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Abstract:

This study examined the potential use of artificial illumination to enhance the escapement of Chinook salmon (*Oncorhynchus tshawytscha*) out an open escape window bycatch reduction device (BRD) in a midwater trawl fished in the Pacific hake (*Merluccius productus*) fishery. More specifically, can artificial illumination influence which escape window they utilize when exiting the BRD? Tests occurred off Oregon during 2013 aboard the *F/V Miss Sue*. Data was collected using video cameras and LED lights. Although a small sample size was examined, results showed Chinook salmon moved towards and out specific escape windows using artificial illumination ($P<0.04$). This finding follows similar results reported on Chinook salmon behavior in relation to this BRD. Chinook salmon escape times ranged from 4 seconds to 38.5 minutes. The mean was 9.5 minutes. Results from this project suggest artificial illumination could be used to enhance Chinook salmon escapement by attracting them towards escape openings on a BRD. Behavioral observations of widow rockfish (*Sebastes entomelas*) and Pacific hake in relation to the BRD are also reported.

Introduction:

The Pacific hake (*Merluccius productus*) fishery represents the largest groundfish fishery by volume off the U.S. West Coast with landings exceeding 267,000 mt in some years (NMFS-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 catcher-processor vessels. Although landed catches consist of mostly Pacific hake, bycatch of Chinook salmon (*Oncorhynchus tshawytscha*), a prohibited take species, is an issue affecting the fishery (Jesse, 2008; PFMC, 2008). While the catch ratio of Chinook salmon caught in the fishery is typically <0.03 fish per metric ton of Pacific hake (Jesse, 2008), there are concerns about bycatch because of the high volume of the Pacific hake fishery, and the incidental capture of ESA (Endangered Species Act)-listed Chinook salmon that occurs at times. Currently, the National Marine Fisheries Service (NMFS) has a biological opinion issued (under the Magnuson-Stevens Fishery Conservation and Management Act on threatened and endangered species, pursuant to section 7 of the Endangered Species Act) in the Pacific Coast groundfish fishery addressing the potential effects of Chinook salmon caught as bycatch in the Pacific hake fishery. If the overall fishery exceeds or is expected to exceed a Chinook salmon bycatch ratio of 0.05 fish per metric ton of Pacific hake and the bycatch of Chinook salmon is expected to exceed 11,000 fish, consultation of the biological opinion will be reinitiated. Developing techniques that reduce Chinook salmon bycatch in West Coast groundfish trawl fisheries are increasingly important to industry and management.

Since 2009, the Pacific States Marine Fisheries Commission (PSMFC), NOAA Fisheries Northwest Fisheries Science Center-Marine Habitat Ecology group, and fishing industry have worked on developing an open escape window bycatch reduction device (BRD) designed to reduce Chinook salmon bycatch in the Pacific hake fishery. This BRD design consists of two square-mesh ramps that are used to guide actively swimming fish towards two large sets of escape windows that have been cut out of each side of the net on the upper portions of the port and starboard side panels of the net (Fig. 1). The concept is that fish displaying strong swimming abilities (i.e. Chinook salmon) can escape through the open windows, whereas fish exhibiting weaker swimming abilities (i.e. Pacific hake) will pass into the codend.

During the 2009 and 2010 field season, we conducted research on the BRD that is the subject of the current study. Data on fish behavior and escapement rates were collected using underwater video cameras and LED lights. Results showed Chinook salmon bycatch was reduced by 63.0%. While the research focus was not to examine the effect of artificial illumination on Chinook salmon escapement, our analysis showed that artificial illumination did influence their behavior as 14 of the 17 (82.4%) Chinook salmon exited out a window where artificial illumination was directed ($P<0.02$). In one instance, a Chinook salmon was noted to exit the forward escape window where the artificial illumination was directed, and then, seconds later, the same fish bumped into the outside of the BRD tube with its snout where the source of the artificial illumination was located before finally swimming away from the trawl. In 2011, the BRD was further tested under “normal” fishing conditions (without the use of video cameras and lights). Escapement of Chinook salmon was quantified using a recapture net. Results showed escapement occurred in only three of the 14 Chinook salmon encountered, 21.4%. When examining the recapture net during preliminary tows to assure the gear was performing as expected (using cameras and lights) one Chinook salmon was observed and it exited the BRD out the escape window where the artificial illumination was positioned. These data suggests that the use of artificial illumination may further enhance the escapement of Chinook salmon by attracting them towards the open escape window areas of the BRD.

The objective of this study was to examine the potential use of artificial illumination to enhance the escapement rates of Chinook salmon out an open escape window BRD in a midwater trawl fished in the Pacific hake fishery. More specifically, can artificial illumination influence which escape window they utilize when exiting the BRD?

Materials and Methods:

Tests were conducted off central Oregon between 43^{o}46′ and 45^{o}30′N and between 124^{o}11′ and 124^{o}57′W during June 2013 aboard the chartered *F/V Miss Sue*; a 24.7 m long, 640 horsepower midwater trawler (Fig. 2). The *F/V Miss Sue's* trawl was used for this project with headrope, footrope, and mouth opening measurements of 125, 164, and 36 m, respectively. Towing occurred over the continental shelf between 74 and 247 m. Average bottom depth was 128 m (SE ±17 m). Towing speed ranged from 2.7 to 3.2 knots. Tow durations were set not to exceed 3 hours to assure the video cameras had sufficient battery power to capture the entire tow.

This research examined the use of artificial illumination to enhance the escapement rates of Chinook salmon out an open escape window BRD in a Pacific hake midwater trawl. The BRD is built around a four-seam tube of netting that is 135 meshes deep and 136 meshes in circumference, excluding meshes in each selvedge (Fig. 1). The BRD was designed to be inserted between the intermediate section of the trawl and the packer/stuffing tube forward of the codend. This BRD design consists of two square-mesh ramps that are inserted inside the BRD tube and used to guide actively swimming fish towards two large sets of escape windows that have been cut out of each side of the tube on the upper portions of the port and starboard side panels of the net.

To examine the influence of artificial illumination on Chinook salmon escapement, a randomized block design approach was used to determine the sequence in which the port and starboard side escape windows were illuminated. DeepSea Power & Light (DSPL) LED Multi-SeaLites® Matrix lights (equivalent to a 250-watt halogen light; white light; 2600 lumens) were used for illumination. One light was placed at each escape window selected from the randomized block design. Each light was placed inside the trawl against the top gore of the net, positioned at the forward most portion of the escape window, and pointed outwards away from the BRD in a 45^{o} angle. Light intensity was measured using Wildlife Computers TDR-MK9 archival tags. Following this study the MK9 tags were calibrated using an International Light IL1700 light meter and PAR sensor. Categorical data (i.e. did the fish exit out the escape window that was illuminated, yes or no) was collected and analyzed using a one-proportion test to determine if artificial illumination significantly influenced ($P<0.05$) which escape window Chinook salmon utilized when exiting the BRD. Only escapes occurring at trawl depths were used when running the one-proportion test. Chinook salmon to exit the BRD near the surface under ambient light levels (i.e. during haulback) were not included when analyzing the data.

Data on fish behavior, escapement rates and escape times were collected using GoPro® Hero2 cameras (placed in 1,000 m rated pressure housings) equipped with DSPL LED Mini-Sealites® (equivalent to a 100-watt halogen light; white light; 850 lumens). Cameras and lights were mounted in rotating aluminum turrets set into ultra-high-molecular-weight (UHMW) boards (15.9 x 5.9 x 0.4 cm). These boards were used to attach the camera systems to the trawl. Just aft of each set of escape windows a camera system was positioned horizontally against the top panel of the net to record fish as they entered and interacted with the BRD. During each deployment, the light side of the camera/light mounting board was attached to the top gore of the BRD tube and positioned to look directly forward towards the escape window selected to be illuminated. For example, if the starboard side escape windows were selected to be illuminated, then the light side of the camera/light mounting boards would be attached to the starboard side top gore and positioned to look directly forward (Fig. 1). The distance between the camera/light mounting board and the light illuminating the escape window was approximately 7.2 m and 4.7 for the forward and aft set of escape windows, respectively.

Unsorted codend catches were delivered to a shore-side processing plant where data on catch compositions were collected via fish tickets. Combined, data collected from the video camera systems and fish ticket data allowed for an accurate measurement of fish escapement. Fish encountered during this work and reported in the results are Chinook salmon, Pacific hake, widow rockfish (*Sebastes entomelas*), and a canary rockfish (*S. pinniger*).

Results:

A total of 14 tows were conducted resulting in 10 Chinook salmon observations. Landed catches of Pacific hake per tow ranged from trace amounts to 55 mt. Escapement occurred in nine of the 10 Chinook salmon encountered, 90.0%. When interacting with the BRD salmon were observed to have a tendency to remain on the side of the trawl that was most illuminated. The total time that Chinook salmon spent on the illuminated side of the trawl as opposed to the non-illuminated side (when in the field of view of the camera) was 84.4% versus 15.6%, respectively. During haulback, near the surface and under ambient light, two Chinook salmon escaped. At trawl depths, seven escapes occurred with six fish (85.7%) exiting the BRD out an illuminated escape window. This result was significant ($P<0.05$). At trawl depths, the approximate mean light level recorded when Chinook salmon where encountered was 1.99E-02 μmol photons m^{-2} s^{-1} (SE ±5.2E-04). Escape times ranged from 4 seconds to 38.5 minutes (Table 1). The mean escape time was 9.5 minutes. Observed Chinook salmon behaviors are summarized in Table 1.

A 32.4% reduction in rockfish bycatch was observed during this work with 24 of 74 widow rockfish and 1 of 1 canary rockfish noted to escape. In contrast to the behavior observed in Chinook salmon, widow rockfish did not select towards an illuminated escape window when exiting the BRD ($P>0.05$). Widow rockfish, however, did show a tendency to escape using the aft set of escape windows as 78.3% of the fish that escaped exited using this set of escape windows. For Chinook salmon, only 33.3% were observed to exit using the aft set of escape windows. Rockfish escape times ranged from 9 seconds to 43.8 minutes.

Differences in widow rockfish behavior were observed when they interacted with the BRD at trawl depths and at haulback. Observations at trawl depths showed widow rockfish actively swimming up and down throughout the BRD area (vertically between the bottom and top panels of the net), whereas during haulback they moved down to the bottom panel of the trawl and vigorously attempted to swim forward. Eventually they would turn and swim aft towards the codend, still remaining near the bottom panel of the trawl, as the trawl neared the surface. This observation suggests a BRD that has a bottom escape mechanisms could potentially increase widow rockfish escapement. As for Chinook salmon, no difference in their behavior was observed between trawl depths and haulback. Pacific hake were noted to be tumbling, passively drifting, or actively swimming but still drifting aft towards the codend during the tow process.

Segments of video footage of Chinook salmon observed during this project can be viewed at the PSMFC Pacific Fisheries Bycatch Program website at: http://www.psmfc.org/bycatch/videos.html

Discussion:

Studies have demonstrated that light can affect the behavior of fish in and around trawl gear (Ryer and Barnett, 2006; Ryer and Olla, 2000; Walsh and Hickey, 1993) and that vision is the primary sense affecting fish behavior in relation to trawl gear (Glass and Wardle, 1989; Kim and Wardle, 1998, 2003; Olla et al., 1997, 2000; Ryer et al., 2010). In the current study, we examined an open escape window BRD in a midwater trawl fished in the Pacific hake fishery and examined if artificial illumination can influence which escape window they utilize when exiting the BRD. Although a limited number of Chinook salmon were encountered, results showed Chinook had the tendency to exit the BRD out an escape window that was illuminated ($P<0.05$). This finding is similar to prior results reported for this BRD by Lomeli and Wakefield (2012); 14 of 17 Chinook salmon escaped out a window that was artificial illuminated($P<0.01$). Though the current study and work by Lomeli and Wakefield (2012) are not directly comparable, these data suggest that artificial illumination could affect which escape window Chinook salmon utilize when exiting an open escape window BRD in a Pacific hake midwater trawl. Combining the data from the current project with data from Lomeli and Wakefield (2012), a total of 20 of 24

Chinook salmon escaped out an escape window that was directly illuminated or that artificial illuminating was directed towards (P<0.0001).

In contrast to Chinook salmon, widow rockfish did not select an illuminated escape window when exiting the BRD (P>0.05). However, they did show a tendency to escape using the aft set of escape windows. This result was also observed in the work by Lomeli and Wakefield (2012). One possible explanation for this result could be changes in water flow within the BRD and the swimming ability of widow rockfish. While water flow was not measured, video observations of fish encountering the BRD showed fish swimming more vigorously when interacting with the forward set of escape windows as compared to the aft set. This suggests water flow in the aft section of the BRD was more favorable towards the swimming capability of widow rockfish and their ability exit the BRD.

Measuring escapement rates for Chinook salmon and rockfishes was possible in the present study using video cameras. However, the video cameras were not effective at quantifying the escapement rates of Pacific hake because of the large volumes encountered at times. Although we were unable to quantify the escapement rates of Pacific hake in the current study, escapement of Pacific hake out this BRD was quantified in 2011 using a recapture net. The observed escapement was 1.2% (NMFS BREP 2011).

In summary, this study demonstrated the ability to attract Chinook salmon towards and out specific escape windows of the BRD using artificial illumination. Although this study examined a small sample size of Chinook salmon, current project findings follow previous research results reported on Chinook salmon behavior in relation to this BRD (Lomeli and Wakefield, 2012; NMFS BREP, 2011). However, it is important to note that further testing continue over a range of fishing conditions (i.e. catch volumes, light levels, tow durations), gear designs, and vessel sizes to better determine the potential efficacy of artificial illumination as a tool to enhance Chinook salmon escapement in the Pacific hake fishery.

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Table 1. Observed behaviors of Chinook salmon encountered during this project.

Tow	Side of illumination	Chinook salmon	Escape	Escape at Trawl Depths (Y/N)	Escape out an illuminated window (Y/N)	Movements towards exiting out an non-illuminated window	Time to escape (min:sec)	Observed Chinook salmon behaviors
1	starboard	1	Y	N	n/a	n/a	14:00	Remains aft the second set of escape windows, rarely observed on video, escapes during haulback under ambient light conditions.
5	starboard	2	Y	Y	Y	1	13:22	Starts to exit out the port window then turns and swims across the BRD to exit out the illuminated starboard window. After exiting the trawl this fish briefly remains near the light before slowly swimming away.
5	starboard	3	N	-	-	0	-	Briefly observed aft of the second set of escape windows.
6	port	4	Y	Y	Y	0	0:06	Encounters the BRD and then immediately begins swimming towards and out an illuminated window.
6	port	5	Y	Y	Y	0	3:14	Primarily remained on the illuminated side of the trawl while interacting with the BRD.
9	starboard	6	Y	Y	Y	0	6:40	From the aft portion of the second set of escape windows this fish darts and then swims diagonally across the BRD (port to starboard) to exit out the illuminated starboard window.
12	port	7	Y	Y	Y	2	7:52	Primarily remained on the illuminated side of the trawl. While interacting with the BRD this fish swims towards the non-illuminated window twice before stopping and swimming back towards the illuminated side of the trawl.
12	port	8	Y	Y	Y	0	2:08	Primarily remained on the illuminated side of the trawl while interacting with the BRD.
14	starboard	9	Y	Y	N	1	0:04	Rapidly enters the BRD and then quickly exits out a non-illuminated window.
14	starboard	10	Y	N	n/a	n/a	38:35	Interacts with the BRD area for several minutes before ultimately exiting the BRD during haulback under ambient light conditions.

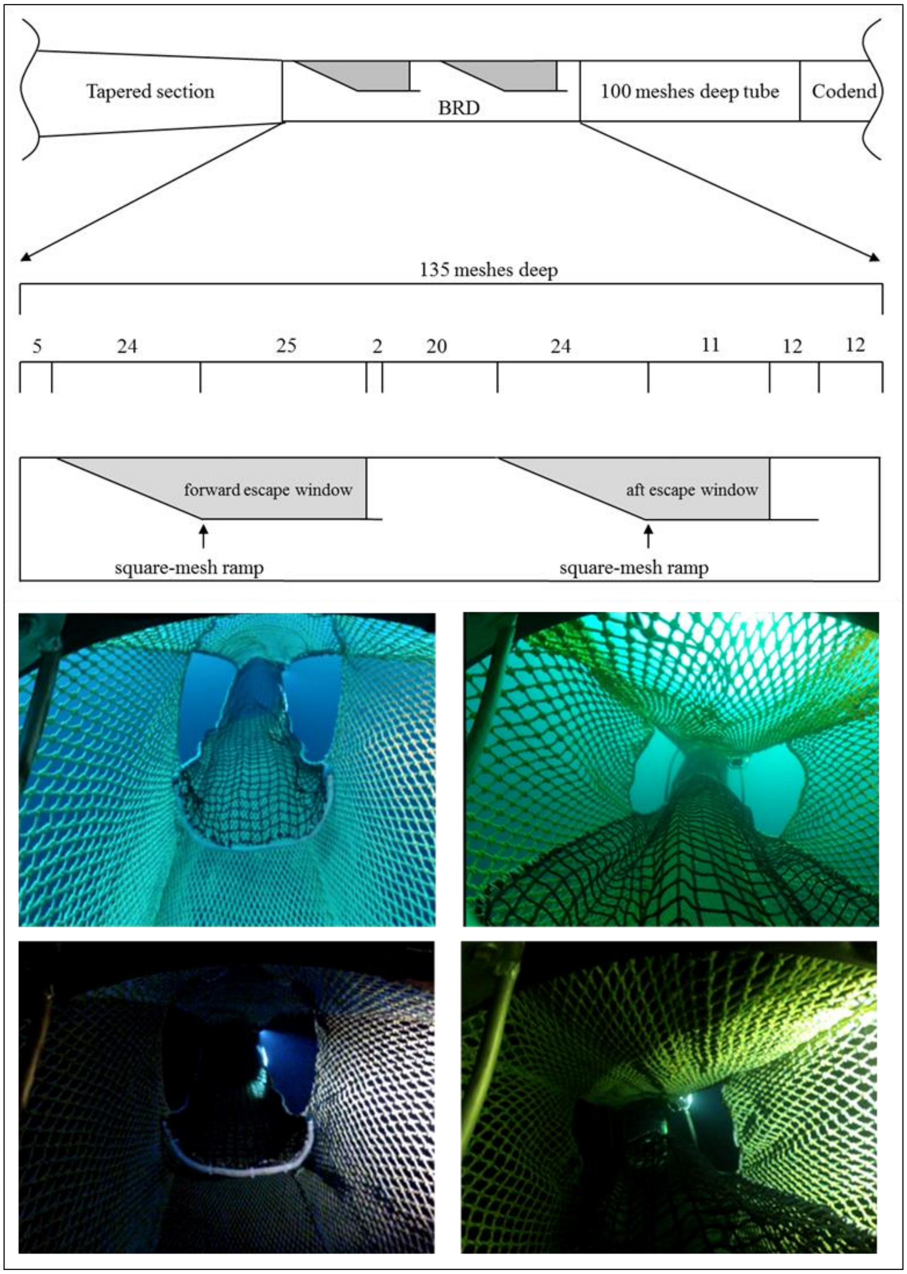

Figure 1. Schematic diagram of the open escape window BRD tested (top); forward view of the forward set of escape windows during haulback under ambient light (upper left image); forward view of the forward set of escape windows at trawl depth where the starboard side escape window is being illuminated (bottom left image); forward view of the aft set of escape windows during haulback under ambient light (upper right image); forward view of the aft set of escape windows at trawl depth where the starboard side escape window is being illuminated (bottom right image).

Figure 2. *F/V Miss Sue* chartered for the research project.