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Recent Advances in Trawl Gear Employed by Oregon's Ocean Shrimp (*Pandalus jordani*) Fishery

Mo Bancroft[1]

Scott Groth[2]

Oregon Department of Fish and Wildlife
Marine Resources Program

[1]2040 SE Marine Science Drive
Newport, Oregon 97365, U.S.A.

[2]63538 Boat Basin Road
Charleston, Oregon, 97420, U.S.A.

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Introduction

Ocean shrimp (also called pink shrimp, *Pandalus jordani*) are commercially harvested using semi-pelagic trawl gear along the West Coast of North America. Catches of ocean shrimp occur primarily on muddy/sandy bottom types from northern California to British Columbia, Canada at depths of 73-256 meters (Zirges and Robinson, 1980). Oregon is geographically and economically central to the North American West Coast ocean shrimp fishery, with the highest volume of catch and number of landings regionally. From 2000-2019, annual landings in Oregon averaged 14.2 thousand metric tons (MT) (31.4 million lbs), valued at an average of 15.9 million USD. During the same 20 years, annual landings in Washington were 5.1 thousand MT, and 1.9 thousand MT in California (PacFIN). Oregon ocean shrimp is sustainably managed and was the first shrimp fishery in the world certified “sustainable” by the Marine Stewardship Council (MSC, 2007).

Oregon’s ocean shrimp fishery began in the late 1950s, but did not reach full capacity until the late 1970s. Introduction of mechanized processing and capitalized investment of the fishery by the federal government helped the fleet become fully modernized (Zirges and Robinson, 1980). Active fleet size has fluctuated, reaching 185 vessels in 1989, falling to 37 vessels in 2006, and settling around 50-70 registered shrimp vessels over the past decade (2010-2019, Figure 1).

The history of the ocean shrimp fishery is well documented (Appendix: Ocean Shrimp Fishery History); however, quantitative information about the trawl gear employed has been gathered only sporadically. Zirges and Robinson (1980) reported on the early evolution of the fishery, but did not quantify major structural changes to trawl gear before, during, and after the shift from predominantly single-rigged to double-rigged vessels (Hannah et al., 1996). Catch effort has long been standardized for comparison between double- and single-rigged vessels with a metric known as single-rig equivalent hours or SREH (1 hour of double-rigged effort is equivalent to 1.6 hours single-rigged, Hannah, 1993), but there has been no way to accurately correct for increasing vessel efficiency over time. Hannah, Jones, and Golden (1996) attempted to correct for vessel efficiency, but their efforts were confounded by the lack of early data. Instead, they conducted a survey of trawl gear used by the fleet in the early 1990s to develop baseline information.

Groth and Hannah (2018) observed that modern ocean shrimp vessels have higher total catch coupled with lower fishing effort. They attributed these optimized harvest levels to improvements in trawl technology, although they were still not able to accurately account for fishing effort. In an effort to include a coefficient of change, they calculated catch-per-unit-effort (CPUE) using an arbitrarily discounted rate of half a percent per year. Our objective for the current study was to analyze recent advances in the trawl gear used by Oregon’s shrimp fishery. We hope this information will provide context and a quantifiable description of changes in fleet characteristics that have occurred over the last 30 years and allow for improved analysis of trends in catch and CPUE in the future.

Methods

Data Sources

Four sources of information were used to characterize recent changes in the ocean shrimp fishery: 1) commercial fishery permits, 2) logbooks, 3) fish tickets, and 4) gear surveys.

1) Fishery Permits

Oregon's ocean shrimp fishery is managed as a limited-entry fishery, restricted to 138 permits. Permits are unique to each vessel and must be renewed by the owner/operator annually. Permit data includes vessel length, horsepower, and federal documentation number.

2) Logbooks

Fishermen record data in logbooks for each haul. Logbook data include information related to effort (number of tows, tow time, catch estimates, etc.), spatial data (depth and location), and more recently, information on bycatch reduction device technology:

1. Excluder type and spacing for the years 2001-2011. As of 2012, rigid excluder grates (Nordmore style) with 19.1 mm (¾ in) spacing are required.
2. LED fishing light brand and number was collected in logbooks from 2015-2017. As of 2018, five fishing lights must be attached along the fishing line (footrope) of each net.

3) Fish Tickets

Fish tickets are the receipt of a transaction between the vessel and the processor that buys their product. Each processor submits fish tickets to the Oregon Department of Fish and Wildlife (ODFW) after delivery. ODFW has fish ticket information from 1983 to the present. Key data from fish tickets include weight of shrimp landed, ex-vessel value, rig type, and the federal documentation number of the vessel.

4) Gear Surveys

Trawl gear specifications are not strictly regulated in Oregon's ocean shrimp fishery, and gear use varies widely depending on vessel size, layout, and operator experience. Some regulations are defined but are generally related to bycatch reduction devices (e.g. excluder grate bar spacing, number of footrope lights, as above). ODFW periodically conducts surveys to better understand trends in use of trawl gear. Several surveys have been quantitative, examining gear types and metrics, while others have been qualitative, enquiring for opinions or suggestions regarding management proposals.

ODFW has conducted four quantitative surveys regarding trawl gear used by Oregon's ocean shrimp fleet: in 1991, 2011, 2017, and 2019. For more information on each survey, refer to the Appendix: Previous Gear Surveys. The number of vessels surveyed during the 1991 survey is reflective of roughly one third of the fleet. We endeavored to contact all active vessels in the fleet for the 2019 survey.

Data Compilation

Vessel and Gear Metrics

Metrics regarding vessels and trawl gear were grouped into seven categories that relate to catch rates: 1) vessel size/power, 2) vessel rigging, 3) door sizes, 4) footrope elements, 5) codend meshes, 6) bycatch reduction devices, and 7) fishing technologies. Fundamental vessel metrics (1. and 2. below) originated from fish ticket data. The remaining metrics are gear specific and were collected from the gear surveys described in the appendix (Appendix: Previous Gear Surveys).

1. *Vessel Size/Horsepower*: The size of a vessel relates to catch hold capacity, practicable number of crew (number of bunks), trip duration and condition of fishable days: larger vessels are able to stay out longer, trawl in worse weather and catch higher volumes of shrimp. Engine horsepower factors into area swept relative to the size and number (i.e. rigging) of nets and doors (Thorson & Ward, 2014; Eigaard et al., 2014).
2. *Vessel Rigging*: Vessels which are able to accommodate towing two nets simultaneously are referred to as “double-rigged” trawlers. Smaller vessels, usually constrained by size and horsepower, are “single-rigged,” trawling with only one net.
3. *Door Sizes*: The size of trawl doors helps determine net spread; larger doors can pull nets tighter, and higher doors increase the height/opening of the net (Mukundan, 1970).
4. *Footrope Components*: Footropes are comprised of two lines: the fishing line (or bolch line), which provides attachment points for the net, and the groundline, which contacts the seafloor. Groundlines are defined by their groundgear type: chain, cable, or rubber roller discs. Footrope lines are often connected by short lengths of chain conventionally called “droppers.” The height of the fishing line off the bottom is an important covariate of shrimp catch and bycatch rates.
5. *Codend Meshes*: Mesh size (measured between stretched knots) in the codend influences catch volume. Larger mesh spacing allows smaller shrimp to pass through the net, reducing count of shrimp per kilogram and catch rates (Hannah et al., 1996).
6. *Bycatch Reduction Devices*: The use of Bycatch Reduction Devices (BRDs), including excluders (or grates) and footrope lighting (i.e. LED fishing lights) has dramatically reduced bycatch without affecting shrimp catch (Hannah et al., 1996, Hannah et al., 2015).
7. *Technology*: Advancements in technology include activities in production (e.g. sorting methods) and new electronics (e.g. remote sensors). Technological improvements are adopted specifically to improve efficiency, and yet, can be most difficult to account for measurable changes in effort.

Results and Discussion

Vessel and Gear Metrics

We endeavored to survey the entire active Oregon ocean shrimp fleet in 2019 (n=69 vessels), from Astoria to Brookings, Oregon. For reference, sixty-seven vessels made deliveries in Oregon in 2018. In 2019, all vessel operators returned surveys, but not all operators answered all questions; in some instances, operators provided multiple answers to questions.

1. *Vessel Size/Horsepower*: Vessel length and horsepower has increased steadily since 1980 (Figure 2, permit derived information). Vessels active in the ocean shrimp fishery in 2019 measured between 14.3-27.4 m (47-90 ft) in length. They were generally constructed of steel, although a few fiberglass and wooden hulls remain active in the fleet. In 1991, vessel operators estimated the average hold capacity for their catch at 35.8 MT (78,906 lbs, n=42). The estimated mean fish hold capacity increased to 36.4 MT (80,328 lbs, n=67) in 2019. Although no actual volume measurements of hold capacity were available for either survey (and we did not conduct analysis to determine whether these estimates were significantly different), the increases in vessel horsepower, fish hold capacity, and length seem to suggest a modest increase in vessel efficiency.

2. *Vessel Rigging*: Prior to 1978, single-rigged vessels were most prevalent in the Oregon ocean shrimp fleet. During the peak years of fishing effort (1986-1994), they composed more than a quarter of the fleet. By 2019, only six single-rigged vessels remained active, compared to 63 double-rigged vessels (Figures 1 & 3).

3. *Door Sizes*: Average door area (length vs width) for both single- and double-rigged vessels has not changed appreciably since 1991 (Table 1: Footrope Length (m) and Door Area (m2) of Oregon's ocean shrimp fishing vessels. This seems to indicate that regardless of improvements to horsepower and length, fishermen are satisfied with the performance of their door configurations, and modifications to height or width would not create perceptible changes.

4. *Footrope Components*: Footrope length was similar in 1991 and 2019 (Table 1: Footrope Length (m) and Door Area (m2) of Oregon's ocean shrimp fishing vessels. Headrope and footrope lengths were approximately equal in length, measuring between 18.2-38.4 m (60-126 ft, 2019 gear survey results). Historically, the vertical opening of the net was reported to be approximately 3.6-5.5 m high (12-18 ft, Zirges and Robinson, 1980), we did not survey this in 2019.

   Most vessels utilize one of five primary groundgear categories (Table 2). Not all vessels fit neatly into one category, however, because twelve percent used multiple or other types of groundgear. One vessel referred to their setup as "transformer gear," which serves multiple purposes: for example, they can remove the center section of the groundgear if the fishing is too muddy.

   Fishing line height (FLH) off the bottom relates to the ratio of captured target and non-target species, irrespective of dropper length. Droppers limit the maximum length between the fishing line and the groundline, but other factors contribute to FLH, including vessel speed. Fishing lines that are closer to the bottom have higher discard (fish and mud) rates. Fishing lines too high off the bottom catch fewer shrimp. As with fish hold capacity, fishing line height is difficult to measure directly, and is an estimate provided by the vessel operators. The mean estimate of FLH in 2011 was 50.8 cm (n=47), and 41.9 cm (n=56) in 2019.

5. *Codend Meshes*: Mean codend mesh size used by Oregon ocean shrimp fishing vessels is typically between 30-38 mm, and has remained fairly consistent since 1991 (Table 3: Codend mesh size used in Oregon's ocean shrimp nets. Data from 1991, 2017, and 2019 gear surveys.. Around the time of the 1991 survey, mesh size was being considered as a management strategy to minimize incidental harvest of small shrimp (>352 shrimp/kg). Currently, Oregon does not require a minimum mesh size, while California requires meshes to be at least 34.9 mm (1⅜ in). Seventy-four percent of Oregon's fleet use the California minimum, reflective of the interstate nature of the fishery.

6. *Bycatch Reduction Technologies*: As of the 2017 survey, excluder devices were nearly standardized in the form of circular, rectangular, or oval grates made from aluminum. The average outside diameter of circular excluders was 118 cm (46.5 in, n=34) in 2011, and 131 cm (51.5 in, n= 41) in 2017. In 2017, seven vessels had rectangular excluders, while one vessel had an oval excluder.

   Current bar spacing requirements for excluders were reduced to 19 mm (¾ in) in 2012 in order to minimize incidental capture of Eulachon smelt. These became known as "Eulachon optimized excluders." Between 2010 and 2011, there was an average reduction of bar spacing in the fleet of approximately 9.5 mm (⅜ in) for 18 vessels, while 15 vessels already met the minimum size requirements (Figure 4: Changes in mean bar spacing (inches) of rigid grate excluders in Oregon's ocean shrimp fishery (2002-2018)..

   Footrope lighting became popular in 2015 after fishermen and scientists (Hannah et al., 2015) discovered their efficacy in reducing bycatch of many fish species. Use of LED fishing lights among the fleet declined slightly in 2016 and 2017, then became mandatory in 2018 (Figure 5: Percentage of vessels using LED fishing lights within Oregon's ocean fleet (2014-2018).. Most fishermen use individual battery powered lights attached to the fishing line. Lithium batteries last several days, but must be replaced regularly. At least one fisherman innovated a string of LEDs powered in series by a battery cell attached on one of the doors.

7. *Technology*: Additional advancements may come in the form of innovative equipment to facilitate sorting on deck, or new electronics in the wheelhouse to monitor gear. These have likely contributed to increased harvest rates resulting in lower effort levels observed by Groth and Hannah (2018), but unlike vessel length and horsepower measurements, these changes are difficult to quantify and associate directly to improvements in efficiency.

   Seventy-seven percent of vessels surveyed (n=53) use "smelt belts." Despite their name, these devices are effective at removing many bycatch species; they are only used on vessels with hoppers. Catch is carried out of the hopper on a plastic conveyor belt onto a "shaker grate," a section of corrugated metal that rapidly moves side to side, distributing catch onto two angled, hydraulically driven sandpaper belts. Most catch (shrimp and bycatch) passes over the first coarse sandpaper belt, on to the next finer sandpaper belt. Bycatch is caught on the grit and dropped into a chute resembling a rain gutter. Water is plumbed into the chute, washing discard into baskets on deck. The speed and angle of the belts are adjustable, allowing crews to fine-tune sorting to adapt to catch conditions (Hannah, et al., 1996). Of note, 12 percent of vessels with hoppers (n=12), did not have smelt belts, while some vessel operators preferred not to use the technology. Instead, they attempt to fish more selectively (e.g. adjusting fishing line height, avoiding areas of high bycatch, tuning footrope lighting, etc.), limiting the need for smelt belts.

Vessels occasionally catch sub-legal shrimp (>353 shrimp/kg) incidentally. Fish processors have employed a tiered system of pay based on grade, which incentivizes harvest of larger shrimp. Thirteen percent of crews (n=9) said they use smelt belts or other technology to sort small shrimp from their catch to improve grade, although, most noted, sorting to improve grade was a means to save a haul, not a routine practice. Most fishermen preferred to move to a new location to find larger shrimp, rather than managing the catch of small shrimp.

Marine electronics have also continuously evolved, improving fleet efficiency. In the 1991-94 surveys, LORAN-C (Long Range Navigation) was the predominant means of navigation, all forty-two vessels surveyed used the system. Of those, only four also had a Global Positioning System (GPS); one early adopter said they first installed GPS in 1987. Satellite navigation was still prohibitively expensive, and less precise (300 m accuracy) than LORAN triangulation. In 2000, the U.S. federal government lifted a program called "Selective Availability" that degraded public and commercial satellite use, improving accuracy to at least 12 meters. In 2010, the federal government dismantled LORAN-C stations nationally, citing the expense of upkeep of outdated (>40 year old) equipment and facilities (gps.gov: Selective Availability, LORAN-C). In 2019, all surveyed vessels (n=69) had at least one GPS unit on board. Unfortunately, we do not have vessel surveys that document the transition from LORAN-C to GPS, but we suspect it played a role in advancing fishing efficiency in the early 2000s.

In the last decade, underwater video systems have become more affordable, and image quality has increased. Video allows real-time or near real-time opportunities to review the outcome of a trawl. Twenty-five percent of vessels (n=17) currently have some means to review video captured while trawling, whether via remote camera (e.g. GoPro) or some other system attached along the net. Nine percent (n=6) currently have a third-wire system (e.g. SimRad FX80) which allows them to actively view underwater video while trawling.

Real-time remote sensing equipment has improved and become more affordable as well. Twenty-two percent (n=15) of vessels currently use door spread sensors, acoustic detection devices attached to each door that ping information directly to the vessel. The sensors monitor door orientation, alignment, and overall performance. Twenty-six percent (n=18) of vessels reported they currently use an acoustic catch monitoring system (e.g. Notus Echo); real-time sensors attached at the excluder which detect the noise of shrimp hitting the aluminum excluder. The sensors also detect the angle of the excluder, indicating how heavy/full the net is, and if the excluder is clogged. The combination of the two technologies sharply reduces the occurrence of "water hauls," when the trawl net comes up empty.

Conclusion

Advancements in technology have shaped the development and efficiency of the Oregon ocean shrimp fleet. Some improvements such as vessel length and horsepower are quantifiable and well documented, allowing for straightforward comparison across time. Other improvements to efficiency, encompassing marine electronics and technological innovation such as Global Positioning Systems, acoustic remote sensors, Bycatch Reduction Devices, etc, are more difficult to quantify and compare directly. These improvements have unequivocally had a net positive influence in the evolution and success of the Oregon ocean shrimp fishery: increased vessel speed and capacity translate to improved catch per unit effort, reduced bycatch rates are coupled with reduced sort times and improved at-sea safety. This combination of innovation and adaptability to conditions and regulations have allowed Oregon ocean shrimp fishermen to lead the way to the world's first certified sustainable shrimp fishery. We hope this report will facilitate future comparisons to recent changes in the fishery.

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Figures & Tables

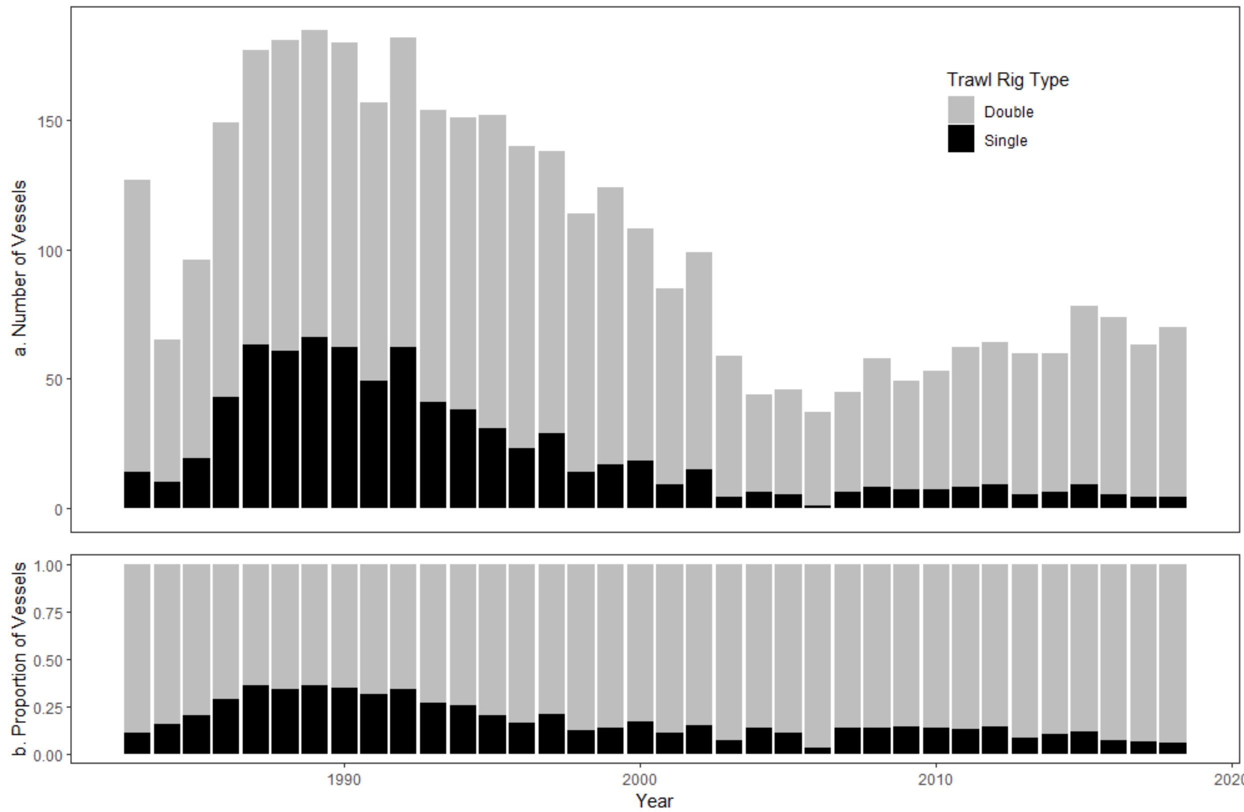

Figure 1: Changes in the (a.) Number and (b.) Proportion of vessels participating in Oregon's ocean shrimp fishery by rig type and year (1984-2019).

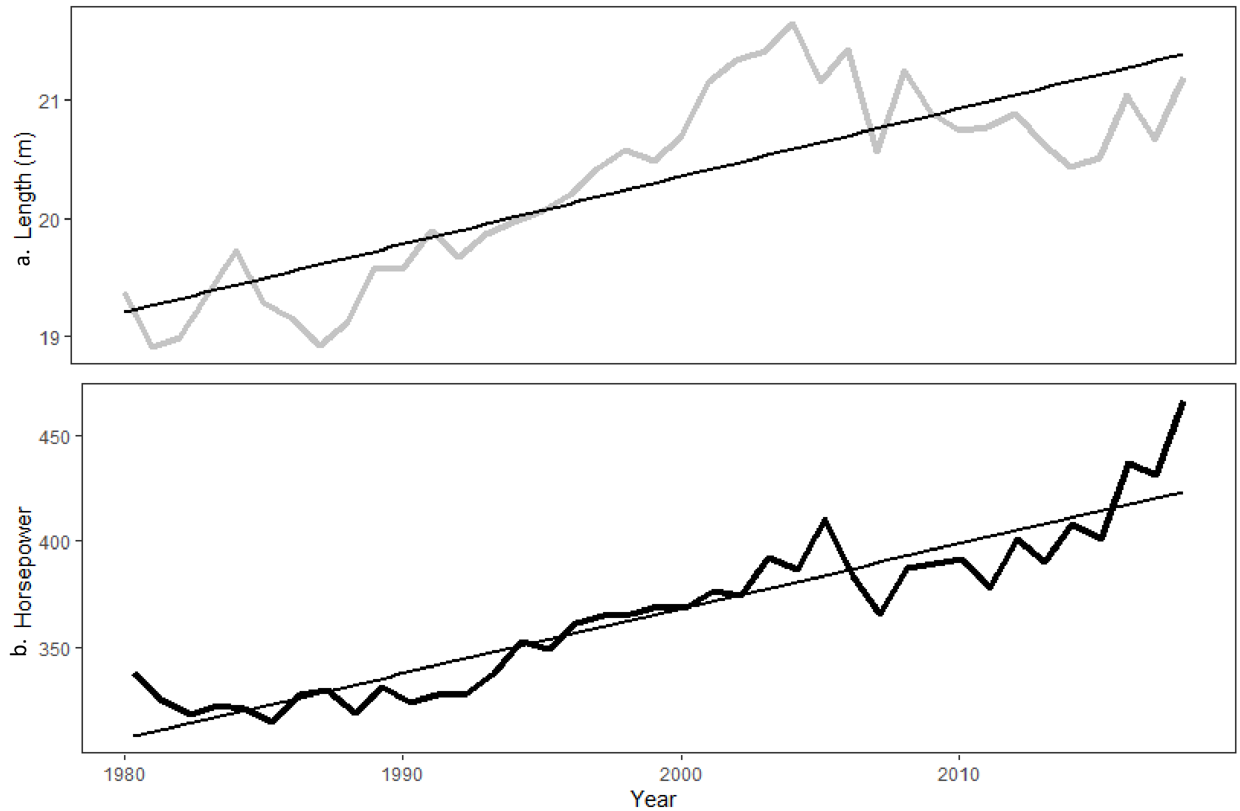

Figure 2: Historical increases in (a.) Mean Vessel Length (m) and (b.) Vessel Horsepower (HP) for Oregon's ocean shrimp fleet (1980 to 2018). Trend line is best fit.

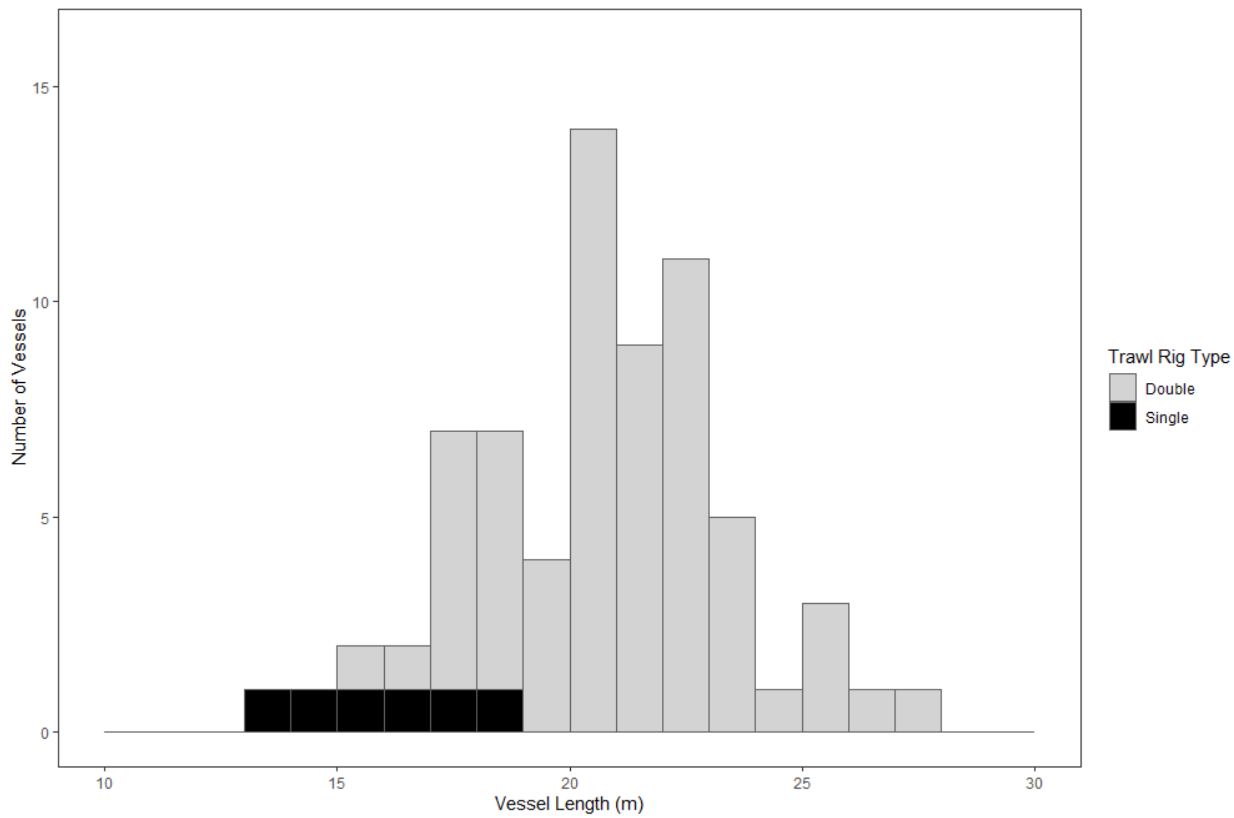

Figure 3: Variability in the length (m) single- and double-rigged trawl vessels that participated in the Oregon ocean shrimp fishery in 2019 (n=69 vessels).

Table 1: Footrope Length (m) and Door Area (m^2) of Oregon's ocean shrimp fishing vessels. Data from 1991, 2011, 2017, and 2019 gear surveys.

	Footrope Length (m)			Door Area (m^2)		
gear	n	mean	std dev	n	mean	std dev
			1991			
single-rig	5	28.2	2.8	5	8.7	1.7
double-rig	36	25.2	4.2	36	17.6	4.6
			2011			
single-rig	4	22.9	2.0	4	7.9	2.5
double-rig	36	27.2	3.0	36	20.7	5.4
			2017			
single-rig	2	22.1	2.3	2	7.6	2.1
double-rig	50	26.5	3.7	50	20.7	5.3
			2019			
single-rig	6	27.3	1.9	6	9.3	3.4
double-rig	58	26.8	3.9	58	20.8	5.3

Table 2: Variability in groundline gear (groundgear) types associated with Double-Rig and Single-Rig trawl vessels active in the Oregon ocean shrimp fishery, 2019.

vessel type	gear type	diagram of gear type	n
Double-Rig	Small donuts only in the center		24
	Continuous cable/chain		20
	Center section removed		10
	Continuous small discs (i.e. ~7.2cm)		5
	Other	*see below	2
	Roller gear (alternating 20.3 cm discs)		1
Single-Rig	Continuous small discs (i.e. ~7.6cm)		3
	Continuous cable/chain		2
	Center section removed		1

*(Multiple nets kept aboard with some of each gear type, excluding roller gear; a ladder chain style)

Table 3: Codend mesh size used in Oregon's ocean shrimp nets. Data from 1991, 2017, and 2019 gear surveys.

year	mesh size (mm)	n
1991	25.4	1
	31.75	2
	34.925	15
	38.1	5
2017	31.75	8
	34.925	38
	38.1	6
	41.275	1
2019	31.75	10
	34.925	51
	38.1	5

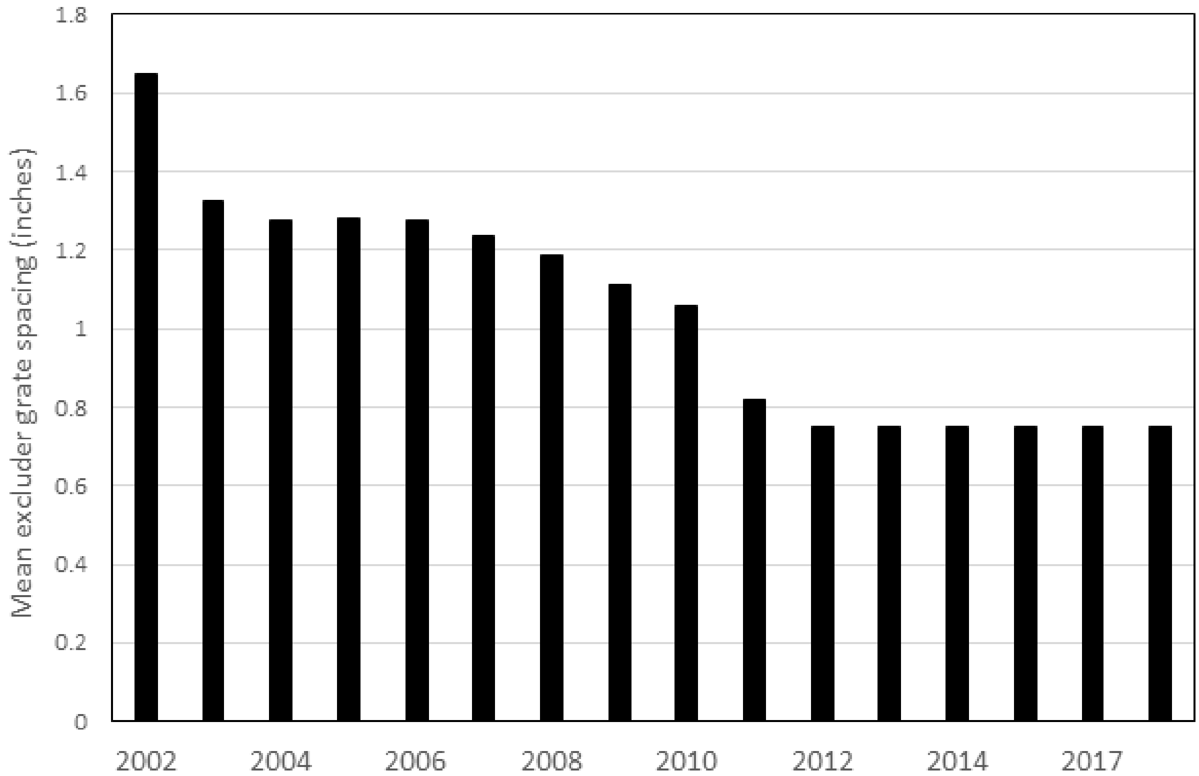

Figure 4: Changes in mean bar spacing (inches) of rigid grate excluders in Oregon's ocean shrimp fishery (2002-2018).

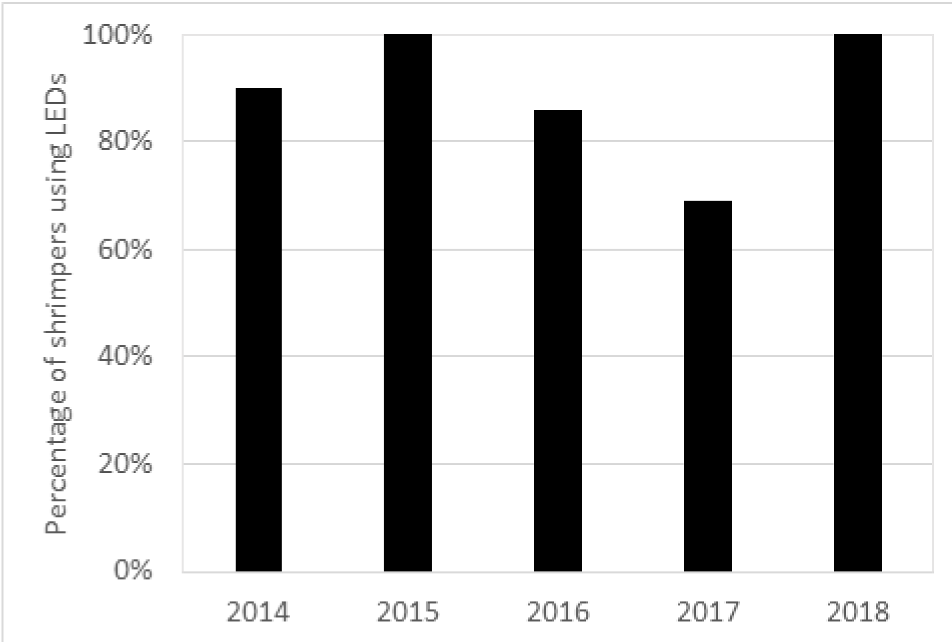

Figure 5: Percentage of vessels using LED fishing lights within Oregon's ocean fleet (2014-2018).

Appendix

Previous Gear Surveys

<u>1991-1992:</u> A general survey of gear types and technologies. Forty-two fishing vessels (n=42) were surveyed between July 1991 and October 1992. An additional question relating to net twine size was added after the first few vessels were surveyed.

Principal survey questions included:

1. Gear specifications: rigging type, door length × height (area), material, net manufacturer, type and model, mesh, and twine sizes in the net body, intermediate and codend, headrope and footrope length, bridle length, net taper, roller gear use, net material, purchase price and age.
2. Sorting techniques: methods of sorting bycatch and/or grading shrimp to improve catch grade.
3. Count per pound methodology: type of device used to measure, and length of time used.
4. Deck gear and date installed: float tank, picking table, hopper, conveyor belt, and/or smelt belt.
5. Electronics and date installed: LORAN, GPS, Chromoscope, plotter, and paper machine.
6. Miscellaneous information: interviewee title and length of time on vessel, crew size, and other fisheries the vessel participated in.
7. Mesh measurements in 10 locations in each of three locations (fore, mid, and aft) on the three main parts of the net: body, intermediate and codend.

<u>2011:</u> Focused on understanding ground gears used in the fishery. Forty-two fishing vessels (n=42. This number was coincidental, although there was some overlap between 1991-92 and 2011) were surveyed between April and May, 2011.

Principal questions included:

1. Ground gear characteristics: material (if present, i.e. center removed), total length, length with doughnuts, doughnut diameter if used, weak link use and whether they fished with a broken weak link.
2. Fishing line characteristics: length compared to groundline length, dropper length in the center, wings, and corners, and whether floats were attached to the fishing line.
3. Rigging type, door length × height (area), and material.
4. Excluder characteristics, i.e. grate style (flat or folding), outside diameter, bar stock diameter, and bar spacing in 2010 and 2011.

<u>2017:</u> Undertaken to understand recent changes to ground gear and technologies. Fifty-seven (n=57) primarily Oregon fishing vessels were surveyed between August 2017 and January 2018.

Principal questions included:

1. Ground gear style (five variations were identified as common, and illustrations were included to clarify), groundline length, dropper length in center.
2. Rigging type, door length × height (area), and material.
3. Codend mesh size, and type (standard, T90, knotless).
4. Excluder characteristics: rectangular (length × height) vs circular (diameter).
5. Technology: door spread sensors, video, etc.

6. LED fishing lights: number and frequency of use, brand, color, spacing along the fishing line and method of attachment.
7. There was also a question regarding industry support behind mandating state-wide LED use on trawl footropes, and another asking whether industry supported the proposed Fishery Management Plan.

2019: This survey focused on asking several of the same questions from the 1991-1992 surveys in order to develop a long-term dataset characterizing the evolution of the fleet. Ninety-seven fishing vessels from all three West Coast states were surveyed: 13 from Washington, 69 from Oregon and 15 from California. This report focuses on the results from the Oregon fleet (n=69).

Principal questions included:

1. Vessel specifications: rigging type and hold capacity.
2. Nets and doors: groundline length and type, codend mesh size, length × height (area), door material, number of LEDs used per net, dropper length at the center, and their best estimate of fishing line height.
3. Deck gear: presence or absence of a sorting table, smelt belts, and whether they practice on-deck sorting to improve grade of shrimp (as surveyed in the 1991-1992 surveys).
4. Technology: door spread sensors, NOTUS sound detection, and either real-time or post-tow video review use.

Definitions

Bolch line: See fishing line. Also spelled bolsh or bolsch line. Also called hanging line.

Documentation number: Is a national form of vessel registration that provides evidence of nationality, and admits vessels to certain trades, such as coastwise trade and fisheries. A uniquely identifiable number is issued by the U.S. Coast Guard National Vessel Documentation Center (NVDC). Numbers are often painted or affixed on either side of the wheelhouse.

Droppers: Lengths of chain that connect the groundline to the fishing line. Droppers and vessel speed control the height of the fishing line off the seafloor.

Excluder: Also called shrimp grates, these are a type of bycatch reduction device, or BRD. An aluminum grate mounted diagonally inside the body of the net just before the codend. Used to prevent fishes and mammals of certain size from capture. As of the publication of this report, the bar size between grates is a minimum of 19.1 mm (¾ in) in Oregon.

Ex-Vessel Value: The price received by the fisherman upon landing product.

Fishing line: Also called the bolch line. The component of the footrope attached to the belly mesh of the net. Named because it is the part of the net that actually captures fishes.

Footrope: The bottommost opening of the net: comprised of the fishing line and groundline. The purpose of the footrope is to maintain continuous contact with the seafloor and ensure the trawl runs smoothly over the ground without damaging the fishing line or the netting panels.

Groundgear: Equipment such as bobbins, rollers, discs, donuts, or cookies. Rubber discs range from 3.8-20.3 cm (1½ to 8 in), and are attached to the groundline. Groundgear maintains direct contact with the seafloor and facilitates rolling the net over obstacles instead of getting stuck on them.

Groundline: The lowest component of the footrope, which comes in close contact with the bottom. Often lined with groundgear, and in the ocean shrimp fishery, sometimes just bare chain or cable.

Headrope: The topmost opening of the net, often lined with floats to open the net while under tow.

Limited Entry Fishery: A control measure used to limit the level of effort in a fishery; set by the number of available permits. As opposed to an *Open Access Fishery*; one without a limit to the number of harvesters.

Mesh type: Net meshes can be characterized by several different metrics, including the length between stretched knots, the angle knots create while under tow (ex. T45 or T90 are 45 and 90 degrees), and whether they are knotted or knotless.

Trawl doors: Also called otter doors. Wooden and/or steel plates used to open the net while under tow. Single-rigged boats generally use the same type of steel doors used for groundfish trawling. Double-rigged boats often use much larger, steel-framed wooden doors.

Vessel sweep: The total area of seafloor fished. The area measurement includes number of nets fished (double or single-rigged), length of the groundline, door height (vertical opening of the net), plus the approximate seafloor distance covered from the time the net begins fishing on the bottom, to the time at first haul back.

Ocean Shrimp Fishery History

1950s

- 1951 – First scientific exploration of shrimp beds occurs along the Pacific coast[1]
- 1957 – Commercial shrimp trawling begins in the Pacific Northwest[1]
- Vessels are restricted to using beam trawls (to reduce bycatch of other fish species), western-seiner type vessels, 15.2-21.3 m, 17.4 m headrope and 1.2 m opening[1]
- 1958 – Fishermen express concern about the safety and inefficiency of beam trawls (one warp). Oregon Fish Commission conducted experiments comparing beam trawls to semi-balloon trawls (as used in the Gulf of Mexico). Shrimp and incidental catch increased, but not expected to impact either stock significantly[1] and fishermen are allowed to use semi-balloon trawls
- Few fishing restrictions, no seasonal closures
- 1959 – the Oregon Fish Commission adopted the limit of 1,360 kg of incidental fish to be landed per shrimp trip[2]

1960s

- Typical vessel was a 15.2-21.3 m single rig boat using a 17.4 m trawl[1]
- Hand peeling limits the expansion of the shrimp fishery. Introduction of peeling machines made it necessary for fishermen to catch larger quantities of ocean shrimp so that processing operations would be economically feasible[3]
- 1964 – Industry members expressed concern regarding increasing rate of fishing pressure/number of landings; crab fishermen wanted to prevent overlap of their fisheries, losing crab markets to shrimp; and overloading processors with shrimp and crab. Additionally, egged females result in processing problems and reduced meat yield per pound landed. Not seen as important to protect egged females. Industry recommended winter closure[1,2]
- 1965 – First shrimp season limitation, April 1st to October 31st[1]
- 1966 – Pre-steam blanch peeling machines introduced and processing facilities located in more ports, minimizing transit time to fishing grounds
- Russian fleet begins fishing
- 1969 – First double rigged shrimp vessel demonstrated increased catch capability. Led to conversion of vessels or importation of vessels from Gulf of Mexico (via the Panama Canal), which were not only already double rigged, but larger as well

1970s

- Significant shift to double rigged vessels
- Introduction/improvement of navigation/fish finding electronics
- Prior to 1976, predominant shrimp net was a 17.4 m headrope, Gulf of Mexico style Marinovitch trawl, 1.2 m vertical opening[1]

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[1] Zirges and Robinson, 1980
[2] Dahlstrom, 1970
[3] PFMC, 1981
[4] Hannah and Jones, 1990
[5] Hannah, 2014
[6] Hannah, Jones, and Golden, 1996
[7] Hannah and Jones, 1999

- 1975-78 Majority of the fleet switches to locally produced 21.3-27.4 m headrope box trawls – proven to be more efficient for ocean shrimp[4]
- 1976 – Magnusson Fishery and Conservation Management Act
- 1978 – Large harvest in 1977, and federal tax incentives encouraged 50% increase in the number of vessels participating in the fishery, spurred investment in new gear and electronics. New vessels typically 21.3 m footropes from 24.4-30.5 m and vertical openings from 3.7-5.5 m. Many newer vessels imported from the Gulf of Mexico. Increases in fishing pressure: more vessels and effort
- 1979 – 96th Congress American Fisheries Promotion Act. 203 active vessels in Oregon

1980s

- 1980 – 248 vessels made landings in Oregon. 343 vessels eligible for licenses in 1980. Shrimp fishery vessel moratorium[1]
- West Coast ocean shrimp fleet characterized by large double rig vessels
- Processing gains efficiency with modernized machine peeling
- 1989 – Shrimpers begin experimenting with excluders to reduce catch of unwanted hake and for new limitations on managed groundfish species

1990s

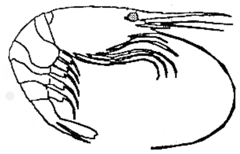
- 1990 – First publication of the Annual Pink Shrimp Review of the 1989 fishing season
- Industry and management work cooperatively to determine the best excluders[6] and footrope configurations[7] to reduce overall bycatch

2000s

- Industry-wide groundfish overfishing declarations (of lingcod, Canary and yelloweye rockfish) show potential to restrict shrimp fishery if high bycatch of these species continues
- 2003 – Oregon adopts 44.5 mm (1¾ in) excluder spacing rules.
- 2007 – Marine Stewardship Council certifies Oregon pink shrimp as the first sustainable shrimp fishery in the world

2010s

- 2010 – Eulachon smelt (*Thaleichthys pacificus*), a common bycatch of the shrimp fishery is listed as threatened on the Endangered Species Act
- 2011 – Investigators found the ocean shrimp fishery was unlikely to have a population level impact on eulachon smelt[5]
- 2012 – Recertified MSC Sustainable (2nd time). Grates with 19 mm (¾ in) spacing, or "Eulachon optimized" were required, substantially reducing the take of eulachon
- 2014 – Fishermen and scientists work together under a NOAA Bycatch Reduction Engineering Program (BREP) grant to continue minimizing eulachon bycatch - green Light Emitting Diodes (LEDs) are found to be very effective when affixed to the footrope
- 2017 – Fishermen and scientists continue collaborative research to determine best use of LED lights. Tests with different placement and numbers of LEDs on nets, as well as with and without excluders conclude that a combination of the two types minimize bycatch of eulachon, rockfish, and flatfish almost 100%
- 2018 – Recertified MSC Sustainable (3rd time). With support from industry, LEDs are adopted in rule: 5 lights per net, mounted on the fishing line (OAR 635-005-0630)

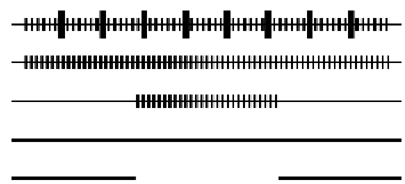


Pink Shrimp Gear Survey

Vessel:__________
Box Number: __________

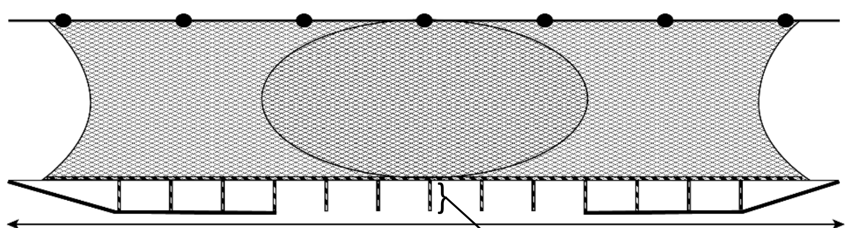
1. Vessel Specifications:
   - Single☐ Double☐
   - Total hold capacity …………………………………………………………………………………________ lbs.

2. Nets and Doors:
   - Groundline length……………………………………………………………………………………________ ft.
   - Which of these 6 types best characterizes your groundline (check one):



☐ Roller gear (alternating 8" discs)
☐ Continuous small discs (i.e. ~3")
☐ Small donuts only in the center
☐ Continuous cable/chain, no discs
☐ Center section removed
☐ Other (e.g. tickler chain), please describe ______________________________

   - Codend mesh size (inches) …………………………………………………….$1^{1/4}$☐ $1^{3/8}$☐ $1^{1/2}$☐
   - Door Height × Length ……………………………………………………………………_____ ft. × _____ ft.
   - Door material …………………………………………………………………Metal☐ Wood☐
   - How many LEDs per net ……………………………………………………………………………_____



Dropper length at center……………………._____ in.
Estimate of Fishing Line Height at center _____ in.

3. Deck Gear:
   - Sorting Table …………………………………………………………………………………Y ☐ N ☐
   - Smelt Belt ………………………………………………………………………………………Y ☐ N ☐
   - Have you practiced on-deck sorting of shrimp to improve grade? …………Y ☐ N ☐
     If yes, please describe____
4. Technology:
   - Door spread sensors ………………………………………………………………………Y☐ N ☐
   - NOTUS sound detection ……………………………………………………………………Y☐ N ☐
   - Real-time video ……………………………………………………………………………… Y☐ N ☐
   - Use of video (e.g. GoPro) ………………………………………………………………Y☐ N ☐

I acknowledge I am the vessel owner/operator, and have received a box of (24) LED fishing lights:

Printed name:________________________ Signature:__________________________ Date:__________

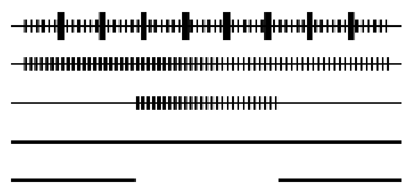
Printed and administered 2019

2019 ODFW Pink Shrimp
Gear Survey Backgrounder

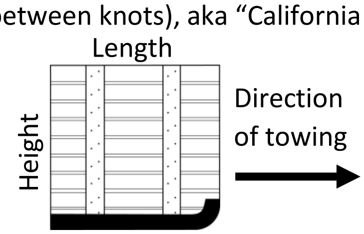
Please make certain to administer this survey before you supply a vessel with a box of LED fishing lights. This survey will allow us to closely replicate surveys conducted in the last 30 years. Return completed surveys to Scott Groth, Scott.D.Groth@state.or.us, or mail to PO Box 5003, Charleston, OR 97420.

1. Vessel Specifications
   - Single vs double-rig: few single-riggers remain on the West Coast, and they are usually smaller (~50 feet).
   - Fish hold capacity: make certain they are talking about shrimp and their answer is in pounds.

2. Nets and Doors
   - Groundline length: the net “footrope” consists of the fishing line (top) and the groundline (bottom); the headrope is the absolute top of the net. The fishing line is the opening of the net, while the groundline is in contact with the seafloor (often lined with discs and/or rollers).
   - We expect there will be about 5 different styles of groundline, but welcome descriptions/ illustrations of any other styles you may encounter:
     - Roller gear (alternating 8” discs)
     - Continuous small discs (i.e. ~3”)
     - Small discs only in the center
     - Continuous cable, no discs
     - Center section removed



   - Codend mesh size: there are no minimum mesh size requirements in Oregon or Washington. In California, mesh sizes must be a minimum of $1^{3/8}$ inches BK (between knots), aka “California codend.”
   - Door height and length is a good proxy for net dimensions.
   - Dropper chains control the distance between the fishing line and the groundline. This is an area of escape for fishes. Fishing Line Height (FLH) is a covariate for bycatch rates.



   - FLH should be the fishermen’s best estimate of how high off the bottom their net is fishing. Sometimes fishermen will attach an old piece of chain at the fishing line to determine this. We have observed fishermen’s estimates of this height may vary with the actual height off the bottom.
   - As of 2018, all Oregon and Washington vessels are required to have 5 fishing lights per net, spaced 4 feet apart in the center 16 feet of the net. California hasn’t adopted the same regulations, but given the box of lights provided at no charge, we encourage adoption purely for the resultant benefits, i.e. reduced Eulachon bycatch, as well as rockfishes and flatfishes.

3. Deck Gear
   - Sorting tables are the simplest/oldest shrimp sorting technology on the back deck. Generally, only smaller, single-rigged vessels will have these, as the process of sorting and dumping…

3. Deck Gear continued
    - …catch below decks can be slow and volume-limited. If they do not have a sorting table, we assume they have a hopper with conveyor belts to sort catch.
    - We suspect most vessels will have a smelt belt in conjunction with a hopper and conveyor belts, but some vessels may have removed them following the advent of LED fishing lights.
    - This question was asked in the 1991 survey, related to sorting smallest shrimp out of catch. Examples may include methodology or equipment:
        - Adjustments of angle of sandpaper/smelt belts.
        - Parallel roller bar system that allows small shrimp to fall out on deck.

4. Technology
    - A door-spread sensor is mounted to each door, sending real-time information to the wheelhouse, indicating door orientation, alignment, and overall performance.
    - NOTUS sound detection sensors are attached at the excluder, detecting if/when shrimp are hitting the aluminum excluder. The sensors also detect the angle of the excluder, indicating how heavy/full the net is, and if the excluder is blocked.
    - Some vessels have installed cameras on their nets to monitor how effective their gear is while fishing. A few systems are real-time (SIMRAD), allowing for immediate adjustments. Other fishermen attach camera systems (like GoPros) to different areas of the net, which they can check and make changes after haul back.
    - If you believe there are/is a vessel using navigation other than GPS, please ask them and indicate somewhere on the survey - we assume everyone uses one at this point, but are curious.

4034 Fairview Industrial Drive SE
Salem, OR 97302