2014

EVALUATION OF A TOPLESS BOTTOM-TRAWL DESIGN FOR FISH CAPTURE IN THE SUMMER FLOUNDER FISHERY

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EVALUATION OF A TOPLESS BOTTOM-TRAWL DESIGN FOR FISH CAPTURE IN THE SUMMER FLOUNDER FISHERY

BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

BIOLOGICAL AND ENVIRONMENTAL SCIENCES

UNIVERSITY OF RHODE ISLAND

2014

MASTER OF SCIENCE THESIS

OF

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2011

ABSTRACT

One of the major threats to sea turtles is the incidental capture as bycatch in marine commercial trawl fisheries. A gear-based approach has been suggested to reduce sea turtle bycatch levels in the summer flounder fishery (*Paralicthys dentatus*). Previous conservation experiments using a turtle excluder device (TED) in the summer flounder fishery resulted in a significant loss of the target species summer flounder, about 35% on average. A topless-trawl design was proposed as an alternative gear design to mitigate sea turtle bycatch. Previous testing showed that a topless-trawl with a headrope length of 48.7 m (160 ft) was effective at reducing sea turtle catch, but had a significant loss of target species, ranging from 51-74% on average, compared to a traditional trawl net with a 19.8-m (65-ft) headrope. In an effort to improve performance of the experimental trawl, a model of the 48.7-m (160-ft) headrope trawl was evaluated at the flume tank at the Memorial University in St. John's, Newfoundland. This experimental net was optimally reconfigured with thirty 20-cm (8-in) plastic floats on the headrope and two restrictor lines. The 48.7-m (160-ft) topless-trawl with 30 floats and two restrictor lines was tested in the summer flounder fishery in the summer of 2013 to assess its ability to catch summer flounder with two different float configurations. With the optimal float arrangement, the 48.7-m (160-ft) headrope topless-trawl with two restrictor lines had a significant loss of target species ($p=0.008$), with 22.7% loss compared to a traditional trawl. With this same float arrangement, the topless-trawl had a 12% loss of skate species (the majority of the catch) with no significance from zero ($p=0.057$). The experimental topless-trawl

reduced the capture of all species overall, including the target species, summer flounder.

ACKNOWLEDGEMENTS

This project would not have been possible without the financial support provided by the National Marine Fisheries Service Northeast Fisheries Science Center Protected Species Division. I would like to express my appreciation and gratitude to my advisor, Dr. David Bengston, for all of his guidance and support during my time at URI. I would also like to thank Dr. Joseph DeAlteris for providing me with the opportunity to participate in this research project and for his incredible support and expertise throughout this project. I would also like to thank Dr. Gavino Puggioni for his guidance and preparation in the analysis and review of the research.

I would like to thank Christopher Parkins for his contributions throughout every step of this project and for his encouragement and assistance, especially during the fieldwork. I would also like to thank Henry Milliken and Eric Matzen from the Northeast Fisheries Science Center for their incredible guidance, expertise and dedication to this project. A huge thank you to Captain Jim Ruhle and the F/V Darana R crew for their incredible knowledge, commitment, and patience.

Lastly I would like to thank my family for always supporting me. I am forever grateful to my parents for instilling a passion and respect for the environment in me at a young age. It is one that has grown with me and is the reason I have chosen this career path that my family has always encouraged me to follow.

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GLOSSARY

Bridles: Wires that attach the wings of the trawl net to the trawl doors.

Cod End: The closed end of a trawl net where the catch is collected.

Cookie Sweep: Protective ground gear equipped with rubber rollers ("cookies") that roll over and keep the net off of obstructions along the ocean bottom and help minimize trawl damage.

Fishing Circle: The mouth of the trawl net.

Footrope: The bottom rope of the fishing circle.

Headrope: The top rope of the fishing circle, usually equipped with plastic floats.

Trawl Doors: Doors (made of wood or steel) that flow through the water at an angle, causing them to spread apart and aid in opening the net horizontally. Doors also kick up bottom sediment as they are towed along the bottom, initializing the herding of fish.

CHAPTER 1

INTRODUCTION

Regulatory Action

In 1977, the National Marine Fisheries Service (NMFS) and the United States Fish and Wildlife Service (USFWS) signed a memorandum of understanding to administer the Endangered Species Act (ESA) with respect to sea turtles (National Oceanic and Atmospheric Administration (NOAA) Fisheries Office of Protected Resources 2013). One of the major threats to sea turtles is the incidental capture as bycatch in marine commercial and recreational fisheries (NOAA Fisheries Office of Protected Resources 2013). In response to the Advance Note of Public Rulemaking (ANPR) by NOAA in February of 2007 with the intent to decrease sea turtle mortality in the mid-Atlantic and southern New England trawl fisheries, ongoing studies have been done to find a suitable method of reducing these sea turtle bycatch levels. In 2009 a Notice of Intent was posted to prepare an Environmental Impact Statement supporting pending regulations to decrease sea turtle interactions in trawl fisheries and to determine new regulations (Department of Commerce 2009). In response, there have been many attempts to reduce bycatch levels through regulations, the fishery observer program, changes in fishing practices, area/time closures, and gear modifications.

REVIEW OF LITERATURE

Sea Turtles and Fishing Gear

A gear-based approach would work to reduce bycatch levels because specific gear is more prone to incidentally capture non-target species (Mitchell et al. 1995).

Sea turtle bycatch regulations are addressed fishery-by-fishery and the focus of this study is the interactions within the summer flounder trawl fishery. The loggerhead species will be the primary sea turtle species of focus because of its relative abundance in the northeast and mid-Atlantic waters and interactions with fishing gear in these areas.

Sub-adult and adult loggerhead sea turtles' prey consists of benthic species such as crustaceans, mollusks, and invertebrates in the bottom sediment (Ruckdeschel and Shoop 2006). From May to October, when sea surface temperatures seasonally increase, loggerheads are found as far north as southern New England to forage before migrating south for the winter (Ruckdeschel and Shoop 2006). In areas south of Virginia, summer is the breeding season for the loggerheads and other sea turtle species, so they are consistently found near shore between nesting cycles (Spotila 2011).

According to the U.S. National Bycatch Report, in 2005 an estimated total of 11,772 individual sea turtles were caught in all U.S. fisheries and an estimated total of 1,062 individual sea turtles, all loggerhead species, were caught as bycatch in the Northeast fisheries (Karp et al. 2011). In general, some of the fisheries with the highest bycatch ratios were bottom trawl fisheries. In addition to the ecological effects of high bycatch levels, there are also economic consequences because the cost of sorting through bycatch is high and time consuming (Kumar and Deepthi 2006).

Trawl gear specifically is a large threat to sea turtles. Historical stranding and observer data have shown that trawl nets have a strong ability to consistently catch sea turtles and have been addressed by NOAA as a priority in reducing sea turtle bycatch

(Gallagher 2009). A trawl net is a mobile, non-selective gear type with high bycatch levels of species that typically have little to no commercial value (Kumar and Deepthi 2006). Trawl nets catch prey through entrainment/herding by actively towing the nets through the water column and catching non-target species (Sasso and Epperly 2006). According to the U.S. National Bycatch Report (Karp et al. 2011) the primary discards in the northeast trawl fisheries are non-marketable species and are discarded as waste. The low selectivity of trawl gear results in the catch of endangered species such as sea turtles, marine mammals, and elasmobranchs. When air-breathing animals, such as sea turtles, are caught in nets they are forcibly submerged and typically drown. Non-target species, such as sea turtles, that are caught as bycatch have key roles in the marine food webs and ecosystem. The natural biodiversity of these systems can be strongly impacted when these species are removed (Kumar and Deepthi 2006). Limited capture of these federally protected species is permitted by the Magnuson Stevenson Act (Magnuson-Stevens Fishery Conservation and Management Act sec. 206).

Turtle Excluder Devices (TED's)

One of the more effective ways to reduce bycatch in trawl fisheries is to alter trawl designs and use gear modifications to increase the selectivity of trawl gear (Kumar and Deepthi 2006, Karp et al. 2011). An example of a trawl fishery that has historically had a high level of sea turtle bycatch is the U.S. shrimp fishery that typically uses a bottom otter trawl to entrain prey (Lutz et al. 2002). The U.S. shrimp fishery ranges from Cape Hatteras, NC to the US/Mexico border in the Gulf of Mexico (National Resource Council [NRC] Committee on Sea Turtle Conservation 1990). Before the required use of a bycatch reduction device (BRD), incidental capture within shrimp trawls was considered the highest human source of mortality on sea turtle populations. Shrimp trawls killed approximately 44,000 sea turtles annually and the main species caught were juvenile loggerheads and Kemp's Ridleys (NRC 1990, Spotila 2011). Due to high levels of bycatch, especially in the Gulf of Mexico, shrimp fisheries have had to implement regulations and use gear modifications to reduce these levels of bycatch.

One gear alteration that has been made to reduce bycatch is the Turtle Excluder Device (TED), which was first introduced to shrimp fisheries in the late 1980's (Mitchell et al. 1995). A TED is an array of angled, spaced bars, positioned in the direction of trawl flow and placed in the trawl net immediately before the cod end to allow entrapped sea turtles to escape (Saunders 1988, Lutz et al. 2002). If the opening of the TED is large enough, all sea turtles should effectively escape. NMFS requires that TED's be 97% effective in sea turtle escapement (Crowder et al. 1994). TED regulations and requirements continuously changed after their initial requirement and as of 1994 TED's were required year round for all inshore and offshore shrimp trawls (Crowder et al. 1994). Within these fisheries, the TED has proven to be a reliable BRD by effectively reducing sea turtle catch and catching shrimp with less than 5% loss of shrimp (Department of Commerce 1987).

Summer Flounder Fishery

The summer flounder fishery is a commercially important trawl fishery in the mid-Atlantic and northeast, ranging from Cape Hatteras, NC to Cape Cod, MA (Terceiro 2006). The summer flounder fishery typically uses a bottom otter trawl net, similar to the shrimp fisheries (Terceiro 2006). Summer flounder (*Paralichthys dentatus*) is a demersal flatfish ranging from the Gulf of Maine to South Carolina (Terceiro 2006). The interactions between sea turtles and fisheries occur because of the overlap in habitat use. The summer flounder is predominantly found in the same sandy substrates as the loggerhead's prey (Perrine et al. 2003).

The bycatch of loggerhead sea turtles caught within the summer flounder fishery was estimated at 192 turtles annually for 2000-2004 (Murray 2008). With an increase in bycatch in Northeast regions, it is anticipated that BRD's will soon be required in the Northeast fisheries (Karp et al. 2011). Since 1992, all bottom trawls for summer flounder south of Cape Charles, VA have been required to use a NMFS-approved Flounder TED. The current TED in the summer flounder fishery is a hard-grid design with $\geq$89 cm width ($\geq$ 35 in) and $\geq$32 cm ($\geq$12 in) height (Gallagher 2010). The northern regions of the flounder fishery including southern New England and the mid-Atlantic currently do not require the use of a TED, but that is likely to change in the future (Gallagher 2010). One of the proposed ways to reduce bycatch in trawl fisheries is to alter trawl designs and focus on changing fishing methods (Kumar and Deepthi 2006, Karp et al. 2011).

The catch efficiency of the NMFS-certified TED required in the Mid-Atlantic summer flounder fishery has been tested in existing fisheries inshore and offshore in the mid-Atlantic regions (DeAlteris and Parkins 2009). Trawl nets with the NMFS-certified flounder TED had a significant reduction of target catch species ranging from 28% to 35% loss (Lawson et al. 2007, DeAlteris and Parkins 2009, DeAlteris and Parkins 2012). A standard TED and experimental TED were tested and both were found to have substantial loss of target species (Lawson et al. 2007). It was suggested that a gear-based approach and alternative net design be made to exclude sea turtles because of the significant loss of target species.

Topless-trawls

The proposed alternative gear design for the summer flounder fishery was a topless-trawl (DeAlteris and Parkins 2012). A topless-trawl is designed by increasing the setback of the headrope, which eliminates the overhung panel (square) to allow pelagic species to exit the net (He et al. 2007, Pol et al. 2003). This type of gear modification considers the behavior of the target species and modifies the gear to match this behavior (Ryer 2007). This trawl type theoretically would not significantly reduce flatfish retention because of the herding behavior of flatfish (Ryer 2007). Flatfish species generally use anti-predator behavior when encountering a trawl net and bury in the sediment or herd low to the seafloor close to the lower panel (Ryer 2007, Thomsen 1993). This increase of headrope length however would allow pelagic species to escape the trawl once they encounter the footrope by swimming upwards.

Topless-trawls have been proposed in other flatfish fisheries as a method of reducing the bycatch of roundfish (Pol et al. 2003, Ryer 2007, Thomsen 1993). In contrast to flatfish, when roundfish encounter a trawl they are able to use bursts of sustained swimming to swim off of the seafloor (Ryer 2007). In a traditional bottom trawl the headrope is forward of the footrope, preventing fish from escaping through swimming upwards once they encounter the footrope (Revill et al. 2006). A topless-trawl was first designed to reduce cod and other roundfish bycatch in flatfish trawls in the Faroe Islands (Thomsen 1993). Underwater video footage showed that flatfish stayed at the lower panel of the trawl and roundfish swam upwards to effectively escape with a setback headrope and this study resulted in a significant reduction of roundfish bycatch with no flatfish catch reduction (Thomsen 1993). A topless-trawl design in the yellowtail flounder fishery was tested as a successful method of reducing juvenile target species and other bycatch (Pol et al. 2003). A similar design, referred to as a "cutaway trawl" was effective at reducing whiting bycatch without any loss of *Nephrops (*Norway lobster) in a European *Nephrops* fishery (Revill et al. 2006). A similar design with the Gulf of Maine pink shrimp fishery was tested as a way to reduce pelagic finfish species and was successful in reducing bycatch (He et al. 2007).

The effectiveness of topless-trawls in other groundfish fisheries suggested that this design could be an effective way to reduce sea turtle bycatch in the summer flounder fishery. An increased headrope for given footrope length increases the escape time for sea turtles and the demersal target species would herd and swim towards the cod end of the net and remain captured (DeAlteris and Parkins 2012). By excluding sea turtles before they are captured, the negative effects of forced submergence can be avoided. Reducing bycatch of large sea turtles (>100 cm length) is challenging in a fishery where the target species is also large (25 cm- 70 cm length). It is challenging to develop gear modifications to exclude large bycatch species but retain large target species so behavior of these species and trawl nets must be identified to effectively do both. In regard to sea turtles, a topless-trawl would ideally work by allowing sea turtles to escape in a similar manner to roundfish in a trawl fishery. Sea turtles would ideally swim upward once they feel the footrope and escape before entering the trawl due to the setback of the headrope and escape the net similarly to roundfish.

A topless-trawl design for the summer flounder fishery has been tested (DeAlteris and Parkins 2012). This evaluation included paired-trawl testing of a control standard flounder trawl and an experimental topless-trawl designs with different headrope lengths. The control net had a 19.8-m (65-ft) headrope and a 24.4-m (80-ft) footrope. Four lengths of modified headrope lengths were tested with lengths of 32.3 m (106 ft), 40.5 m (133 ft), 44.8 m (147 ft), and 48.7 m (160 ft), and all with a 24.4-m (80-ft) footrope and identical sweeps (DeAlteris and Parkins 2012). The net with a 32.3-m (106-ft) headrope was successful at capturing summer flounder but ineffective at reducing sea turtle capture. A trawl with a headrope length increased to 48.7 m (160 ft) with a 24.4-m (80-ft) footrope was successful at reducing sea turtle capture but when tested in the summer flounder fishery had substantial loss of summer flounder (DeAlteris and Parkins 2012). Results of this study showed that further rigging modifications, such as use of additional floats, are needed to improve physical performance of the topless-trawl in order for it to be efficient at catching summer flounder and reducing sea turtles (DeAlteris and Parkins 2012). Floats are useful in stabilizing the TED in water and prevent the trawl from rolling over during deployment and retrieval (Mitchell et al. 1995).

The purpose of this study was to increase the catch performance of the topless-trawl and test a modified topless-trawl in the summer flounder fishery for the retention of target species, summer flounder. A model net was designed and tested in the flume tank to create a set of gear modifications and optimally configure the trawl before it was tested in the field. The null hypothesis was that there would be no significant difference of catch between the control net and the experimental topless-trawl at $\alpha=0.05$. The alternative hypothesis was that the control net would catch on average more summer flounder than the experimental topless-trawl. Because this net was designed for use in a commercial fishery, it was also important to consider the size distribution of the summer flounder captured. The null hypothesis was that there would be no significant difference between the length frequency of the flounder with $\alpha=0.05$. The alternative hypothesis was that there would be a difference between the two net types in the length frequency for summer flounder.

METHODOLOGY

Flume Tank Testing

A 1/5th to 1/6th scale model net of the topless-trawl with a 48.7-m (160-ft) headrope and 24.4-m (80-ft) footrope was tested in the flume tank at the Memorial University at St. John's, Newfoundland on May 6-8, 2013 to determine why it was ineffective at catching flounder. A total of 16 modifications (rigs) of the net were tested and are described below.

- Rig No. 1: The original 48.7-m (160-ft) headrope topless-trawl with sixteen 20-cm (8-in) floats and the extension at full length.
- Rig No. 2: The 48.7-m (160-ft) headrope topless-trawl with sixteen 20-cm (8-in) floats and the extension shortened by 38.1-cm (15-in) as an attempt to pull the headrope forward.
- Rig No. 3: The 48.7-m (160-ft) headrope topless-trawl with sixteen 20-cm (8-in) floats and the extension shortened by 69.9 cm (27.5 in)
- Rig No. 4: The 48.7-m (160-ft) headrope topless-trawl with twenty-three 20-cm (8-in) floats on the headrope
- Rig No. 5: The 48.7-m (160-ft) headrope topless-trawl with twenty-three 20-cm (8-in) floats and the extension shortened by 38.1 cm (15 in)
- Rig No. 6: The 48.7-m (160-ft) headrope topless-trawl with thirty 20-cm (8-in) floats on the headrope and the extension shortened by 38.1 cm (15 in)
- Rig No. 7: The 48.7-m (160-ft) headrope topless-trawl with thirty 20-cm (8-in) floats on the headrope and the extension back at full length.
- Rig No. 8: The 48.7-m (160-ft) headrope topless-trawl with thirty-seven 20-cm (8-in) floats on the headrope with the extension at full length.
- Rig No. 9: The 48.7-m (160-ft) headrope topless-trawl with thirty-seven 20-cm (8-in) floats on the headrope with the extension shortened by 38.1 cm (15 in)

In response to the maximum number of floats (thirty-seven 20-cm (8-in)) not having enough influence on increasing the wing spread and wing and headrope opening, two restrictor ropes were added on the headrope for Rig 10-15 in an attempt to increase wing and headrope height.

- Rig No.10: The 48.7-m (160-ft) headrope topless-trawl with thirty-seven 20-cm (8-in) floats, extension at full length, and the addition of a 10.4-m. (34.2-ft) restrictor rope and 8.1-m (26.7-ft) restrictor rope.
- Rig No. 11: The 48.7-m (160-ft) headrope topless-trawl with thirty 20-cm (8-in) floats, extension at full length, and the 10.4-m. (34.2-ft) and 8.1-m (26.7-ft) restrictor ropes.
- Rig No. 12: The 48.7-m (160-ft) headrope topless-trawl with twenty-three 20-cm (8-in) floats, extension at full length, and the 10.4-m. (34.2-ft) and 8.1-m (26.7-ft) restrictor ropes.
- Rig No. 13: The 48.7-m (160-ft) headrope topless-trawl with twenty-three 20-cm (8-in) floats, extension at full length, and the 10.4-m. (34.2-ft) and 8.1-m (26.7-ft) restrictor ropes.
- Rig No. 14: The 48.7-m (160-ft) headrope topless-trawl with sixteen 20-cm (8-in) floats, extension at full length and the 10.4-m (34.2-ft) and 8.1-m (26.7-ft) restrictor ropes.
- Rig No. 15: The 48.7-m (160-ft) headrope topless-trawl with twenty-three 20-cm (8-in) floats, extension at full length and the 10.4-m. (34.2-ft) and 8.1-m (26.7-ft) restrictor ropes on the headrope, and two additional restrictor ropes on the dorsal side of the cod end. (Same as Rig No. 13, but modified with cod end restrictor ropes)
- Rig No. 16: The model topless-trawl with a 32.3-m (106-ft) headrope and sixteen 20-cm (8-in) floats on the headrope (used in previous field studies). This configuration was tested as a comparison because in the field it effectively caught summer flounder but ineffectively reduced sea turtle catch.

All riggings (16) of the net were tested at a towing speed of 5.5 km-per-hour (3 knots), and at target bridle angles of 11 and 15 degrees. Rigs No. 6-10 were also tested at a target angle of 9 degrees to gather additional measurements. Measurements of the upper wing spread, left wing spread, mean wing end spread, wing height, headrope height, port tension, starboard tension, total tension, mouth area, mouth drag, and bridle angle were recorded.

Gear for Field Work

A two-seam standard summer flounder trawl (referred to as control trawl) and a two-seam experimental topless-trawl (referred to as experimental trawl) were designed and constructed by Trawlworks Inc., Narragansett RI. The control net was designed as a traditional trawl net used in the summer flounder fishery with an 18.8-m (65-ft) headrope and was rigged with sixteen 20-cm (8-in) plastic floats. The experimental trawl was designed with a 48.7-m (160-ft) headrope with two restrictor ropes. One restrictor rope was attached to the head rope behind the first top wing and was 10.4 m (34.2 ft) in length and the other was attached at the next sewing seam back and was and 8.1 m (26.7 ft) in length. The experimental trawl was rigged with thirty 20-cm (8-in) plastic floats. Both nets had 320 x 15.24-cm fishing circles and had a 24.4-m (80-ft) footrope. The nets were equipped with 27.4-m (90-ft) bridles and 137.1 m (450 ft) of ground gear with a cookie sweep.

Field Work

Field work was performed aboard the F/V Darana R, which is a typical summer flounder trawl vessel from Hampton, VA and is captained by Captain Jim Ruhle. The vessel is 27.4 m (90 ft) in length and powered by a 670-HP engine. The field trials was conducted June 23-June27, July 12-July 16, and August 8-August 11, 2013. The field sampling was offshore between Block Island Sound and Long Island Sound with GPS locations taken for all completed tows (Figure 4). During the three field trials on the F/V Darana R, a total of 41 comparative paired tows (82 tows total) were completed. The bridle length, ground gear, and number of floats were consistent throughout all 41 pairs. The only modification was the rearrangement of two wing floats between float configuration #1 and #2. All tows were conducted in an ABBA alternate paired tow methodology (A=experimental net and B=control net) as a way to maximize efficiency and likeness between the tows. Tows were conducted in conditions that would best represent the mid-Atlantic and southern New-England trawl fishery and maximize flounder catch. Most tows were completed during daylight and began after sunrise and ended before sunset. Any night pairs conducted had the entire duration of the tows completed at dark. Each tow within the pair was identical in location, tow time, speed, etc., and all tows were 90 minutes in length.

The first field trial included 11 successful paired tows (22 tows total) using float configuration #1 and took place from June 23-June 27. The second field trial included 17 successful paired tows (34 tows total) and took place from July 12-July 16, 2013. One pair during the second trial was conducted with float configuration #1 but the headrope heights with this configuration measured low overall, so a float on each wing end (two floats total) was moved further along the wings. The remaining 16 paired tows (32 tows total) of this trial were conducted with the configuration of the rearranged floats (float configuration #2). The third and final field trial included twelve successful paired tows (24 tows total) and took place from August 8-August 11, 2013. During the third field trial one pair was completed with float configuration #1 and the remaining eleven pairs with float configuration #2. The paired tows with float configuration #1 during field trials two and three were done to attempt to gather additional gear measurements. The rearrangement of two floats total on the wing ends of the net was the only modification made during testing to have sufficient data, minimizing the possibility of Type II error in the analysis.

Information recorded for each paired tow included tow location, time of tow, depth, surface temperature, and weather conditions. Detailed catch data were recorded for all catch that came aboard and length data were recorded for target species and other commercially important species. For each tow, the catch was sorted by species into bushel baskets and weighed on a Marel motion-compensated scale. If protected species were captured during sampling, information was taken on those as well, following NMFS protocol.

Depth sensors were attached to various positions on the topless-trawl to gather headrope height and wing height data. The headrope readings could be compared to information gathered from the model net tested at the flume tank. Some underwater video recording of the trawl was successfully gathered at different sections of the topless-trawl as an attempt to view physical performance of the net and examine fish behavior around the net.

Data Analysis

Locations, expressed in Latitude and Longitude, were recorded by GPS for all starting points on the tow and were recorded for the duration of the field work (Tables 2, 3, and 4, Figure 4). Door spread was calculated in feet and sensor data were collected for a sample of tows from field trials 1 and 2, and analyzed as an effort to evaluate the opening of the net throughout the duration of the tows (Tables 7 and Figures 6, 7, and 8). Data were compiled using Microsoft Excel and R for analysis. For sensor analysis, the measurements are the differences between two sensors vertically stacked on the headrope and footrope of the starboard-wing and are measured at hundreds of time points throughout each tow. The “mean opening” is the overall average for the duration of the tow, “start opening” is the average at the beginning of the tow, and “end opening” is the average at the end of the tow (Tables 7 and 8).

Catch weights were compared using one-tailed paired T-tests to compare the catch of summer flounder and the bycatch between the experimental net and control net with a significance value of $p<0.05$. Mean catch weights for the topless and control trawls for the two topless-trawl float configurations are reported in kilograms per tow. A catch ratio (experimental catch/control catch) was calculated for all paired tows to determine the percent loss of catch overall for summer flounder and skates. Length frequency graphs were created using “R” to evaluate the difference in size distributions between the control and experimental net for float configurations#1 and #2. A Kolmogorov-Smirnov test was performed to determine if there was a significant difference between length frequency distributions between the control and experimental nets for float configuration #1 and float configuration #2.

In the bycatch analysis, the skate complex included little, winter, and clearnose skate species. All other bycatch was sorted by species. The only species considered in this analysis of the net performance are summer flounder and skate species. Skate catch was considered because of the consistent high volumes of catch with both nets. Because the sampling period took place from June 20-August 11 the species composition varied greatly throughout the summer sampling due to temporal changes in occurrence. The average catch in pounds and percent of total catch was calculated for the bycatch species consistently captured during all field trials (Table 14).

RESULTS

Flume Tank

A summary of the towing speed, bridle angle, upper wing spread, lower wing spread, mean wing end spread, wing height, and headrope height is shown in Table 1 and Figure 3. When floats were added to the headrope for Rigs No. 1-9 the headrope height and wing height gradually increased, but there was a strong difference, especially in the headrope opening, when the target bridle angle was increased to 15 degrees. At 15 degrees the mean wingspread was drastically wider and the headrope opening was reduced. The addition of the restrictor ropes on Rig No. 10 reduced the mean wing end spread from approximately 18 m at a target bridle angle of 15 degrees to approximately 16 m at a target bridle angle of 11 degrees (Table 1, Figure 3) The restrictor ropes also minimized the changes of the physical dimensions of the gear when the bridle angle increased from 11 degrees to 15 degrees. With the addition of the restrictor lines, the headrope opening and wing-opening also increased. With the thirty-seven 20-cm (8-in) floats on Rig No. 10, the headrope and wing-openings were too high, so the floats were reduced to reduce the headrope height (Table 1, Figures 4 and 5). The mean wing end spread showed little change with the addition of floats, but the wing and headrope opening were slightly reduced (Table 1, Figures 3 and 4). The optimal configuration was Rig No. 11, with thirty 20-cm (8-in) floats on the headrope and the two restrictor lines (Figure 4).

Field Work

Float Configuration #1

Gear Measurements

The average door spread and bridle angle were estimated for all pairs with float configuration #1. The average door spread for the topless-trawl was 111.3 m (365.3 ft) compared to the average door spread for the control trawl, which was 112.0 m (367.7 ft) (Table 5). Based on results from flume-tank testing with a scale model of the net, the estimated average observed bridle angle in the field testing was 15.4 degrees for both the topless-trawl and control models (Table 5).

Data from the depth sensors on the wing-opening were gathered for a sample of paired tows with float configuration #1 (Table 7). The topless-trawl starboard-wing height averaged from 0.03 m (0.1 ft) to 1.62 m (5.3 ft) and the control-trawl starboard-wing height averaged from 0.8 m (2.8 ft) to 0.95 m (3.1 ft) (Table 7). The majority of tows for the topless-trawl showed a decrease in wing height from the beginning to the end of the tow with a slope significantly different from zero (Table 7, Figure 6). The three tows for the control trawl had a slope closer to zero for wing-opening over time (Table 7). A linear regression model was fit for the gear measurements for Haul 3 on June 24, 2013 for the experimental net as an example of the vertical wing-opening changes during the duration of the tow (R^2=0.2866 and p-value<0.0001) (Figure 6). A linear regression model was fit for the gear measurements for Haul 3 on June 25, 2014 for the control net as an example of the vertical wing-opening changes during the duration of the tow (R^2=0.0092 and p-value=0.0324) (Figure 9).

Summer Flounder

For float configuration # 1, the topless-trawl had an average loss of 30.4% summer flounder compared to the control trawl and this was a significant difference from zero, (p=0.0016)(Table 10). This is based on a mean catch per tow of 78.9 kg (174.1 lbs) with a standard deviation of 31.9 kg for the topless-trawl as compared to a mean catch per tow of 110.3 kg (243.2 lbs) with a standard deviation of 42.2 kg for the control trawl (Table 9). The catch varied greatly between tows in the first field trial from June 20-June 27, 2013 for both net types, possibly due to a low volume of fish. For float configuration #1, the summer flounder was on average 7.5% of the total catch for the topless-trawl and 7.4% of the total catch for the control trawl (Table 10).

A Kolmogorov-Smirnov two-sample test was used to compare the length frequency distributions of summer flounder between the control trawl and experimental topless trawl for float configuration #1. The Kolmogorov-Smirnov test indicated a statistically significant difference between the two distributions. However this test is very sensitive to large sample sizes and although the test indicates a significant difference, the distributions still appear similar between the control and experimental nets (Figure 10).

Bycatch

For float configuration #1, the skate complex was on average 84.8% of the total catch for the topless-trawl and was on average 86.0% of the total catch for the control trawl (Table 12). For float configuration #1, the topless-trawl caught on average 30.1% less skates than the control trawl with significant difference from zero (p=0.0070) (Table12). This is based on a mean catch per tow of 894.5 kg (1972.1 lbs) and standard deviation of 306.2 kg for the topless-trawl compared to 1281.6 kg (2825.5 lbs) and standard deviation of 462.7 kg for the control trawl.

For the topless-trawl, summer flounder and skate species were 92.2% of the total catch with the remaining 7.8% of bycatch species varying by tow (Table 15). On average the primary bycatch species, expressed as percent of total catch, were windowpane flounder (1.7%), sea robin (1.4%), smooth dogfish (1.6%), black sea bass (0.4%), winter flounder (0.5%), squid (0.1%), 4-spot flounder (0.1%) and the remaining ~2% of total catch was variable by tow (Table 15). For the control trawl, summer flounder and skate species accounted for 93.4% of the total catch with the remaining 6.7% of the bycatch species varying by tow (Table 15). On average the primary bycatch species were windowpane flounder (1.8%), sea robin (1.0%), smooth dogfish (1.0%), black sea bass (0.3%), squid (0.1%), winter flounder (0.2%), 4-spot flounder (0.1%), and the remaining ~2% varying by tow (Table 15).

Float Configuration #2

Gear Measurements

For float configuration #2 the average door spread for topless-trawl was 107.3 m (351.9 ft) compared to an average door spread of 112.0 m (367.7 ft) for the control trawl (Table 6). The average bridle angle for the topless-trawl with an assumed a wingspread of 14.0 m (46 ft) was 14.8 degrees and was compared to the average bridle angle for the control net with an assumed wingspread of 15.2 m (50 ft) was 15.1 degrees (Table 6). Data from the depth sensors were gathered on a subset of paired tows with float configuration #2 for the experimental trawl (Table 8). The topless-trawl center headrope opening averaged from 0.21 m (0.7 ft) to 1.46 m (4.8 ft) (Table

8). All tows for the topless-trawl showed a decrease in headrope opening from the beginning to the end of the tow with a slope significantly different from zero (Table 8). A linear regression model was fit for the gear measurements for Haul 6 on July 14, 2014 for the experimental net as an example of the headrope height changes over time (R^2=0.573 and p-value<0.0001 (Figure 10).

Summer Flounder

Float configuration #2 had an average loss of 22.7% summer flounder when compared to the control trawl and this was a significant difference from zero (p=0.008)(Table 11). This is based on a mean catch per tow of 126.1 kg (277.9 lbs) with a standard deviation of 47.2 kg for the topless-trawl as compared to a mean catch per tow of 163.2 kg (359.7 lbs) with a standard deviation of 99.1 kg for the control trawl (Table 9). For float configuration #2, the summer flounder was on average 11.2% of the total catch for the topless-trawl and 12.2% of the total catch for the control trawl (Table11).

A Kolmogorov-Smirnov two-sample test was used to compare the length frequency distributions of summer flounder between the control trawl and experimental topless trawl for float configuration #2. The Kolmogorov-Smirnov test indicated a statistically significant difference between the two distributions. However this test is very sensitive to large sample sizes and although the test indicates a significant difference, the distributions still appear similar between the control and experimental nets (Figure 10).

For float configuration #2, a total of 21 pairs were completed during the day, and for these pairs the topless-trawl caught on average 16.0% less summer flounder than the control net (Table 11). On average, the percent of summer flounder in the total catch for paired tows conducted during the day was 8.7% for the topless-trawl and 9.3% for the control trawl (Table 11). A total of seven night pairs were completed with float configuration #2. For night pairs, the topless-trawl caught on average 30.5% less summer flounder than the control trawl (Table11). On average, for the seven night pairs completed, the percent summer flounder of total catch was 23.6% for the topless-trawl and 23.6% for the control trawl (Table 11).

Bycatch

For float configuration #2, the topless-trawl caught on average 12.0% less skates than the control net which was not significantly different from zero (p=0.0570)(Table 14). This is based on a mean catch per tow of 948.8 kg (2019.8 lbs) and a standard deviation of 842.7 kg for the topless-trawl as compared to 1080.2 kg (2381.5 lbs) and a standard deviation of 822.3 kg for the control trawl. On average, the percent skate of total catch was 84.6% for the topless-trawl and 81.0% for the control trawl (Table 14). For the 21 paired tows completed during the day, the topless-trawl caught on average 10.0% less skates than the control trawl (Table 14). For the pairs completed during the day, on average skates were 81.2% of the total catch for the topless-trawl and 79.5% of the total catch for the control trawl (Table 14). For night pairs, the topless-trawl caught on average 23.5% less skates than the control trawl (Table 14). For the seven night pairs completed, on average skates were 71.4% of the total catch for the topless-trawl and 64.8% of the total catch for the control trawl (Table 14).

For all paired tows with float configuration #2, summer flounder and skate species on average accounted for 95.8% of the total catch for the topless-trawl with the remaining 4.2% of bycatch species varying by tow. On average the primary bycatch species were windowpane flounder (1.5%), sea robin (1.5%), smooth dogfish (0.5%), black sea bass (<0.1%), winter flounder (<0.1%), squid (<0.1%), and the remaining ~1% of total catch was variable by tow (Table 15). For the control trawl, summer flounder and skate species on average accounted for 93.2% of the total catch with the remaining 6.8% of the bycatch varying by tow. On average the primary bycatch species were windowpane flounder (1.1%), sea robin (1.1%), smooth dogfish (0.7%), black sea bass (<0.1%), winter flounder (<0.1%), squid (0.1%), and the remaining ~3% of total catch was variable by tow (Table 15). Because summer flounder and skate species made up the major proportion of the catch, the remaining species captured will not be used in an effort to evaluate the catch efficiency of the topless-trawl.

A total of two sea turtles were captured with the pairs conducted with float configuration #2. One loggerhead sea turtle was captured with the experimental trawl on July 13, 2013. One Kemp's ridley (*Lepidochelys kempii)* sea turtle was captured with the control trawl on August 8, 2013. Both sea turtles captured were captured and released alive and in healthy condition with no indicators of injury and should not reflect the net's ability to exclude sea turtles.

DISCUSSION

Flume Tank

The flume tank work allowed us to evaluate why the original 48.7-m (160-ft) topless-trawl had a significant loss of target species. Without restrictor lines, the headrope height was low at 1.4 m (4.5 ft), and it is assumed that flounder were escaping in the wing section because the wings of the net were lying flat (Table 1). It appeared that there was not enough lift of the headrope because the wings of the net were lying flat due to the significant setback of the headrope. With an increased bridle angle the spread increased and the headrope height decreased to 0.9 m (3.1 ft). At the maximum spread, the wings of the net spread wider and the headrope height was low allowing for even less retention of summer flounder (Figure 3). Attempting to shorten extensions did not have an influence on the configuration. The additional float on Rigs No. 1-9 increased the headrope height slightly but the wings continued to lie flat at the increased bridle angle (Figure 3). The addition of floats allowed for a larger wing height opening, but not enough of a difference to address the fishing issues.

With the addition of two restrictor lines the net took proper shape and the wings and headrope increased in height. The addition of the restrictor ropes strongly influenced the upper and lower wing spread, bringing the two wings closer together and increasing the wing height and headrope height (Figure 3). For Rigs No. 11-15, the configuration included the two restrictor ropes in the same position as Rig No. 10 but the number of floats was altered to now reduce the height of the headrope. At the maximum number of floats (thirty-seven 20-cm (8-in)), the headrope height was 2.7 m (7 ft) and there was concern that the net would not effectively decrease sea turtle catch

(Table 1). With the decrease of floats, the wing-opening decreased overall and the headrope opening decreased slightly (Figures 4 and 5). Before the cod end of the net, a "pocket" developed when the meshes between the headrope and cod end should have remained streamlined. The optimal configuration, Rig No. 11, was with thirty 20-cm (8-in) floats along the headrope and was the model used to design the gear for the field study (Figure 4).

Field Trials

Overall, float configuration #1 and float configuration #2 both resulted in a statistically significant reduction of summer flounder. Therefore we can reject the null hypothesis that there is no significant difference between the catch of flounder between the 48.7-m (160-ft) headrope topless-trawl and the control trawl and accept the alternative hypothesis that there is statistical difference between the two nets.

Float configuration #1 resulted in significant loss of target species with 30.4 % loss (p value=0.0016). The percent of fluke of total catch was 7.5 % for the topless-trawl and 7.4% for the control trawl, indicating that the experimental net was reducing overall catch of all species including summer flounder. The rearrangement of floats after the initial eleven pairs helped to evenly distribute the lift of the headrope, which increased catch efficiency. After this modification, float configuration #2 was more effective at catching summer flounder with the 22.7% loss of summer flounder compared to the control trawl, although there was still significant difference between the two net types (p=0.0080). The tows completed using float configuration #2 had a higher percent of summer flounder of total catch for both net types, indicating that more summer flounder were present at the time. The percent of summer flounder of total catch was 11.2% for the experimental trawl and 12.2% for the control trawl, indicating that the experimental net is reducing overall catch, not just catch of the summer flounder with both float configurations.

For all pairs with float configuration #2, a total of seven paired tows were completed at night. There was a quantitative and observational difference between the night and day pairs. For the seven night pairs completed with float configuration #2, the topless-trawl caught 30.5% less summer flounder and 23.5% less skates than the control trawl. For the twenty-one day pairs completed with float configuration #2, the topless-trawl caught 17.7% less flounder than the control trawl (Table 11). More flounder were caught on average during the night pairs compared to day pairs, but there was less difference between the two nets during the day pairs. So, although the topless-trawl performed better at night overall, there was less of a difference between the two net types during the paired tows completed during the day.

Based on video data obtained from the underwater camera footage collected throughout the study, a pocket that had formed before the cod end of the net that was seen to “clog” with fish throughout the tow. This was similar to the “pocket” seen in the flume tank and the issue addressed with Rig No. 15. It is possible that this pocket caused the headrope center opening and starboard vertical wing-opening to decrease in height throughout the duration of the hauls and could contribute to the loss of flatfish (Figure 6 and 10). An increase of catch throughout the duration of a trawl could cause physical changes in the net and bring the headrope down and interfere with functionality of the net. This loading of fish before the cod end and decrease in headrope height throughout the tow was not seen in the control trawl.

Although there was still significant loss of flounder with the topless-trawl, this design had the lowest loss of target species when compared to past gear modifications. A loss of 22.7% target species is still a lower loss than seen when using a TED (28%-35% loss), and the original 48.7-m (160-ft) headrope (51%-74% loss) (DeAlteris and Parkins 2012; Lawson et al. 2007). Because the null hypothesis was rejected and there was statistical significance between the two net types, there is not an opportunity for Type II error. A power analysis on a data set is only necessary when the null hypothesis is false, which is a Type II error (Zar 1984). Therefore Type II error did not occur in this study and there is not a need to perform a power analysis on the data examined.

The decrease in loss of target species is due to the additions of the restrictor lines within the net that help to elevate the long wings of the topless-trawl, thus maintaining the proper shape of the trawl opening. So although there is still significant difference between the catch efficiency of the two nets, the 48.7-m (160-ft) headrope design for the topless-trawl with the addition of two restrictor lines could be a positive method to mitigate sea turtle interactions within the mid-Atlantic and southern New England summer flounder fishery. This topless-trawl was later tested for its ability to reduce sea turtle bycatch, which is not included in this thesis. Using the same control trawl and experimental topless-trawl design, a total of 132 paired tows were conducted in October of 2013 off the coast of Brunswick, GA (DeAlteris et al. 2014). A total of 56 sea turtles were captured during this study and 37 turtles were captured in the control trawl and 19 turtles were captured in the experimental trawl indicating that the topless-trawl reduced the catch of sea turtles by approximately 50% overall (DeAlteris et al. 2014). These preliminary results show that the 48.7-m (160-ft) topless-trawl has some conservation benefits in regards to sea turtle protection, but these benefits may be outweighed by the 22.7% loss of target species in the summer flounder fishery. It would be beneficial to conduct further studies in the flume-tank to optimally configure the experimental topless trawl by excluding the "pocket" that was seen before the cod end. Potentially if this "pocket" were removed, the clogging of fish could be reduced and the headline height would remain more stable while fishing rather than decreasing in height.

APPENDICES

Table 1: Gear measurements for all rigs tested in the flume tank (1-16).

			Spread (meters)				*Opening (meters)*
Rig	**Towing Speed (kt)**	**Bridle Angle (Degrees)**	**Upper Wing**	**Lower Wing**	**Mean Wing End**	**Wing**	**Headrope**
1	3	11.1	16.7	13.1	14.9	0.4	1.4
1	3	15.3	20.3	15.4	17.9	0.3	0.9
2	3	10.9	16.6	13.0	14.8	0.4	1.4
2	3	15	20.1	15.6	17.8	0.3	0.9
3	3	11	16.2	13.0	14.6	0.5	1.5
3	3	15.1	19.9	15.5	17.7	0.4	1.0
4	3	10.8	17.2	13.0	15.1	0.7	1.5
4	3	14.9	20.7	15.6	18.1	0.6	1.1
5	3	10.9	16.9	12.9	14.9	0.7	1.6
5	3	15	20.3	15.6	18.0	0.5	1.1
6	3	8.9	14.0	11.3	12.7	1.1	2.0
6	3	11	16.6	12.9	14.7	0.9	1.7
6	3	14.9	20.4	15.6	18.0	0.8	1.2
7	3	8.7	14.6	11.5	13.0	1.2	2.0
7	3	10.9	16.8	13.0	14.9	1.0	1.7
7	3	14.8	20.8	15.7	18.2	0.9	1.1
8	3	8.8	14.4	11.4	12.9	1.5	2.2
8	3	10.8	16.9	13.1	15.0	1.4	1.9
8	3	14.9	20.7	15.6	18.1	1.1	1.3
9	3	8.9	14.0	11.3	12.7	1.3	2.2
9	3	11	16.4	13.0	14.7	1.2	1.9
9	3	14.9	20.6	15.7	18.1	1.2	1.3
10	3	9.3	12.7	11.2	11.9	1.8	2.7
10	3	11.8	139.1	12.4	13.3	1.8	2.7
10	3	16.3	16.2	14.6	15.4	1.8	2.4

11	3	11.8	13.8	12.3	13.1	1.6	2.4
11	3	16.5	15.9	14.4	15.2	1.6	2.2
12	3	11.8	13.9	12.4	13.1	1.2	2.1
12	3	16.5	15.8	14.5	15.2	1.2	1.9
13	3	11.9	13.7	12.2	12.9	1.2	2.6
13	3	16.5	15.6	14.4	15.0	1.1	2.4
14	3	11.9	13.5	12.4	13.0	0.9	2.0
14	3	16.6	15.5	14.4	15.0	0.8	1.9
16	3	11.9	13.7	12.3	13.0	0.9	1.9
16	3	16.2	16.5	14.8	15.6	0.9	1.5

Table 2: Start and end tow locations, expressed in degrees and ten thousandths of a degree, for all pairs conducted during field trial 1 from June 23-June27, 2013.

		Start		*End*	
Date	**Tow #**	**Latitude**	**Longitude**	**Latitude**	**Longitude**
6/23/2013	1	40.97600	-72.0025	40.9469	-72.0946
6/23/2013	2	40.95000	-72.0771	40.96223	-71.9722
6/24/2013	1	40.93776	-72.0988	40.91012	-72.1976
6/24/2013	2	40.91055	-72.1951	40.94148	-72.0896
6/24/2013	3	40.95416	-72.0655	40.96387	-72.0938
6/24/2013	4	40.98668	-71.9669	40.95308	-72.0597
6/24/2013	5	40.94999	-72.0771	40.91787	-72.1765
6/24/2013	6	40.87968	-72.2799	40.9168	-72.1950
6/25/2013	1	40.91399	-72.1749	40.87262	-72.2608
6/25/2013	2	40.87369	-72.2666	40.91787	-72.1765
6/25/2013	3	40.91636	-72.1732	40.86833	-72.2618
6/25/2013	4	40.87624	-72.2514	40.91765	-72.1656
6/25/2013	5	40.91184	-72.1875	40.8931	-72.1879
6/25/2013	6	40.87968	-72.2799	40.9168	-72.1950
6/26/2013	1	40.88053	-72.2504	40.84747	-72.3512
6/26/2013	2	40.84347	-72.3631	40.87518	-72.2700
6/26/2013	3	40.87626	-72.2758	40.84747	-72.3512
6/26/2013	4	40.91118	-72.1791	40.87753	-72.2682
6/26/2013	5	40.87091	-72.2710	40.84472	-72.2932
6/26/2013	6	40.83039	-72.3689	40.87137	-72.2928
6/27/2013	1	41.29608	-71.6669	41.28027	-71.7720
6/27/2013	2	41.28177	-71.7648	41.28027	-71.7720

Table 3: Start and end tow locations, expressed in decimal degrees, for all pairs conducted during field trial 2 from July 12-July 16, 2013.

		Start		*End*	
Date	**Tow #**	**Latitude**	**Longitude**	**Latitude**	**Longitude**
7/12/2013	1	40.95049	-72.0505	40.92135	-72.1564
7/12/2013	2	40.91916	-72.1689	40.92908	-72.2081
7/12/2013	3	40.93442	-72.1296	40.90025	-72.2314
7/12/2013	4	40.91402	-72.2478	40.90025	-72.2314
7/12/2013	5	40.92869	-72.1621	40.88802	-72.2913
7/12/2013	6	40.88738	-72.2829	40.91703	-72.2058
7/13/2013	1	40.86376	-72.3386	40.89683	-72.2516
7/13/2013	2	40.8979	-72.2574	40.85573	-72.3624
7/13/2013	3	40.85449	-72.37	40.31737	-72.0679
7/13/2013	4	40.85608	-72.3862	40.85133	-72.3768
7/13/2013	5	40.85849	-72.358	40.8906	-72.2761
7/13/2013	6	40.90751	-72.1641	40.83957	-72.3993
7/14/2013	1	40.89424	-72.2667	40.92198	-72.1647
7/14/2013	2	40.92651	-72.1747	40.89338	-72.2718
7/14/2013	3	40.89638	-72.2298	40.92435	-72.1873
7/14/2013	4	40.92478	-72.1848	40.88503	-72.2847
7/14/2013	5	40.87798	-72.29	40.84693	-72.3913
7/14/2013	6	40.857	-72.3548	40.88867	-72.2753
7/15/2013	1	40.89123	-72.2844	40.92155	-72.1915
7/15/2013	2	40.92284	-72.184	40.8846	-72.2872
7/15/2013	3	40.92004	-72.1882	40.88782	-72.2804
7/15/2013	4	40.92435	-72.1873	40.8906	-72.2761
7/15/2013	5	40.92824	-72.1646	40.96155	-72.0714
7/15/2013	6	40.96484	-72.0647	40.92807	-72.1538
7/15/2013	7	40.91529	-72.1916	40.88225	-72.289
7/15/2013	8	40.8861	-72.2905	40.91875	-72.1958
7/16/2013	1	40.92824	-72.1646	40.96155	-72.0714

7/16/2013	2	40.95978	-72.0813	40.92758	-72.1805
7/16/2013	3	40.92004	-72.1882	40.88782	-72.2804
7/16/2013	4	40.88867	-72.2753	40.9263	-72.1638
7/16/2013	5	40.9484	-72.157	40.96733	-72.098
7/16/2013	6	40.96359	-72.1071	40.93797	-72.1687
7/16/2013	7	40.92176	-72.1781	40.88545	-72.2821
7/16/2013	8	40.88225	-72.289	40.91832	-72.1983

Table 4: Start and end tow locations, expressed in decimal degrees, for all pairs conducted during field trial 3 from August 8-August 11. 2013.

		Start		*End*	
Date	**Tow #**	**Latitude**	**Longitude**	**Latitude**	**Longitude**
8/8/2013	2	40.95889	-72.0863	41.0056	-71.9215
8/8/2013	3	40.93805	-72.1446	40.91015	-72.2219
8/8/2013	4	40.91251	-72.2202	40.9516	-72.1154
8/9/2013	1	40.94788	-72.1246	40.91595	-72.2243
8/9/2013	2	40.9166	-72.2084	40.95312	-72.1188
8/9/2013	3	40.91309	-72.257	40.89188	-72.2685
8/9/2013	4	40.89747	-72.2599	40.93912	-72.1504
8/9/2013	5	40.94327	-72.1387	40.90607	-72.2338
8/9/2013	6	40.91251	-72.2202	40.95445	-72.1113
8/10/2013	1	40.8876	-72.2695	40.853	-72.3667
8/10/2013	2	40.8625	-72.3461	40.95988	-72.269
8/10/2013	3	40.90843	-72.232	40.94362	-72.1604
8/10/2013	4	40.93867	-72.1529	40.911	-72.2169
8/10/2013	5	40.79872	-72.5407	40.77482	-72.63
8/10/2013	6	40.77438	-72.6203	40.79265	-72.5165
8/10/2013	7	40.69224	-72.8467	40.6526	-72.952
8/10/2013	8	40.64658	-72.9414	40.69437	-72.8582
8/11/2013	1	40.70224	-72.8563	40.69437	-72.8582
8/11/2013	2	40.70224	-72.8563	40.65242	-72.94
8/11/2013	3	40.69384	-72.8224	40.72383	-72.7222
8/11/2013	4	40.73044	-72.7167	40.69818	-72.8055
8/11/2013	5	40.69078	-72.8171	40.66437	-72.9092
8/11/2013	6	40.6504	-72.9144	40.69275	-72.8167
8/11/2013	7	40.69364	-72.8105	40.66407	-72.9113
8/11/2013	8	40.66241	-72.9096	40.69128	-72.827

Table 5: The calculated door spread in meters and bridle angles in degrees for all paired tows with float configuration #1.

	Experimental; Wing Spread=14.02 m			*Control; Wing Spread=15.24 m*		
Date	**Tow #**	**Door Spread (m)**	**Bridle Angle (Degrees)**	**Tow #**	**Door Spread (m)**	**Bridle Angle (Degrees)**
6/23/2013	1	111	15.3	2	114	15.7
6/24/2013	2	113	15.7	1	116	16.0
6/24/2013	3	110	15.2	4	84	10.8
6/24/2013	6	111	15.4	5	113	15.5
6/25/2013	1	113	15.7	2	116	16.0
6/25/2013	4	111	15.4	3	113	15.5
6/25/2013	5	110	15.2	6	116	16.0
6/26/2013	2	113	15.7	1	116	16.0
6/26/2013	3	111	15.4	4	114	15.7
6/26/2013	6	113	15.7	5	116	16.0
6/27/2013	1	110	15.2	2	116	16.0
7/12/2013	2	110	15.2	1	113	15.5
8/11/2013	6	104	14.2	5	108	14.7

Table 6: The calculated door spread in meters and bridle angles in degrees for all paired tows with float configuration #2.

	Experimental; Wing Spread=14.02 m			*Control; Wing Spread=15.24 m*		
Date	**Tow #**	**Door Spread (m)**	**Bridle Angle (Degrees)**	**Tow #**	**Door Spread (m)**	**Bridle Angle (Degrees)**
7/12/2013	3	110	15.2	4	111	15.2
7/12/2013	6	107	14.7	5	111	15.2
7/13/2013	1	107	14.7	2	113	15.5
7/13/2013	4	111	15.4	3	108	14.7
7/14/2013	3	110	15.2	4	113	15.5
7/15/2013	1	108	14.9	2	110	15.0
7/15/2013	4	108	14.9	3	111	15.2
7/15/2013	5	107	14.7	6	108	14.7
7/15/2013	8	108	14.9	7	111	15.2
7/16/2013	1	108	14.9	2	110	15.0
7/16/2013	5	107	14.7	6	107	14.5
8/8/2013	2	111	15.4	1	110	15.0
8/8/2013	3	110	15.2	4	110	15.0
8/9/2013	2	110	15.2	1	113	15.5
8/9/2013	3	105	14.4	4	114	15.7
8/9/2013	6	108	14.9	5	110	15.0
8/10/2013	1	101	13.7	2	110	15.0
8/10/2013	4	104	14.2	3	108	14.7
8/10/2013	5	105	14.4	6	111	15.2
8/10/2013	8	105	14.4	7	108	14.7
8/11/2013	1	104	14.2	2	114	15.7

Table 7: The mean headline opening for the experimental and control trawl with float configuration #1. Significance indicates if the trendline is significantly different from zero (*: P value <0.05; **: P Value<0.01).

Experimental: Float Configuration #1			
Date	**Tow #**	**Mean Headrope Opening (m)**	**Significance**
6/23/2013	1	1.10	Yes**
6/24/2013	2	1.62	Yes**
6/24/2013	3	1.46	Yes **
6/24/2013	6	1.46	No
6/25/2013	1	1.31	Yes
6/26/2013	2	0.12	No
6/26/2013	3	0.03	Yes *
6/26/2013	6	0.06	Yes **
Date	**Tow #**	**Mean Opening (m)**	**Significance**
6/25/2013	2	0.94	No
6/25/2013	3	0.87	Yes*
6/25/2013	6	0.95	No

Table 8: The mean headline opening for the experimental trawls with float configuration #2. Significance indicates if the trendline is significantly different from zero (*: P value <0.05; **: P Value<0.01).

Experimental: Float Configuration #2			
Date	**Tow #**	**Mean Opening (m)**	**Significance**
7/13/2013	1	0.21	Yes**
7/13/2013	4	1.31	Yes**
7/13/2013	5	0.18	Yes*
7/14/2013	2	1.28	Yes**
7/14/2013	3	1.46	Yes**
7/14/2013	6	1.28	Yes**
7/15/2013	1	1.34	Yes**
7/15/2013	4	1.25	Yes*
7/15/2013	5	1.25	Yes**
7/16/2013	1	1.13	Yes**

Table 9: The statistical summary for all paired tows for float configurations#1 and #2.

Float Configuration 1		
	Experimental	Control
Minimum	15.1	27.7
1st Quartile	63.9	90.4
Median	77.1	108.8
Mean	79.0	110.3
3rd Quartile	93.1	129.0
Maximum	147.0	176.8
St. Dev	31.9	42.2
Float Configuration 2		
	Experimental	Control Net
Minimum	6.9	23.6
1st Quartile	43.0	104.4
Median	58.1	141.5
Mean	69.45	163.2
3rd Quartile	80.55	195.4
Maximum	243.0	535.6
St. Dev.	47.2	99.1

Table 10: Catch weights, in kilograms, percent of total catch, and pair ratio for summer flounder for all paired tows with float configuration #1.

	Experimental			*Control*			
Date	**Tow #**	**Flounder (kg)**	**% Flounder of Total**	**Tow #**	**Flounder (kg)**	**% Flounder of Total**	**Pair Ratio (E/C)**
6/23/2013	1	77.4	7.1	2	129.0	7.0	0.60
6/24/2013	2	80.7	9.8	1	117.8	9.4	0.69
6/24/2013	3	93.1	7.8	4	90.4	7.0	1.03
6/24/2013	6	49.0	6.9	5	108.8	7.9	0.45
6/25/2013	1	118.5	8.5	2	152.2	10.1	0.78
6/25/2013	4	69.8	8.5	3	176.8	6.7	0.39
6/25/2013	5	63.0	8.5	6	100.6	5.7	0.63
6/26/2013	2	77.1	8.3	1	120.3	8.2	0.64
6/26/2013	3	76.0	6.0	4	75.4	7.2	1.01
6/26/2013	6	96.4	6.1	5	104.8	6.4	0.92
6/27/2013	1	15.1	0.8	2	27.7	1.3	0.55
7/12/2013	2	63.9	11.6	1	59.8	8.3	1.07
8/11/2013	5	147.0	14.8	6	170.6	18.9	0.86

Table 11: Catch weights, in kilograms, percent of total catch, and pair ratio for summer flounder for all paired tows with float configuration #2.

	Experimental			*Control*				
Date	**Tow #**	**Flounder (kg)**	**% of Catch**	**Tow #**	**Flounder (kg)**	**% of Catch**	**Pair Ratio (E/C)**	**Night/ Day Pair**
7/12/2013	3	103.6	20.4	4	121.4	15.0	0.85	Day
7/12/2013	6	163.8	6.6	5	124.9	3.4	1.31	Day
7/13/2013	1	195.5	6.0	2	105.3	5.5	1.86	Day
7/13/2013	4	60.1	4.5	3	131.3	6.3	0.46	Day
7/13/2013	5	111.1	7.1	6	85.3	4.7	1.30	Day
7/14/2013	2	218.0	17.0	1	167.6	9.8	1.30	Day
7/14/2013	3	118.6	12.0	4	291.6	25.4	0.41	Day
7/14/2013	6	118.7	17.5	5	101.9	11.2	1.17	Day
7/15/2013	1	155.7	13.8	2	113.2	12.4	1.38	Day
7/15/2013	4	82.4	8.7	3	169.4	14.8	0.49	Day
7/15/2013	5	123.8	5.8	6	221.9	8.1	0.56	Day
7/15/2013	8	283.7	21.9	7	535.6	35.7	0.53	Night
7/16/2013	1	135.4	3.7	2	107.2	3.5	1.26	Day
7/16/2013	4	44.2	5.0	3	96.2	8.5	0.46	Day
7/16/2013	5	64.2	3.0	6	76.1	3.2	0.84	Day
7/16/2013	8	155.5	21.9	7	290.5	24.3	0.54	Night
8/8/2013	2	82.3	13.6	1	138.9	19.9	0.59	Day
8/8/2013	3	210.4	42.8	4	245.5	53.7	0.86	Night
8/9/2013	2	255.7	54.2	1	247.9	46.7	1.03	Night
8/9/2013	3	136.8	40.0	4	160.5	48.3	0.85	Day
8/9/2013	6	52.7	18.3	5	163.1	42.2	0.32	Day
8/10/2013	1	119.7	12.8	2	91.1	13.5	1.31	Night
8/10/2013	4	12.6	9.5	3	23.6	5.4	0.53	Day
8/10/2013	5	40.2	6.1	6	48.8	5.3	0.82	Day
8/10/2013	8	66.8	13.3	7	202.4	12.1	0.33	Night

8/11/2013	1	147.0	17.4	2	170.6	11.2	0.86	Night
8/11/2013	4	117.3	16.4	3	193.0	18.4	0.61	Day
8/11/2013	8	154.3	21.8	7	144.1	17.7	1.07	Day

Table 12: Count and % of total flounder in size category of total, categorized by class size for the experimental and control net for float configurations#1 and #2.

Float Configuration #1				
	Topless		*Control*	
Size class (cm)	**Count**	**% of Catch**	**Count**	**% of Total**
Sub-Legal ≤ 36	7	0.7%	13	0.9%
Small37-45	611	58.8%	837	59.8%
Medium46-55	350	33.7%	475	34.0%
Large56-65	63	6.1%	71	5.1%
Jumbo≥ 66	8	0.8%	3	0.2%
Float Configuration #2				
	Topless		*Control*	
Size class (cm)	**Count**	**% of Catch**	**Count**	**% of Total**
Sub-Legal ≤ 36	74	2.4%	59	1.2%
Small37-45	2705	87.1%	3191	66.0%
Medium46-55	97	3.1%	1287	26.6%
Large56-65	205	6.6%	261	5.4%
Jumbo≥ 66	24	0.8%	34	0.7%

Table 13: The catch weight, percent of total catch, and pair ratio (experimental catch/control catch) for skate complex catch, for all paired tows with float configuration #1.

	Experimental			*Control*			
Date	**Tow #**	**Skate (kg)**	**% of Catch**	**Tow #**	**Skate (kg)**	**% of Catch**	**Pair Ratio (E/C)**
6/23/2013	1	952.1	87.7	2	1581.5	85.8	0.60
6/24/2013	2	717.0	87.3	1	1047.8	84.1	0.68
6/24/2013	3	1000.1	83.8	4	1038.5	80.9	0.96
6/24/2013	6	610.4	86.3	5	1210.2	88.8	0.50
6/25/2013	1	1130.1	81.8	2	1227.6	81.7	0.92
6/25/2013	4	704.1	85.9	3	2302.3	88.0	0.31
6/25/2013	5	614.7	83.3	6	1601.2	91.1	0.38
6/26/2013	2	794.1	85.4	1	1231.4	84.7	0.64
6/26/2013	3	1085.0	86.7	4	876.4	84.3	1.24
6/26/2013	6	1407.6	90.0	5	1442.1	88.6	0.98
6/27/2013	1	1444.9	84.9	2	1779.4	86.9	0.81
7/12/2013	2	472.3	85.8	1	617.3	86.1	0.77
8/11/2013	5	700.7	70.8	6	705.4	78.3	0.99

Table 14: The catch weight, percent of total catch, and pair ratio (experimental catch/control catch) for skate complex catch, for all paired tows with float configuration #2.

	Experimental			*Control*				
Date	**Tow #**	**Skate (kg)**	**% of Catch**	**Tow #**	**Skate (kg)**	**% of Catch**	**Pair Ratio (E/C)**	**Night/ Day Pair**
7/12/2013	3	366.4	72.4	4	648.3	80.2	0.57	Day
7/12/2013	6	2238.7	91.4	5	3375.8	92.0	0.66	Day
7/13/2013	1	2978.3	91.5	2	1697.6	90.0	1.75	Day
7/13/2013	4	1236.2	93.3	3	1872.4	91.0	0.66	Day
7/13/2013	5	1376.7	88.6	6	1216.4	67.2	1.13	Day
7/14/2013	2	1025.0	80.3	1	1499.5	87.9	0.68	Day
7/14/2013	3	836.9	84.7	4	825.1	72.1	1.01	Day
7/14/2013	6	518.2	76.7	5	774.7	85.4	0.67	Day
7/15/2013	1	945.7	84.2	2	780.7	85.6	1.21	Day
7/15/2013	4	840.3	89.6	3	942.5	82.6	0.89	Day
7/15/2013	5	1955.5	92.3	6	2442.5	90.1	0.80	Day
7/15/2013	8	975.8	75.4	7	870.0	58.1	1.12	Night
7/16/2013	1	3419.9	95.4	2	2870.0	95.8	1.19	Day
7/16/2013	4	814.6	92.9	3	1026.6	91.1	0.79	Day
7/16/2013	5	1906.3	91.7	6	2221.8	95.3	0.86	Day
7/16/2013	8	534.8	75.6	7	866.1	72.6	0.62	Night
8/8/2013	2	476.2	79.1	1	515.1	74.0	0.92	Day
8/8/2013	3	251.3	51.2	4	173.4	37.9	1.45	Night
8/9/2013	2	157.7	33.4	1	246.6	46.5	0.64	Night
8/9/2013	3	184.8	54.1	4	145.5	43.8	1.27	Day
8/9/2013	6	166.9	58.1	5	188.3	48.8	0.89	Day
8/10/2013	1	791.4	85.1	2	555.8	82.3	1.42	Night
8/10/2013	4	104.0	78.8	3	376.8	86.7	0.28	Day
8/10/2013	5	560.3	86.2	6	644.3	70.3	0.87	Day
8/10/2013	8	401.1	80.1	7	1164.5	69.8	0.34	Night

8/11/2013	1	625.3	74.1	2	1009.8	66.4	0.62	Night
8/11/2013	4	437.8	61.3	3	751.4	71.8	0.58	Day
8/11/2013	8	440.8	62.3	7	544.3	67.2	0.81	Day

Table 15: Average species composition for all paired tows with float configurations #1 and #2.

Configuration 1					
	Experimental		*Control*		
Species	**Average Catch (kg)**	**Average % of Catch**	**Average Catch (kg)**	**Average % of Catch**	**Pair Ratio (E/C)**
Summer flounder	79.0	7.5%	110.3	7.4%	0.72
Skate complex	894.9	84.8%	1281.6	85.9%	0.70
Windowpane	17.7	1.7%	26.4	1.8%	0.67
Sea robin	14.6	1.4%	18.1	1.0%	0.80
Smooth dogfish	16.7	1.6%	14.3	1.0%	1.16
Black sea bass	3.7	0.4%	4.2	0.3%	0.89
Winter flounder	5.1	0.5%	3.6	0.2%	1.41
Squid	0.6	0.1%	2.1	0.1%	0.27
4-Spot flounder	0.6	0.1%	1.6	0.1%	0.41
Configuration 2					
Summer flounder	126.1	11.2%	163.2	12.2%	0.77
Skate complex	948.8	84.6%	1080.2	81.0%	0.88
Windowpane	16.6	1.5%	14.1	1.1%	1.17
Sea robin	17.2	1.5%	27.6	<0.1%	0.62
Smooth dogfish	5.6	0.5%	9.8	0.7%	0.57
Black sea bass	0.5	<0.1%	0.8	<0.1%	0.66
Winter flounder	0.1	<0.1%	0.7	<0.1%	0.21
Squid	0.5	<0.1%	1.2	0.1%	0.41
4-Spot flounder	0	0.0%	0.0	0.0%	0.00

Figure 1: The schematic of 320 x 15.24-cm control trawl with 19.8-m (65-ft) headrope.

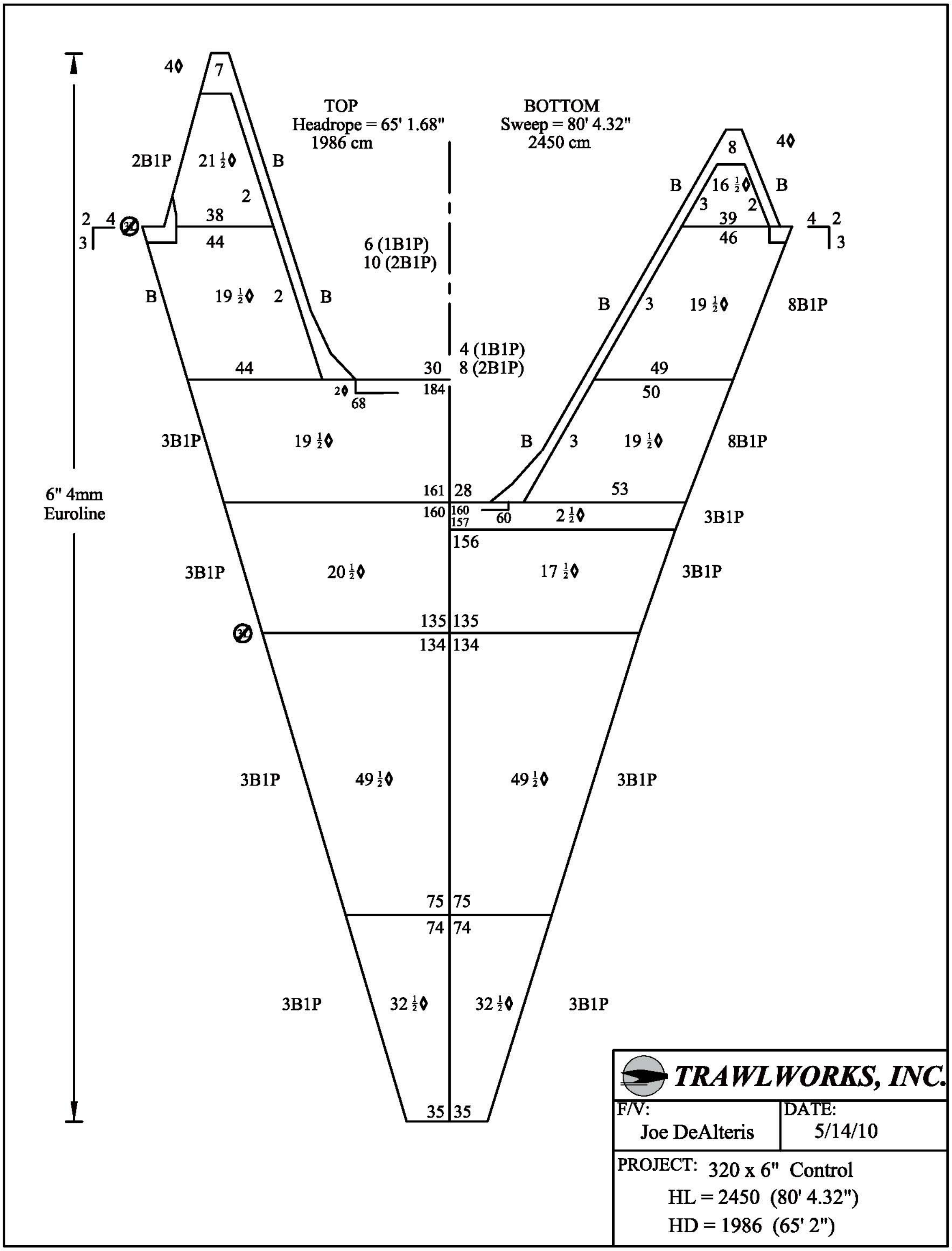


Figure 2: The schematic of 320 x 15.24-cm topless-trawl with 48.7-m (160-ft) headrope used in this study (Not shown, two restrictor lines).

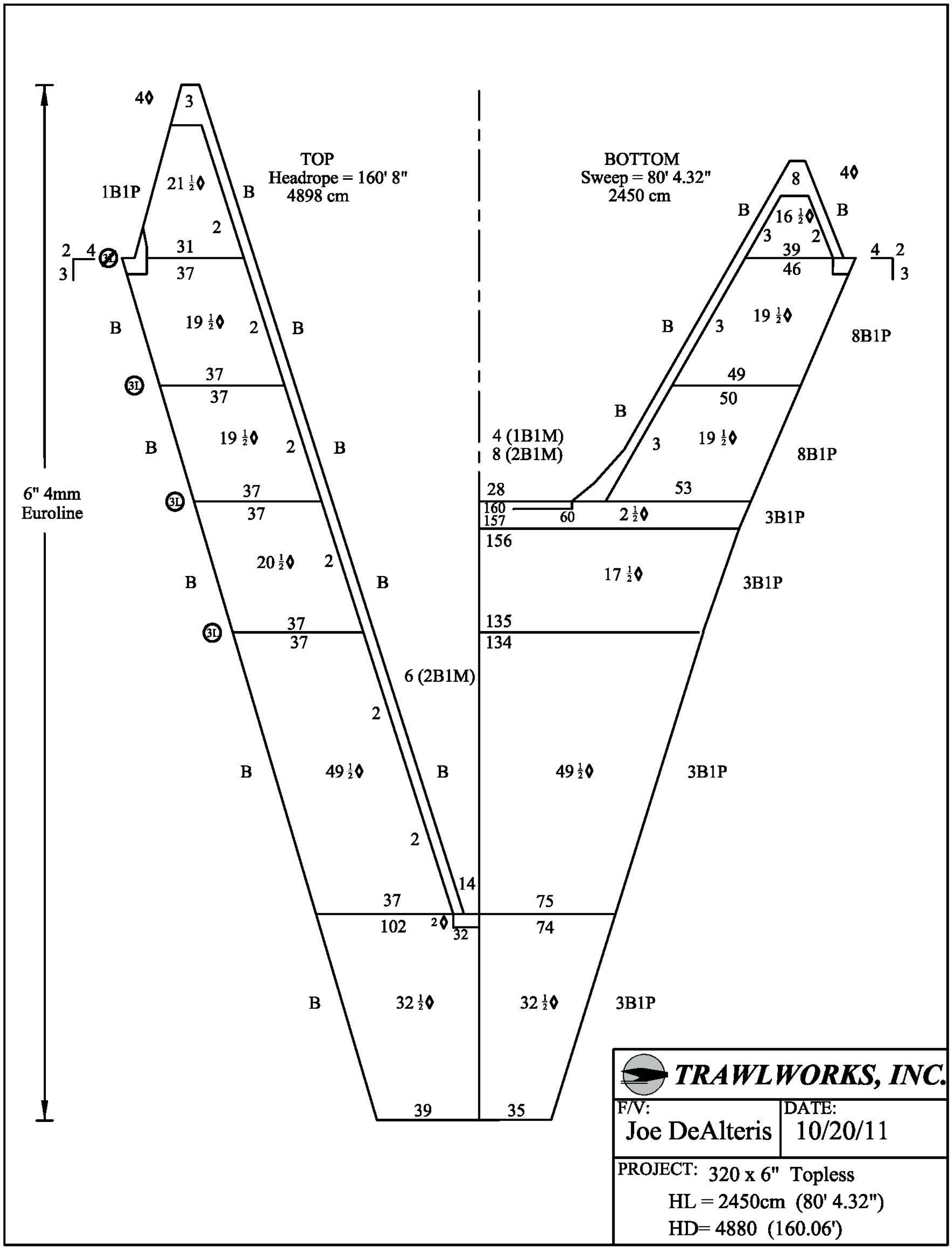


Figure 3: The mean wing spread, wing-opening, and headrope opening in meters from the flume tank testing for Rigs No. 1-14 and Rig No 16.

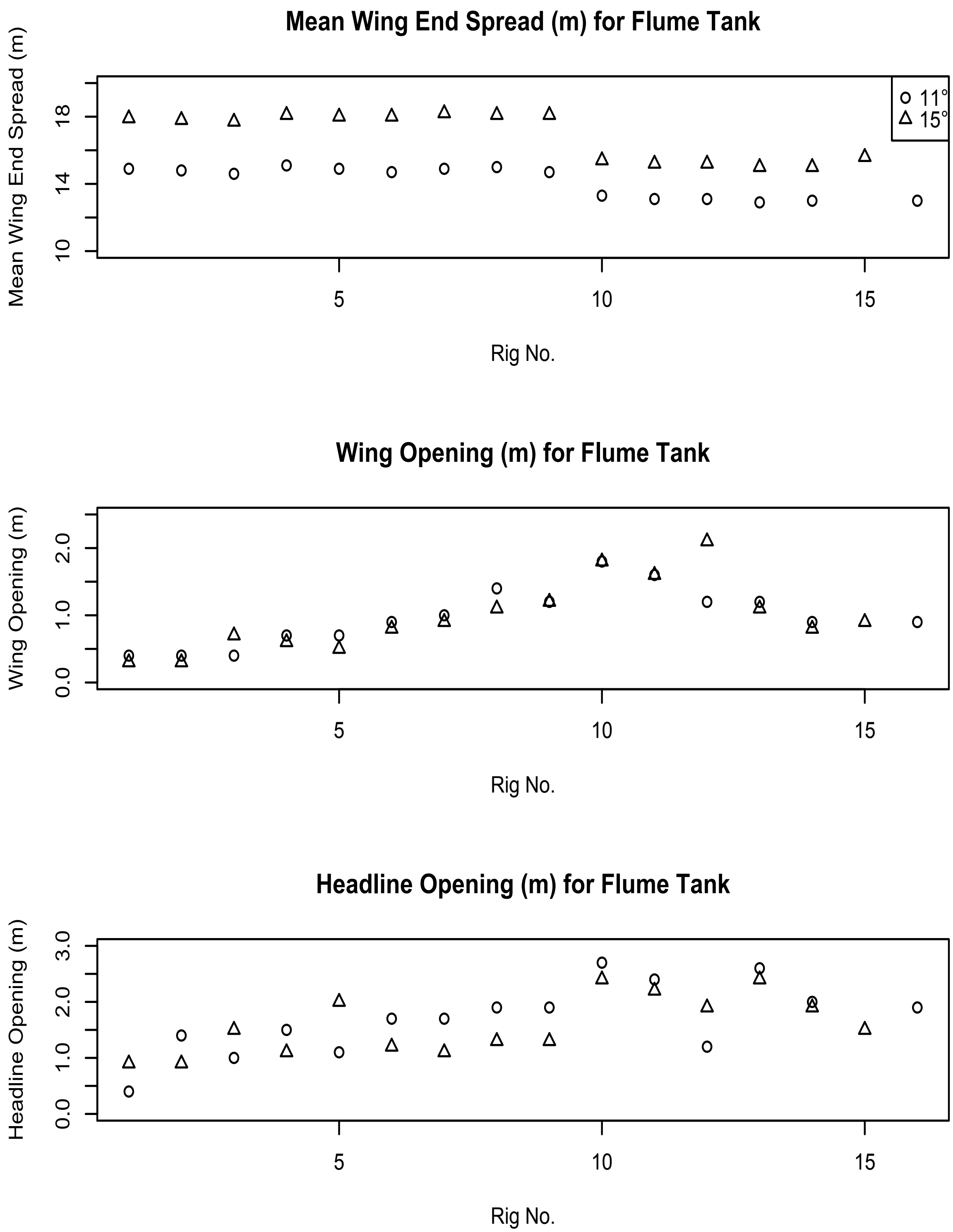
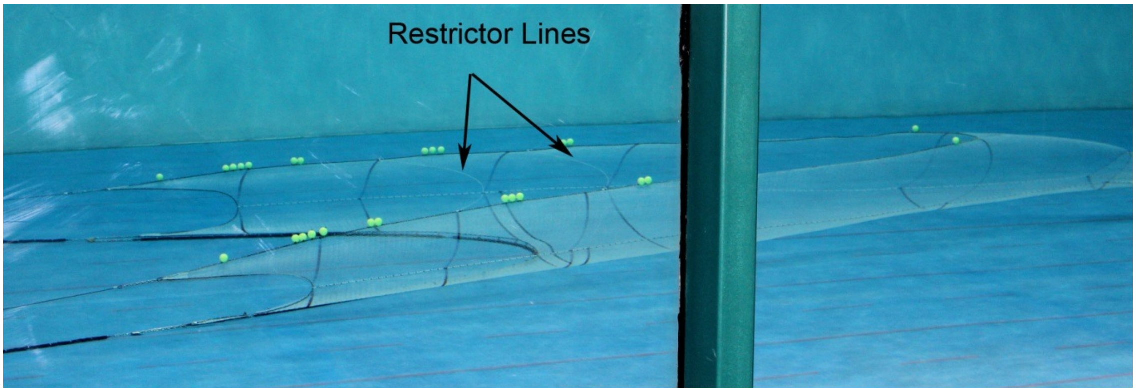


Figure 4: A portion of the 48.7-m (160-ft) headrope model net in the flume tank with the addition of two restrictor lines that were added to the experimental net used in field work.



F**igure 5:** The start tow locations for all tows during the duration of the sampling.

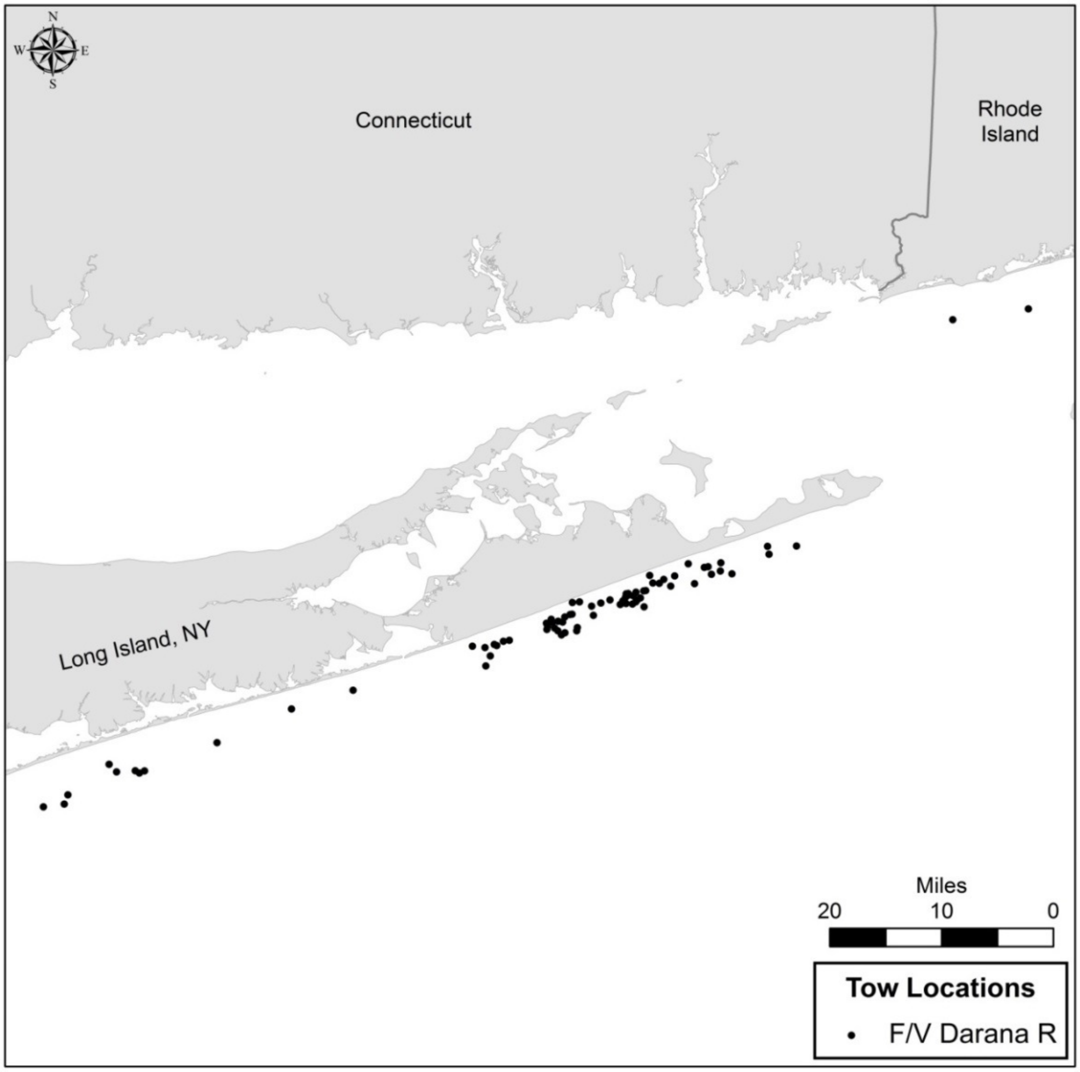


Figure 6: The height of the vertical opening of the starboard-wing end for the experimental net for 6/24/2013 Haul 3.

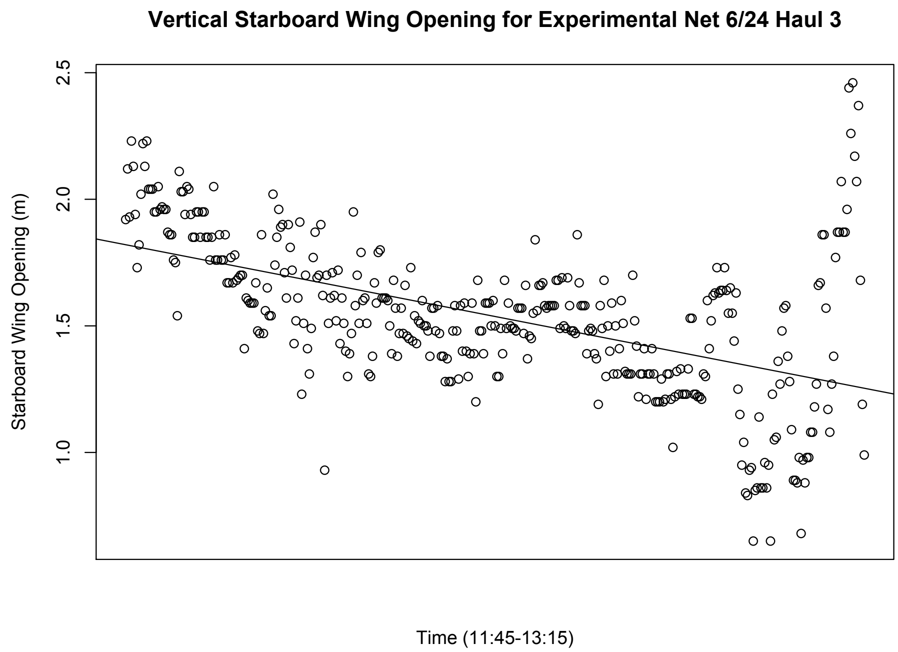


Figure 7: The height of the vertical opening of the starboard-wing end for the control net for 6/25/2013 Haul 3.

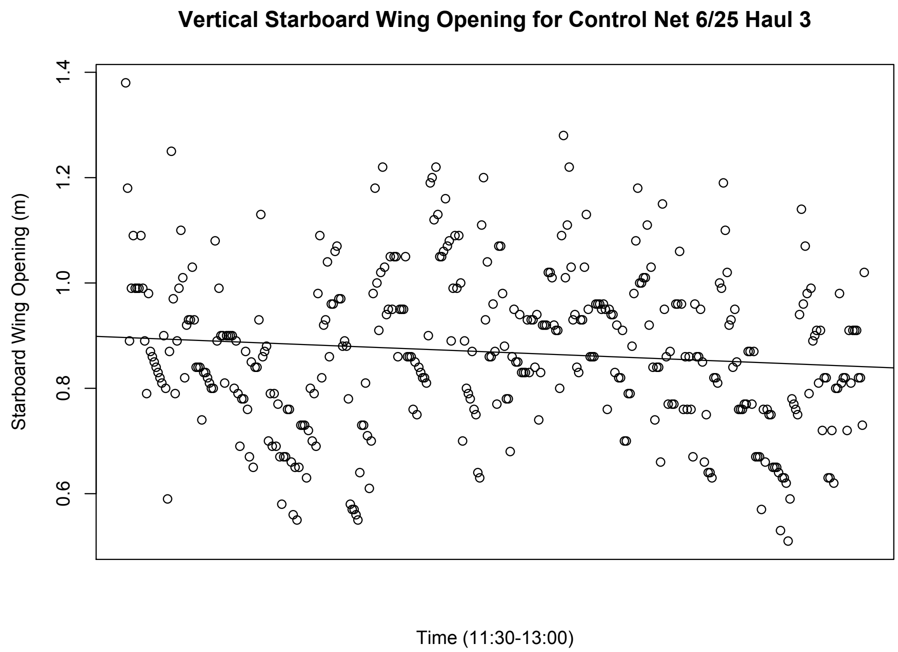


Figure 8: The height of the vertical opening of the headrope for the experimental net for 7/14/2013, Haul 6, Float Configuration #2

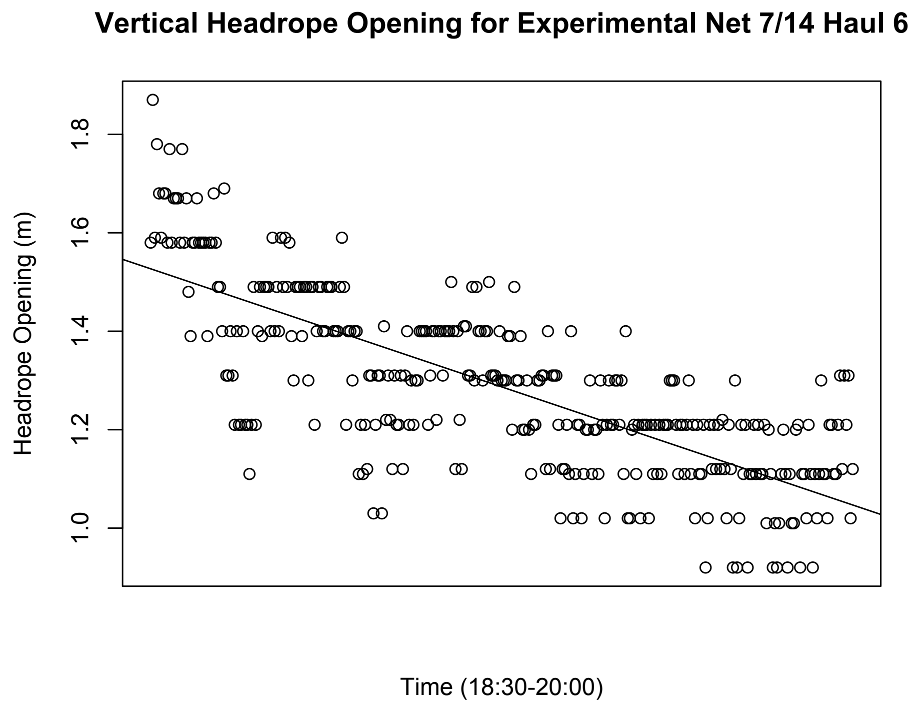


Figure 9: Overall catch density for float configuration #1and float configuration #2.

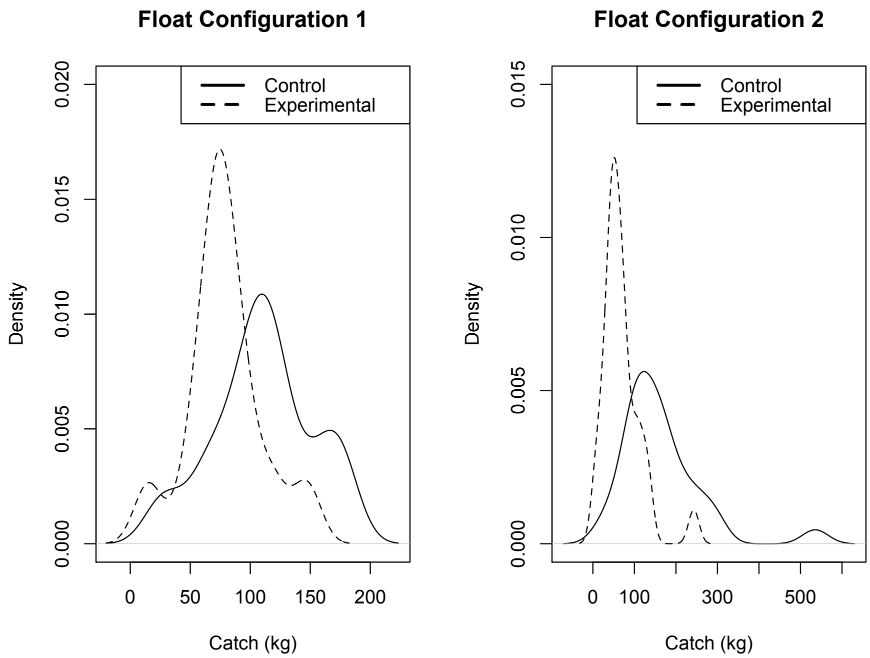
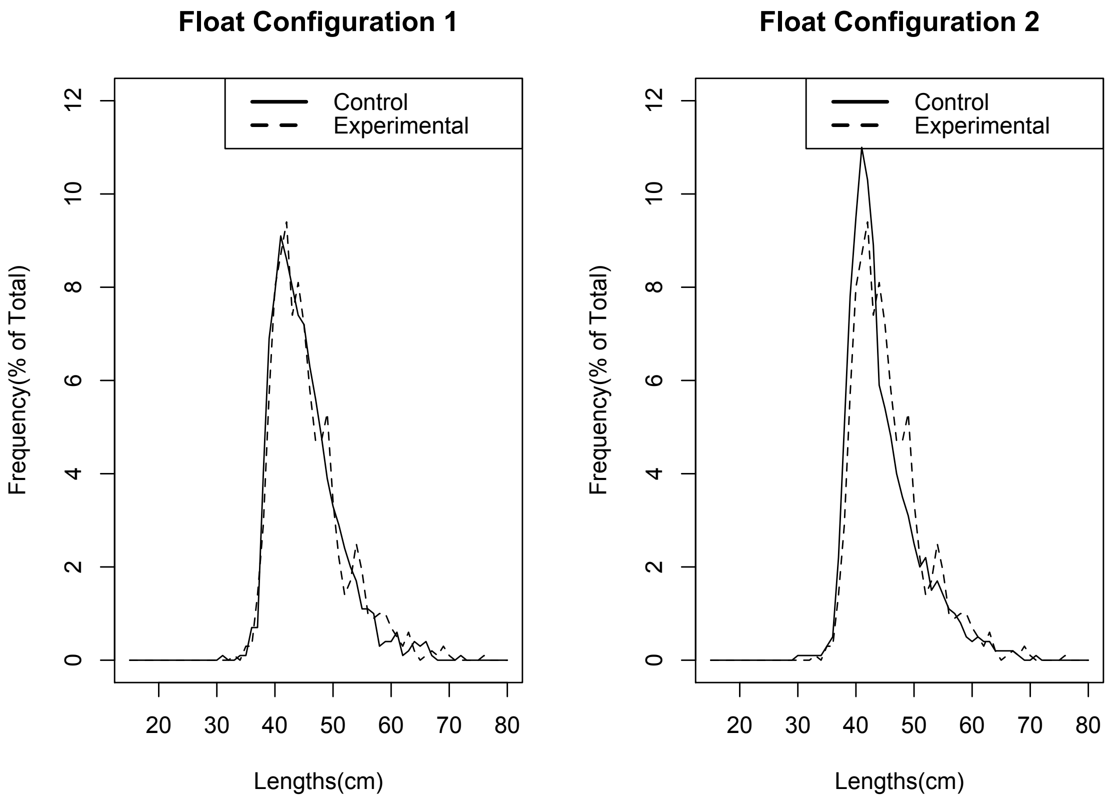


Figure 10: Length Frequency for float configuration #1 and float configuration# 2 by percent of total.



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