Study on catch retention using a larger TED in the summer flounder trawl fishery

Revised Final Report:

Submitted to NOAA/NMFS/NEFSC Protected Species

Contract Award Number:

EA133F-08-CN-0230

Contract Period of Performance:

September 18, 2008 – November 30, 2009

Submitted By:

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Date:

January 27, 2010

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Summary

The capture and mortality of sea turtles in demersal trawl nets is considered to be a major threat to the survival of these animals. In an effort to reduce their impact on sea turtles, fishermen operating in specified locations in the Mid-Atlantic summer flounder trawl fishery are required to install and use a turtle excluder device (TEDs) in their trawl nets. This requirement has existed for almost two decades. Initial, but limited, testing of TEDs in the early 1990’s indicated that these devices did not reduce the catch of summer flounder. However, in 2007 a more rigorous study with a NMFS-certified Flounder TED showed a significant 35% difference in catches of summer flounder. This finding resulted in testing a larger Flounder TED, which was approximately 25% larger than the standard Flounder TED.

In 2009, the larger Flounder TED was tested during May, July, and September in the Mid-Atlantic Bight aboard the F/V Nordic Viking. An alternate haul experimental method was used to compare catches of summer flounder and bycatch between a codend fitted with the larger TED and a standard codend without a TED. In the codend fitted with the TED, the summer flounder catch rate was 13.4% lower than in the standard codend with a TED, but this reduction was not statistically significant. However, the catch rate of large, “jumbo” summer flounder was much lower (-43%) in the TED-equipped net, presumably because the bar spacing of the TED hindered the passage of larger-sized fish to the codend. While the reduction in summer flounder reported in this study is a cause for concern and further modifications and testing are required, the larger Flounder TED resulted in a greater retention of summer flounder than occurred with the TED used in the 2007 study.

Acknowledgements
This project could not have been completed without the extraordinary help of several fishing industry participants. We are indebted to Richard Hoff, owner of the F/V Nordic Viking for making his vessel available for this research, and Captain James Lund and crew, John, Tom, and Jay, for their assistance during the fieldwork, particularly exchanging nets between tows and sampling the catch, and hospitality. We also appreciate the efforts of Greg DiDomenico, Executive Director of the Garden State Seafood Association, for his assistance with vessel selection and fieldwork management.

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Introduction

The capture of sea turtles in demersal trawl nets is considered to be a major threat to the survival of these species (Plotkin 1995) due to drowning when they are not released from the fishing gear in a timely manner (Ogren et al. 1977). In the early 1980s, the National Marine Fisheries Service (NMFS) responded to these concerns by spearheading efforts to develop turtle excluder devices (TEDs) for the Southeastern U.S. shrimp industry. These devices consist of an inclined grid to guide turtles (and other large animals) towards an escape opening located either in the top or bottom of the codend (Eayrs, 2007). Small animals, including shrimp, pass through the grid and are retained in the codend. During this period of research, the use of TEDs was voluntary but they were not widely adopted by shrimp fishermen (Connor 1987). In 1987, however, it became a Federal requirement for fishermen to minimize the capture of sea turtles by installing a NMFS-certified TED into each trawl net (Federal Register 1987).

The summer flounder or fluke, *Paralichthys dentatus*, supports commercial and recreational fisheries primarily between Cape Cod, Massachusetts and Cape Hatteras, North Carolina. In 1990, a large number of dead sea turtles were reported washed up on the beaches of the Outer Banks in North Carolina, and this stimulated efforts to develop TEDs for the summer flounder trawl fishery (Anonymous 1992). Research into the effect of several different TED designs on catches of summer flounder was reported to be minor; however, low catch rates and a limited number of completed tows were issues that affected this work (Monaghan 1992, Watson 1992). In 1992, the use of a NMFS-certified Flounder TED became a requirement for fishermen operating in the summer flounder trawl fishery south of Cape Charles, Virginia, to the boundary between North Carolina and South Carolina (Federal Register 1992). Most of these waters are referred to as the Sea Turtle Protection Area, although certain spatial and temporal exceptions to this requirement currently exist when the capture of sea turtles is not expected. In waters north of this region, fishermen in the summer flounder trawl fishery are currently not required to use a Flounder TED, although this could change as NMFS is currently considering extending northward the requirement to use these devices.

A recent assessment of the bycatch of loggerhead sea turtle, *Caretta caretta,* in the Mid-Atlantic bottom trawl fishery between 1996 and 2004 indicated that an estimated 616 loggerheads were taken annually between Cape Hatteras, NC and Long Island, NY (Murray 2006). According to Conant et al. (2009), the incidental capture of loggerhead sea turtles in commercial fishing gear is the most significant man-made factor affecting the conservation and recovery of this species. In response to concern over catches of these sea turtles, the NMFS published an advanced notice of proposed rulemaking that included plans to consider expanding TED requirements for all trawl fisheries in the Mid-Atlantic region, including the use of TEDs with enlarged escape openings to facilitate the escape of large loggerhead sea turtles, and to extend northward of the Sea Turtle Protection Area the requirement to use NMFS-certified TEDs (Federal Register 2007).

In January 2007, the Northeast Fisheries Science Center (NEFSC) contracted the University of Rhode Island (URI) to host a fishing industry workshop and discuss bycatch reduction technologies to mitigate sea turtle bycatch in trawl fisheries in the Mid-Atlantic and

Southern New England (DeAlteris, 2007). Outcomes from this workshop included calls for evaluating the performance of a TED with a larger grid and escape opening, and grid modifications to specifically improve the retention of summer flounder and release other bycatch. The NMFS subsequently funded the URI to assess the performance of the standard Flounder TED (hereafter called the SF-TED) in the summer flounder fishery during the summer of 2007. This evaluation detected a significant 35% reduction in summer flounder catch when the trawl was equipped with the SF-TED (Lawson et al. 2007). To evaluate whether retention of summer flounder could be increased in a TED-equipped net, in 2009 the Gulf of Maine Research Institute tested a larger, NMFS-designed, Flounder TED (hereafter called the LF-TED) in the Mid-Atlantic Bight region of the fishery.

Methods

In May, July, and September 2009, GMRI tested the LF-TED onboard the F/V Nordic Viking (O.N. 547331), a steel otter trawler based in Cape May, NJ (Figure 1). The trawler measured 77′ (23.5 m) in length overall, with a volume of 174 gross tons (118 net tons) and an engine rating of 1,400 horsepower (1044 kilowatts). Testing of the TED was conducted in the Mid-Atlantic Bight region of the fishery (Figure 2) using a paired alternate haul design (ABBA), with the standard net and plain extension designated the control net (A) and the standard net with a LF-TED fitted into the extension designated the treatment net (B). Alternate, paired tows were completed along the same approximate tow path with equal tow duration and vessel speed. All tows were accomplished during daylight hours. Decisions on actual tow location were based on historical catches of summer flounder and local-area knowledge by the Captain.

The grid (frame) used in the construction of the LF-TED measured 51″ (129.5 cm) high by 43 ⅜″ (110 cm) wide (Figure 3). The grid was 25% wider than the SF-TED tested in 2007, although total grid height, upper bar spacing, and bottom window height remained identical to the SF-TED. The LF-TED was fished in a top opening configuration with the escape opening located in the top panel of the codend. The escape opening of the LF-TED extended the width of the frame, and satisfied the requirements of the so-called leatherback sea turtle modification (i.e., a 142-inch or 361 cm circumference with a corresponding 71-inch or 180-cm straight line stretched measurement).

The LF-TED was installed into the extension piece of a 4-seam flounder trawl net used by the vessel to target summer flounder. The headrope of the trawl net measured 52.5′ (16 m) and the 72.5′ (21.1 m) footrope was constructed with chain attached to a 5″ (13 cm) rubber cookie sweep. The ground cables were 60 fathoms (110 m) in length and covered with 3″ (8 cm) rubber cookies. The main part of the net (trawl wings and body) was composed of 5 ½″ (14 cm) polyethylene diamond mesh[1] webbing with a fishing circle of 344 meshes. The codend was 5 ½″ (14 cm) double-mesh, knotted, green polyethylene webbing material hung on the diamond. The trawl net was spread open with Thyboron 80″ Type II doors, which were towed at an average speed of 3.1 knots (1.6 m/s).

The LF-TED was fitted into a webbing extension piece at a 55° angle from the horizontal plane, with two 8″ (200 cm) hard plastic floats attached to both sides of the TED. The extension piece, measuring 100 meshes in circumference by 33 meshes deep, was constructed from 3 ½″ (9 cm) mesh, and was inserted between the body of the trawl net and the codend. An identical extension piece without a TED fitted was used in the control net. Attachment of the extension piece to the trawl net was facilitated by threading a line through plastic rings attached to the extension piece and trawl net (Figure 4). An identical technique was used with rings attached to the extension piece and codend. This rigging arrangement allowed for a quick and easy exchange of extensions between hauls.

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[1] Mesh size was measured from center of knot to center of opposing knot.

All data were recorded on standard NMFS Observer data logs. Information recorded for each tow included gear number, haul pair, date, time and position of net deployment and retrieval, fishing depth, towing speed, wire out and weather conditions. The catch was separated by species and disposition, and weighed to the nearest tenth of a pound (lbs) using a Marel M1100 PL4200 marine scale. In each tow, summer flounder were measured for total length to the nearest centimeter. Length measurements of other species, including various flounder species, monkfish, and black sea bass, were taken as time allowed. Large catches of summer flounder and some bycatch species were estimated using relevant sub-sampling methods with the assistance of the captain and crew.

To facilitate data analysis, all catch weights for each tow were standardized to a towing duration of 60 minutes. Paired tows were omitted from all analyses of a species which did not occur in either the control or the corresponding treatment catch. All catch rates were initially tested for normality using a two sample F-Test for Variances ($\alpha = 0.05$) and, when necessary, were logarithmically transformed (Log pounds/hour + 1) to normalize the data and stabilize the variance (Fowler et al. 1998).

A one-tailed, paired t-Test ($\alpha = 0.05$) was used to compare the mean catch rates of summer flounder between the control and treatment gear. The null hypothesis was that catch rates of summer flounder were equal in the two gear types. The alternate hypothesis was that catch rates of summer flounder were reduced when the LF-TED was used. We then conducted post-hoc one-tailed, power analysis ($\alpha = 0.1$) of the mean difference in catch rates between the control and treatment nets to determine the reliability of the paired t-Test results. A Kolmogorov-Smirnov (K–S) test ($\alpha = 0.05$) was used to test for significant differences, by sampling month and all months combined, in the length frequency distributions of summer flounder retained in the two gears. An evaluation was also conducted of monthly summer flounder catch rates to determine if month influenced TED performance. As well, the effect of summer flounder, dogfish, skate, and total bycatch volume on TED performance was evaluated.

Catches of summer flounder by market category were also compared between the control and treatment gear (Table 1). Summer flounder market size categories were based on information supplied by the captain and crew.

Table 1. Summer flounder market size categories.

Market category	Size
Sub-legal	< 14 inches (<36 cm) total length
Small	14 – 16 inches (36 – 41 cm) total length
Medium	16 – 18 inches (41 – 46 cm) total length
Large	18 – 22 inches (46 – 55 cm) total length
Jumbo	> 22 inches (> 56 cm) total length; > 4 lbs (> 1.8 kg)

Catch rates of other commercially valuable species and dominant bycatch species were also analyzed. The null hypothesis was that the mean catch rates of these species were identical in the LF-TED and the control net. The alternate hypothesis was that catch rates of these species were reduced when the LF-TED was used. Both a one-tailed paired t-Test and a one-tailed, power analysis ($\alpha = 0.1$) on the mean difference in catch rates was used with these data sets. A Kolmogorov-Smirnov (K–S) test ($\alpha = 0.05$) was used to test for a significant difference in the size frequency distributions of black sea bass, monkfish, winter flounder, and windowpane between the two gears. For all remaining bycatch species, only proportional changes in the standardized catch rates of each species were evaluated.

Results

Forty successful paired tows (80 total tows) were completed over 16 sampling days in Mid-Atlantic waters between Delaware and Long Island, New York in May (23 pairs), July (8 pairs) and September (9 pairs). The average water depth was 13.7 fathoms (25 m) and ranged between 6 and 38 fathoms (11 m and 69.5 m). The scope of wire used was 75 fathoms (137 m) for all tows except one pair of offshore tows (depth = 38 fathoms; 69.5 m) where a scope of 100 fathoms (183 meters) of wire was used. Tow duration for pairs of tows ranged from 50 to 120 minutes, with a mean towing duration of 77.3 ± 15.7 minutes. The mean difference in towing duration between pairs of tows was 1.7 ± 4.2 minutes. Vessel speed for all tows averaged 3.1 knots, with a mean difference of 0.01 ± 0.11 knots between paired tows.

Overall, a 31.5% reduction in total catch (all species combined) occurred in the treatment net (45,902.7 standardized total pounds) compared to the control net (67,009.1 standardized total pounds). This difference was highly significant ($t = 1.68$, $df = 39$, $p = <0.001$, power = 0.996).

Summer Flounder (lbs/hr per tow)

We recorded a 13.4% reduction in the total catch of summer flounder in the treatment net, although this reduction was not statistically significant ($t = 1.68$, $df = 39$, $p = 0.172$, power = 0.368). We also recorded a 13.9% reduction in catch of kept or legal-sized (≥14″) summer flounder in the treatment net, but this was also not statistically significant (Table 2). The reduction in kept summer flounder was greatest in May and highly significant ($t = 1.72$, $df = 22$, $p = 0.001$, power = 0.977). Kept summer flounder catch rates were highest in July, followed by September and May (Figure 5).

When summer flounder catch rates were low (i.e., less that 100 lbs/hr in the control net per tow), the mean catch rate of legal-sized summer flounder in the treatment net was 24% lower than in the control net (Table 2) and this difference was highly significant ($t = 1.72$, $df = 20$, $p = 0.005$, power = 0.937). The average catch rate of legal-sized summer flounder in the TED net was also significantly lower ($t = 1.75$, $df = 16$, $p = 0.003$, power = 0.969) when dogfish catches exceeded 250 lbs in the control net per tow, but not when dogfish catches were less. When large skate catches occurred in the control net (greater than 1000lbs/hr per tow), the mean catch rate of legal-sized summer flounder was lower (-17%) in the treatment net, although this difference was not statistically significant. When the skate catch was lower, however, there was almost no difference in the mean catch rates of summer flounder between the two gears. Large quantities of bycatch (greater than 2,000 lbs/hr per tow) also resulted in a reduced (albeit non-significant) catch rates of legal-sized summer flounder in the treatment net, compared to when low amounts of bycatch occurred.

Sub-legal (or discarded) summer flounder accounted for 2.3% and 2.8% of the total summer flounder caught (by weight) in the control and treatment nets, respectively, and catch rates of these fish were highest in September than in May or July (Figure 6). The average catch rate of sub-legal summer flounder in the treatment net was 7.9% lower than that in the control net for all tows combined (Table 3). During September, the mean catch rate of sub-legal summer flounder was 15% lower in the treatment net vs. the control net in September, but was only 3.7% lower in May. However, in none of these cases, was the difference in catch rates statistically significant between the two gear types.

Table 2. Average catch rate of legal-sized summer flounder in pounds per hour per tow by major category. *n* = number of paired tows; a negative reduction indicates treatment catch > control catch; Power indicates the result of power analysis.

Category	Control (SD)	Treatment +/- SD	Reduction (%)	Power
Total flounder (*n* = 40)	193.0 +/- 289.8	166.3 +/- 263.4	13.9	0.374
May (*n* = 23)	43.5 +/- 37.8	31.4 +/- 27.0	27.8 *	0.977
July (*n* = 8)	585.0 +/- 449.1	490.7 +/- 427.2	16.1	0.258
September (*n* = 9)	226.6 +/- 99.9	222.5 +/- 124.6	1.8	0.140
Control > 100 lbs/hr of summer fl. (*n* = 19)	365.8 +/- 347.7	319.4 +/- 320.2	12.7	0.308
Control < 100 lbs/hr of summer fl. (*n* = 21)	36.7 +/- 31.6	27.8 +/- 24.8	24.3 *	0.937
Control > 250 lbs of dogfish (*n* = 17)	45.3 +/- 38.5	31.5 +/- 26.9	30.4 *	0.969
Control < 250 lbs of dogfish (*n* = 23)	302.2 +/- 344.2	265.9 +/- 313.2	12.0	0.295
Control > 1000 lbs of skates (*n* = 27)	228.4 +/- 336.4	189.4 +/- 303.6	17.0	0.371
Control < 1000 lbs of skates (*n* = 13)	120.5 +/- 140.7	119.7 +/- 154.0	0.7	0.111
Control total bycatch > 2000 lbs (*n* = 15)	225.2 +/- 388.6	188.1 +/- 366.0	16.5	0.248
Control total bycatch < 2000 lbs (*n* = 25)	173.7 +/- 217.7	153.2 +/- 184.8	11.8	0.303

* significant at α = 0.05

Table 3. Total weight of sub-legal (discarded) summer flounder in pounds per hour per tow by sampling period. n = number of paired tows with summer flounder in the catch; negative sign indicates treatment catch > control catch; Power indicates the result of power analysis.

Sampling period	Control (lbs/hr)	Treatment (lbs/hr)	Reduction (%)	Power
All months ($n = 34$)	167.0	180.2	- 7.9	0.211
May ($n = 21$)	61.2	59.0	3.7	0.145
July ($n = 4$)	8.6	9.6	- 12.3	0.144
September ($n = 9$)	97.2	111.6	- 14.8	0.217

Summer flounder (length frequency)

A total of 2,947 and 2,723 summer flounder were measured from the control and treatment nets, respectively, and relatively few from either net were sub-legal (Figure 7). The average length of summer flounder retained in the control and treatment nets respectively was 40.8 cm ± 6.6 and 40.2 cm ± 6.2 in May, 45.8 cm ± 6.3 and 44.8 cm ± 5.6 in July, and 41.3 cm ± 5.6 and 40.9 cm ± 5.4 in September. The length range of all measured individuals for May, July and September, ranged between 21 – 68 cm, 31 – 77 cm and 21 – 62 cm respectively (Figure 8). There was no significant difference in length frequency distributions between nets when all sampling periods were combined, or in May or September (Table 4). A significant difference was recorded between length frequency distributions in the control and treatment in July (Table 4).

Table 4. Kolmogorov-Smirnov evaluation ($\alpha = 0.05$) of summer flounder length frequencies in the control and treatment nets, by sampling period. **D** = observed unsigned difference between the relative cumulative frequency distributions.

Sampling period	**D**	$\mathbf{D}_{0.05}$	n (control, treatment)
All months	0.035	0.036	2947, 2723
May	0.055	0.069	901, 674
July *	0.084	0.066	840, 832
September	0.041	0.055	1206, 1217

* significant at $\alpha = 0.05$

There was a substantial reduction (33% - 46%) in the catch of jumbo summer flounder in the treatment net during all months and when all months were combined (Figure 9). Overall, fewer large summer flounder were retained in the treatment net, although in July and September there was little or no difference between nets. In May, however, there was a 42% reduction in the catch of these flounder in the treatment net. There was an increase in the catch of small and medium summer flounder in the treatment net in July, and of sub-legal and small summer flounder in September. There was an overall reduction in catches of legal-sized summer flounder, across all legal size categories, in the treatment net, but also a slight increase in sub-legal catches of summer flounder.

Bycatch

Analysis of all bycatch species and groups captured in paired tows indicated a significant reduction of all bycatch in the treatment net (Table 5). The bycatch was dominated by skate species (which included clearnose, winter. and little skates) and, as a group, skates accounted for approximately 76% of the total weight of bycatch. The dressed, smoothed dogfish category reflects a catch of exceptionally large individuals (approximately 125 cm or longer) that were processed for sale, while all other smooth dogfish were

Table 5. Standardized comparison and one-tailed, paired t-test results for total catches of bycatch and commercially important species and groups in the Mid-Atlantic trawl fishery. *n* = number of paired tows with species occurrence; negative sign indicates treatment catch > control catch; Power value indicates the result of power analysis.

Species/group	Control (total catch)	Treatment (total catch)	Reduction (%)	*p*-value	Power
bycatch, all (*n* = 40)	59121.4	39071.5	33.9	< 0.001 *	0.997
skates, all (*n* = 40)	42859.5	31927.3	25.5	0.002 *	0.990
horseshoe crab (*n* = 24)	5391.5	1144.6	78.8	< 0.001 *	0.407
spiny dogfish (*n* = 22)	3897.8	2230.3	42.8	0.006 *	0.875
smooth dogfish (*n* = 33)	3372.5	1566.2	53.6	0.007 *	0.992
dressed smooth dogfish (*n* = 14)	237.7	61.5	74.1	< 0.001 *	0.969
monkfish (*n* = 17)	219.5	56.5	74.2	< 0.001 *	0.979
Atlantic croaker (*n* = 9)	173.9	214.2	-23.2	0.374	0.167
whelk (*n* = 8)	151.4	123.5	18.5	0.190	0.347
scup (*n* = 20)	114.7	83.5	27.2	0.228	0.301
black seabass (*n* = 34)	68.0	68.8	-1.2	0.153	0.107
sea scallop (*n* = 5)	24.7	18.0	26.9	0.245	0.270
Loligo squid (*n* = 11)	24.4	17.6	28.0	0.106	0.496
butterfish (*n* = 14)	12.3	2.2	82.2	0.016 *	0.847

* significant at $\alpha = 0.05$

discarded at sea. For all skate species combined, the treatment net caught fewer skates in 28 of 40 paired tows (Figure 10). The treatment net also caught fewer dogfish in 22 of 29 paired tows, although respectively 96.5% and 98.2% of dogfish were caught in the control and treatment nets in May (Figure 11). All monkfish were caught in May, and in 7 of 8 paired tows the treatment net caught fewer monkfish (Figure 12). For most other bycatch species the catch was less in the treatment net compared to the control net (Table 6). Four species were not recorded in the treatment net but were recorded in the control net; they were, Atlantic sturgeon (# of fish = 5), Atlantic angel shark (# of fish = 3), sand tiger shark (# of fish = 1) and striped bass (# of fish = 1). Four species were recorded in very small amounts in the treatment net only; they were silver hake, chain dogfish, tautog, and menhaden.

Table 6. Standardized catch comparison for remaining bycatch species. *n* = number of paired tows with species occurrence; negative sign indicates treatment catch > control catch.

Species	Control (lbs)	Treatment (lbs)	Reduction (%)
Windowpane flounder (*n* = 39)	839.0	726.1	13.5
Atlantic sturgeon (*n* = 2)	452.0	0.0	100.0
Bluntnose stingray (*n* = 2)	244.0	1.2	99.5
Northern sea robin (*n* = 28)	224.6	247.7	-23.1
Striped sea robin (*n* = 24)	217.7	190.7	12.4
Fourspot flounder (*n* = 22)	175.4	160.5	8.5
Spiny butterfly ray (*n* = 4)	89.1	17.1	80.8
Southern stingray (*n* = 5)	87.4	19.9	77.2
Atlantic angel shark (*n* = 2)	80.8	0.0	100.0
Bullnose ray (*n* = 4)	60.5	115.0	-90.0
Witch flounder (*n* = 8)	24.7	21.1	14.7
Winter flounder (*n* = 11)	22.0	18.1	17.7
Sand tiger shark (*n* = 1)	14.1	0.0	100.0
Northern stargazer (*n* = 5)	12.0	12.4	-3.3
Spotted hake (*n* = 4)	8.9	6.1	31.7
Striped burrfish (*n* = 1)	7.4	1.7	77.0
Striped bass (*n* = 1)	6.0	0.0	100.0
Ocean pout (*n* = 4)	4.5	4.1	8.9
Northern kingfish (*n* = 3)	2.1	1.0	52.4
Spot (*n* = 3)	0.7	1.9	-171.4
Silver hake (*n* = 2)	0.0	5.2	-
Chain dogfish (*n* = 1)	0.0	1.8	-
Tautog (*n* = 1)	0.0	4.1	-
Menhaden (*n* = 1)	0.0	1.4	-

Length frequency sampling was conducted on four of the bycatch species: black sea bass (Figure 13), monkfish (Figure 14), winter flounder (Figure 15) and windowpane flounder (Figure 16). A comparison of the paired tow data indicated that the average catch rates of these species were lower in treatment net than in the control net. For each of the four species, no significant difference in length frequency distributions was detected between the two nets (Table 7). Although no actual lengths were taken, the five Atlantic sturgeon caught were all approximately 180 cm in total length, and the three Atlantic angel sharks and the one sand tiger shark were all approximately 125 cm in total length.

Table 7. Kolmogorov-Smirnov evaluation ($\alpha = 0.05$) between length frequencies recorded in the control and treatment nets for selected bycatch species. **D** = unsigned difference between the relative cumulative frequency distributions.

Species	**D**	$\mathbf{D}_{0.05}$	*n* (control, treatment)
Black sea bass	0.144	0.160	163, 130
Monkfish	0.222	0.315	60, 27
Winter flounder	0.163	0.355	32, 27
Windowpane flounder	0.106	0.291	45, 42

Discussion

This study attempted to provide a baseline evaluation of the effect of the LF-TED (treatment) on summer flounder catch in the summer flounder trawl fishery. An important factor that influenced the results of this study was high variability in the summer flounder catch between tows and sampling months. A power analysis conducted for the various comparisons of summer flounder catch, bycatch, and other species groups between the two gears indicated the results of the paired t-Test may result in a Type II error (accepting a false null hypothesis) due to a combination of low sample sizes and high standard deviations (Sokal and Rohlf, 1995). We acknowledge that, in certain instances, the data were not robust enough to show statistical significance. Nonetheless, the catch rate comparisons provide insight on the impact of the LF-TED on catches of summer flounder and other species.

Summer Flounder (by volume)

Overall, the catch of kept summer flounder was highest in July and September, although no significant difference was detected during these periods. Our analysis suggests that the number of completed paired tows was insufficient during these two months. Our analysis also indicates that LF-TED performance on the kept (legal-sized) summer flounder catch was influenced by the volume of the summer flounder catch. The significant reduction in kept summer flounder in May was synchronous with low catch rates (<100 lbs/hr) of kept summer flounder.

It is difficult to determine the full extent that dogfish had on the performance of the LF-TED with respect to summer flounder retention. High catches of dogfish (>250 lbs/tow) resulted in a significant difference in kept summer flounder between the two gears, but all 17 paired tows used for the high dogfish catch analysis occurred in May, when overall catch rates of summer flounder were also low. The analysis of skate and total bycatch on catches of summer flounder was also inconclusive, as there was too much variability in catch differences between the gears and insufficient paired tows to draw any definite statistical conclusions from the results.

While we cannot draw conclusions regarding the influence of summer flounder catch volume on LF-TED performance, a significant reduction in summer flounder in May could be linked to large catches of dogfish, skates, and other bycatch. During this month catches of dogfish, monkfish, and sea bass were highest, and the skate catch was also substantial. Analysis using paired t-tests was unable to detect an influence of skate or total bycatch on summer flounder catch, although this was not the case when large dogfish catches were recorded. However, despite these results, it is likely that large catches of these species in May contributed to the loss of summer flounder. As these species reached the LF-TED in large numbers, they may have blocked the grid and preventing the ingress of summer flounder into the codend. This would increase the likelihood that summer flounder would detect and swim through the escape opening in the codend. Therefore, a possible conclusion is that large catches of skate and other bycatch resulted in poorer LF-TED performance with respect to kept summer flounder retention than when bycatches of these species were smaller.

Summer flounder (by length)

In July, when a significant difference was found between the control and treatment length distributions, larger summer flounder were encountered in both gears. In May and September, when the distributions were not significantly different, the overall size of caught summer flounders was smaller. This would imply the LF-TED bar spacing was restricting the passage of larger sized summer flounder to a greater extent than the small ones.

The restriction of larger sized summer flounder into the codend was clear, particularly the catch of "jumbo" summer flounder. An implication of this result is a decrease in the gross value of landed summer flounder to the vessel. For summer flounder, as with many commercial species that are sold by market category, larger sizes usually command a higher price paid by dealers. This result is a concern, and future research using TEDs should include this as a priority, particularly as loss of valuable catch may impact on uptake and compliance with TED use.

An unexpected outcome from this study was an increase in the retention of sub-legal summer flounder in the treatment gear over the control. While these differences were not significant, and was a greater problem in September, it is unclear why this would occur. There would appear to be a need for more research with camera and trawl monitoring gear to determine if this is the result of changes in gear performance, an unusual behavioral response by small summer flounder to the LF-TED, or just simply the result of chance. This is particularly important given the uncertain nature of this result and the potential threat it could pose to sub-legal summer flounder and the stock of summer flounder.

Summer flounder (SF-TED v LF-TED)

While the vessel and trawl nets were not identical between the present study and the work by Lawson et al. (2007), results in all comparable catch categories indicate that the LF-TED design was superior at retaining summer flounder catch than the SF-TED design (Table 8). The reduction of the overall summer flounder catch in the treatment gear in our study was less than half of the reduction recorded by Lawson et al. (2007). In addition, a decreased reduction in summer flounder catches when the LF-TED was used was reported in the other catch categories as well. One area of concern noted in the present study was the loss of "jumbo" summer flounder, but unfortunately no comparisons can be made with the SF-TED as Lawson et al. (2007) did not report on losses by flounder size.

Of the nine comparable catch categories presented, all percent reductions observed with the SF-TED were statistically significant (Lawson et al. 2007) while only one in the present study were statistically significant. The SF-TED showed significant reductions in summer flounder catch regardless of the volume of summer flounder, while our work only showed a significant reduction when summer flounder catch rates were low. Lawson et al. (2007) stated that summer flounder catch retention appeared to be related to the volume of bycatch in a given tow. They indicated clogging of the grid by large catches was a significant factor that influenced SF-TED performance; however, they also showed significant reduction of summer flounder when small catches were encountered, but to a lesser degree. Similarly to our study, Lawson et al. (2007) reported the same trend of greater loss of summer flounder when bycatch volume was high; however, with the exception of large dogfish catches, this effect was not significant.

Table 8. Comparison of summer flounder catch reductions between the LF-TED and the SF-TED using catch categories adapted from Lawson et al. (2007). *n* = number of paired tows satisfying the requirements of each catch category.

Catch category	LF-TED reduction (%)	*n*	SF-TED reduction (%)	*n*
All tows	13.4	40	35 *	37
Total weight of summer flounder > 50 kg for at least one tow	13.2	24	35 *	18
Total weight of summer flounder < 50 kg in each net	18.0 *	16	37 *	19
Dogfish weight > 100 kg for at least one tow	27.2 *	20	39 *	20
Dogfish weight < 100 kg in each net	11.7	20	14 *	17
Skate/ray weight >500 kg for at least one tow	17.4	26	39 *	23
Skate/ray weight < 500 kg in each net	- 1.8	14	29 *	14
Total catch weight > 900 kg for at least one tow	16.7	21	42 *	21
Total catch weight < 900 kg in each net	5.6	19	16 *	16

* significant at $\alpha = 0.05$

This comparison suggests that the LF-TED has less impact on catches of summer flounder compared to the SF-TED because it can filter larger catches with less loss of the target catch. Better target catch retention with the use of larger TEDs and increased filtering area has been demonstrated in several shrimp fisheries worldwide, including the Northern Prawn Trawl Fishery in Australia (Eayrs 2007). Video observations are required, however, to confirm that clogging is reduced when using the LF-TED.

Bycatch

The significant reduction in overall bycatch by the LF-TED was clearly driven by the volume and dominance of the skates in the bycatch. Due to body form, the significant reduction of skates by the treatment gear was not surprising as their broad, rhombic disk shape (Murdy et al. 1997) does not lend itself to easily passing through the narrow spaced bars in the grid. For both spiny and smooth dogfish, it would appear that size was a major factor in reduction by the LF-TED. Most dogfish encountered in this study were mature adults that would more than likely be excluded by a TED or sorting grid, and this is supported by the highly significant reduction in dressed smooth dogfish retained in the treatment net in this study. For monkfish, the significant reduction was a result of both size and body character. Salerno et al. (in prep) demonstrated monkfish girth to be surprising large for even small monkfish, and this may have contributed to their high exclusion rate from the net. It is unclear why there was a significant reduction in catches of butterfish when the LF-TED was used. Based on their morphology and size, it would seem reasonable to expect that butterfish would pass easily through the grid, but perhaps there is a behavioral reaction to this gear that is unknown at this time.

For horseshoe crabs, a significant decrease was observed in the treatment catch, but a low power analysis output indicated that an insufficient number of paired tows were completed with this species in the catch. One anomalous paired tow in September resulted in a catch of 4,500 and 500 pounds in the control and treatment gear, respectively. Without this pair of tows, the proportional reduction would have been reduced to an insignificant 27.7% ($p = 0.059$); however, the power analysis (power = 0.620) still confirmed an insufficient number of tows. Even though this pair of tows was an atypical occurrence in our study, we did not remove these data from analysis because the distribution of summer flounder (Packer et al. 1999) overlaps with the distribution of horseshoe crab (Botten et al. 2003) and could potentially result in large catches of horseshoe crabs during normal commercial operations.

For the remaining commercially important bycatch species encountered in this project, it is difficult to determine the true impact of the LF-TED due to insufficient numbers of paired tows. However, some generalizations can be made. We believe that most larger-sized individuals will be excluded from the catch when the LF-TED is employed. This was evident by the complete removal from the treatment catch of striped bass, Atlantic sturgeon, Atlantic angel shark, and sand tiger shark, and markedly reduced catch rates in the treatment net of horseshoe crab, bluntnose stingray, spiny butterfly ray, and southern stingray. Presumably, most smaller-sized individuals of these species pass through the grid and into the codend.

For some time there have been discussions in regard to developing a Flounder TED with a wider bar spacing (DeAlteris 2007). Presently, both the SF-TED and LF-TED have 4-inch bar spacing across the larger top section of the grid. If a wider bar spacing was used, it would likely have resulted in more flounder passing through the grid and into the codend, and perhaps reduce the loss of jumbo summer flounder from the catch. However, this could also increase the capture and mortality of sea turtles in this region, although at this time the efficacy of bar spacing in this fishery is not well known.

Black sea bass, monkfish and winter flounder lengths were collected due to their importance as commercial species, and windowpane flounder lengths were collected because of their ubiquitous occurrence throughout the study. The lack of differences in size composition between the control or treatment catches of these four species can be explained by the bar spacing of the LF-TED. The 4 inch width was sufficient to allow all sizes of these species to pass through and into the codend. However, this research was directed towards summer flounder, and these length distributions may not be a true representation of the catch in a directed black sea bass or monkfish trawl fishery where larger individuals would presumably be encountered.

Overall bycatch reduction between this study (33.9%, $t = 1.68$, $df = 39$, $p = <0.001$) and Lawson et al. (2007) (36%, $t = 1.69$, $df = 36$, $p = 0.001$) was analogous, and indicated that the two TED designs functioned in a similar manner with respect to reducing the amount of bycatch in the treatment tows. Both studies also showed a significant reduction in skate species. For spiny and smooth dogfish, however, only our study found a significant reduction for these species, and it would therefore appear that the LF-TED was better at reducing dogfish catch. As no lengths were collected for these species in either study, it can not be determined if the wider grid was responsible for these differences or if the size of dogfish encountered in the two studies was dissimilar.

Problems Encountered

Several operational problems were noted when the LF-TED was used.

- During two haul-backs, the LF-TED at the sea surface was observed to be partially clogged by large winter skates. Due to the grid's size, however, an area around the grid was still clear. It is unknown if clogging of the grid was a major issue while fishing, but further work with cameras should be able to answer this question. A clogged grid can be a major problem, particularly during the early stages of a tow, and result in massive loss of commercial catch. In some fisheries this is referred to as being "TEDed" (Eayrs, 2007).

- Chaffing of the extension meshes along the bottom side of the LF-TED was noted early during the field work, even though the TED was equipped with four 8-inch floats. This may have been the result of the LF-TED's larger size and thus greater weight. Chaffing gear was added to the extension (Figure 17) to prevent further damage. The captain also expressed interest in adding two more 8-inch floats or using 10-inch floats instead in the future.

- For most tows in which the LF-TED was used, the retrieval codend process was more complicated than for tows without the LF-TED. Typically, the LF-TED would not lie flat and wind around the net drum (Figure 18). The crew would then have to lift and maneuver the TED and codend using two cargo winches in order to bring the codend aboard. This additional lifting and maneuvering delays hauling the codend onboard and has the potential to increase the safety risk to the crew aboard, particularly in poor weather conditions.

- The aforementioned LF-TED position also contributed to the total destruction of a TED during a haul-back. Weather conditions at the time were 20 knot winds with

4 foot seas. With the LF-TED located astern of the net drum, the stern of the vessel surged upward from the force of the waves, and with the weight of the codend pulling against the LF-TED, it collapsed completely. The total weight of the catch in the codend was approximately 900 pounds. This LF-TED had been used for 14 tows. As this occurred before the TED was wound around the net drum, we surmise that this could potentially occur during any tow when the net is hauled in heavy weather, and consideration should be given to increasing the strength of grid materials.

- Another LF-TED had to be replaced during field operations because the welds connecting the bars to the outer frame failed. It is unknown if these welds broke due to normal wear and tear on the gear or if there was contact with an unknown obstruction underwater. These broken welds appeared after nine tows.

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Figure 1. F/V Nordic Viking, Cape May, New Jersey (77´ LOA).

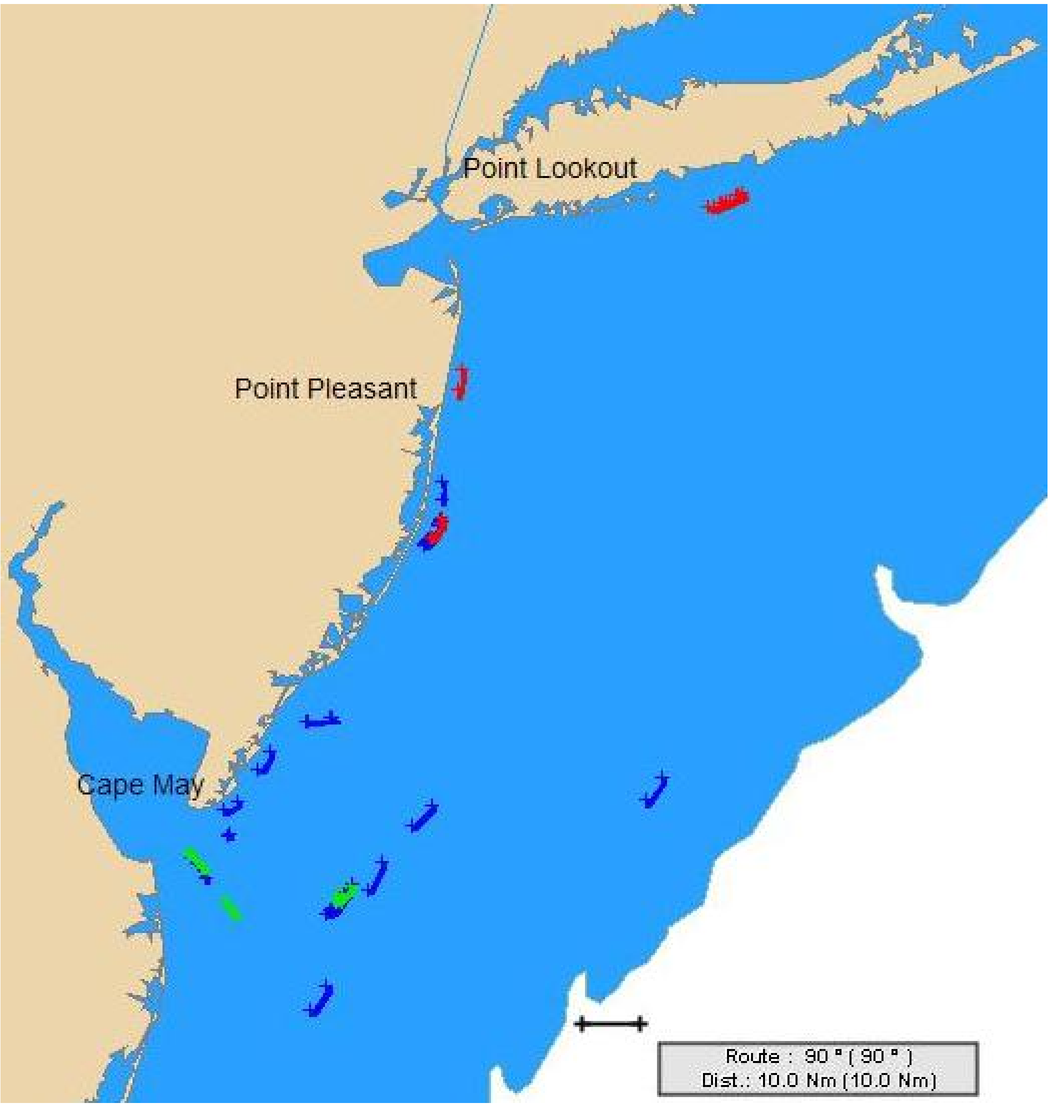
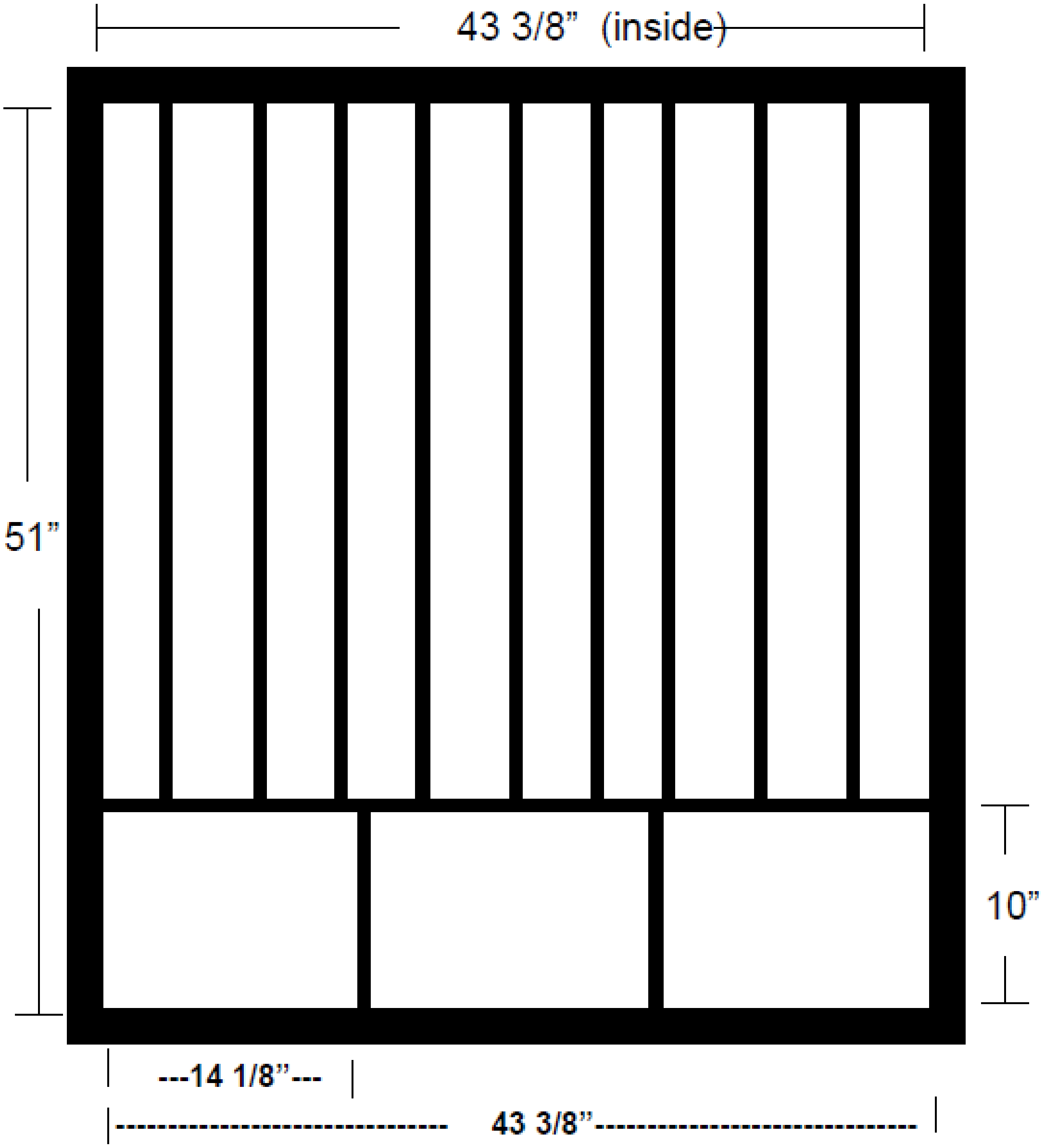


Figure 2. Paired tow locations. (blue – May, red – July, green – September)



Flat bars 3/8"x1.5" (all inside bars)
Round bars 1.6" O.D. (outer frame)
Bottom Windows = 10"h x 14 1/8" w
Bar spacing (top) = 4"
Frame – inside width measurement – 43 3/8"
Frame – inside height measurement =51"

Figure 3. Measurements and dimensions of the LF-TED.

Figure 4. Rings and line rigging for extension exchanging.

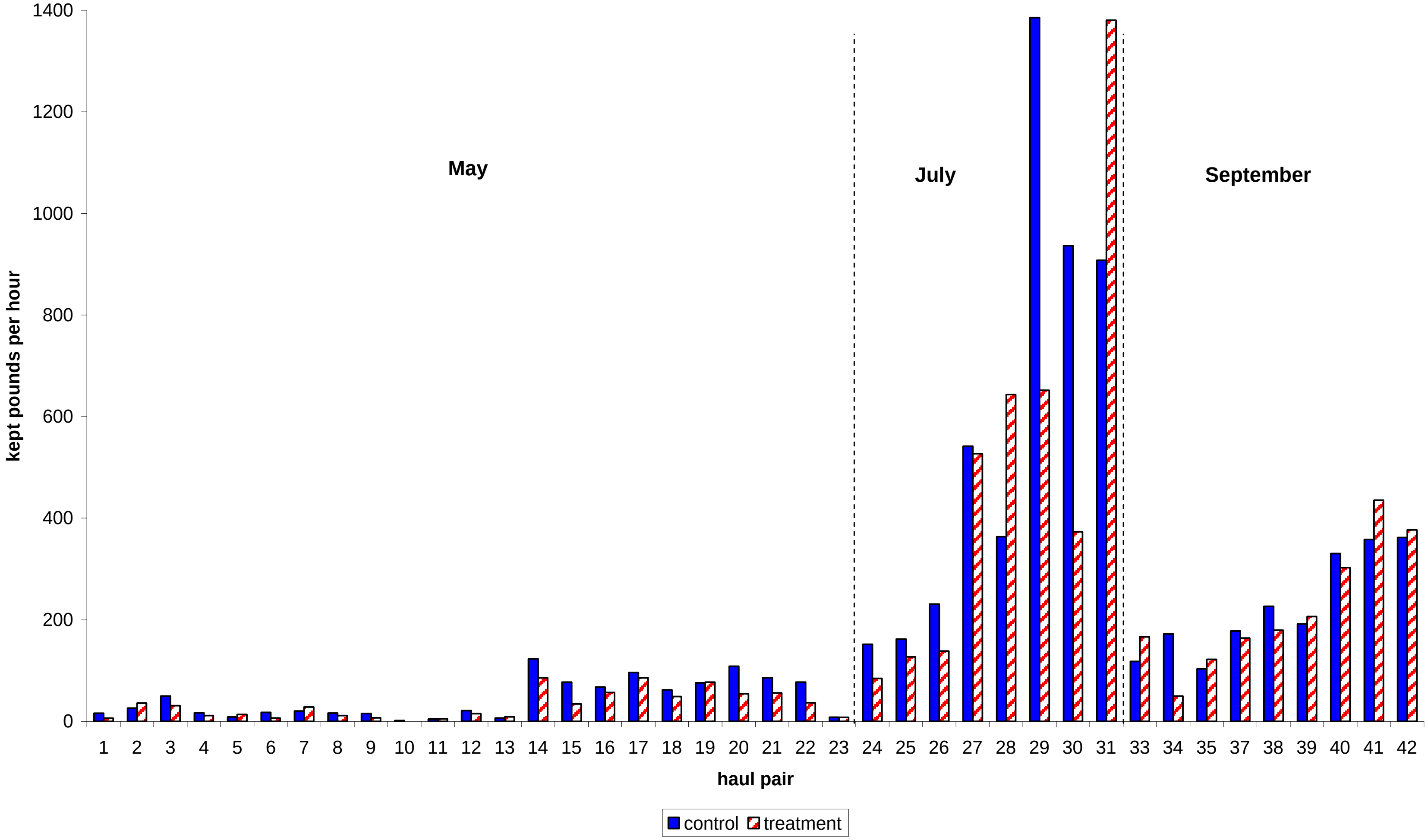


Figure 5. Kept summer flounder catch in pounds per hour by haul pair and month.

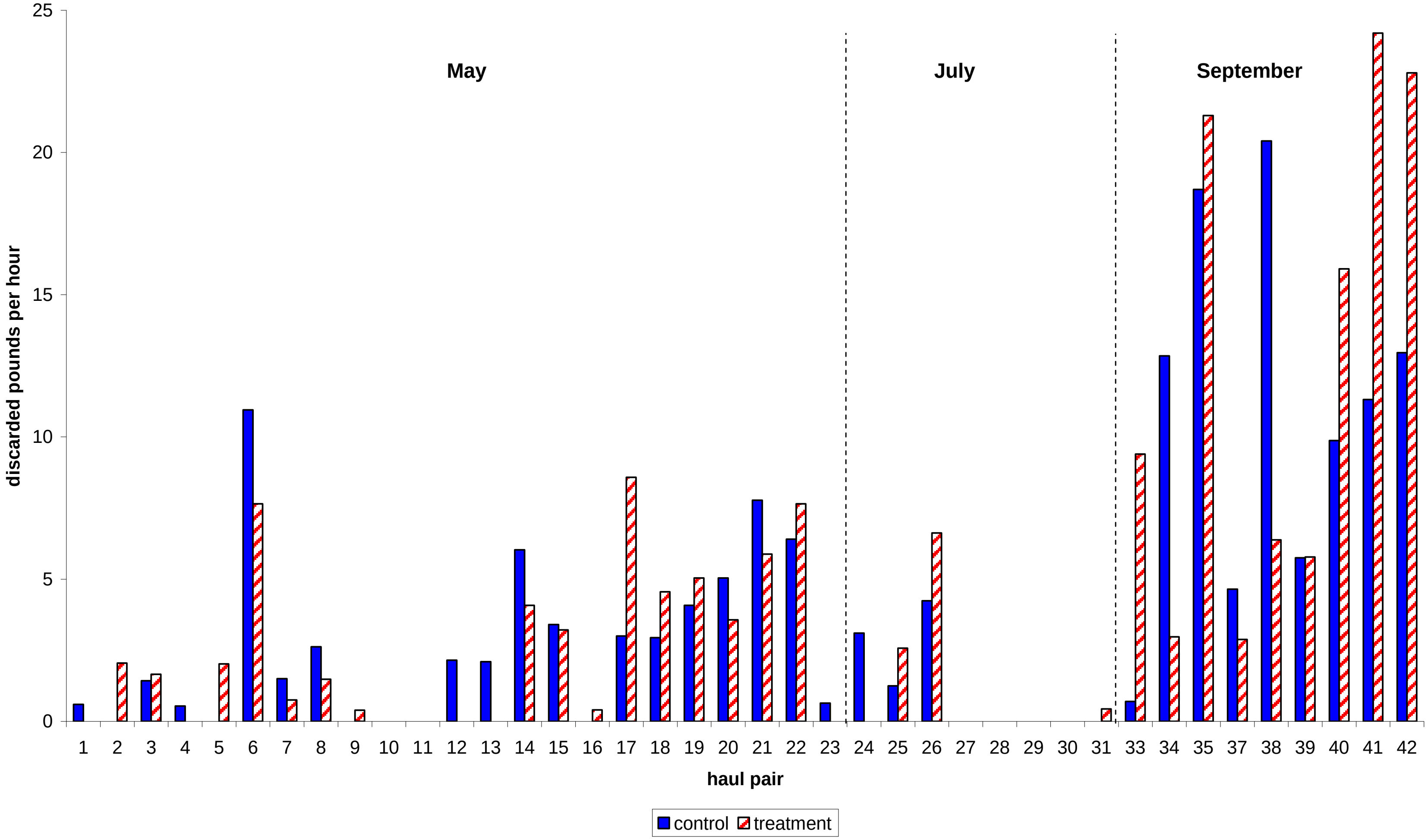


Figure 6. Sub-legal summer flounder catch in pounds per hour by haul pair and month.

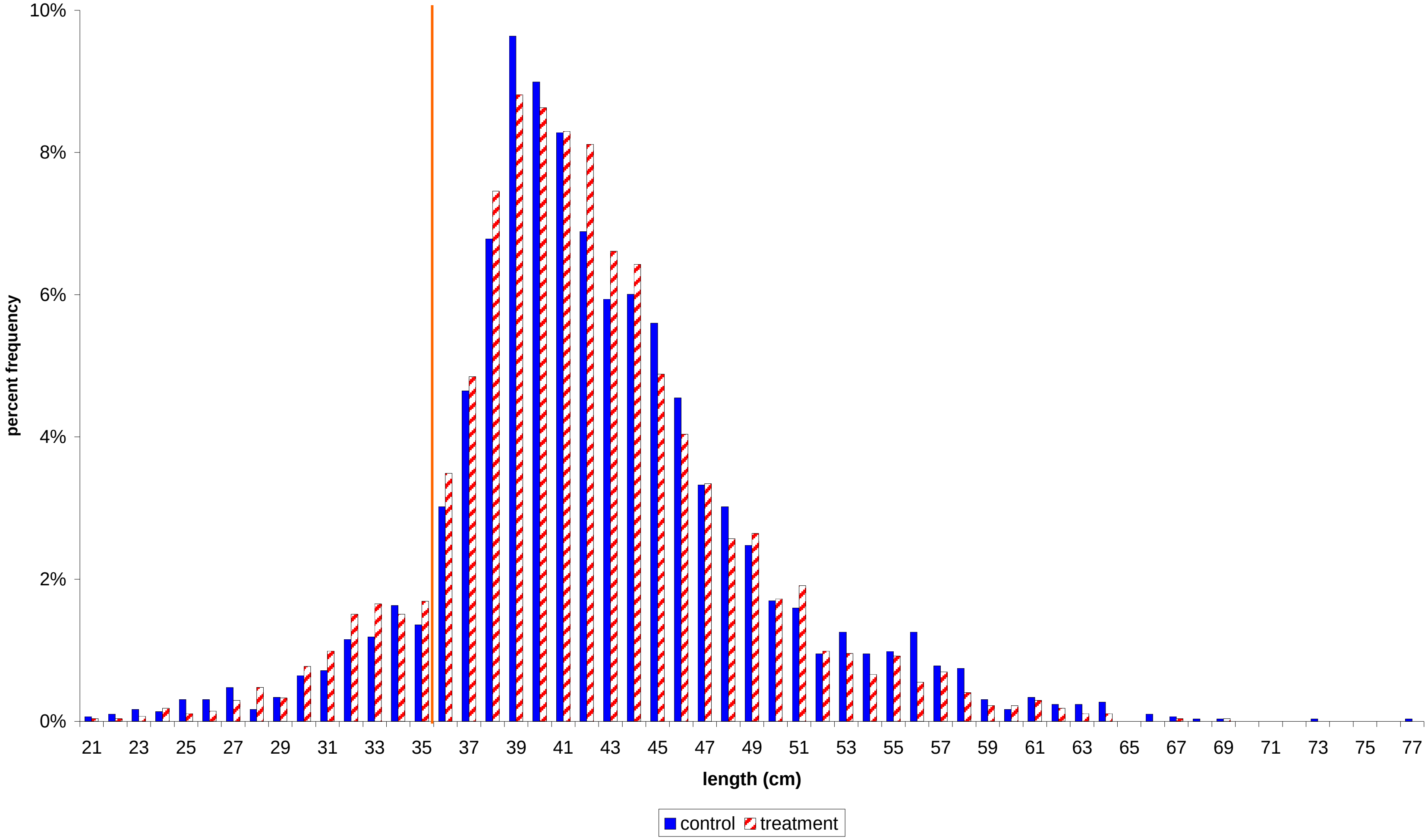


Figure 7. Summer flounder percent length frequency distribution for the control and treatment net.
(Orange line indicates the minimum size limit for summer flounder at 14 in. or 35.6 cm.)

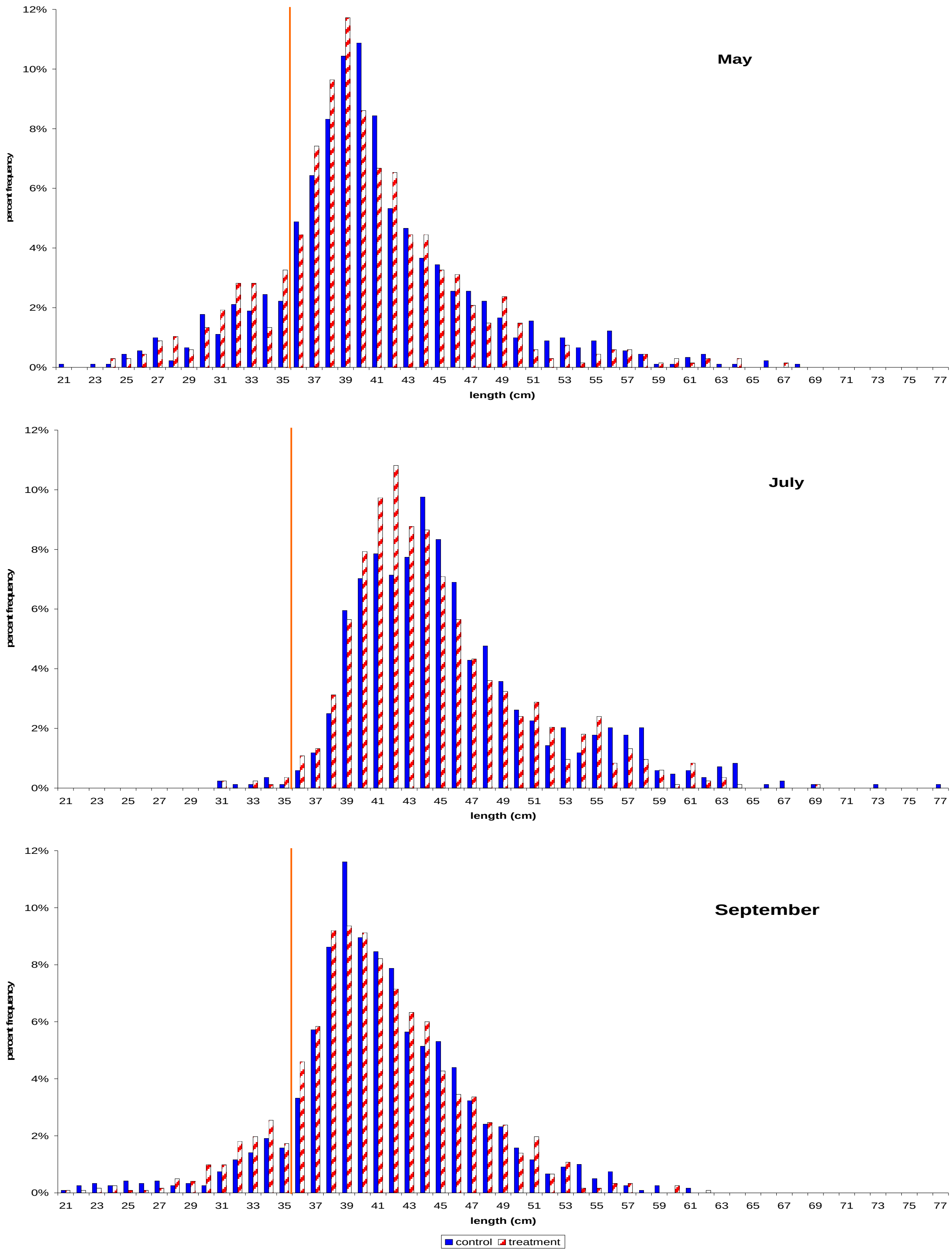


Figure 8. Summer flounder percent length frequency distribution for the control and treatment net by month. (Orange line indicates the minimum size limit for summer flounder at 14 in. or 35.6 cm.)

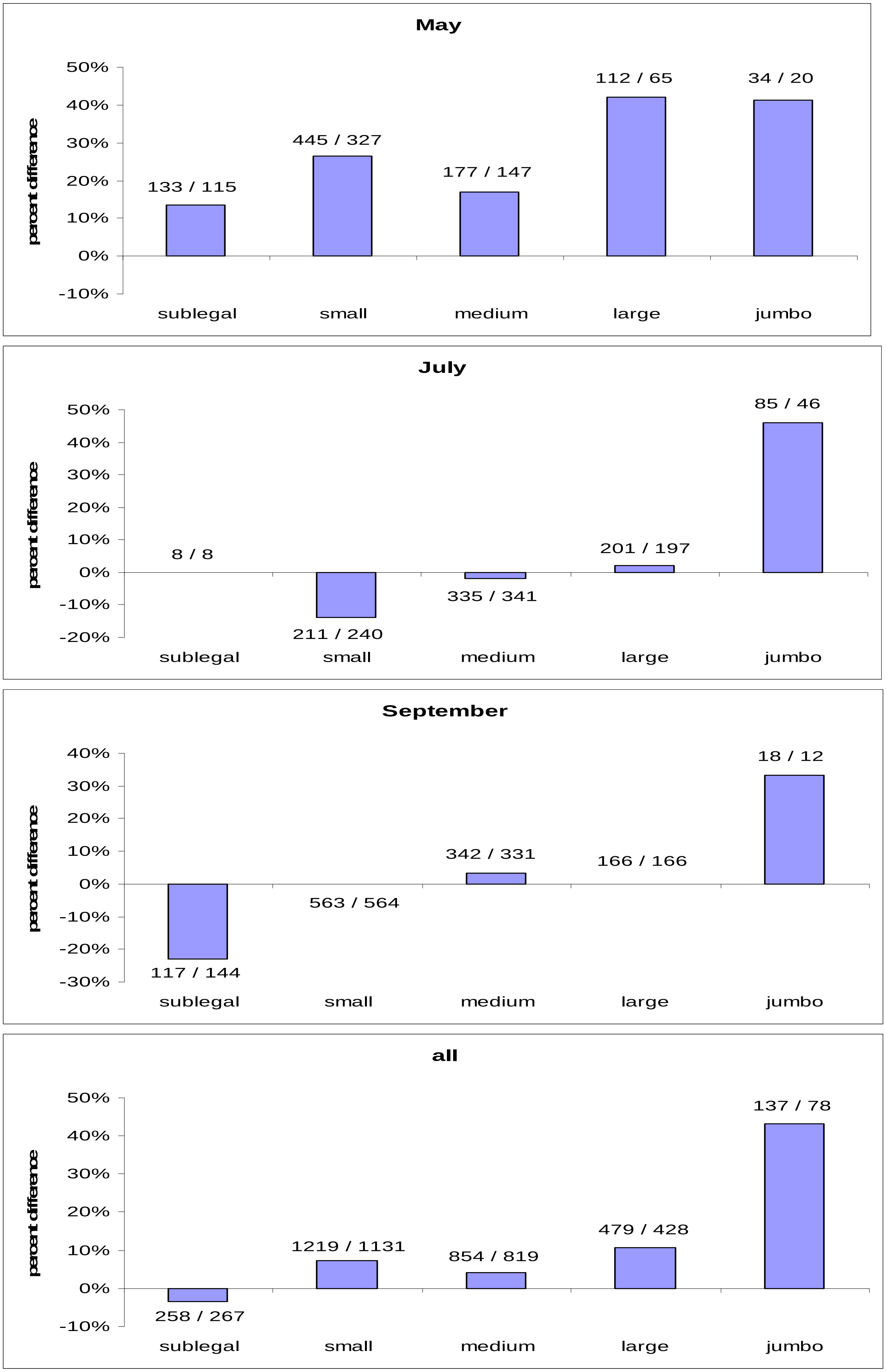


Figure 9. Percent difference in the number of summer flounder by approximate market size category. Ratios for each category indicate the number of summer flounder in control net (left) and numbers of summer flounder in treatment net (right).

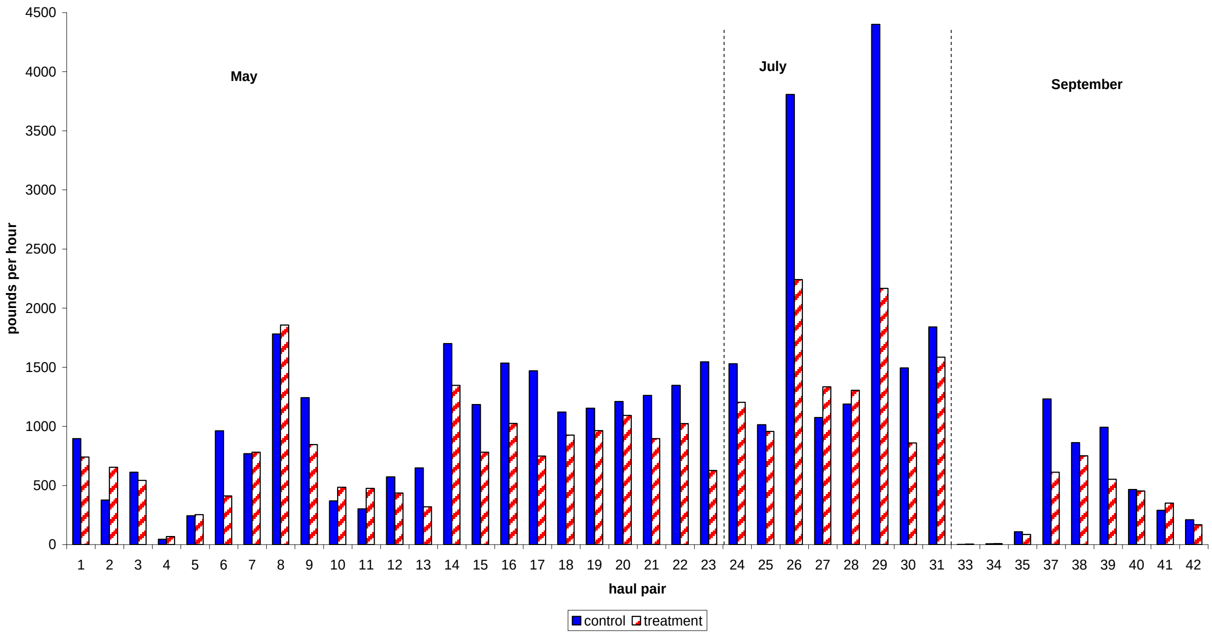


Figure 10. All skate species catch in pounds per hour by haul pair and month.

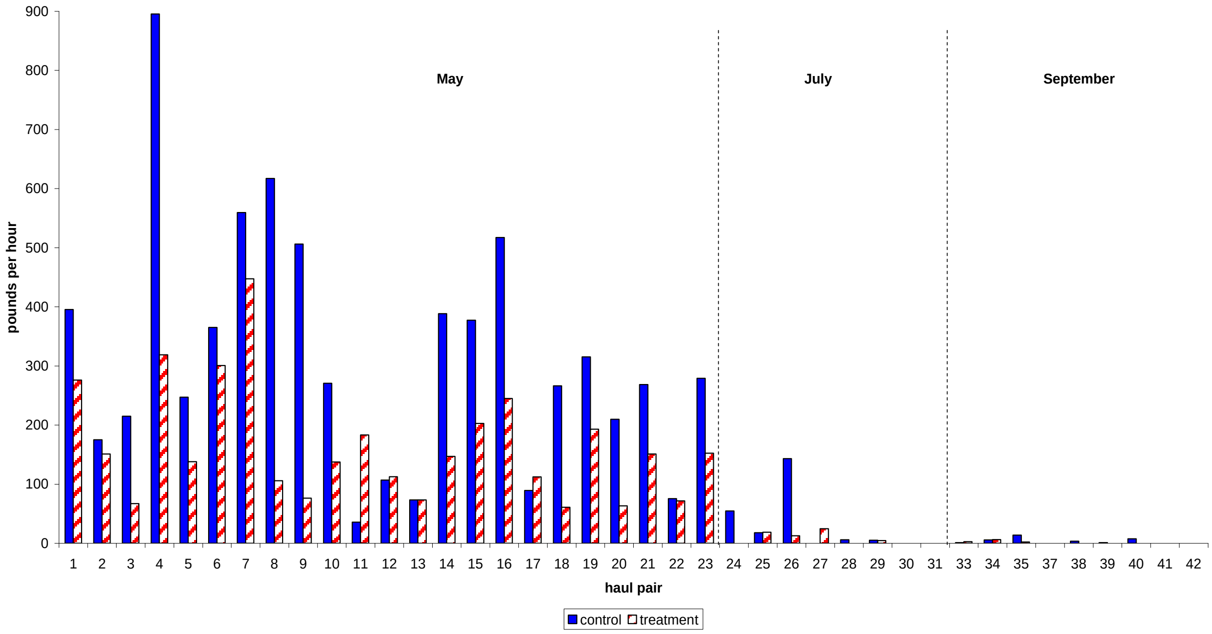


Figure 11. All dogfish species catch in pounds per hour by haul pair and month.

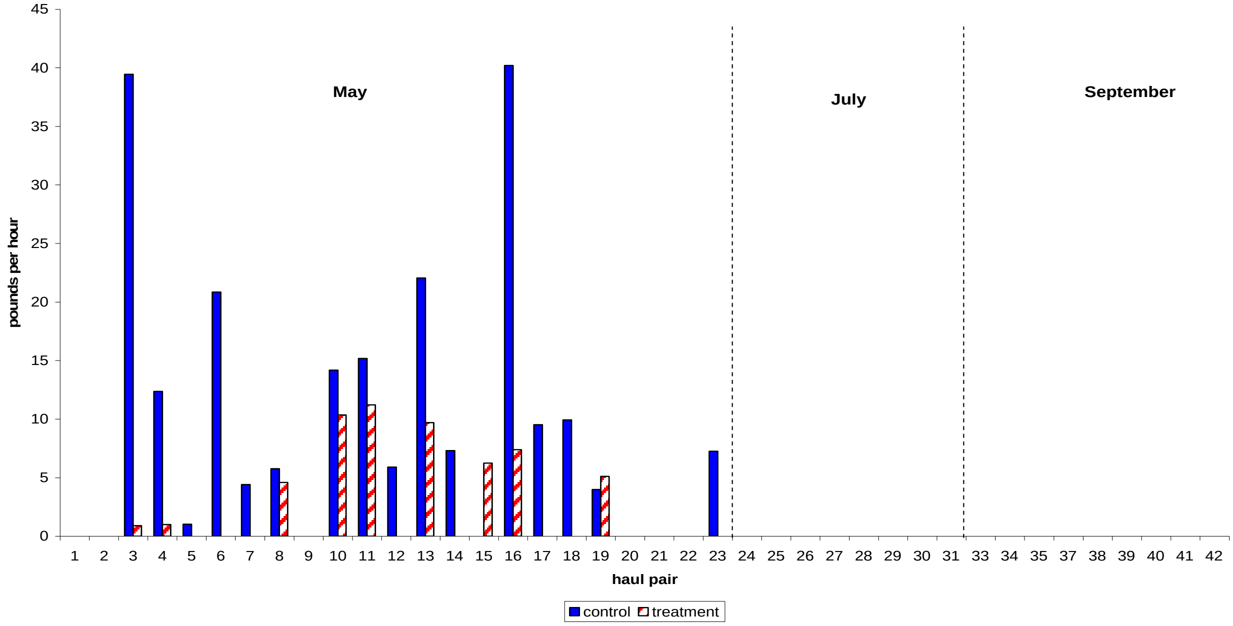


Figure 12. Monkfish catch in pounds per hour by haul pair and month.

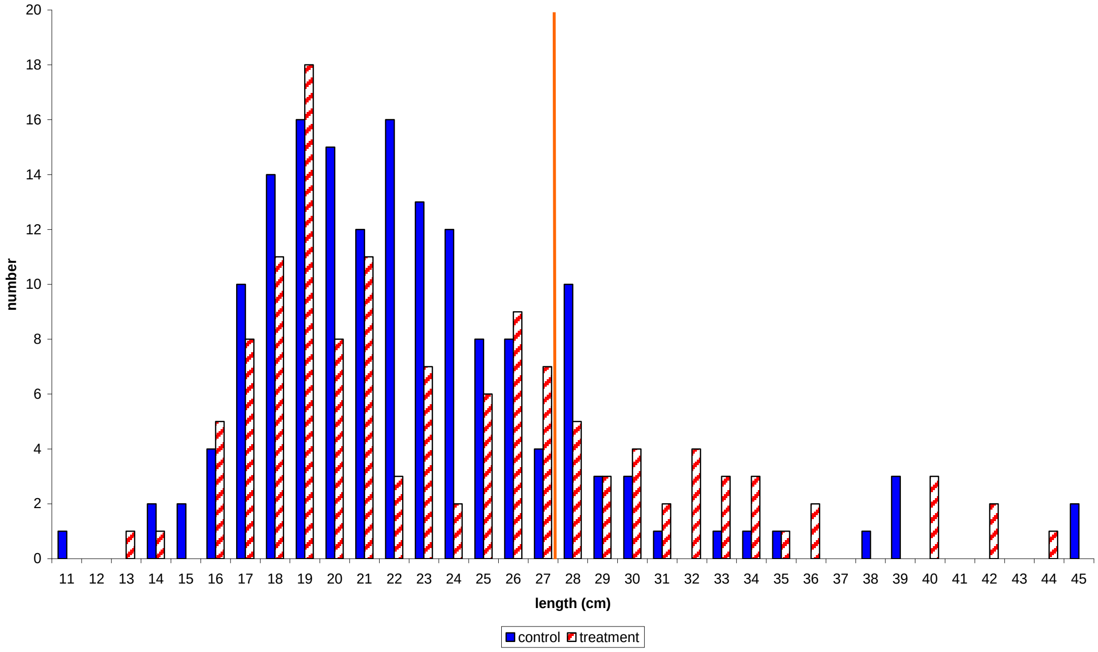


Figure 13. Black sea bass length frequency distributions from the control and treatment nets. (Orange line indicates the minimum size limit for black sea bass at 11 in. or 27.9 cm.)

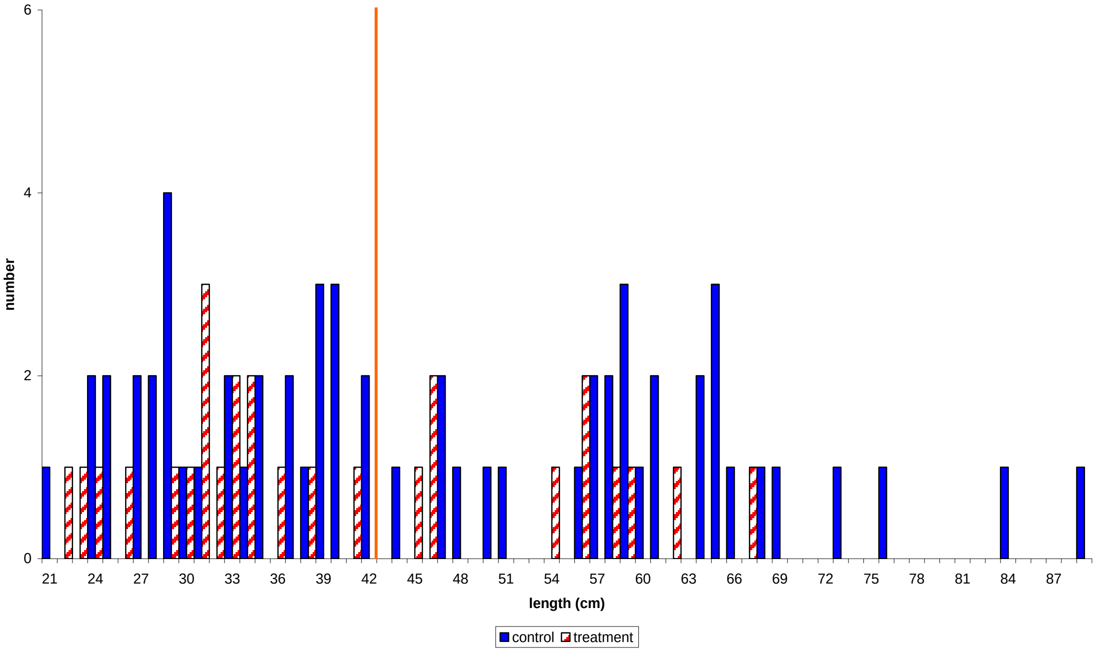


Figure 14. Monkfish length frequency distributions from the control and treatment nets. (Orange line indicates the minimum size limit for whole monkfish at 17 in. or 43.2 cm.)

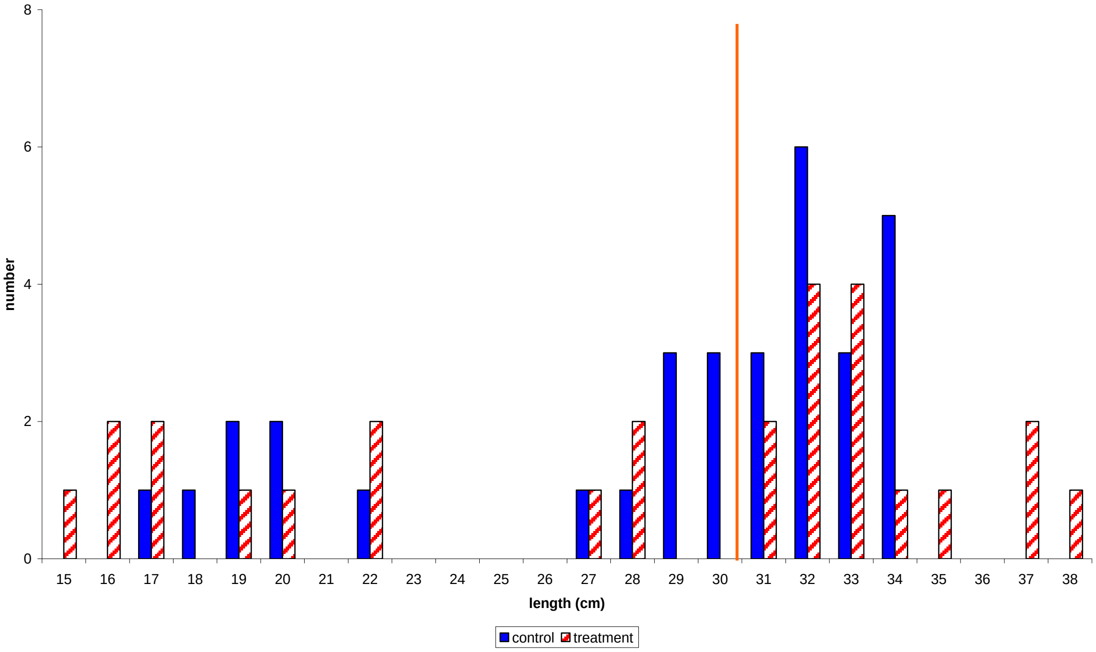


Figure 15. Winter flounder length frequency distributions from the control and treatment nets. (Orange line indicates the minimum size limit for winter flounder at 12 in. or 30.5 cm.)

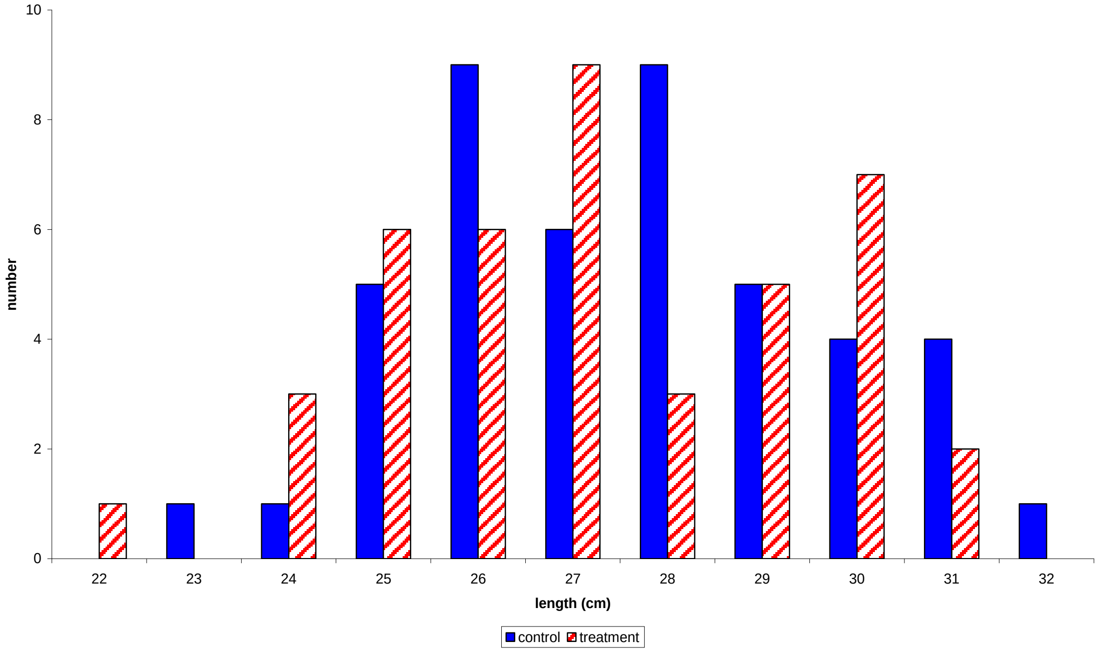


Figure 16. Windowpane flounder length frequency distributions from the control and treatment nets.

Figure 17. Chaffing gear added to protect wearing of the extension meshes.

Figure 18. Typical LF-TED position on net drum during haul-back.