Artificial light: Its influence on Chinook salmon escapement out a bycatch reduction device in a Pacific hake midwater trawl

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: Tel.: 541 867-0544, Fax: 541 867-0505, email: mlomeli@psmfc.org

This document should be cited as follows:

Lomeli, M.J.M., and W.W. Wakefield. 2016. Artificial light: Its influence on Chinook salmon escapement out a bycatch reduction device in a Pacific hake midwater trawl. Pacific States Marine Fisheries Commission Report, 16 pp.

Abstract:

The Pacific hake (*Merluccius productus*) midwater trawl fishery represents the largest groundfish fishery by volume along the U.S. west coast. While landed catches consist of mostly Pacific hake, bycatch of Chinook salmon (*Oncorhynchus tshawytscha*) is an issue affecting the fishery. Although the catch ratio of Chinook salmon caught in the fishery is typically <0.03 fish per metric ton of Pacific hake, bycatch is a concern because of the high volume of the fishery and the incidental capture of Endangered Species Act listed salmon. In this study, we examined the use of artificial light as a technique to reduce Chinook salmon bycatch. Specifically, we tested if Chinook salmon can be attracted towards and out specific escape windows/openings of a bycatch reduction device (BRD) using artificial light. Data on fish behavior and escapement was collected using underwater video camera systems. During sea trials, video observations were made on 437 Chinook salmon with escapement occurring in 298 individuals (68.2% of fish). At trawl depths, 266 Chinook salmon escaped with 230 individuals (86.5% of fish) exiting out a window that was illuminated. This result was highly significant (P<0.00001). These data show that light can influence where Chinook salmon exit a BRD, but also suggest that light could be used to enhance their escapement overall.

Introduction:

The Pacific hake (*Merluccius productus*) fishery represents the largest groundfish fishery by volume along the U.S. west coast. In 2014, landings reached 263,595 mt resulting in an ex-vessel value of ca. $58.6 million (PacFIN, 2014). 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. 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 of Chinook salmon (*Oncorhynchus tshawytscha*), a prohibited species that currently has nine Endangered Species Act (ESA) listed Evolutionary Significant Units (ESUs), is an issue that can affect the fishery (PFMC, 2008; NMFS WCR, 2014a).

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 ESA) in the Pacific coast groundfish fishery addressing the potential effects of Chinook salmon bycatch in the Pacific hake fishery. Within a calendar year, 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 or the bycatch of Chinook salmon is expected to exceed 11,000 fish, ESA consultation of the biological opinion will be re-initiated. Exceeding one of these thresholds also requires NMFS to implement the Ocean Salmon Conservation Zone (NMFS WCR, 2014b). This conservation zone prohibits vessels targeting Pacific hake from fishing shoreward of the 183 m depth contour line, where increased Chinook salmon bycatch rates typically occur. In 2014, the fishery exceeded the 11,000 Chinook salmon bycatch threshold; which affected fishermen's access to the Pacific hake stock. Hence, developing techniques that minimize Chinook salmon bycatch are important to the fishermen, coastal communities, management, and the recovery of ESA listed salmon ESUs.

Bycatch reduction research in the Pacific hake fishery, suggested that artificial light could be used to influence Chinook salmon escapement out a bycatch reduction device (BRD). During 2009 and 2010, Lomeli and Wakefield (2012) 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. While the study was not focused on the effect of artificial light on behavior of Chinook salmon, their analysis showed 14 of 17 (82.4%) Chinook salmon exiting out a window where artificial light was directed ($P<0.02$). In 2013, Lomeli and Wakefield (2014) specifically tested if artificial light could influence which BRD escape window Chinook salmon utilize. A randomized block design was used to determine the sequence in which the port- and starboard-side escape windows were illuminated. During this study, video observations were made on 10 Chinook salmon with escapement occurring in nine of the individuals encountered. Although a small sample size of Chinook salmon was examined, the study demonstrated the ability to attract individuals towards and out specific escape windows of the BRD using artificial light.

The objective of the current study was to continue testing the effect of artificial light on Chinook salmon behavior and its ability to attract individuals towards and out specific escape areas of the BRD.

Materials and Methods:

BRD design

The BRD used was built around a four-seam tube of 101.6 mm diamond netting (knot-knot measurement) that is 135 meshes deep and 136 meshes in circumference, excluding meshes in each selvedge. The gear is design to be inserted into the intermediate section of the trawl. This BRD design consists of two square-mesh ramps that are inserted inside the BRD tube of netting 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 (Fig. 1). This BRD is the same gear tested by Lomeli and Wakefield (2012), but with a larger aft escape window opening area.

Sea trials and sampling

Sea trials occurred aboard the *F/V Miss Sue*, a 24.7 m long, 640 horsepower trawler out of Newport, Oregon. 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. We completed 16 tows off Oregon between 43º30′ and 45º09′N and between 124º17′ and 124º55′W, in September 2015 during daylight hours (Fig. 2). Average headrope fishing depth was ca. 137 m while the average seafloor depth was ca. 194 m. Towing speed ranged from 2.7 to 3.2 knots. Tow durations were set not to exceed 3.5 hours to assure the video cameras (detailed below) had sufficient memory and battery power to capture the entire tow.

Lindgren-Pitman (LP) Electralume® LED blue lights (centered on 460 nm wavelength, ≥0.5–2.0 lx) were used in this experiment to test if artificial light could influence which escape window Chinook salmon use when exiting the BRD. Blue light was selected as it penetrates well through open ocean water. The sequence in which the port- and starboard-side escape windows were illuminated was randomly selected (e.g., ABBA, ABAB). For example, if the port-side window was selected then lights would be attached to the forward and aft escape windows of the port-side. The LP lights were attached over the distance of an escape window to the outermost mesh of the top panel inside the trawl at ca. 60.9 cm apart. For a forward escape window, 16 LP lights were used for illumination, whereas 12 LP lights were used to illuminate an aft escape window.

Data on fish behavior and escapement rates were collected using GoPro® Hero cameras placed in aluminum housing units. Because the LP lights could not provide enough light for the GoPro® cameras to obtain a clear image of the BRD area, a DeepSea Power and Light nano Sealite® (color = white; color temperature = 6500-8000K; lumens = 700; beam pattern 70º flood) was used with each camera to provide the necessary light for a suitable imagery. The cameras and lights were mounted on ultra-high-molecular-weight boards (60.9 x 30.4 x 2.54 cm L x W x H). Each camera system was placed inside the trawl against the top panel of the net, three meshes aft of each escape window set, to record fish as they entered and interacted with the BRD. The boards were positioned with the nano Sealites® centered against the top panel of the trawl, evenly illuminating the BRD area. Therefore, the only change in areas illuminated by artificial light was due to the location of the LP lights. Categorical data (e.g., did the fish exit out the escape window that was illuminated, yes or no) was collected and analyzed using a one-proportion test. Acknowledging that Chinook salmon may exhibit different behavioral effects under ambient light conditions, data collected at trawl depths (in the absence of ambient light) and during haulback operations (near the sea surface) were analyzing separately.

Light levels were measured using a Wildlife Computers TDR-MK9 archival tag attached, facing upward, to the frontward center section of the forward square-mesh ramp. Prior to field sampling, the MK9 tag was calibrated using an International Light IL1700 light meter and PAR sensor. The calibration function used to convert the MK9 relative light units to irradiance units was:

y = 1 × 10−9e0.1476x

where x is the relative light unit from the MK9 and y is the corresponding irradiance unit in mol photons m−2s−1.

Results:

Video observations were made on a total of 437 Chinook salmon with escapement occurring in 298 individuals (68.2% of fish, Table 1). At trawl depths, 266 Chinook salmon escaped with 230 individuals (86.5% of fish) exiting out a window that was illuminated (Table 2). This result was highly significant ($P<0.00001$). On a few occasions, individuals would begin swimming towards and out a non-illuminated window before changing direction and swimming across the net to exit out the illuminated window. During haulback, when the BRD was near the sea surface, 32 Chinook salmon escaped with 12 fish exiting out an illuminated window (Table 3). This finding was not significant ($P=0.2153$). However, observing an equal proportion of fish to exit out illuminated- and non-illuminated-windows would be anticipated under these conditions (light levels >4.75E-01 µmol photons m^{-2} s^{-1}) as the LED lights are nearly non-detectable at the surface. Mean light levels at trawl depths ranged from 1.02E-03 to 6.26E-03 µmol photons m^{-2} s^{-1} with a mean of 3.49E-03 (Table 4).

Additional fish species observed, but encountered in too large of numbers to enumerate, included Pacific hake, Pacific herring (*Clupea pallasii*), and widow (*Sebastes entomelas*), yellowtail (*S. flavidus*), and shortbelly (*S. jordani*) rockfishes. When encountering the BRD area, Pacific herring and shortbelly rockfish would generally school near the top panel of the BRD and remain in the trawl until haulback, at which time they would exit the BRD in large numbers. Juvenile Pacific hake (ca. 20-30 cm in total length) were primarily encountered. Observations showed they rarely were able to swim forward in the trawl with most individuals either tumbling or passively drifting back towards the codend. Widow and yellowtail rockfishes moved throughout the BRD area before either exiting out the BRD or drifting back to the codend. While in the net, these rockfishes were often observed net feeding on Pacific herring. On one occasion, a Chinook salmon was noted to net feed on a shortbelly rockfish. With the exception of Chinook salmon, artificial light did not appear to influence which escape window fish utilized when exiting the BRD.

Various 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, Hannah et al., 2015) 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 demonstrated the ability to attract Chinook salmon towards and out specific escape windows of the BRD using artificial light. This finding supports previous research suggesting that light can influence where Chinook salmon exit this BRD (Lomeli and Wakefield 2012, 2014). While the mechanism(s) triggering Chinook salmon to exhibit this behavior is unclear, we hypothesize that the lights are enhancing their ability to perceive one escape area (e.g., illuminated window), and the nearby surroundings outside the trawl, more than the other (e.g., non-illuminated window).

Results from the current study and reports for this BRD by Lomeli and Wakefield (2012, 2014), where lighted cameras were used, differ from findings noted in 2011 when the BRD was tested under normal fishing conditions (e.g., without the use of lighted cameras) aboard the *F/V Predator*. Fish escapement was quantified using a recapture net. Escapement of Chinook salmon was low as only 3 of 14 individuals (21.4%) encountered exited the BRD. Chinook salmon were noted in five of the 15 tows made. The mean catch loss of Pacific hake was minimal, 1.2% by weight (NMFS BREP, 2011). Although the above studies are not directly comparable, as they occurred under different fishing operations and volumes of Pacific hake, these results suggest that the use of artificial light might possibly enhance Chinook salmon escapement overall. An alternate haul study design comparing Chinook salmon escapement rates between tows made with and without the use of artificial light would contribute valuable information to this area of research.

In this study, a large sample size of Chinook salmon was analyzed. Results showed artificial light significantly affected their behavior and could attract them towards and out specific escape areas of the BRD. While positive results were achieved, scientific questions remain as to how light intensity, color, and placement around escape areas of BRDs, and type of BRD design being illuminated can affect Chinook salmon escapement. The BRD examined in this study is one of a few salmon excluder designs being used in the fishery. While the designs used differ in configuration, the concept of the devices used are the same (e.g., large open escape areas to allow Chinook salmon to exit). Finally, while this study was conducted in the Pacific hake fishery, the results have potential applications in west coast and Alaska bottom trawl fisheries and the walleye pollock (*Theragra chalcogramma*) midwater trawl fishery in Alaska where Chinook salmon bycatch also occurs.

Acknowledgements

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

References:

Glass, C.W., Wardle, C.S., 1989. Comparison of the reactions of fish to a trawl gear, at high and low light intensities. Fish. Res. 7, 249-266.

Hannah, R.W., Lomeli, M.J.M., Jones, S.A. 2015. Tests of artificial light for bycatch reduction in an ocean shrimp (*Pandalus jordani*) trawl: strong but opposite effects at the footrope and near the bycatch reduction device. Fish. Res. 170: 60-67.

Kim, Y.H., Wardle, C.S., 1998. Modeling the visual stimulus of towed fishing gear. Fish. Res. 34, 165-177.

Kim, Y.H., Wardle, C.S., 2003. Optomotor response and erratic response: quantitative analysis of fish reaction to towed fishing gears. Fish. Res. 60, 455 – 470.

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. 2014. Examining the potential use of artificial illumination to enhance Chinook salmon escapement out a bycatch reduction device in a Pacific hake midwater trawl. NMFS Northwest Fisheries Science Center Report, 15 pp.

National Marine Fisheries Service, West Coast Region (NMFS, WCR). 2014a. Implementation of the ocean salmon conservation zone and reapportionment of darkblotched rockfish between catcher/processor and mothership sectors. NMFS-SEA-14-23, October 17, 2014. National Marine Fisheries Service, West Coast Region, 7600 Sand Point Way NE, Seattle, WA 98115. www.westcoast.fisheries.noaa.gov/index.html

National Marine Fisheries Service, West Coast Region (NMFS, WCR). 2014b. Federal pacific coast groundfish regulations for commercial and recreational fishing 3-200 nautical miles off Washington, Oregon, and California. 50 CFR part 660, subparts c – g, 441 pp.

NMFS-BREP Report. 2011. Annual Report to Congress on the Bycatch Reduction Engineering Program. http://www.nmfs.noaa.gov/by_catch/bycatch_BREP.htm

Olla, B.L., Davis, M.W., Schreck, C.B., 1997. Effects of simulated trawling on sablefish and walleye pollock: the role of light intensity, net velocity and towing duration. J. Fish. Biol. 50, 1181-1194.

Olla, B.L., Davis, M.W., Rose, C., 2000. Differences in orientation and swimming of walleye pollock *Theragra chalcogramma* in a trawl net under light and dark conditions: concordance between field and laboratory observations. Fish. Res. 44, 261-266.

PacFIN (Pacific Fisheries Information Network) report # 020Wtwl. 2014. Pacific States Marine Fisheries Commission, Portland, Oregon. http://pacfin.psmfc.org/.

PFMC (Pacific Fishery Management Council), 2008. Pacific Coast Groundfish Fishery Stock Assessment and Fishery Evaluation, Volume 1. Pacific Fishery Management Council, Portland, OR. March 2008.

Ryer, C.H., Barnett, L.A.K., 2006. Influence of illumination and temperature upon flatfish reactivity and herding behavior: potential implications for trawl capture efficiency. Fish. Res. 81, 242-250.

Ryer, C.H., Olla, B.L., 2000. Avoidance of an approaching net by juvenile walleye Pollock *Theragra chalcogramma* in the laboratory: the influence of light intensity. Fish. Res. 45, 195-199.

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.

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.

Table 1. Chinook salmon catch data (trawl depths and haulback combined) for the 16 tows conducted. S = starboard; P = port. n/a = sample size too small to run test. Values in parentheses represent upper and lower 95% confidence interval limits surrounding the mean value.

		Overall			
Tow	LED side	# observed	# in codend	# to escape	% escapement
1	S	117	33	84	71.8
2	P	6	6	0	0
3	P	0	0	0	-
4	S	11	5	6	54.6
5	P	51	17	34	66.7
6	S	25	6	19	76.0
7	P	3	0	3	100.0
8	S	12	7	5	41.7
9	P	34	10	24	70.6
10	S	26	10	16	61.5
11	S	11	2	9	81.8
12	P	38	14	24	63.2
13	P	11	3	8	72.7
14	S	53	8	45	84.9
15	P	15	8	7	46.7
16	S	24	10	14	58.3
Total		437	139	298	68.2 (63.8-72.6)

Table 2. Chinook salmon exiting the BRD at trawl depths for the 16 tows conducted. S = starboard; P = port. n/a = sample size too small to run test. Values in parentheses represent upper and lower 95% confidence interval limits surrounding the mean value.

		At trawl depths			
Tow	LED side	# to escape	# escape out illuminated window	% escape out illuminated window	P-value
1	S	73	67	91.8	<0.0001
2	P	0	-	-	n/a
3	P	-	-	-	n/a
4	S	6	5	83.3	n/a
5	P	32	27	84.4	0.0001
6	S	17	16	94.1	0.0003
7	P	3	3	100.0	n/a
8	S	5	5	100.0	n/a
9	P	21	19	90.5	0.0002
10	S	14	12	85.7	0.0130
11	S	6	6	100.0	n/a
12	P	19	15	79.0	0.0192
13	P	7	5	71.4	n/a
14	S	45	38	84.4	<0.0001
15	P	7	6	85.7	n/a
16	S	11	6	54.6	1.0000
Total		266	230	86.5 (82.4-90.6)	<0.0001

Table 3. Chinook salmon exiting the BRD during haulback for the 16 tows conducted. S = starboard; P = port. n/a = sample size too small to run test. Values in parentheses represent upper and lower 95% confidence interval limits surrounding the mean value.

	At haulback			
Tow	# to escape	# escape out illuminated window	% escape out illuminated window	P-value
1	11	6	54.5	1.000
2	0	-	-	-
3	0	-	-	-
4	0	-	-	-
5	2	0	0.0	n/a
6	2	0	0.0	n/a
7	0	-	-	-
8	0	-	-	-
9	3	2	66.7	n/a
10	2	1	50.0	n/a
11	3	0	0.0	n/a
12	5	2	40.0	n/a
13	1	1	100.0	n/a
14	0	-	-	-
15	0	-	-	-
16	3	0	0.0	n/a
Total	32	12	37.5 (20.7-54.3)	0.2153

Table 4. Mean MK9 archival tag data recorded at trawl depths for the 16 tows conducted. n/a = data not available.

Tow	Depth (m)	Temperature (°C)	Light level (µmol photons m^{-2} s^{-1})
1	154	8.66	1.16E-03
2	239	7.44	2.83E-03
3	212	7.42	1.54E-03
4	217	7.79	4.90E-03
5	192	8.08	1.02E-03
6	171	8.21	1.04E-02
7	202	7.94	5.21E-03
8	156	8.18	4.00E-03
9	164	8.26	3.60E-03
10	201	7.86	5.08E-03
11	185	8.16	n/a
12	219	7.56	2.18E-03
13	215	7.47	1.67E-03
14	211	7.68	3.09E-03
15	178	7.93	2.86E-03
16	180	8.06	6.26E-03

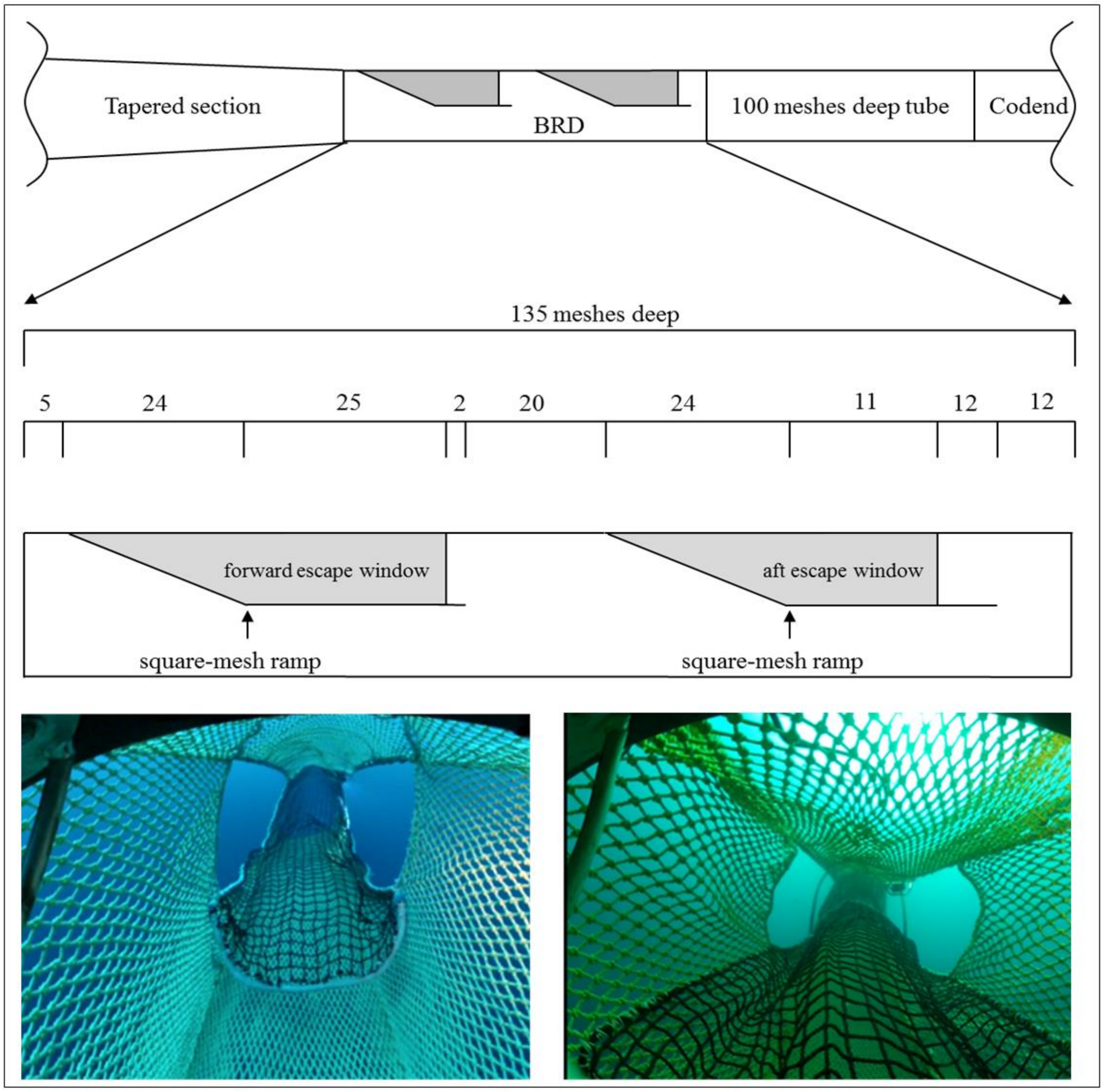

Figure 1. Schematic diagram of the open escape window BRD testing (top); forward view of the forward set of escape windows under ambient light (left image); forward view of the aft set of escape windows under ambient light (right image).

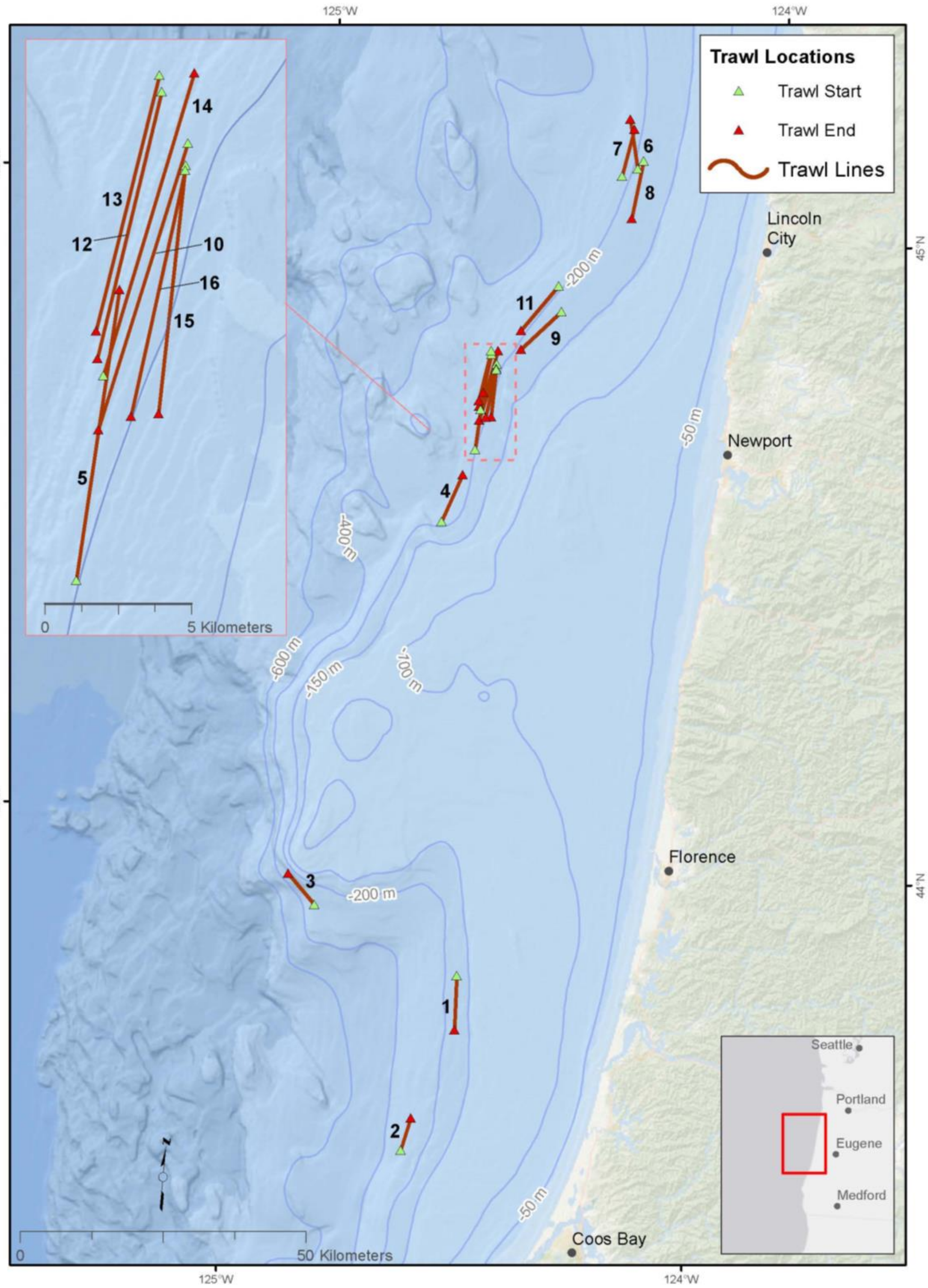

Figure 2. Map depicted the study area and location of the 16 tows conducted.