Building on promise: continued investigation in using a 4-seam bottom trawl to improve escapement of small haddock and cod

Final Report to the Northeast Consortium

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Abstract
Two 4-seam bottom trawls were constructed, based on a modified 2-seam groundfish trawl. The side panels of the Control trawl were made of 6" (152.4mm) netting in the diamond configuration, and the Experimental trawl had side panels of 5.5" (139.7mm) netting, in the square configuration. Ten days of fishing trials were conducted, to assess the ability of the Experimental trawl to improve escapement of juvenile cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). Two days of fishing the Experimental trawl were conducted separately, with covers to retain and evaluate side panel escapees. For these two days, regulations required fishing with an open codend.

Data indicated no significant difference in catch weights for any species evaluated, but significant differences in the length frequency distributions did exist for cod and haddock, with the Experimental trawl promoting escapement of undersize individuals. Length frequencies for grey sole (*Glyptocephalus cynogolossus*), American plaice (*Hippoglossoides platessoides*) and redfish (*Sebastes marinus*) were similar between nets.

Captured side panel escapees included large numbers of dogfish species (*Squalus acanthias* and *Mustelus canis* grouped together), indicating a behavioral pattern that includes some level of lateral movement and escape attempts prior to entering the codend.

While the fishing trials revealed a trend toward lower average catch weights of marketable cod and haddock in the Experimental trawl, the length frequency patterns and weight data indicate that a 4-seam trawl may have utility as a gear to improve selectivity, by virtue of reduced retention of undersized roundfish individuals, and no change for retention of flatfish and other commercially important species such as monkfish (*Lophius americanus*). Given that most trawls are of 2-seam designs in the Northeast multispecies groundfish fishery, an effective 4-seam design could be of considerable use in preserving roundfish stocks. We theorize that a 4-seam trawl with 5" or 4.5" square mesh side panels may improve both retention of marketable roundfish, and escapement of sublegal individuals, when compared to standard 2-seam trawls.

Introduction
The modification of trawl gear to reduce the retention of unwanted marine organisms - bycatch - is an area of lasting interest to fishermen, scientists, conservationists and resource managers alike. The field of Conservation Engineering has resulted in many discoveries that have reduced bycatch and discards, and has proven a fertile ground where fishermen and scientists can work together, and share their expertise on a common goal.

The issue area is certainly important in the Northeast US; in 2005, the New England Fisheries Management Council issued their Research Priorities, including:

Research on fishing practices or gear modifications that may change the ratio of component catch species or improve selectivity of gear.

The current project evolved as a logical outgrowth from an effort funded by the Northeast Consortium in 2004, entitled: *Selective Gear Research and Development to Reduce Bycatch: Investigating the Use of Square Mesh Side Panels and Increased Taper in a Groundfish Trawl.* The idea for the project originated with the late Capt. Stanley Coffin, of Edgecomb, ME, who proposed that a 4-seam trawl would increase escapement of small roundfishes such as cod and haddock, and that increasing the taper of the belly section would increase such escapement even more. Data from the project indicated that the taper change did not have a great effect, but that the inclusion of a side panel of 6" twine hung on the square did indeed have effect on escapement of small cod and haddock. Length frequency patterns indicated that there was a real behavior present, that allowed lateral escapement in the belly section, but losses of market sized fish were too high in that project for likely commercial adoption. However, given the emphasis on conservation of cod and haddock stocks in the Gulf of Maine in recent years, the concept was found worthy of a follow-on study, one which ideally would maintain good escapement of juveniles, but also maintain good retention of market sized fish.

The original plan for this study was to employ 6" hexagonal mesh in the side panels of the trawl, thinking that the shape would be most conducive to good roundfish escapement. Attempts to source such material indicated that a recent change in manufacturing practices yielded a non-hexagonal shape, and an uncertain supply of the material. As a result, the project partners substituted 5.5" (139.7mm) mesh, hung in the square configuration, in lieu of hexagonal mesh. This arrangement was intended to retain some of the legal-sized individuals that had been suspected of escaping in the previous project, while still promoting escapement of sublegal fish.

As a general statement, most experiments on trawl selectivity and fish behavior have focused on the codend or the trawl mouth. For example, many experiments have investigated the effects of mesh size and shape in the codend (He, 2007; Robertson and Stewart, 1988), and work has investigated the use of raised sweeps (Morse, 1994; Pol and McKiernan 2004), separator panels in the trawl mouth (Carr and Caruso, 1992; Cooper, 1992; Main and Sangster, 1982), mesh size and shape in the forward part of the trawl (Beutel et al, 2008; Milliken and DeAlteris, 2004), and various combinations of these parameters. Other investigations have focused on the use of devices in the aft portions of the trawl as mechanical or behavioral separators, such as the SORT-X system, or the Nordmore Grate.

The belly of the trawl, aft of the square section, has traditionally received much attention, and Capt. Coffin accurately identified the region as worthy of investigation. One particular reason is that, in a 2-seam design, the meshes of the belly become elongated as one moves toward the gore seam. These closed meshes contribute little toward effective escapement; in fact, they have the opposite effect. The 4-seam design addresses this deficiency, and thus represents a broad opportunity for investigation. Some of the early work on escapement first identified the concept, such as observations by Margetts (1963), Ellis (1963) and Main and Sangster (1981).

As of this writing, we have not encountered a project similar to the present study, which sought to understand the selectivity of a 4-seam trawl in the Northeast groundfish fishery, based on the mesh size and shape of the side panels. Similarly, comparisons of 2-seam designs to 4-seam designs are also scarce, although some clues are given in other fisheries, in studies by Dremiere et. al.(1999), and Deshpande et al (1972).

Given the data generated in this study, we feel that the modification does hold promise in reducing sublegal roundfish retention, and in reducing mortality of trawl escapees.

Project Objectives and Scientific Hypotheses:
Objectives of this project are as follows:
1. Modify side panels to improve juvenile escapement, while maintaining retention of market size cod and haddock.
2. Verify escapement of fish through the side panels
3. Conduct appropriate reporting and transfer of project results to other fishermen, scientists and interested parties.

The scientific hypotheses that arise from the objectives and project plan are:
Null Hypothesis (H_O): Square mesh side panels inserted into a two seam trawl do not affect retention of small roundfish such as haddock and cod
Alternate Hypothesis (H_A): Square mesh side panels inserted into a two seam trawl will reduce the retention of small roundfish such as haddock and cod.

Methods and Materials
Nets, areas, fishing pattern:
Two groundfish trawls, typical of those in use by Capt. Coffin and Capt. Pinkham were built by Capt. Pinkham for the project. The net is a 100'/120' design, outfitted with a sweep consisting of rubber 'floppy' disks and spacers. Sweep disks ranged from 10" to 14" in diameter, with the larger sizes in the bosum of the trawl. A net diagram of the Experimental (4-seam) trawl was produced by Tor Bendiksen of Reidar's Manufacturing in Fairhaven, MA, and this is shown in Figure 1. Note that mesh measurements in Fig. 1 are given as 'knot center to knot center' and therefore larger than an inside-knot measurement. The Control trawl was identical to the Experimental, but for the following features:
- The Control net used 6.0" mesh in the side panel, oriented in the diamond position
- The Experimental net used 5.5" netting in the side panel, oriented in the square position.
- The Experimental net included three 8-inch trawl floats on the upper gore of each side panel, and a length of 1/2" lead line attached to each bottom gore.

Both nets were fitted with identical codends of doubled twine, diamond in shape, with a nominal 6.5" (165.1mm) mesh size. Codends were 50 meshes around by 50 meshes long. Mesh measurements were made on both codends with a Top-ME spade-type mesh gauge, fitted with a 5kg weight. Three rows of 10 meshes each were haphazardly chosen for measurement from each codend. Mean mesh sizes were 6.33" (Std. Error = 0.168) for the Control codend and 6.31" (S.E. = 0.141) for the Experimental. No chafing gear was used.

The vessel used for the project was the F/V Bad Penny, owned by Ms. Claudia Coffin, of Edgecomb, Maine. The vessel is 54' in length, powered by a 300 hp Volvo TAMD engine.

Trawl warp used for the project was 9/16" (14.3mm), attached to 66" (1.67m) Poly Ice doors. As a '1-legged' trawl, behind the doors was a 40-fathom shot of 1/2" (12.3mm) wire, with 2.5" (60 mm) rubber cookies.

Ten days of experimental fishing were conducted between June and August of 2007. General location of the fishing days was an area called the Kettle Bottom, approximately 20 to 30 miles south of Boothbay Harbor, Maine. Figure 2 shows the general locations of each days' fishing, including the paired tows and the side-codend tows described below. An alternate-tow approach was used, with one tow with the Control trawl and one with the Experimental trawl constituting one experimental unit, the tow pair. Tows were generally two hours in duration, and the normal day included two tows of each trawl. Since the bottom in this area is uneven, and depths range between 50 and 80 fathoms, tows were not conducted in a straight line; there were frequent turns. Tows in a given pair were made in close physical proximity to one another, however. Standard information was collected on each tow, including: date, location and time of start/finish of each tow, depth (recorded in fathoms), towing speed (knots) and amount of towing warp deployed.

At the end of the initial fieldwork, two fishing days were devoted to trials with 'side codends' attached. The side codends were constructed of single twine diamond mesh. Fifteen meshes were chosen at random from a section of representative twine, and measured with an Omega mesh gauge, calibrated at 80mm, and 125 Newtons. Mean mesh size and standard error were 114.6mm (4.51") and 0.289, respectively. The side covers began at the forward end of the side panel, and followed its entire length, extending five meshes past the end of the panel, to form the 'codend'. Because of permit restrictions, the cod-end of the main portion of the net was left open during these two days of fishing.

Catch enumeration and description:
Catch for all tows - the initial 10 days and the subsequent two days with the side codends - was whole-hauled; weights were taken for all finfish species separately, and lengths were obtained for all individuals of species of interest (cod, haddock, flatfish species, hake spp (*Urophycis spp*), pollock (*Pollachius virens*), and redfish, on an erasable plastic length-frequency board. Lengths were recorded to the nearest centimeter. Weights for crab species were aggregated, as were weights for skate species. All catch weight data were taken via a digital scale (Northern Industrial Tools 300 lb. Remote Display Scale, www.northerntools.com). Weights of the containers, such as a standard fish tote or orange scale basket, were zeroed out of the weight measurements.

Data Analysis:
Data sheets from the project first underwent an initial review, to check for significant differences in tow times, notes on hang-ups or interrupted tows, and other relevant deviations from the sampling plan. Tow pairs that experienced a significant loss of time for either of the constituent tows, or where there were recorded problems such as a hang-up, were discarded from the analysis. Tow times for the Control and Experimental nets were compared for significant differences, via paired t-Test.

Weight data was analyzed by species. An F-test was performed on the weight data, to evaluate potential differences in variance between treatments, followed by an appropriate paired t-test - for either similar or dissimilar variances. All tests were done at alpha= 0.05, or at the 95% confidence level.

Length data was also compiled by species, according to the established one-centimeter increments. Comparisons were made between the Control and Experimental trawls using the Kolmogorov-Smirnov test, applied at the 95% confidence level.

Results and Conclusions

Data Review:

An initial data review indicated that one tow pair (#14) had a strong discrepancy with respect to tow times and catch, and therefore that tow pair was removed from the data set, yielding 18 pairs of tows used for the subsequent analyses. Tows were made between June 15 and July 13th, 2007. Mean tow durations (in minutes, ± Std. Error) were 119.5± 2.06 and 119.4 ± 2.03 for the Control and Experimental respectively, and were not significantly different.

Weight Data:

Catch weight totals over the 18 tow pairs are summarized in Table 1. F-Test results are displayed in Table 2, and the results of t-Test analyses are given in Table 3; all tables reflect catches given as pounds per tow. Table 1 indicated reductions in the mean catch of codfish, dogfish, haddock and redfish. Plaice, grey sole, monkfish and skate species appeared relatively unchanged, and there was a small increase in the pounds of pollock caught with the Experimental gear. Difference in variance were observed with respect to catches of Cod, Dogfish, Haddock and Redfish, and while reductions in average catch weights were seen for some species, t-Tests detected no significant differences between the overall catch weights of either gear, for any species measured.

Length Data:

Kolmogorov-Smirnov tests detected differences between the length frequency distributions for two of the five species measured: cod and haddock. No significant differences were observed for the two flatfish species evaluated, plaice and grey sole, or for redfish. Although length measurements were taken during the fishing trials for pollock, numbers were too low to produce meaningful results from length-frequency analysis. The summary of K-S test results is shown in Table 4, and cumulative length frequency charts are given by species in Figures 3-7.

Side Codend Data:

Seven tows of the Experimental trawl only, outfitted with the side codends for retention of side panel escapees were conducted on August 3 and August 7, 2007. Of the seven tows, one (August 3, Tow #3) was missing information regarding tow length, depth, speed and amount of main wire deployed. Since this portion of the experiment was more qualitative than quantitative (such as judging the side-codend Experimental vs. the Control), the data from that tow is retained in subsequent descriptions.

Tow duration for the six tows containing full descriptive data averaged 2.6 hours. No significant problems were reported when towing the gear with the additional twine, and it appeared to function reasonably well, although no underwater video was available to observe the net directly, and see if the side panels were obscured by the side codends.

Side codend *catch weight* data is presented in Table 5. Modest catch weights of grey sole (25.0 lbs), and plaice (24.5 lbs), were reported, and some retention in the side codends for hake (42.0 lbs) were observed. It appeared that cod had some level of retention in the side codends at 76.5 lbs, and redfish as well (121.0 lbs). These patterns were not unexpected, but the retention of dogfish in the side codends did prove surprising with 988.5 pounds observed.

Lengths of fish retained in the side codends:
Length-frequency charts of the fish retained in the side codends are given in Figures 8 (cod), 9 (red and/or white hake), 10 (monkfish), 11 (plaice), 12 (grey sole), and 13 (redfish). Lengths were not taken in the field for dogfish, and only one haddock was captured in the side codend tows.

The requirement that we keep the main codend open during this portion of the project was an unfortunate regulatory addition, as it will have had undetermined effects on the behavior of the fish, and the subsequent catches observed in the side codend. This limits the degree to which these data can be extrapolated to other 'real life' situations where the main codend is closed, but also indicates that behavior due to the netting alone is such that at least some individuals are driven to escape attempts, even absent a closed codend. Future work, with a closed codend, would help to refine our observations.

Figures and Tables

Figure 1. Net plan of the experimental trawl, courtesy of Tor Bendiksen, Reidar's Manufacturing, Fairhaven, MA.

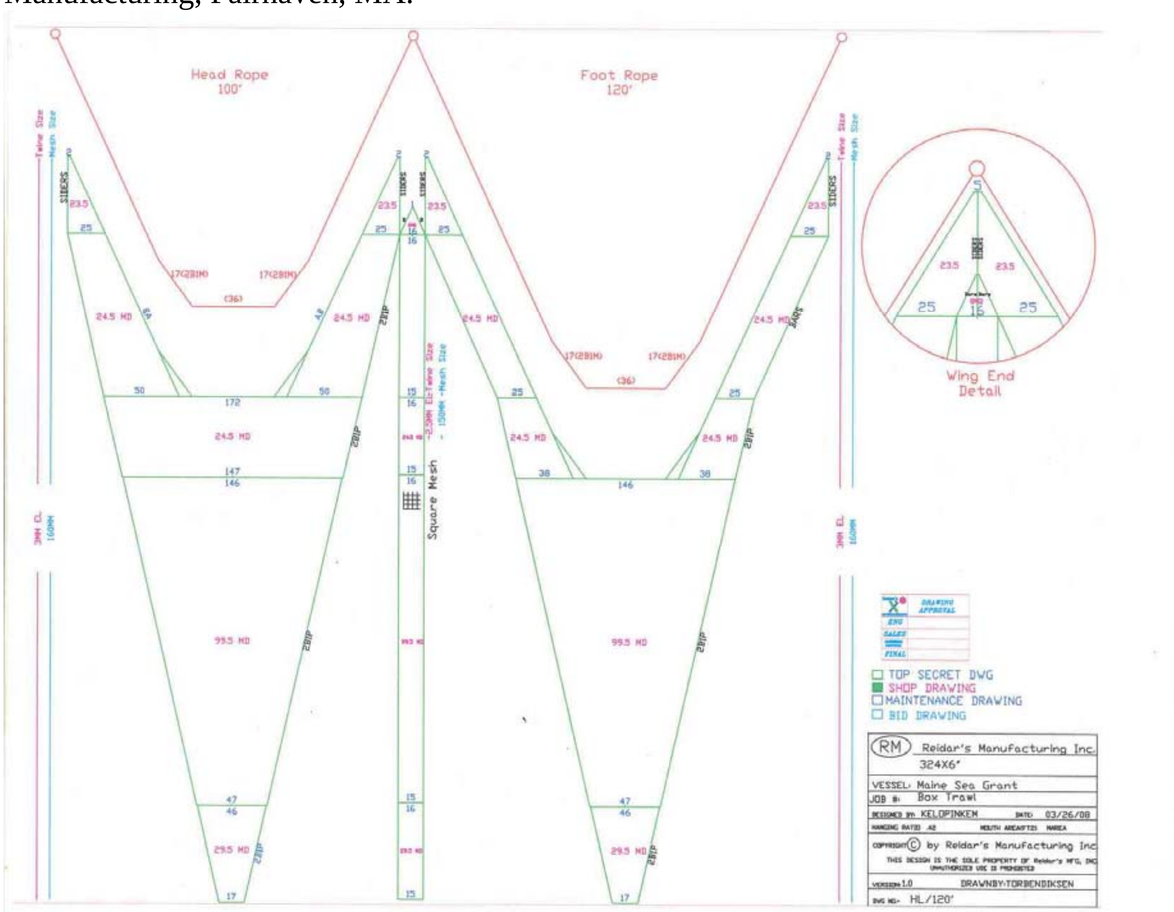


Figure 2. Region of fishing activities; black squares note the general area fished during each of the 10 days of paired tow tests, the green circles identify the areas fished during the side-codend tests.

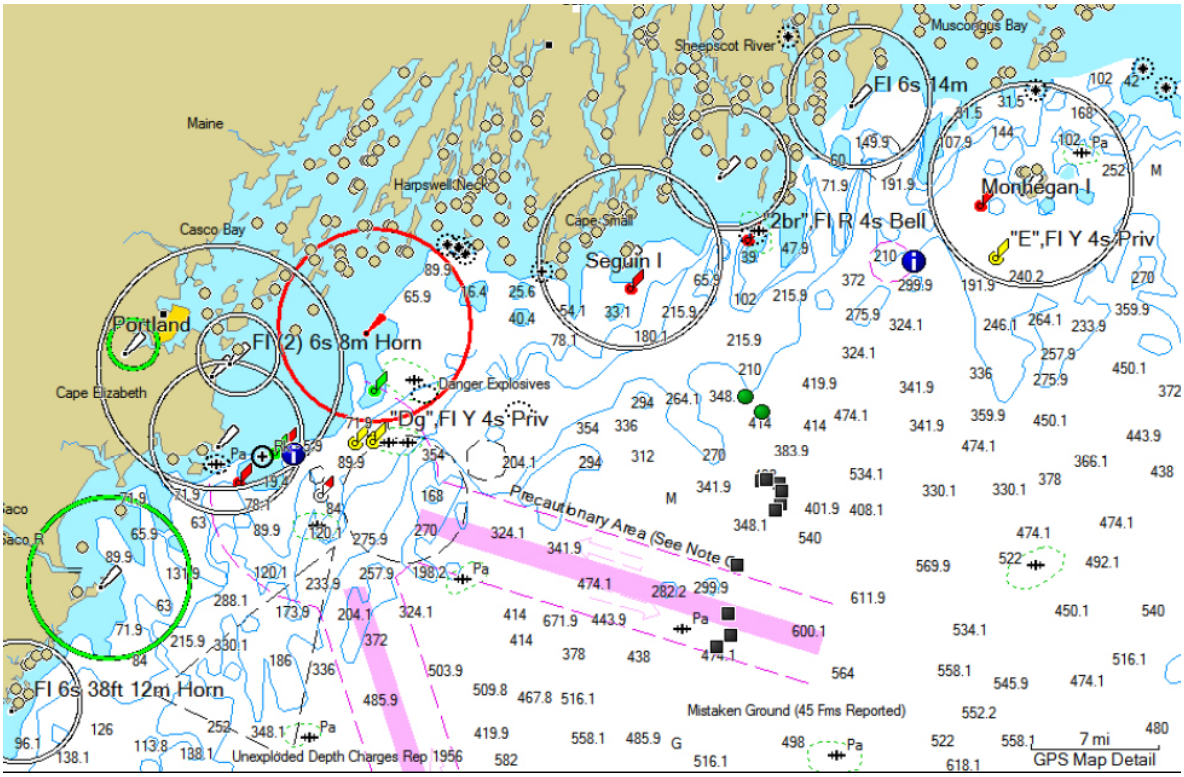


Table 1. Summary of catch weights in pounds, by species, for all tows, and the number of tows in which each species was observed.

Species	*Control*	*Experimental*	Cont. Tows	Exp. Tows
Cod	1798.0	1031.0	17	17
Crab	10.0	3.0	1	2
Dabs	326.0	298.0	18	18
Dogfish	1331.5	614.5	18	18
Eelpout	0.0	0.0	0	0
Grey Sole	213.0	205.8	18	18
Haddock	553.5	309.0	18	18
Hake sp.	28.5	6.0	7	2
Halibut	0.0	29.0	0	1
Herring	0.0	0.0	0	0
Lobster	65.5	50.0	7	8
Lumpfish	1032.5	937.0	17	18
Monkfish	2852.5	2865.0	18	18
Pollock	91.0	117.0	18	18
Redfish	103.0	56.5	18	18
Sculpin	0.5	0.0	1	0
Sea Robin	10.5	5.5	4	2
Skate	1446.5	1323.5	18	18
Whiting	30.0	0.2	1	1
Other	77.0	55.0		
TOTAL	**9969.5**	**7906.0**		

Table 2. Results of F-tests on catch weights for all tows, for species of interest. Red numbers indicate cases where sample variances were significantly different.

	Cod		Am. Plaice		Dogfish		Grey Sole		Haddock		Monkfish		Pollock		Redfish		Skate
	Control	*Exper.*	*Control*	*Exper.*	*Control*	*Exper.*	*Control*	*Exper.*	*Control*	*Exper.*	*Control*	*Exper.*	*Control*	*Exper.*	*Control*	*Exper.*	*Control*
Mean	105.765	60.647	18.111	16.556	73.972	34.139	11.833	11.433	30.750	17.167	158.472	159.167	5.056	6.500	5.722	3.139	80.361
Variance	6774.941	2064.711	47.693	53.703	10580.867	1779.259	85.588	70.868	1784.978	711.588	2374.926	4816.647	62.438	85.294	67.565	27.406	2750.200
Observations	17.000	17.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000
df	16.000	16.000	17.000	17.000	17.000	17.000	17.000	17.000	17.000	17.000	17.000	17.000	17.000	17.000	17.000	17.000	17.000
F	3.281		0.888		5.947		1.208		2.508		0.493		0.732		2.465		1.530
P(F<=f) one-tail	0.011		0.405		0.000		0.351		0.033		0.077		0.264		0.036		0.195
F Critical one-tail	2.333		0.440		2.272		2.272		2.272		0.440		0.440		2.272		2.272

Table 3. Results of t-Test analyses of catch weights, for species of interest.

Species	Cod *		Plaice		Dogfish*		Grey Sole		Haddock*		Monkfish		Pollock	
Tow Type (Cont. v. Exp.)	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*
Mean	105.765	60.647	18.111	16.556	73.972	34.139	11.833	11.433	30.750	17.167	158.472	159.167	5.056	6.500
Variance	6774.941	2064.711	47.693	53.703	10580.867	1779.259	85.588	70.868	1784.978	711.588	2374.926	4816.647	62.438	85.294
Observations	17.000	17.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000
Pearson Correlation			0.571				0.591				0.454		-0.010	
Hypothesized Mean Difference	0.000		0.000		0.000		0.000		0.000		0.000		0.000	
df	25.000		17.000		23.000		17.000		29.000		17.000		17.000	
t Stat	1.979		0.999		1.520		0.211		1.153		-0.046		-0.502	
P(T<=t) one-tail	0.029		0.166		0.071		0.418		0.129		0.482		0.311	
t Critical one-tail	1.708		1.740		1.714		1.740		1.699		1.740		1.740	
P(T<=t) two-tail	0.059		0.332		0.142		0.835		0.258		0.964		0.622	
t Critical two-tail	2.060		2.110		2.069		2.110		2.045		2.110		2.110	

*** indicates a t-test assuming unequal variances**

Table 4. Results of Kolmogorov-Smirnov (K-S) tests, for species of interest.

Species	Cont. N	Exp. N	Observed D-value	Critical D-value	Significant Difference?
Cod	472	187	31.79	11.75	Yes
Haddock	151	74	33.29	19.30	Yes
Am. Plaice	319	302	6.80	10.91	No
Grey Sole	188	180	9.56	14.18	No
Redfish	72	32	23.26	28.89	No

Figure 3. Length frequency distributions of catches in the Control and Experimental nets, for Cod. Catch numbers are divided by legal and sub-legal individuals for each gear type.

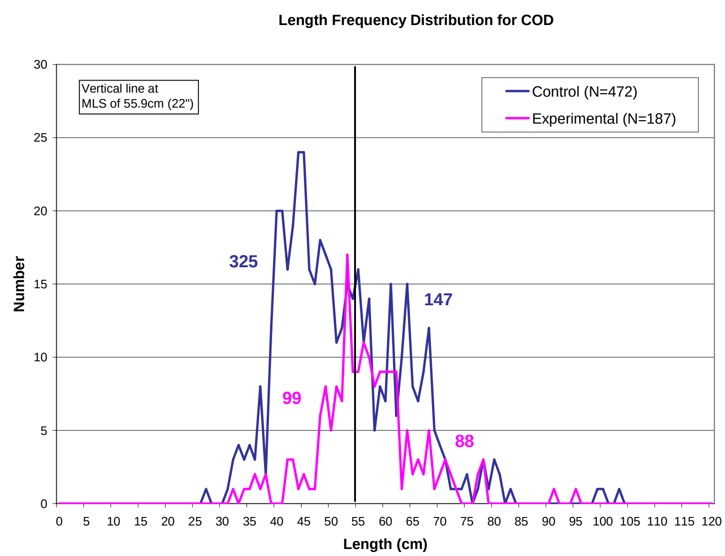


Figure 4. Length frequency distributions of catches in the Control and Experimental nets, for Haddock. Catch numbers are divided by legal and sub-legal individuals for each gear type.

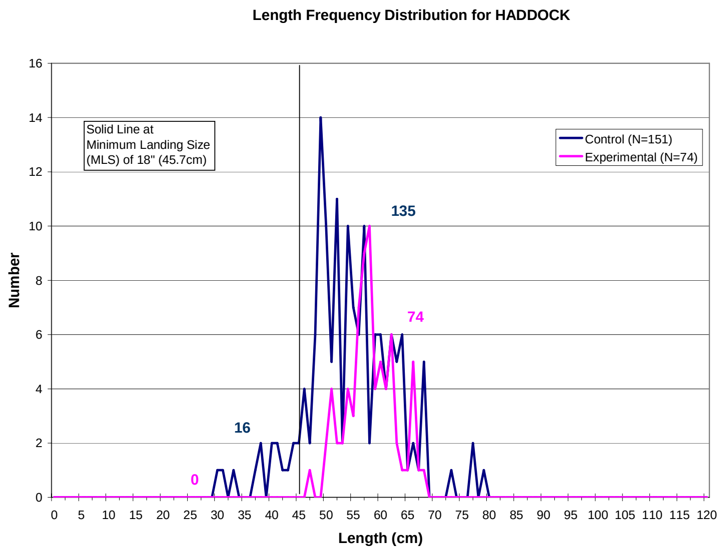


Figure 5. Length frequency distributions of catches in the Control and Experimental nets, for American Plaice (dabs). Catch numbers are divided by legal and sub-legal individuals for each gear type.

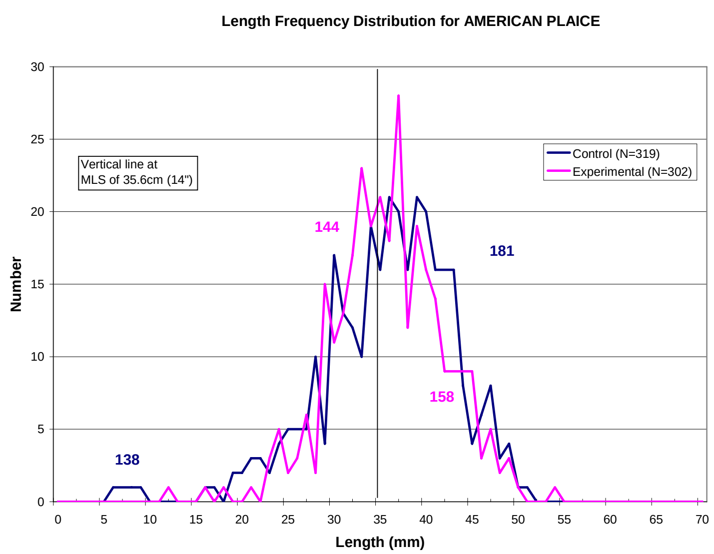


Figure 6. Length frequency distributions of catches in the Control and Experimental nets, for Grey Sole. Catch numbers are divided by legal and sub-legal individuals for each gear type.

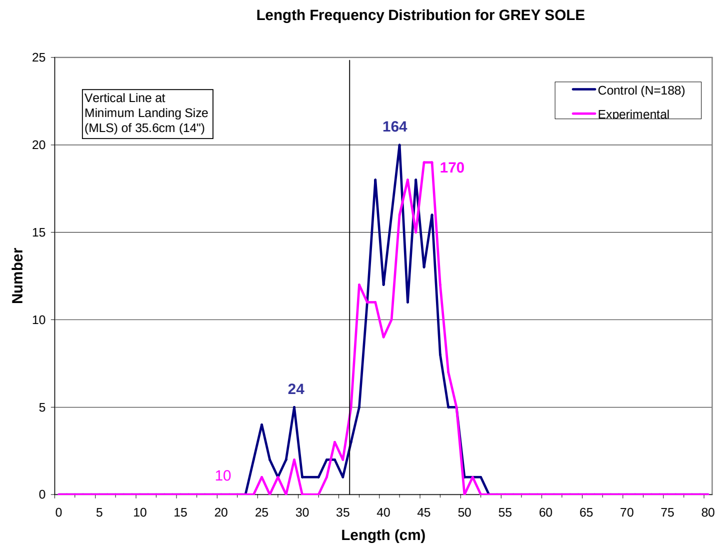


Figure 7. Length frequency distributions of catches in the Control and Experimental nets, for Redfish. Catch numbers are divided by legal and sub-legal individuals for each gear type.

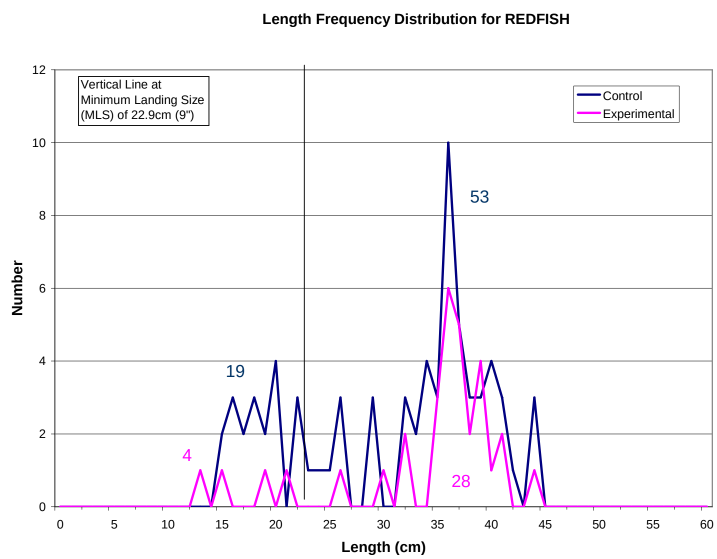


Table 5. Summary of tow statistics and catch weights from side codends, during six tows of the Experimental net, with side codends attached.

Tow Number	1	2	3	1	2	3	4	
Date	8/3/2007	8/3/2007	8/3/2007	8/7/2007	8/7/2007	8/7/2007	8/7/2007	Totals
Depth (fa)	75	85		62	90	82	89	
Tow Duration (min)	175	135		100	120	120	137	
Wire out (fa)	175	200		175	200	200	200	
Speed (kts)	2.3	2.3		2.3	203	203	2.3	
Cod	17.5	7.0	11.5		15.5	18.0	7.0	76.5
Crab								0.0
Dabs	5.0	2.0	5.0	3.0	4.0	1.0	4.5	24.5
Dogfish	424.0	62.5	114.5	180.0	56.0	55.5	96.0	988.5
Eelpout								0.0
Grey Sole	1.5		2.0	0.5	0.5	1.5	1.5	7.5
Haddock				2.0				2.0
Hake sp.	5.5	1.5	6.5	3.0	12.5	7.0	6.0	42.0
Halibut								0.0
Herring								0.0
Lobster								0.0
Lumpfish								0.0
Monkfish	2.0	8.5	2.5	1.0	1.0	0.5	1.0	16.5
Pollock								0.0
Redfish	13.5	58.0	21.5		23.0	1.5	3.5	121.0
Sculpin								0.0
Sea Robin								0.0
Skate								0.0
Whiting		5.5						5.5
Other								
TOTAL	469.0	145.0	163.5	189.5	112.5	85.0	119.5	1284.0

Figure 8. Length frequency distribution of Cod individuals retained in small mesh side codends.

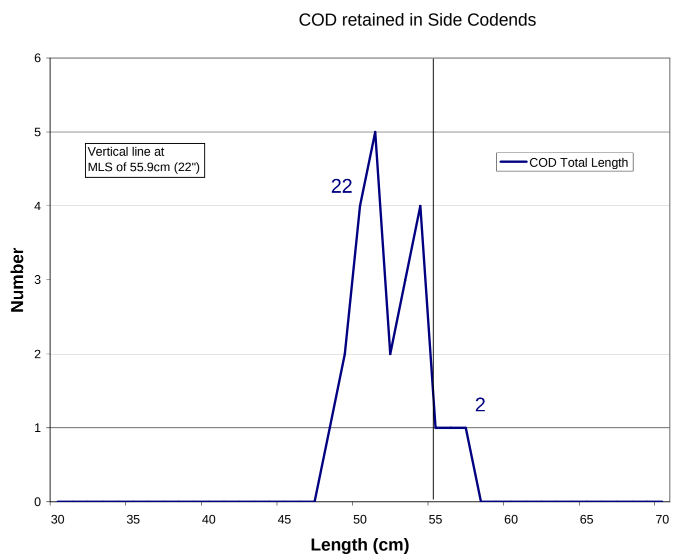


Figure 9. Length frequency distribution of Red and White Hake individuals retained in small mesh side codends.

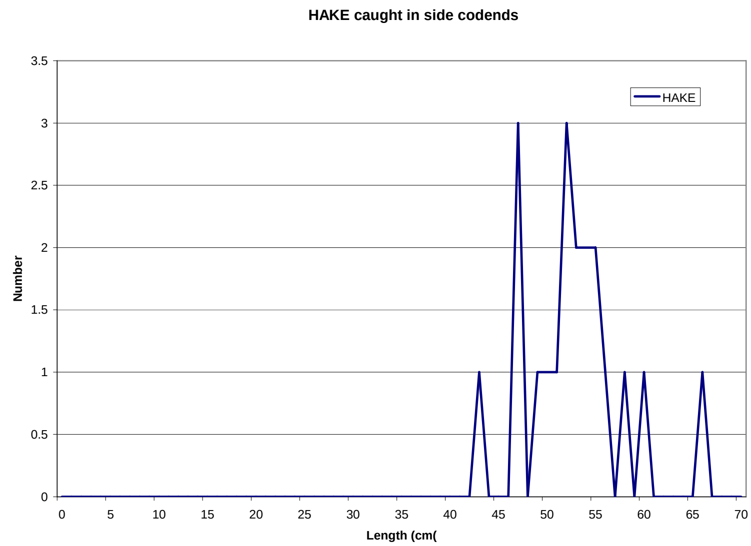


Figure 10. Length frequency distribution of Monkfish individuals retained in small mesh side codends.

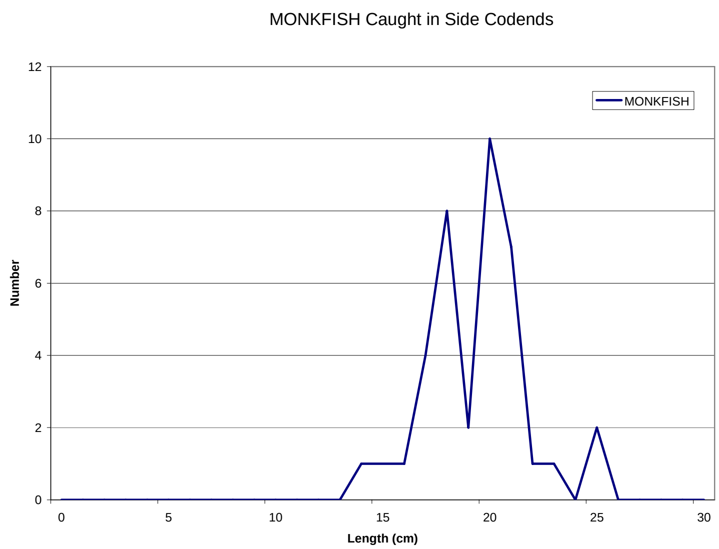


Figure 11. Length frequency distribution of American Plaice individuals retained in small mesh side codends.

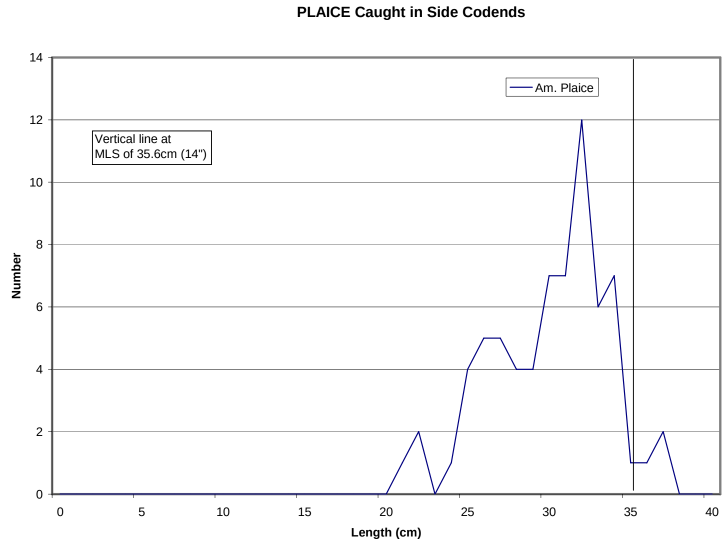


Figure 12. Length frequency distribution of Grey Sole individuals retained in small mesh side codends.

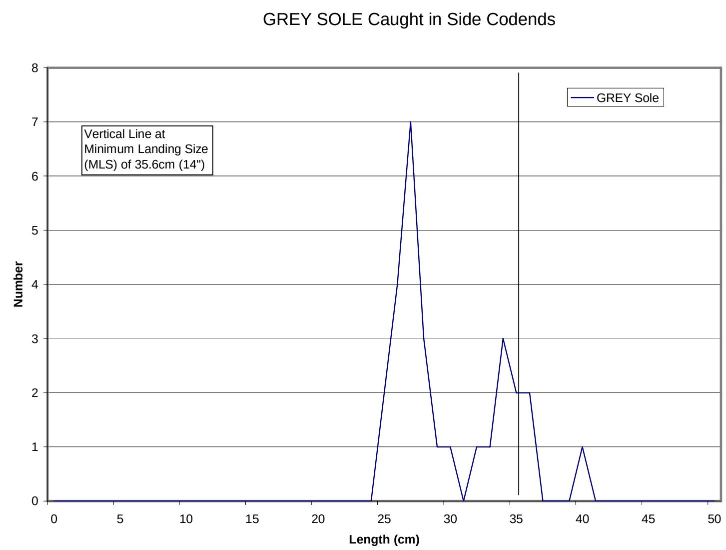
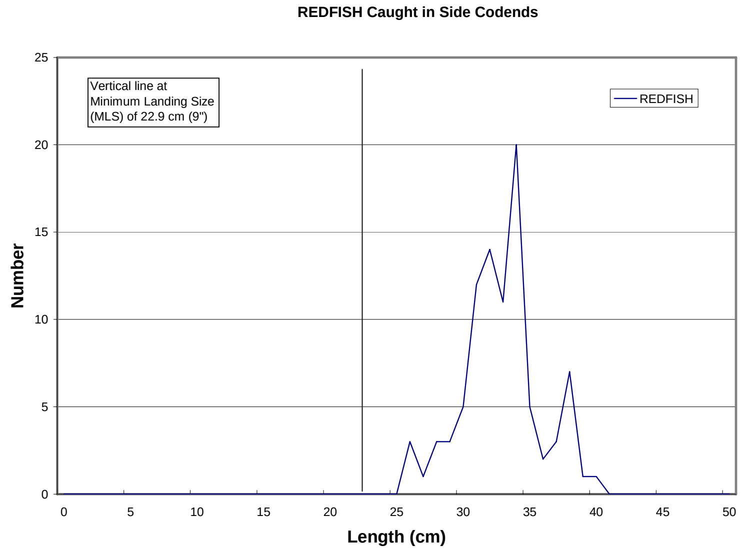


Figure 13. Length frequency distribution of Redfish individuals retained in small mesh side codends.



Partnerships:

This project was a successful partnership, similar to the earlier projects done between the participants. We have found a reasonable method to work with each other such that the scientific needs of the project are met, while still working within the bounds of considerations necessary to fishing operations. It is evident that a collaborative approach yields benefits to both the science and industry partners.

Impacts and Applications:

Regarding 2-seam vs. 4-seam comparisons:

This project has the potential for impact in some fishing areas, given further refinement. For example, comparisons of mesh size and shapes within the codend are reasonably well studied, including for cod, haddock and flatfish species (Cooper and Hickey, 1987; Robertson and Stewart, 1988; He, 2007). Although it appears that the behavior of some fish species is such that a four-seam trawl provides additional opportunity for escapement of undersized individuals, studies examining side panel escapement from 4-seam trawls are relatively scarce. Thorsstein (1980) reported on escapement of northern shrimp (*Pandalus borealis*) via the side panels of a 4-seam trawl, and Hanna et. al. (2005) investigated a reverse situation in the flatfish fishery on the western coast of the US, where a 4-seam trawl was the standard gear, and escapement of rockfish from a 2-seam trawl was evaluated.

We propose that this sort of direct comparison between 2-seam and 4-seam trawls warrants further inquiry. Cod and haddock come to mind in this regard; even though we did not detect significant differences in the catch weights of these species with the modified trawl, the length frequency distributions showed a statistically-significant tendency to provide escapement for undersized individuals, and overall, there were relatively low numbers of fish encountered during the project. We therefore ask the question: would a more robust data set have detected significant differences in catch weight?

By contrast, we did not detect a decrease in the catch weights of flatfish species or monkfish, nor did we observe a smaller length-frequency distribution for these species in the Experimental trawl. Further, the pattern of reduced numbers of retained cod and haddock in the Experimental during field comparisons alludes to potentially significant movement of fish through the sides of the trawl for these species.

Regarding dogfish:
The reduction in catch weights of dogfish and observations of large numbers of them in the side codend indicates that the current design may be useful in areas where excessive catches of dogfish exist. Our data does not detect a significant difference by catch weight, but the trends we observed may be of interest to fishermen, and to scientists interested in increasing dogfish escapement. Dogfish are frequently cited as being in problem at certain times and in certain areas and a technique to reduce their retention would be a useful development.

Regarding redfish:
The side codend tows indicate that redfish behavior in the belly of the trawl includes an escape response laterally. The length-frequency histograms and the catch numbers showed 91 individuals - all of whom were above the MLS of 22.9cm (9") - caught in the side codends. The losses of redfish seen in the 'regular' paired tows may therefore be somewhat confidently explained by escapement through the square mesh panels, as opposed to escapement through the codend or other part of the Experimental trawl. Given the number of escapees caught in the side codends, it may be useful to employ square mesh side panels in areas where avoidance of landing redfish is a goal, although more work is needed to precisely evaluate the appropriate mesh size for the escapement desired.

Why were no small redfish individuals retained in the side codends? The answer is unknown, but it is possible that undersize individuals were not caught by the net during these tows, or that they passed through a different part of the trawl - including the open codend - or perhaps they escaped the mesh of the side codends.

Regarding trawl design in the belly and extension:
The trawl used in this project had no extension piece, and a continuous 2 Bar, 1 Point taper from the wings all the way through the bellies. While an extension piece is a useful place to insert selectivity devices such as a grid or a large mesh panel (ie: Nordmore grate, Sort-X), and is helpful in instances where catches are very large (T. Bendikson, pers. comm.), in the current application, an extension piece has no immediate, obvious benefit, and may in fact have assisted in maintaining tautness in the side panels.

In addition, the lack of an extension in a given trawl may pay dividends in successful escapement, escapee survival, and sharper selectivity. Robertson (1983) cited that escapee survival is improved, if the fish can escape the trawl as early on in the capture process as possible, by virtue of lowered scale loss, bruising, or reduced physiological stress. Given that our data indicate that square mesh side panels can function well as escape areas, they provide an escape option ahead of the extension and codend, and therefore should presumably improve survival.

Lastly, net geometry of the Experimental trawl remained largely a mystery, a problem that deserves remedy. The lack of an extension piece, and the creation of roughly a box-shaped cross section at the belly-codend joining, may indicate that the codend meshes were able to remain somewhat more open. This in turn would have an obvious effect on the selective parameters of the codend, and an effect on the catch actually landed to the deck. Observations by Robertson and Ferro (1988) support such a possibility.

Regarding selection patterns caused by side panel escapement:
In addition, we propose that the selectivity curves for various species according to mesh size in the codend may be different than the selection curves that arise from escapement through square mesh panels in a 4-seam trawl. The meshes in the side panels - as we saw from our original work on trawl tapers and side panels (described below in 'Related Projects') - seem to stay well oriented, and at their maximum square opening. Since they occur in the belly and wing sections, the fish that encounter the side panels are in a different behavioral and physiological state than when they are in the codend. Taken together, we suspect that a larger roundfish can escape the side panels, than through a comparably-sized mesh located in the codend.

Since codend-based studies of square mesh vs. comparably-sized diamond mesh generally indicate that square meshes sharpen selectivity curves and increase L_{50}'s for haddock and cod (Cooper and Hickey, 1987; Graham et. al., 2002), we also suspect that square mesh side panels could promote steep selection curves for these species.

Through this project, and the one before it (below), it appears that a 4-seam design with a square mesh panel may be a viable design change to improve escapement of undersized roundfish, without reducing catch of other valuable species. Escapee survival could potentially be positively impacted as well. However, there is presently too high a loss of marketable sized individuals for the modification to stand as a commercially-viable one.

Related Projects:
This project was a follow-on to the NEC-funded project entitled: *Selective Gear Research and Development to Reduce Bycatch: Investigating the Use of Square Mesh Side Panels and Increased Taper in a Groundfish Trawl.* These projects began through the ideas of the late Capt. Stanley Coffin, and his work with Capt. Pinkham.

Presentations:
Maine Fishermen's Forum, 2008
UNH Haddock Workshop, April 3, 2007.
We plan to continue the outreach from this effort, past the end of the reporting period.

Images:
A few photos were taken during the course of the field experiments, and these are available for NEC use upon request. In addition, it may be helpful to note that the earlier work mentioned in 'Related Projects' resulted in some photo and video images, that could be useful to individuals interested in this line of investigation.

Future Research:

The net that was investigated in this project appeared to be easy to tow and to service, and appeared to improve escapement of some undersized roundfish and dogfish, with no significant loss of catch for flatfishes or monkfish. However, we do note some loss of catch with respect to market-sized roundfish. We do feel that this research warrants further inquiry, and should focus on the following areas:

- Evaluating the openness of side panel meshes, through both modeling and underwater video.
- Based on the results of modeling work and of existing mesh selection studies, smaller mesh (such as 5") should be evaluated in the side panels.
- Future trials should include side-codends, and these trials should be conducted with the main codend closed. Side codends should similarly be designed and tested in model studies, to limit the masking effect of side panel meshes. Selection Range (SR), Selection Factor (SF) and L_{50} metrics should be established.
- Full instrumentation, including trawl geometry and video monitoring of fish behavior, should be attached to the trawl in future work.

Literature Cited

Beutel, D; Skrobe, L; Castro, K; Ruhle, P; O'Grady, J; Knight, J. 2008. *Bycatch reduction in the Northeast USA directed haddock bottom trawl fishery*. Fish. Res., Vol. 93, No. 2. pp. 198-198.

Carr, H.A. and P. J. Caruso. 1993. *Application of a horizontal separating panel to reduce bycatch in the small-mesh whiting fishery*. In MTS '92 Proceedings. Marine Technology Service.

Cooper, CG and Hickey, WM. 1987. *Selectivity experiments with square mesh cod-ends on haddock and cod*. Dept. of Fisheries and Oceans, Halifax, NS, Canada. 6pp.

Cooper, C. 1992. *Cod and haddock separator trawl*. Project Summary, Dept.of Fisheries and Oceans, Scotia-Fundy Region, Halifax, NS. No. 38.

Deshpande, SD; Sivan, TM; Kartha, KN; Ramarao, SVS. 1972. *Comparative catch efficiency studies between two-seam and four-seam otter trawls*. Proc. Indo-Pac. Fish Council, Vol. 13, No. 3, pp. 444-449.

Dremiere, PY; Fiorentini, L; Cosimi, G; Leonori, I; Sala, A; Spagnolo, A. 1999. *Escapement from the main body of the bottom trawl used for the Mediterranean international trawl survey (MEDITS).* Aquat. Living Resour./Ressour. Vivantes Aquat. Vol. 12, No. 3, pp. 207-217.

Ellis, R. 1963. *Experiments to investigate the escape of fish through the meshes of different parts of the trawl.* ICNAF Spec. Pub. No. 5. pp. 97-101.

Graham, N; Kynoch RJ; Fryer, RJ. 2002. *Square mesh panels in demersal trawls: further data relating haddock and whiting selectivity to panel position*. Fish. Res. Vol. 62, Issue 3, pp. 361-375.

Hannah, RW; Parker, S; Buell, TV. 2005. *Evaluation of a selective flatfish trawl and diel variation in rockfish catchability as bycatch reduction tools in the deepwater complex fishery off the US West Coast*. N. Am. J. Fish. Mgt. Vol. 25, No. 2, pp 581-593.

He, P. 2007. *Selectivity of large mesh trawl codends in the Gulf of Maine, comparison of square and diamond mesh*. Fish. Res. Vol. 83, No. 1, pp. 44-59.

Main, J and Sangster, GI. 1981. *A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle*. Scottish Fisheries Research Report, No. 23.

Main, J and Sangster, GI. 1982. *A study of a multi-level bottom trawl for species separation using direct observation techniques*. Scottish Fisheries Research Report, No. 26.

Margetts, AR. 1963. *Escapes of fish through the component parts of trawls*. ICNAF Spec. Pub. No. 5. Pp. 158-165.

Milliken, HO, and DeAlteris, JT. 2004. *Evaluation of a large-mesh panel to reduce the flatfish bycatch in the small-mesh bottom trawls used in the New England silver hake fishery*. N. Am. J. Fish. Mgt. Vol. 24, No. 1, pp. 20-32.

Morse, DL. 1994. *The effects of sweep design on the species selectivity of trawls in the silver hake fishery of New England*. MS Thesis, Univ. of RI. 127 pp.

Pol, M. and McKiernan, D. 2004. *Expanding the use of the sweepless raised footrope trawl in small-mesh whiting fisheries.* NOAA/NMFS Cooperative Research Partners Initiative, Unallied Science Grant NA16FL2261. 43pp.

Robertson, JHB and Ferro, RST. 1988. *Mesh selection with the cod-end of trawls. The effects of narrowing the cod-end and shortening the extension.* Scottish Fisheries Research Report No. 39.

Robertson, JHB. 1983. *Square mesh nets help young fish escape.* Fishing News, London, No. 3652, pp. 10-11.

Robertson, JHB and Stewart, PAM. 1988. *A comparison of size selection of haddock and whiting by square and diamond mesh codends.* ICES J. Mar. Sci. 44(2): 148-161.

Thorsstein, G. 1980. *On the influence of mesh size and hanging ratio on the escape of Pandalus borealis through the side panels of a 4-seam bottom trawl*. ICES Council Meeting, 6 Oct. 1980, Copenhagen (Denmark).
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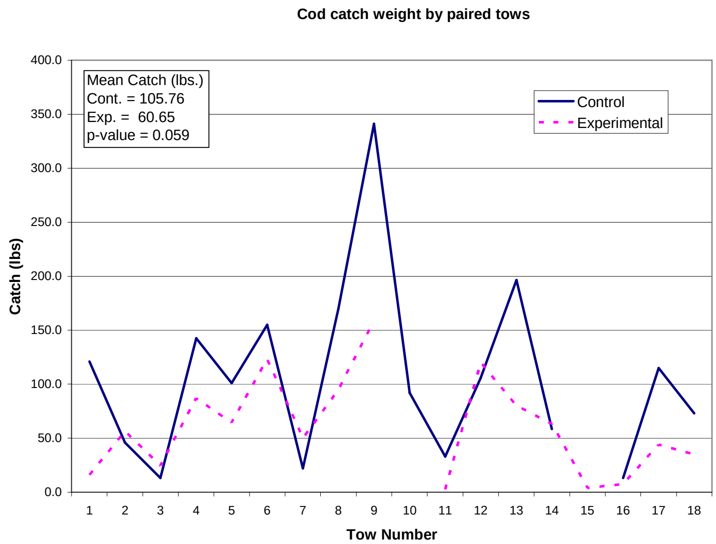
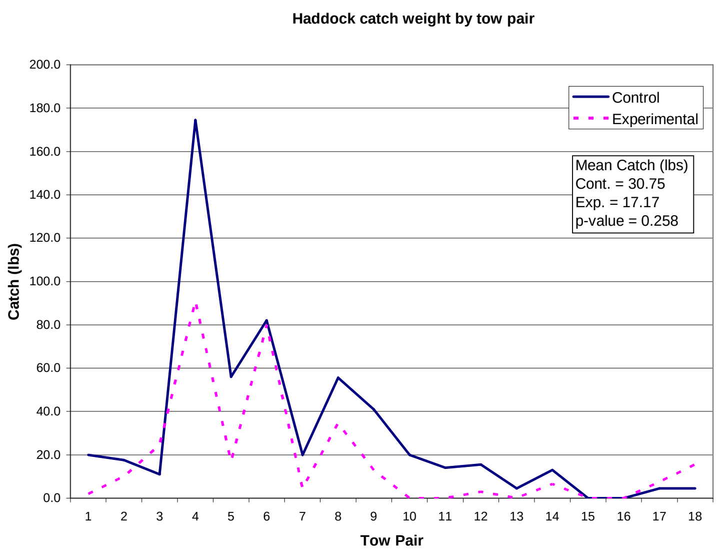
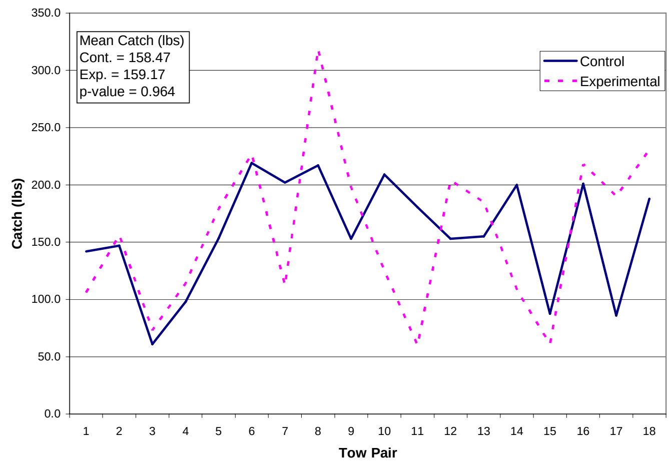
Appendix A. Catch weights of species of interest, during the 10-day comparative fishing experiment.

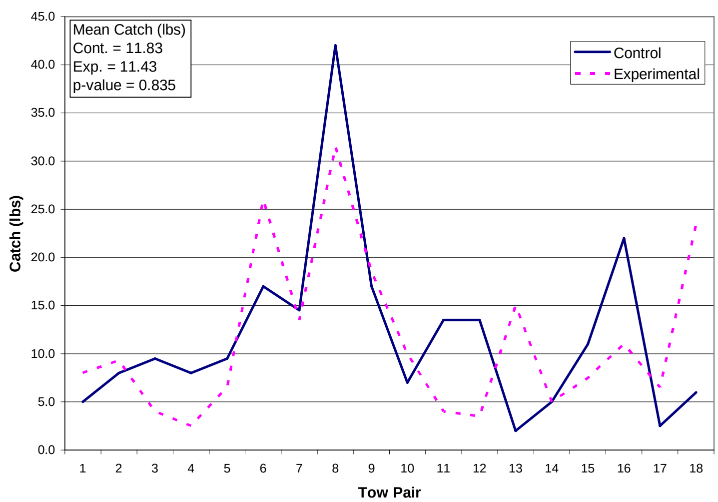




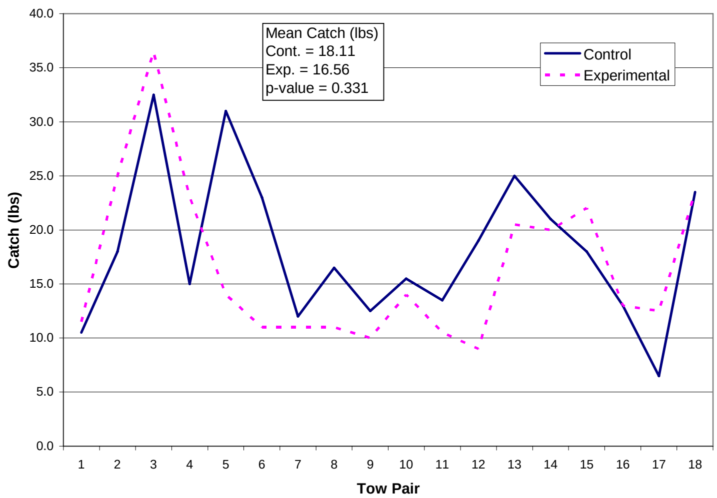
Monkfish catch weight by tow pair



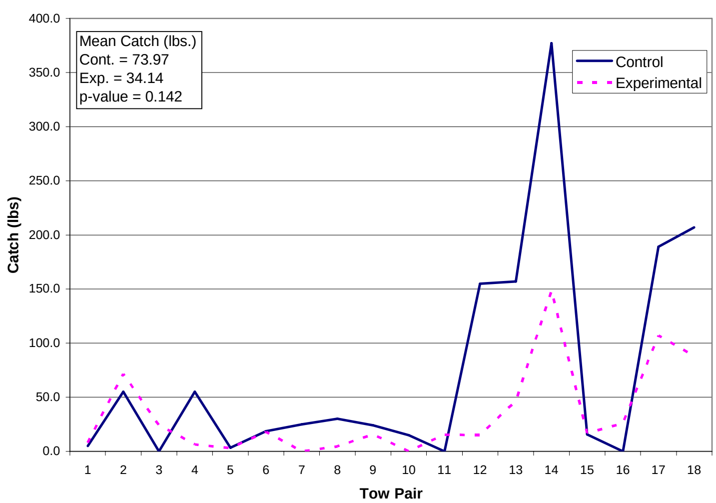
Grey Sole catch weight by tow pair

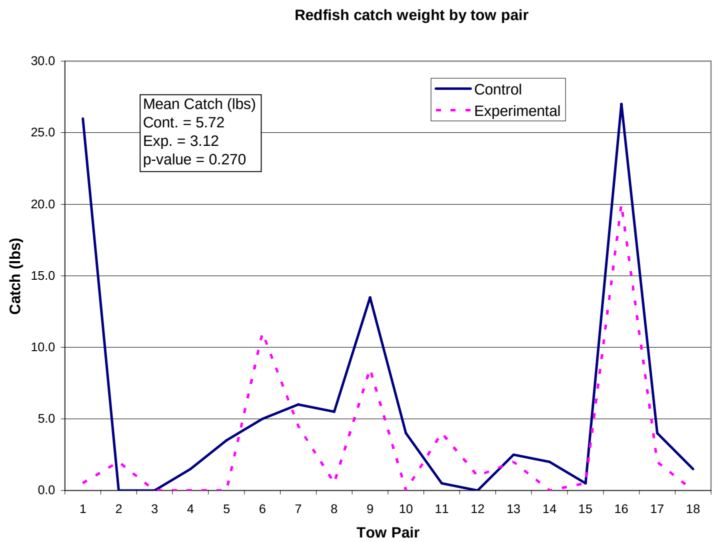


American Plaice catch weight by tow pair



Dogfish catch weight by tow pair




Redfish catch weight by tow pair
Mean Catch (lbs)
Cont. = 5.72
Exp. = 3.12
p-value = 0.270
Control
Experimental
Catch (lbs)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Tow Pair