Selective Gear Research and Development to Reduce Bycatch: Investigating the Use of Square Mesh Side Panels and Increased Taper in a Groundfish Trawl

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ABSTRACT:
This project examined the effect of escape panels in the sides of a typical groundfish trawl on the catches of undersized cod and haddock. A Control trawl was constructed by modifying a typical design from a 2-seam to a 4-seam trawl, where the side panel was constructed of 6" mesh, oriented in the diamond position. Two experimental trawls were constructed of identical design save the side panel, and the taper of the belly section. In the first Experimental trawl, the side panel was oriented in the square position. In the second Experimental trawl, the side panel remained it its' square orientation, but the taper of the belly was increased from 2:1 to 5:1. Catches were sampled to examine the effect of these modifications on the escapement of undersized cod and haddock through the side panels.

Ten days of fishing trials were allocated for each test, using an alternate tow approach. In the first set of trials, which tested the effect of the side panels at the standard 2:1 taper, 21 paired tows were completed. 19 paired tows were completed for the evaluation of the second set of trials, which examined the effect of the side panels together with a 5:1 taper.

In both trials, t-Tests applied to catch weight data revealed significant differences between the Control and the Experimental nets, for catches of undersized cod and haddock, with some impact to the catches of market sized individuals. Catch weights of flatfish in both trials was not significantly affected. Similarly, length frequency analysis revealed significant differences between the length frequency distributions for cod and haddock (all sizes) in both trials, but no significant differences were detected for grey sole or plaice.

It appears that the inclusion of side panels have resulted in excellent escapement for some species of groundfish, but also that some of the marketable catch is lost. Subsequent trials will focus on modifications to retain market fish while maintaining good juvenile escapement.

Introduction:
Bycatch reduction and gear selectivity are critical issues in marine fisheries around the US and the world, as illustrated by the research priorities of the New England Fisheries Management Council, the Northeast Consortium, and reports such ‘Managing the Nations’ Bycatch’ from the National Marine Fisheries Service.

For example:
- Bycatch reduction and selectivity has a strong relation to NEFMC Level I, II and II priorities, as generated by the Research Steering Committee in 2001.
- Northeast Consortium Funding Priorities include “Selective Gear Research and Development:” Selective fishing gear to reduce or eliminate technical barriers to trade, minimize harvest losses, reduce bycatch and improve fishing practices.
- Bycatch in general is a national priority for the National Marine Fisheries Service, exemplified by the recent development of/investment in- the NMFS National Standing

Working Group on Fishing Technology.
- Bycatch reduction requirements exist in statutes such as the National Standard 9 of the Magnuson-Stevens Act (MSA).

While bycatch and discard rates vary from place to place and time to time, discards (both regulatory and otherwise) are wasteful from the resource and labor points of view. Gear that allows undersized fish to escape the trawl helps the fisherman by minimizing work on deck, and helps the resource by reducing fishing mortality. Fishing mortality is an obvious outcome that applies to those fish that are landed to the deck of the vessel, but also to those fish that escape the trawling process at some point. This latter effect is more difficult to quantify, but nonetheless exists. In addition, it is believed that the escape mortality is reduced when fish can escape early on in the capture process, and before they make it to the codend.

Modern selectivity research hinges on the knowledge of fish behavior, as well as how the gear itself operates. The understanding of fish behavior during the trawling process and the incorporation of that knowledge into new trawl designs is an evolving craft. Though investigations on escapement through different parts of the trawl are not new (Lyon, 1904; Todd, 1908), it was not too long ago when was posited that the vast majority of fish selectivity via escapement occurred only in the codend (DeAlteris et al, 1990). However, we now know that various species exhibit different behaviors in other parts of the trawl, and that fishermen can use these behaviors to minimize the catch of unwanted fish. Collaborative research projects in the Northeast region of the US have consequently focused on the sweep (Morse, 1994), ground gear (Morse and Daley, 1999), headrope and square region (Pol et al 2003), bottom belly (Milliken and DeAlteris, 2004) and extension (Glass et al, 2003). In short, our view of where and how escapement occurs has broadened, and our modifications have become more specific to the application.

The present project arose because of the observations and hypotheses of the late Capt. Stanley Coffin, and his discussions with Capt. Kelo Pinkham. He speculated that roundfish might naturally attempt to escape through the sides of a trawl in the area near the gore, but that the design of most traditional nets prevented such attempts from being successful. He further speculated that by providing openings in this area, and by increasing the angle of attack of the netting, he could improve escapement by undersized roundfish such as cod and haddock. We thus arrived at the goals and hypotheses of this project.

Project objectives and scientific hypotheses:
As listed in the original proposal to the NEC, there were two objectives identified in this project. They were:

1.To evaluate the escapement properties both of square mesh side panels in a 4-seam groundfish trawl, and of square mesh panels used in conjunction with increased taper in the trawl belly.

2. To conduct outreach about the project and its results to the funding agency, industry,

and other interested parties.

Though not identified in the project proposal, the null and alternate hypotheses were:

Test #1 - Incorporation of square mesh panel, with both Control and Experimental at 2:1 taper
H_o: Inserting a square mesh side panel into the sides of a bottom trawl has no effect on escapement of juvenile cod and haddock.
H_a: Inserting a square mesh side panel into the sides of a bottom trawl will reduce catches of small cod and haddock.

Test #2 - Incorporation of a square mesh panel into a bottom trawl *and* increasing the taper in the belly to 5:1
H_o: Inserting a square mesh side panel into the sides of a bottom trawl, together with an increased belly taper, has no effect on escapement of juvenile cod and haddock.
H_a: Inserting a square mesh side panel into the sides of a bottom trawl, together with an increased belly taper, will reduce catches of small cod and haddock.

Participants:
The principal participants in this project included:
Capt. Stanley Coffin, and Mrs. Claudia Coffin - Edgecomb, ME
Capt. Kelo Pinkham, and Morgan Pinkham - Trevett, ME
Dana Morse - Maine Sea Grant Program

Contact information is listed on the cover sheet.

The concept for this project was developed by Capt. Coffin. Tragically, Capt. Coffin passed away in 2004 after a brief and unexpected illness. In his stead, Capt. Pinkham, a lifelong friend of Capt. Coffin, operated the *Bad Penny*, and was in charge of sea trials. Mrs. Claudia Coffin remains the vessel owner to this day. Morgan Pinkham served as sea sampler for the work. Mr. Morse served as science partner, and was responsible for project design, data analysis and reporting.

Methods:
All nets in the study were designed by Capt's Coffin and Pinkham, and Capt. Pinkham was responsible for net construction. They are typical of those used in their commercial activities, and of nets used by similarly sized boats of the region. Some relevant specifications for the nets are below:

Headrope length = 100 ft.
Footrope length = 120 ft., 3/8" chain
Ground gear = 3" cookies over wire
Upper leg = 20 fathoms bare wire, Lower leg = 20 fathoms 3" cookies over wire
Sweep = 3/8" chain, with rubber disks of 6" increasing to 12" in the bosum, with 4" rubber disks in between.

The vessel used was the F/V *Bad Penny*, home ported in Boothbay Harbor ME. The vessel is 54" in length, has a beam of 16.5 feet, a Volvo engine at rated at 300 HP, and uses steel doors weighing 650 lbs. each.

Fieldwork for this project was conducted under an alternate-tow system: the Control net was fished in a certain area and for certain duration, and then the Experimental net was fished in the same area, for the same time. Tow duration and areas fished were typical of industry, and were decided on by the commercial partners. As suggested by the goals, above, we undertook the fieldwork in two segments. The first set of trials (referred to as the '2:1 nets') were conducted such that the Control net was a typical two-seam trawl, but with side panels of 6" diamond mesh inserted into the sides, from the belly and back. The Experimental was identical except for the side panels, which were hung so that the twine remained in the square configuration. The Experimental trawl also incorporated six 8-inch floats attached to each upper gore spaced in even intervals, and 3/8" lead line attached along the entire the lower gore. The weight/flotation was added to enhance the side openness of the side panel. Both nets in this set of trials had 2:1 tapers in the belly section.

In the second set of field trials, the Control trawl remained the same, but the Experimental trawl was constructed such that the belly section incorporated a 5:1 taper. The square mesh side panel remained the same, as well as the weight and flotation added to the upper and lower gore.

Codend mesh sizes were measured in the Control and Experimental nets, using an Omega mesh gauge, set at 125 Newtons and calibrated against a rigid test plate (140mm expansion) prior to use. Measurements were taken on sets of 5 contiguous meshes at different points in the codend, chosen haphazardly.

Data:

Towing Data:

Standard data were recorded for each time, including: start/end time, start/end location, depth, amount of towing cable deployed, date, and towing speed.

Catch data:

Catch data were grouped generally into weight data and length data. For each tow, total catch weights were taken on the following species:

Atlantic Cod	*Gadus morhua*
Haddock	*Melanogrammus aeglefinus*
American Plaice	*Hippoglossoides platessoides*
Witch Flounder (Grey Sole)	*Glyptocephalus cynoglossus*
Pollock	*Pollachius virens*
Goosefish (a.k.a. 'monkfish')	*Lophius americanus*

Lobster	*Homarus americanus*
Atlantic Halibut	*Hippoglossus hippoglossus*
Silver Hake (Whiting)	*Merluccius bilinearis*
Northern Sea Robin	*Prionotus carolinus*
Rosefish	*Sebastes fasciatus*
Ocean pout	*Macrozoarces americanus*

...and the following species groups: crabs, skates, hakes, sculpins, herrings and dogfish.

For cod, pollock, haddock, plaice and grey sole, weights were kept for fish both above and below the Minimum Landing Size (MLS). Those sizes were:

Cod	22" (55.9cm)
Haddock	19" (48.3cm)
Plaice	14" (35.6cm)
Grey Sole	14" (35.6cm)
Pollock	19" (48.3cm)

All catch weights were directly observed; no sub-sampling was necessary.

Observations on *individual fish lengths* focused on just a few species: cod, haddock, grey sole and plaice (dabs). In only one case was sub-sampling necessary, which included a catch of haddock, and thus the lengths recorded represent nearly 100% of the catch of our species of interest. Individual fish were measured to the nearest cm (total length), on a standard measuring board, and recorded manually.

Catch and tow detail information was entered into an Excel spreadsheet for analysis. **Catch weight data were analyzed - and are presented - in pounds per tow**. Towing durations of the Control and Experimental nets were analyzed for similarity/dissimilarity of variances (F-test), followed by the appropriate t-Test to compare means, in both sets of field trials. Catch weights were analyzed in similar fashion: examination of homogeneity of variance, followed by t-Test for samples of either similar or different variance.

Length data were compiled to develop a length frequency curve for all individuals of a given species, during both sets of field trials. Those length frequencies were analyzed using the Kolmogorov-Smirnov (K-S) test, which evaluates the differences between cumulative length frequencies for two samples. Calculated KS values for the species samples were compared against critical values, based on sample size and level of confidence. All tests were conducted at the 95% confidence level.

Results and conclusions:

Mesh Size:

25 meshes were measured in the control codend, and 15 meshes in the experimental. Results of the mesh measurements were:

Control: mean mesh size = 164.08mm, Std. Dev. = 2.40.

Experimental: mean mesh size = 164.93mm, Std. Dev. = 1.83.

It should be noted that though the mesh sizes were not significantly different from one another, an error in planning (attributable to the PI) resulted in the mesh measurements being taken after fishing activities finished.

Tow Times:

T-tests revealed no differences between the tow times for the Experimental or Control codends, for either the 2:1 or the 5:1 experiments. Some of the relevant statistics:

2:1 Trial Tow Times, in Minutes (21 tow pairs)

	Mean	Std. Error
Control	159.6	16.4
Experimental	157.2	19.3

p-value (2 tailed test):0.93

5:1 Trial Tow times, in Minutes (18 tow pairs)

	Mean	Std. Error
Control	136.8	7.6
Experimental	131.6	6.8

p-value (2 tailed test): 0.61

Catch Data: WEIGHTS

Catch data are displayed in Tables 1 and 2, and are listed in pounds, for both sets of trials. Both experimental trawls were effective in reducing the catch of undersized cod and haddock, though numbers of small haddock were extremely low in the 5:1 trial, and were used only on a limited basis. Catch of legal cod was improved with the 2:1 experimental, and reduced by approximately 24% in the 5:1 experimental. In both experimental trawls, the catch of legal haddock was markedly reduced. From an industry point of view, such losses of marketable sized catch are unacceptable. This observation forms the basis of the follow up study, described below.

Note: In Tables 1 and 2, the columns labeled "# Obs" refers to the number of tows in which the species appeared.

Table 1. Catch weights and results of t-Tests for species of interest, during trials of net with 2:1 taper.

	2:1 Tapered Trawl					
Species / Category	**Cont.**	**Exp.**	**Cont.**	**Exp.**	**t-Test**	**2-tailed**
	# Obs.	**# Obs.**	**Total**	**Total**	**difference?**	**p-value**
			(lbs)	(lbs)		
Cod - sublegal	16	5	521.5	25.5	Yes	<.01
Cod - legal	21	20	3225	3657.5	No	0.53
Haddock - sublegal	16	3	107	4	Yes	<.01
Haddock - legal	20	19	3015.5	667.5	Yes	0.01
Plaice - sublegal	21	21	65.5	67	No	0.88
Plaice - legal	21	21	678	657.5	No	0.84
Grey sole - sublegal	19	18	43.5	26	No	0.21
Grey sole - legal	21	19	311	291	No	0.82
Monkfish	21	20	5030.5	5180.5	No	0.76
Skate spp.	21	21	2217	1971.5	No	0.64
Eelpout	8	6	183.5	116	No	0.59
Dogfish	3	1	351	33.5	N/A	N/A

Table 2. Catch weights and results of t-Tests for species of interest, during trials of net with 5:1 taper.

	5:1 Tapered Trawl					
Species / Category	**Cont.**	**Exp.**	**Cont.**	**Exp.**	**t-Test**	**2-tailed**
	# Obs.	**# Obs.**	**Total**	**Total**	**difference?**	**p-value**
			(lbs)	(lbs)		
Cod - sublegal	17	13	287.5	56.5	Yes	<0.01
Cod - legal	18	17	2489.9	1868	No	0.46
Haddock - sublegal	7	1	16	1	N/A	N/A
Haddock - legal	18	14	1093.5	464	No	0.16
Plaice - sublegal	18	16	63	52.5	No	0.85
Plaice - legal	18	18	470	485.5	No	0.84
Grey sole - sublegal	14	16	20.5	17.5	No	0.42
Grey sole - legal	18	18	275.5	324.3	No	0.33
Monkfish	18	18	6431.5	7066	No	0.56
Skate spp.	18	18	1430.5	1349	No	0.83
Eelpout	10	7	226.5	214.5	No	0.16
Hake spp.	14	11	253.5	146.5	No	0.38

t-Tests show the statistical differences between the catches of legal and sublegal cod and haddock, and also the catches of other species of interest. Essentially, the catches of other species such as monkfish, hake and dabs were unchanged in either of the experimental trawls.

Catch Data: LENGTHS

The length frequencies for cod, haddock, plaice and grey sole in the 2:1 trial are shown in Figures 1,2,3 and 4 respectively. Note that the y-axis reflects the percent of the total number measured for length frequency analysis, rather than total numbers. In the cases

of cod and haddock, the trend is for the L-F curve to be shifted to the right, whereas the L-F curves for the flatfish species are relatively similar.

Figure 1. Cod length frequencies by percent, 2:1 taper.

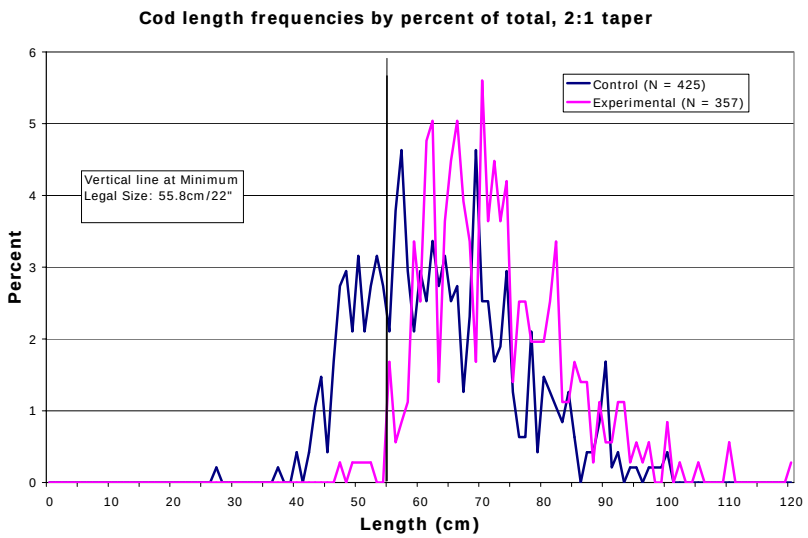


Figure 2. Haddock length frequencies by percent, 2:1 taper.

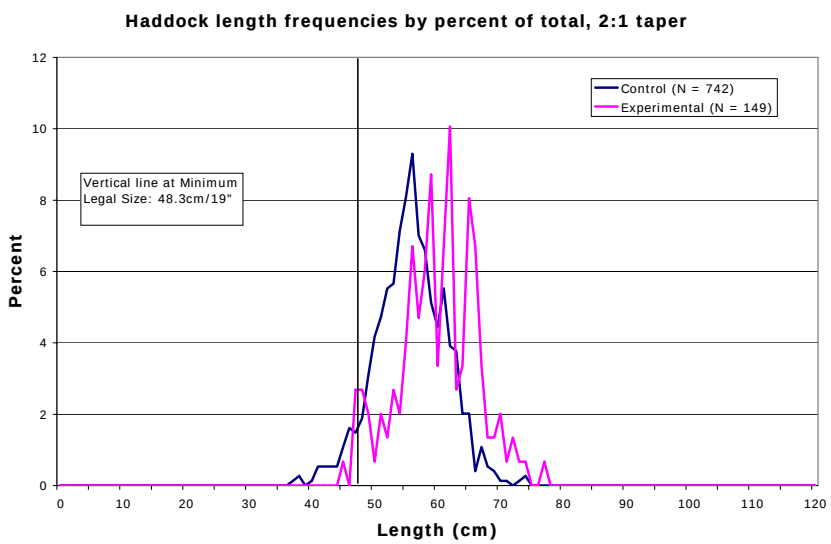


Figure 3. American plaice length frequencies by percent, 2:1 taper.

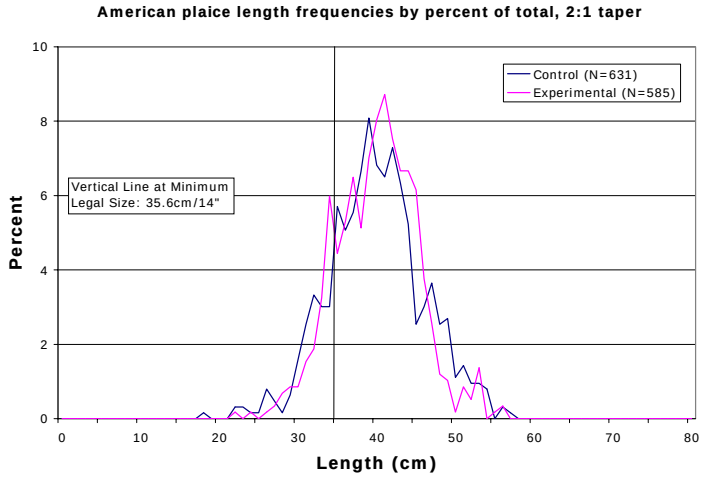
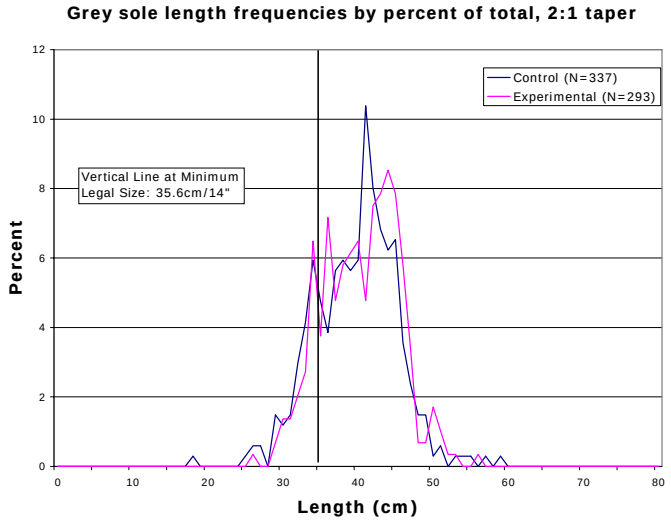


Figure 4. Grey sole (witch flounder) length frequencies by percent, 2:1 taper.



L-F curves for cod, haddock, plaice and grey sole for the 5:1 trial are shown in Figures 5, 6, 7 and 8, respectively. The similar general trend for the curves occurred in these trials, where the experimental net L-F curves were shifted toward larger cod and haddock, and the L-F curves for flatfish remained fairly consistent.

Figure 5. Cod length frequencies by percent, 5:1 taper.

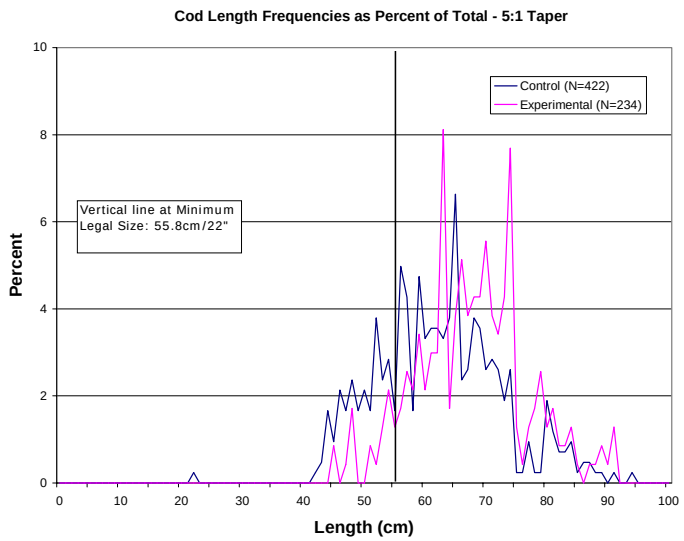


Figure 6. Haddock length frequencies by percent, 5:1 taper.

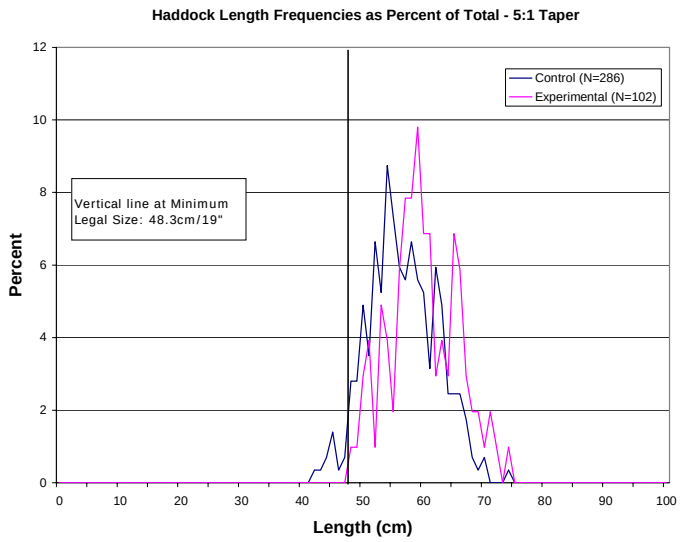


Figure 7. American plaice length frequencies by percent, 5:1 taper.

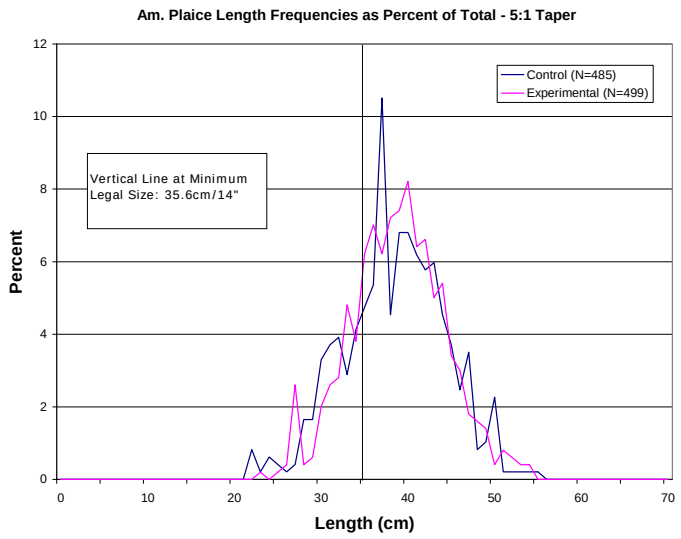
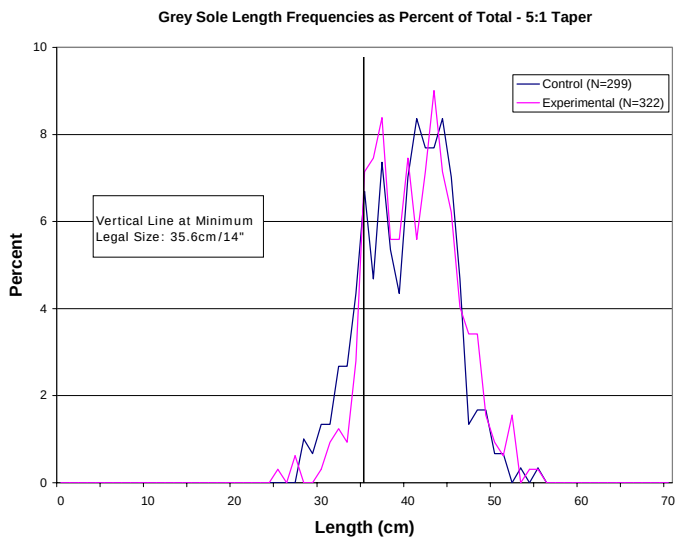


Figure 8. Grey sole (witch flounder length frequencies by percent, 5:1 taper.



Kolmogorov-Smirnov tests supported the graphical evidence to this effect, detecting differences for cod and haddock, but none for plaice and grey sole. A table summarizing K-S results is shown in Table 2.

Table 2. Kolmogorov-Smirnov test results for all length frequencies of four species of interest in both the 2:1 and 5:1 trawl trials.

2 to 1 Results					
21 Tow Pairs					
Species	**Cont.**	**Exp.**	**Observed**	**Predicted**	**Significant**
	N	**N**	**test statistic**	**test statistic**	**difference?**
Cod	475	357	0.3545	0.0952	Yes
Haddock	742	149	0.3126	0.1221	Yes
Plaice	631	585	0.0637	0.0781	No
Grey Sole	337	293	0.0770	0.1086	No

5 to 1 Results					
19 Tow Pairs					
Cod	422	234	0.2504	0.1108	Yes
Haddock	286	102	0.2527	0.1568	Yes
Plaice	485	499	0.0508	0.0867	No
Grey Sole	299	322	0.0690	0.1092	No

The results noted above are quite promising, but are not compelling enough to suppose that industry adoption will occur. It is a good sign that for several species such as monkfish, plaice and gray sole, reductions of marketable catch were not observed. Similarly, the reductions in undersized cod and haddock landed to the deck of the boat are good news. However, the loss of marketable haddock and cod is a significant concern, and given the extreme limitations on industry access to the resource, fishermen will not likely use a trawl that compromises the legal catch.

Upcoming work will help to further examine the utility of the 4-seam modification, and is described below.

The approach that we are undertaking appears to be nearly unique for the mixed-species fishery in New England. Net modifications aimed at improving selectivity in the groundfish fishery abound for the regions of the net mouth, forward portions of the belly, extension, and codend. Trials of 4-seam nets exist for pelagics such as mackerel and herring, and for shrimp fisheries in several regions around the world. However, the effects of using a four seam trawl are apparently less well known, as far as escapement of cod and haddock is concerned.

We do have some starting points regarding cod and haddock behavior. Wardle (1986) gave a behavioral summary partly built by Main and Sangster (1981) and subsequently observed by others, whereby cod and haddock follow some fairly well-established patterns once they pass the footrope. The pattern includes a turn where the fish - once overtaken by the trawl mouth - turns and swims toward the codend, presumably faced with a 'tunnel' of mesh, down which it can swim. At some later imprecisely-determined point, it makes one last turn and faces front, as it encounters an increasingly smaller tunnel of netting.

We believe that is at this point that a burst of escape behavior occurs, with cod and haddock 'charging' the twine to either side, in line with those observations made by Main and Sangster, in 1981. In 2-seam designs, the meshes close to the gore are largely closed down, but in a 4-seam design, an avenue for escape exists, particularly when the mesh is hung square. Flotation and weight on the upper and lower gores, and the weight of any fish in the codend, help to keep the side panels of netting taut, presenting a more fully open mesh to the escaping fish.

The aft end of the belly, and the region around the gore ropes seems to have received little attention, although investigations utilizing square mesh in the extension and the codend are plentiful (Arkley and Dunlin, 2002; Graham and Kynoch, 2001; Halliday et al, 1999; Joppe-Mercure et al, 2005), as well as the role of the dimensions of the extension and codend in determining escapement and selectivity (Robertson and Ferro, 1988). We hope that by focusing on the sides of the trawl and in the region of the aft belly, we will open up new areas of inquiry useful to improving the escapement of undersized gadoids such as cod and haddock.

Partnerships:
This project was a successful collaboration between industry and science. Given that this idea was generated by industry, tested using accepted scientific protocols, and that useful data was generated, both sides were able to contribute effectively and constructively. The project partners have worked together in the past, and the current project only served to deepen the relationship. Allowing for the usual glitches that accompany cooperative research, the planning, implementation and analysis of this project went off very smoothly, and the topic itself - reducing bycatch of undersized roundfish - is one eminently of interest to fishermen and scientists. .

Impacts and applications:
The immediate impact of the present study will be positive, but likely of limited scope, due to small scope of the study itself. More work needs to be done to the trawl modification to make it of real interest to industry; eg: losing so many market haddock is not acceptable. On the other hand, as a general concept, the study demonstrated promise for the notion of improved escapement by a four-seam trawl. In addition, we feel that additional investigation into the rear of the bellies is warranted, and that opportunities for improved escapement by haddock will result.

Related projects:
N/A

Presentations:
American Fisheries Society
Anchorage Alaska, September 11-15,2005
Poster, by Dana Morse, Stanley Coffin, Kelo Pinkham

NEC Annual Meeting
October 27, 2005, Portsmouth NH

Poster, by Dana Morse, Stanley Coffin, Kelo Pinkham

Maine Fishermen's Forum
March 2-4, 2006, Rockport, ME
Poster, by Dana Morse, Stanley Coffin, Kelo Pinkham

Haddock Workshop
April 3, 2007, Univ. of New Hampshire
Presentation, by Dana Morse and Kelo Pinkham

Photos and some data have been used by Mr. Paul Winger, of the Marine Institute of Memorial University, in a presentation concerning strategies for haddock bycatch reduction.

Student participation:
No student participated in this project.

Published reports and papers:
No peer-reviewed publication have been produced, although a project description was written for Commercial Fisheries News, which ran the article in the November 2006 issue, page 17A. Title: Coffin Haddock Net Yields Mixed Results.

Images:
A small number of images are available from this project, in JPEG format.

Future research:
This project was certainly positive enough to stimulate a follow on study, and one has been funded by the Northeast Consortium, entitled: Building on promise: continued investigation in using a 4-seam bottom trawl to improve escapement of small haddock and cod. PI's in that project include Mr. Morse, Capt. Pinkham and Ms. Claudia Coffin. We intend to use 5.5" square mesh in the side panels of an experimental trawl (2:1 belly taper), in hopes of maintaining good escapement of small roundfish, while retaining individuals of legal size. To date: the NEPA review has been completed and approved, and the application for an Exempted Fisheries Permit is complete, and fieldwork was completed in summer of 2007.

If such work is indeed successful at reducing the catch of undersized fish without compromising the legal catch, it can be supposed that work would then broaden out to the fishing community. The goal there would be to test the 4-seam modification on vessels and nets of different size, fishing in different locations and times of year. Thus, a case could hopefully be built for adoption by fishermen region-wide, and offered as a management option.

Literature Cited:

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DeAlteris, J.T., Castro, K. and Testaverde, S.A. 1990. Effect of mesh size in the body of a bottom trawl on the catch retained in the cod end. IN: Proceedings of the Fisheries Conservation Engineering Workshop, J.T. DeAlteris and M. Grady, eds. National Sea Grant Publication #RIU-W-90-002.

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