacing lasers) was towed across trawl paths (onboard the *R/V Oceanus* in November 2021) to measure how each trawl configuration interacted with the seafloor.

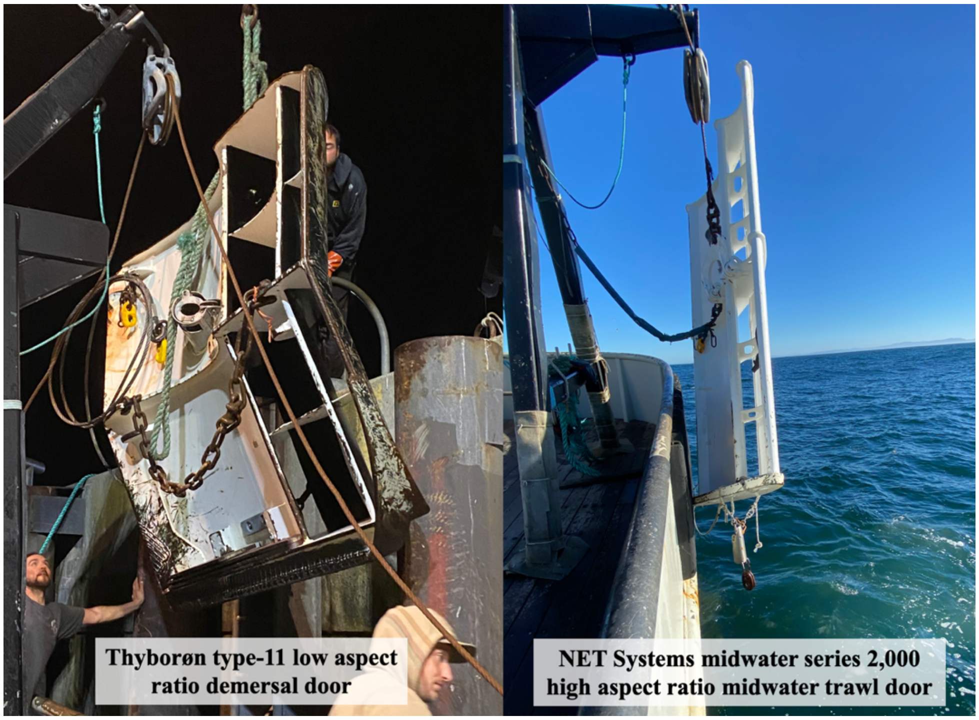

Figure 1. Image of the Thyborøn type-11 bottom trawl door (left image; size = 4.8 m^2; weight = 995 kg) and a NET Systems midwater 2000 trawl door (right image; size = 4.5 m^2; weight = 568 kg) used on the conventional and semi-pelagic trawl, respectively.

Table 1. Order in which the bottom (B) and midwater (MW) trawl doors were fished on the conventional and semi-pelagic trawl designs, respectively.

Fishing trip 1	Door fished	Fishing trip 2	Door fished	Fishing trip 3	Door fished
Day 1	MW	Day 1	B	Day 1	MW
Day 2	MW	Day 2	B	Day 2	MW
Day 3	B	Day 3	MW	Day 3	B
Day 4	B	Day 4	MW	Day 4	B

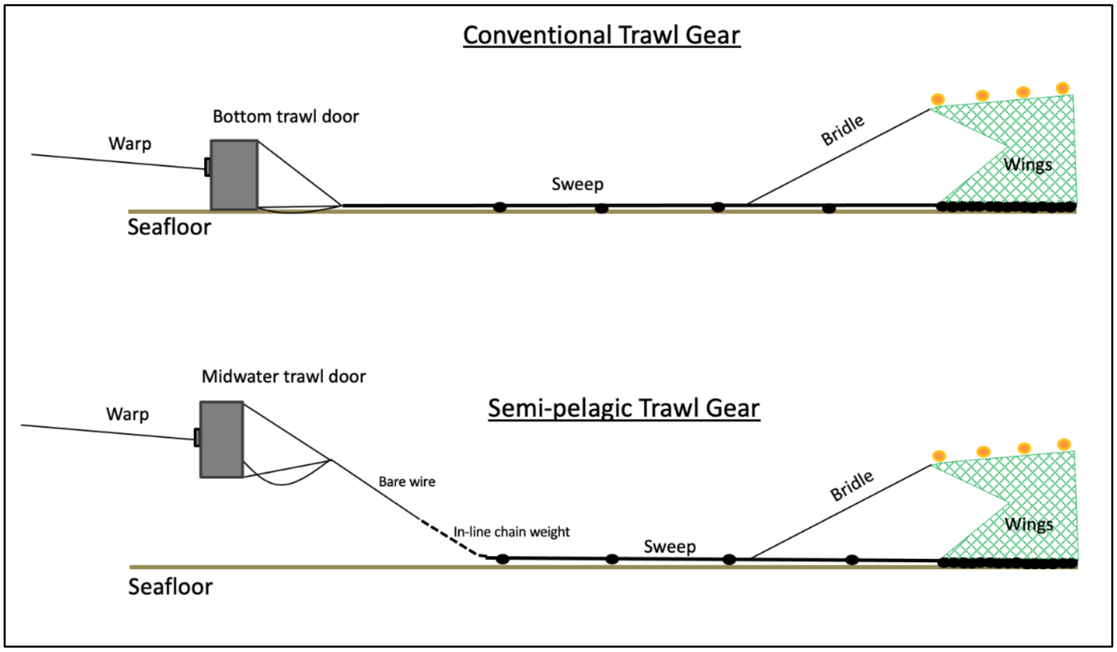

Figure 2. Schematic comparing conventional trawl gear rigged with bottom tending doors (top image) to semi-pelagic trawl gear rigged with midwater trawl doors (bottom image).

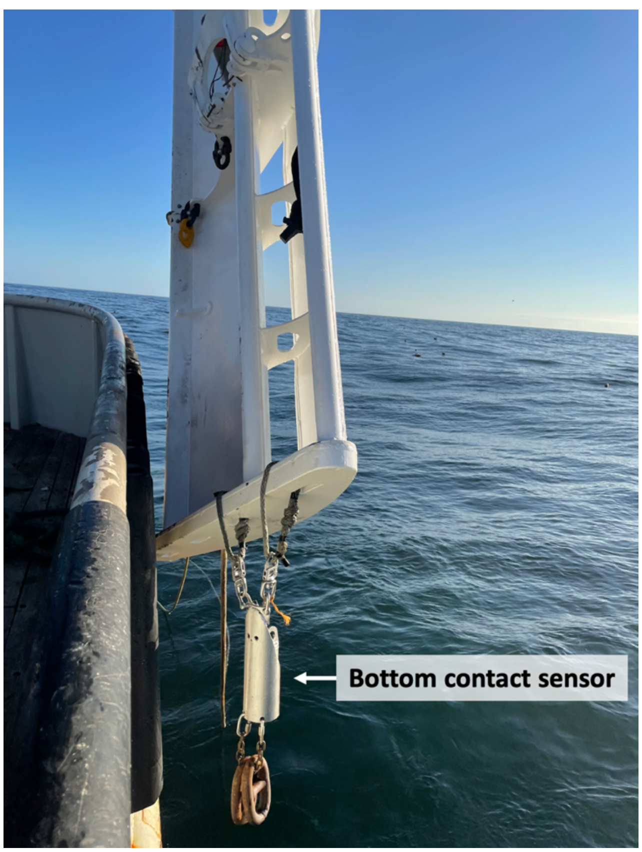

Figure 3. Image of a bottom contact sensor rigged to the semi-pelagic midwater trawl door.

2.2. Analyses – Groundfish catches and DIDSON imaging sonar footage

We performed catch comparison sampling and analyses to determine how changing from conventional bottom trawl gear to semi-pelagic trawling technology affects the mean CPUE of target groundfishes (e.g., lingcod, sablefish, shortspine thornyhead, Dover sole, petrale sole). For both trawl designs, CPUE was standardized to 1 hour. A bootstrapping method (Lomeli et al., 2019) was used to estimate the Efron 95% percentile confidence limits (CLs) (Efron, 1982) for the mean CPUE values. This technique accounts for uncertainty due to between-tow variations by selecting *m* hauls with replacement from the *m* hauls available during each bootstrap repetition (1,000 bootstrap repetitions were conducted). To determine if the delta $CPUE_{mean}$ of a species differed significantly between the two trawl designs, we examined the 95% CLs for a lack of overlap. If the 95% CLs between a species comparison does not overlap, then a significant difference in CPUE is present. On the contrary, if the 95% CLs between a species comparison overlaps, then a significant difference in CPUE is not present. To examine the percent change in mean CPUE ($\Delta CPUE_{mean}$) for each species between the conventional and semi-pelagic trawl, the following equation was used:

$$\Delta CPUE_{mean} = 100 \times \frac{(SP_{mean} - C_{mean})}{C_{mean}} \qquad (2)$$

where SP_{mean} is the mean CPUE for the semi-pelagic trawl and C_{mean} is the mean CPUE for the conventional trawl. The 95% CLs for the $\Delta CPUE_{mean}$ was estimated using the bootstrapping method applied for the catch comparison analysis described above. If the semi-pelagic trawl has an increase in mean CPUE, then the $\Delta CPUE_{mean}$ value will be above zero. On the other hand, if the semi-pelagic trawl has a decrease in mean CPUE, then the $\Delta CPUE_{mean}$ value will be below zero. The statistical package SELNET (Herrmann, 2012), software version date 21 September 2022, was used for the analyses described above.

We used the measuring tool within the DIDSON sonar software (V5.26) to analyze the imaging sonar footage and measure the width of tracks (or the lack of) created by the doors and sweeps of the two trawls.

3. Results

3.1. Fishing effort and catch comparison

For the conventional trawl and semi-pelagic trawl, a total of 23 and 21 tows, were completed, respectively. Tow speeds ranged from 2.2 to 2.4 knots at bottom fishing depths ranging from 93 to 184 m (mean depth = 128 m).

The total catch by weight for the conventional trawl was 33,606 kg, whereas the total catch by weight for the semi-pelagic trawl was 38,403 kg. For both trawls, the most abundant species caught by weight were sablefish, Dover sole, shortspine thornyhead, petrale sole, and lingcod. Mean CPUE for Dover sole, lingcod, and petrale sole were slightly higher in the semi-pelagic trawl, whereas the conventional trawl showed a slightly higher mean CPUE for shortspine thornyhead (Fig. 4). These catch results, however, were only trends and not significant as indicated by their overlapping 95% CLs. For sablefish, a significant catch result was observed with the semi-pelagic trawl catching significantly more fish than the conventional trawl as indicated by their 95% CLs not overlapping (Fig. 4). Further, examining the percent change in mean CPUE for sablefish, shows a 169.8% (95% CLs: 38.9-327.9) increase in the semi-pelagic trawl over the conventional trawl (Fig. 5).

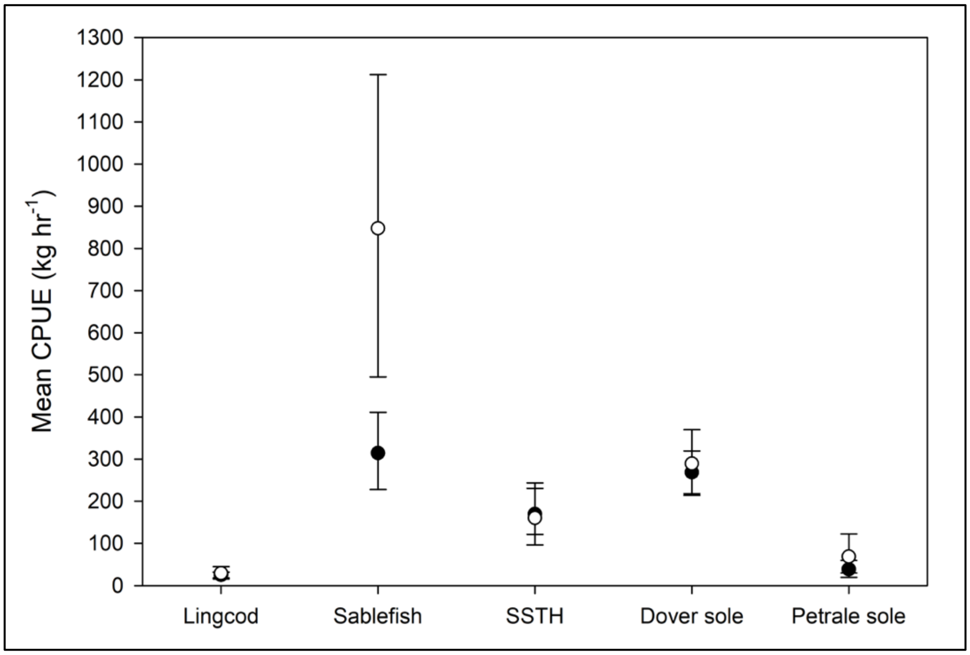

Figure 4. Comparison of mean CPUE (kg hr^{-1}) for lingcod, sablefish, shortspine thornyhead (SSTH), Dover sole, and petrale sole between the conventional trawl (closed circles) and semi-pelagic trawl (open circles). Circles are mean CPUE. Vertical lines are the 95% CLs.

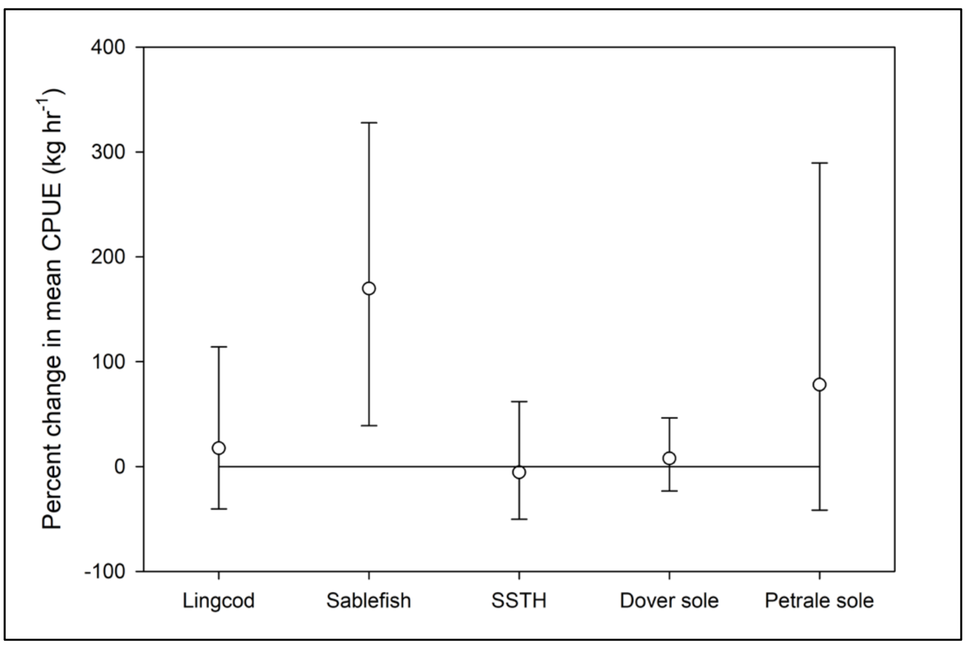

Figure 5. Percent change in mean CPUE (kg hr^{-1}) for the semi-pelagic trawl for lingcod, sablefish, shortspine thornyhead (SSTH), Dover sole, and petrale sole. Open circles are mean CPUE . Vertical lines are the 95% CLs.

3.2. Trawl seafloor-interactions

The trawl door sensors showed the semi-pelagic trawl exhibited a 42.1 m increase in door spread compared to the conventional trawl (150 vs. 107 m, respectively). Regarding door bottom contact (or the lack of), the bottom contact sensors placed on the midwater doors showed the doors on average fished a minimum of 0.8 m above the seafloor. Doors tracks from trawl paths of the semi-pelagic trawl were not identified by the DIDSON imaging sonar, confirming that the midwater doors were fishing off bottom. Moving fore to aft along the sweep of the semi-pelagic trawl, the mean distance between the bobbin tracks gradually increased from 8.1 to 11.1 m due to variation in the sweeps angle of attack. The overall mean distance between each bobbin track was 9.5 m. The mean furrow width of the bobbins created by the semi-pelagic trawl was 29 cm. For the conventional trawl, the DIDSON imaging sonar detected the door tracks (Fig. 6). The bobbin and footrope tracks created by the two trawls were also detected by the DIDSON sonar (Fig. 7). In terms of furrow widths created by the conventional trawl doors and sweeps, the DIDSON analysis measuring tool showed the doors created a mean furrow width of 53 cm while the bobbins created a mean furrow width of 27 cm. Moving fore to aft along the sweep's length, the mean distance between the bobbin tracks gradually increased from 8.8 m to 9.6 m. The overall mean distance between each bobbin track was 9.1 m.

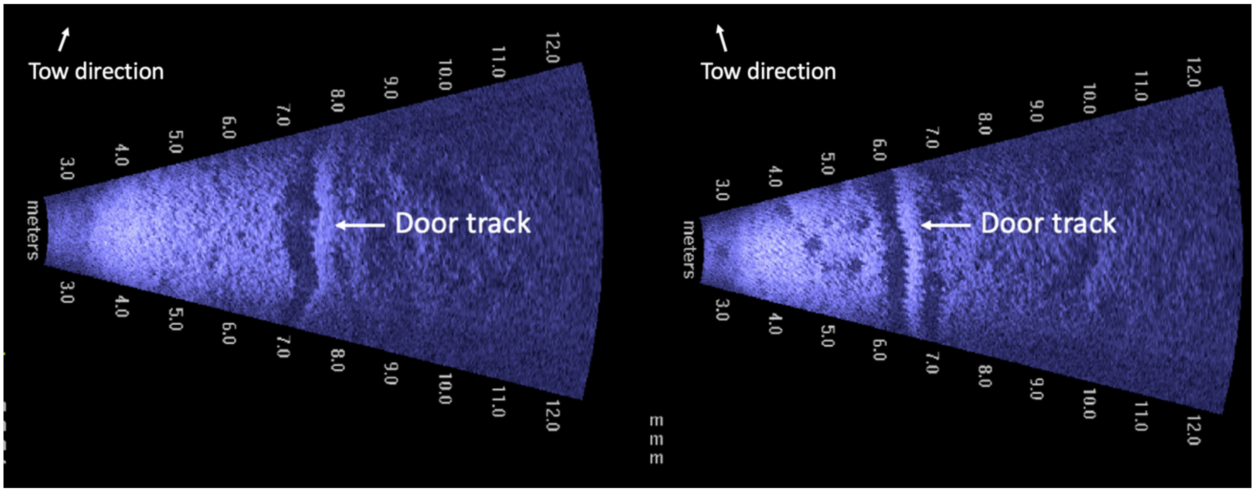

Figure 6. DIDSON imaging sonar frame grabs showing door tracks created by the conventional bottom door on two different tows.

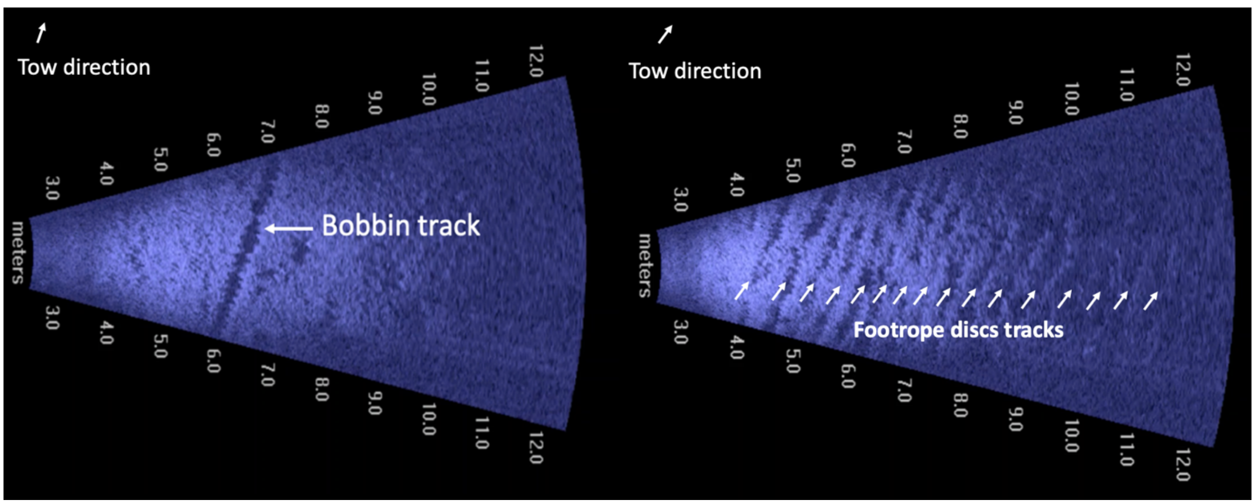

Figure 7. DIDSON imaging sonar frame grabs showing a bobbin track created by the elevated sweeps (left image), and an 8 m long section showing a portion of the tracks created by the footrope.

4. Discussion

We evaluated how changing from a conventional trawl rigged with bottom tending doors to a semi-pelagic trawl rigged with midwater doors affected the catch efficiency of demersal fishes in the West Coast groundfish bottom trawl fishery. Results showed that the semi-pelagic trawl had a higher mean CPUE for lingcod, Dover sole, and petrale sole compared to the conventional trawl. However, this increase in CPUE was not significant. For sablefish, there was a significant effect of trawl design with CPUEs of 874 and 314 kg hr^{-1} for the semi-pelagic and conventional trawls, respectively. In terms of trawl geometry, the presence of the low-aspect-ratio midwater doors fishing off bottom increased the door spread of the semi-pelagic trawl over the conventional trawl by 42.1 m. An increase in angle of attack of the sweeps near the trawl footrope resulted in an increase in the distance between the bobbin tracks. This larger fishing area swept by the semi-pelagic trawl when compared to the conventional trawl likely contributed to its significant increase in sablefish catches and trends of increased catches for lingcod, Dover sole, and petrale sole.

Bottom-tending trawl doors constitute a small portion (3-10%) of the groundgear that contacts the seafloor along the towline for any given trawl event (Valdemarsen et al., 2007). However, they are considered a significant source of bottom impact because of their large size, heavy weight, and wide angle of attack, which can impact structure-forming invertebrates (e.g., deep sea corals, sponges, sea pens), and the physical structure of seafloor habitats that can provide fish refuge (e.g., bedforms). In our study, we demonstrated the ability to replace conventional bottom-tending doors with midwater doors (that fish off bottom) rigged to a bottom trawl designed to harvest demersal fishes in the West Coast groundfish bottom trawl fishery. Further, we documented the trawl doors of the semi-pelagic trawl fished above the seafloor at a minimum height of 0.8 m, providing sufficient clearance for lower-profile epifaunal and infaunal organisms to pass under the doors without contact or disturbance. While we did not measure fuel efficiency or energy consumption during our study, Grimaldo et al. (2015) have shown semi-pelagic trawl gear to decrease energy consumption by 17.1% compared to conventional bottom trawl gear. It is likely that the semi-pelagic trawl gear that we evaluated exhibited a similar effect. However, further research to quantify the energy consumption between the two trawl designs is warranted.

Our study combined with Lomeli et al. (2019) demonstrates that modifications can be made to conventional bottom-tending doors and sweeps to reduce trawl-seafloor interactions and potential disturbances to benthic habitats and organisms. "Flying" the trawl doors off bottom and elevating long sections of the sweeps to fish above the seafloor can result in a reduction of door/sweep-seafloor interactions by >85%. Building off the present study and Lomeli et al. (2019), the next logical gear modification to make to further reduce trawl-seafloor interactions would be to the footrope. Conventional bottom trawls are constructed with footropes consisting of chain running through dense and tightly packed rubber discs along their length to raise and fix the altitude of the trawl's fishing line, ensure the gear maintains continuous seafloor contact, and protect the lower forward section of the trawl. Because of their heavy weight (often >1,500 kg, weight in air) and the configuration of the packed rubber discs, the footrope often digs into the seafloor creating furrows and other seafloor disturbances. However, digging into the seafloor and potentially disturbing infaunal organisms is not necessary for the footrope to effectively herd groundfishes into the mouth of the trawl. The footrope accounts for ~25% (by length) of the groundgear that contacts the seafloor. In terms of weight, the footrope is the second-heaviest component of the groundgear contacting the seafloor, with the doors being the heaviest. In the NE Atlantic groundfish trawl fishery, a novel lite-touch high density polyethylene (HDPE) semi-circular footrope design developed by SINTEF Ocean (Grimaldo, 2014), has been shown to increase the catch efficiency of cod and haddock when compared to a conventional rockhopper footrope (Larsen et al., 2018). Furthermore, the weight of the HDPE semi-circular footrope is ~67% lighter in air and 30% lighter in water than the conventional footrope. The unique semi-circular shape and reduced weight of this footrope prevents the footrope from digging into the seafloor, mitigating against furrowing, interactions with infaunal organisms (common prey items for many demersal groundfishes), and other seafloor disturbances. In the West Coast groundfish bottom trawl fishery, research testing the HDPE semi-circular footrope design and examining its footrope-seafloor interactions is recommended.

In conclusion, our research has demonstrated that semi-pelagic trawl gear can be effectively used to harvest demersal groundfishes in the West Coast groundfish bottom trawl fishery while significantly reducing trawl-seafloor interactions. In addition, our research addressed one of the Pacific Fishery Management Council's highest-priority Research and Data Needs for groundfish EFH, to "*test bottom trawl gear modifications that minimize bottom contact duration and intensity*" (PFMC, 2018), as well as statutory mandates in Magnuson-Stevens Act (MSA) Sec 408 to "*develop technologies or methods designed to assist fishing industry participants in reducing interactions between fishing gear and deep-sea corals*" (16 U.S.C. 1884 MSA § 408). Further, following the completion of this research, findings were presented to the Oregon Trawl Commission and Midwater Trawlers Cooperative (two groups representing Oregon trawlers). As a result of this outreach and education, some fishers have now switched from conventional trawl gear to semi-pelagic trawl gear with positive gear performance and catch efficiencies reported.

Acknowledgements

We thank the NOAA Fisheries Bycatch Reduction Engineering Program and Deep Sea Coral Research and Technology Program for project funding support (Award # NA20NMF4720274); the Oregon Trawl Commission for student funding support; the *F/V Last Straw* and *R/V Oceanus* for their assistance with this research; the NOAA Fisheries Northwest

Fisheries Science Center for use of research facilities and bottom contact sensors; Bent Herrmann for analysis assistance with the SELNET statistical software, and Meagan Abele for her participation during gear trials.

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*Scientific classification of the species listed in this final report: rockfishes (*Sebastes* spp.), sablefish (*Anoplopoma fimbria*), lingcod (*Ophiodon elongatus*), Dover sole (*Microstomus pacificus*), petrale sole (*Eopsetta jordani*), cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), Dungeness crab (*Metacarcinus magister*), brown box crab (*Lopholithodes foraminatus*), sea whips (*Stylatula* spp. & *Halipteris* spp.), sea pens (*Ptilosarcus gurneyi*), sea stars (Asteroidea), urchins (Echinoidea), sponges (Porifera), anemones (Cnidaria).