The Use of Positively Buoyant Ground Cables and Sweep to Reduce Seabed Contact and to Enhance Species Selectivity

Prime Award Number: NA05NMF4721057
Subaward Number: PZ07062
Period of Performance: 4/1/06 to 6/30/09

Principal Investigator, Project Leader
Dana L. Morse
Maine Sea Grant / UMaine Cooperative Extension
Darling Marine Center
193 Clark's Cove Rd.
Walpole, ME 04573
207.563.3146 x205
fax: 207.563.3119
E-Mail: dana.morse@maine.edu

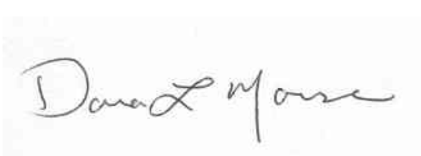
Lead Institution:
Maine Sea Grant College Program
Lynn Wardwell
University of Maine, Coburn Hall
Orono, ME 04469
207.581.1448
Fax: 207.581.1426
E-Mail: wardwell@maine.edu

Additional Key Project Participants:

Capt. Kelo Pinkham
167 West Side Road
Trevett, ME 04571
207.633.6315
kpinkham@gwi.net

Capt. Bill Lee
F/V Ocean Reporter
25 Pleasant Street
Rockport, MA 01966
978.546.2748
oceanreporter@comcast.net

PLEASE NOTE: *This project was originally written and undertaken by Capt. Pinkham. Post-award, the administration was moved to the Maine Sea Grant program, and thus Mr. Morse is listed as the Project Leader, but it should recalled that this is principally for reasons of consistency in administration, and Capt. Pinkham's leadership in the project should be recognized.*



Date: 28 Jan, 2010

Dana L. Morse
Maine Sea Grant

Abstract:
A groundfish net was modified to limit its bottom contact and to improve escapement of bottom-tending fish species. A model was first evaluated in the flume tank facility of Memorial University, followed by field trials. Two trawl configurations were tested against a Control, during fishing experiments in 2007 and 2008. In the first configuration, the goal was to fish the net approximately 1.5' off the seabed, to retain cod and haddock while reducing catches of flounders and other demersal species. In the second rig, the Experimental trawl was fished up to 3' off the seabed, to retain haddock while reducing catches of cod, flounders and other demersal species.

Flume tank tests indicated that a stable condition and proper fishing heights were achieved with a combination of floats on the headrope, footrope and ground gear, combined with weights attached to the wing ends. Field trials followed the recommendations developed in the laboratory, and video observation revealed a stable fishing condition, with little contact with the seabed. Catch information was hampered by low fish availability, but indicated that the correct escapement pattern was occurring, with the exception of higher-than-desired escapement of haddock during the second experiment.

Introduction:
One consistent research priority for the New England Fisheries Management Council was has been to focus on research on fishing practices or gear modification that may change the ratio of component catch species or improve selectivity of gear.

The Sustainable Fishery Act (SFA) requires reducing seabed impact of fishing operations and the protecting of essential fish habitat. There has been increasing worldwide concern over the effects of trawling on the seabed. The New England Council has been under increasing pressure to lessen the effects of fishing activity on fish habitat, and increasing the use of species selective trawl gear. Gear capable of taking haddock (*Melanogrammus aeglefinus*) without taking cod (*Gadus morhua*) and gear capable of taking haddock and cod without taking yellowtail (*Limanda ferruginea*) has been a pressing area of gear development.

The approach for the project stemmed from discussions between Capt. Pinkham and Mr. Morse. Earlier work by Main and Sangster (1981 a, 1981 b) and Wardle (1983, 1986) indicated that flatfish and roundfish have very different primary reactions to fishing gear, and therefore operate based on differing stimuli. In effect, roundfish are herded primarily by sight and secondarily by touch, whereas flatfish are herded primarily by touch, and secondarily by sight. The visual cues of importance are the gear itself, and the sand/mud clouds caused by the gear passing over the bottom. Tactile cues include the trawl doors, the links between the doors and the net (the bridle) and the sweep of the trawl itself.

Swimming patterns of roundfish and flatfish also differ. Flatfish tend to zigzag along the bottom, moving at 90 degrees to the oncoming gear, while roundfish move roughly parallel to the converging sand clouds (Wardle, 1986). Once in the trawl mouth, the zigzag behavior and subsequent low-height escape responses of flatfish are different than the rise-and-turn behaviors that became the basis for separator trawls, semi-pelagic trawls such as the sweepless and 5-points trawls (Pol and McKiernan, 2004; Morse, 1994) and - as regards cod and haddock - the newly-developed Ruhle Trawl (Carr and Caruso, 1993; Beutel et. al. 2008). The *height* to which different species have been observed to swim or flip was an important factor in the design of the present study, and the works cited above were helpful in generating our approximate target heights off bottom for the gear, as was work in Canada by Cooper (1992) and Main and Sangster (1982).

Bottom impact has been a topic by which other fishing gears have been developed or other strategies adopted, and a review of some of these approaches can be found in Valdemarsen et. al. (2007). More locally, while 'sweepless' and the 5-points trawls reduce bottom contact, they are limited in their applicability in the Gulf of Maine, because the bottom is frequently uneven and broken, with large rocks and complex bottom contour. Tows are rarely conducted in a straight line, and the full sweep that we employed is desirable because it allows the net to travel over such bottom more easily, and to be protected from damage during frequent turns and depth changes. The buoyant sweep (dubbed 'The Floaty Frame') was therefore a concept hybridized from roller nets and semi-pelagic nets, which would fit the local fishing conditions encountered in Maine's nearshore and offshore waters.

Given these observations, and the then-current fisheries management objectives of selective fishing and of reducing benthic impacts from mobile gear fisheries, we undertook the present study. Our **project objectives** were:

- To reduce seabed contact while trawling, of both the net and ground gear.
- To separate out fish species by using their instinctive response to fishing gear, both before encountering the net and while entering the net
- To reduce stresses imposed upon non-target species by allowing them to pass under the ground gear and net.
- To attempt to document, by use of underwater video cameras, fish behavior in the presence of both standard and the experimental ground gear and net as well as fish behavior in the mouth of the nets and the effects of each type of net on the sea floor.
- To distribute the results of our work to fish managers, fishermen and those people concerned with the effects of trawling on the seafloor and essential fish habitat.

There were two types of species separation that were desired in this study. In the first case (referred to below as the 'Cod Rig') our goal was to equip the net such that it would eliminate flatfish from the catches, yet retain roundfish such as cod and haddock. In the second case (referred to as the 'Haddock Rig') we attempted to equip the net such that it would eliminate flatfish and cod, and retain haddock and other roundfish.

Participants:

The principal participants in this study were:

Capt. Kelo Pinkham, Trevett, Maine. Capt. Pinkham conceived of the study, and drew up the original proposal. Capt. Pinkham oversaw all aspects of gear construction and fishing operations.

Mr. Dana Morse, Maine Sea Grant / Univ. of Maine Cooperative Extension. Mr. Morse supported Capt. Pinkham in project development, and coordinated logistics for tow tank testing, data collection/analysis, and reporting.

Capt. Bill Lee, Rockport MA. Capt. Lee was contracted to conduct at-sea trials to tune the full-scale equipment, to participate in all phases of the flume tank testing, and to use his expertise in underwater videography to observe the gear during fishing activities. Capt. Lee also produced a DVD as an outreach product.

Mr. Harold DeLouche, Mr. George Legge and Ms. Tara Perry. All three individuals are fishing gear professionals employed at the Flume Tank Facility of Memorial University, St. John's, Newfoundland. Mr. DeLouche and Ms. Perry built the scale model trawl, and all three contributed to the three days of observation in the flume tank itself.

Methods:
During the later months of 2006, a 1/6 scale, engineering-quality model of the proposed gear was built by staff at the Center for Sustainable Aquatic Resources (CSAR), of Memorial University, in St. John's, Newfoundland. Three days of flume tank experiments were undertaken, from January 3-5, 2007. During this time, project participants investigated the geometry of the trawl under different flow conditions, and varied the number and placement of floats on the lower leg of the bridle, flotation on the headrope, and both flotation and weight along the footrope.

At the end of the three days of testing, the project partners felt they had enough data with which to commence field testing, which would in turn begin with tuning the gear in full scale, to attain the desired heights off bottom. Data sheets and photographs from the work at the CSAR flume tank facility are available. However, to achieve what appeared to be appropriate heights for selecting out flatfish (or flatfish and cod, as the case might be) the following arrangement of flotation and weight was suggested for the full scale gear:
- Ten, 8-inch trawl floats to be attached to the lower leg of each bridle.
- Twenty-five, 8-inch trawl floats attached to the headrope

For the Cod Rig, 53 lbs (24.1kg) of chain would be tied to each wing end, and allowed to drop approximately 1.5 feet (0.46m) to the seabed. For the Haddock Rig, the same weight of chain would be attached, but allowed to extend approximately 3 feet (0.91m). General representations of the Cod and Haddock Rigs are shown in Figures 1 and 2; precise parameters for testing are given below.

Figure 1. Model trawl shown in the high position, also referred to as the 'Haddock Rig'.

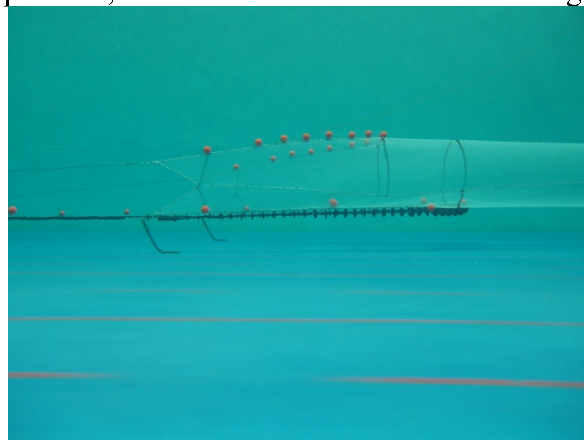
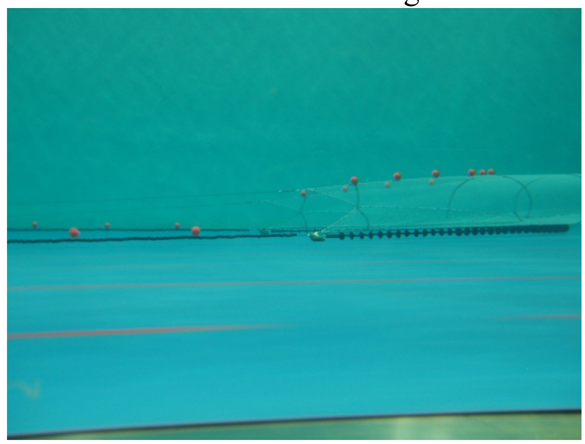


Figure 2. Model trawl shown in the low position also referred to as the 'Cod Rig.'



The above specifications would constitute the Experimental trawl for subsequent field tests. The Control version of this trawl would be arranged by removing all flotation from the bridle, and tying up all wing end weight tightly to the footrope.

Constructing the trawl

The full-scale trawl was designed and constructed by Capt. Pinkham. The net has a footrope length of 70 ft. (21.3m) and a headrope length of 55 ft. (16.8m). The net body was of 3mm (0.12") polypropylene twine, green in color, with a nominal stretched mesh size of 6" (152.4mm). The net terminated in a codend of 4mm (0.16") green doubled twine, and was 50 meshes around by 50 meshes long.

The sweep was a roller-type design, with rubber disks (floppies) spaced at 1-foot (30.5cm) intervals, strung on 7/16" (11mm) a combination wire footrope. Spaces between the disks were occupied by 2.5" (6.4cm) rubber 'cookies' strung on the footrope. Rubber disks were 8" (20.3cm) diameter along the wings, rising to 10" (25.4cm) in the trawl quarters, and 12" (30.4cm) in the bosum of the trawl.

Codend mesh measurements were made with a spade-type gauge, manufactured by Top-ME, with an 8kg weight attached. Three rows of 10 meshes each were measured, in the following regions of the codend: top, bottom (not under the chafing gear) and bottom under the chafing gear. Mean codend mesh size was 163.3mm (6.43"), with a standard error of 0.0257 inches.

Videography, bottom interaction observations: Spring, 2007

Five days were spent with the net and ground gear, on the F/V Ocean Reporter, owned and operated by Capt. Bill Lee, of Rockport MA (www.oceanreporter.com). Video observations were made in Ipswich Bay, Massachusetts, in depths generally less than 10 fathoms. During this time, project partners experimented with different numbers of floats, amount of weight on the sweep and wing ends, and floats on the lower leg of the bridle. Starting points for this experimentation were taken from the measurements made at the flume tank.

During video observations, trawl floats on the ground gear and the trawl itself were marked with painted letters or numbers; numbers on one side and letters on the other, ascending in order of distance from the vessel. Drop chains were spray painted for visibility, and to allow observers to estimate height of the sweep off bottom. The lettering/numbering scheme provided a frame of reference in conditions of low visibility or when the towed camera was upside down, and worked extraordinarily well.

Figure 3. Laying out the floated groundlines, Rockport Harbor, May, 2007.

Trawl Geometry:
During trials aboard the F/V Ocean Reporter, we were fortunate to have the assistance of the Mass. Division of Marine Fisheries, and the expertise of Bill Hoffman, who outfitted the trawl with NetMind trawl sensors. A set of Star-Oddi sensors was tried as well, though without good result. The NetMind was deployed on the doors, wings and the headrope. There was an unsuccessful attempt later in the day to retrieve information about height of the sweep off bottom. Concrete data was retrieved from the sensors as the net was deployed in its 'Control' position, with no floats on the ground gear. Chains were however deployed on the wing ends (53 lbs), weights on the port quarter of the sweep (27 lbs) the starboard quarter (28 lbs) and the sweep center (18 lbs). All chains were tied as tightly as possible to the sweep, to maximize the bottom-tending of the net.

During some points of the tows, the NetMind data became very variable, for unknown reasons. Therefore, an attempt to cope with these erroneous readings was made, as follows: all data was plotted, which revealed a fairly discrete mean reading, as well as the outliers. Outlying data that ranged plus or minus 25% from the observed initial mean was discarded. Mean values and standard errors were recalculated, and the data re-plotted for presentation in the sections below.

Following these trials, one day was spent on examining the visual evidence left by the trawl. Short-duration tows were made in fairly shallow water (less than 10 fathoms), to increase the chances of good water clarity. Immediately afterward, the video camera was deployed, and the vessel crossed the towing path at right angles, so that marks left on the seabed would be evident.

Substrate appeared to be a sandy mud, to sand. During these tows, the only extra weights on the net were those on the wing ends.

Fishing trials, Jeanne C description

Fishing trials of the so-called Cod Rig were carried out during 2007 and 2008, on the following dates: Oct 16, 17, 18, 22 and 24 of 2007, and June 15, 20, 23, 24 and July 2 of 2008. The reason for the split of the trials was a lack of sufficient fish in 2007; project partners thought that a more accurate assessment of the gear would be undertaken when fish populations rebounded in the following year.

Fishing trials of the Haddock Rig were carried out in 2008, on the following dates: July 26, 28 and 31, and August 1, 9, 10, 11, 13, 14, 15.

For all field trials, an alternate-tow approach was used. The net was rigged in its Control configuration (bridle floats removed, sweep/wing end weight tied tightly) and fished vs. its appropriate Experimental configuration. The paired Control-Experimental tows constitute one experimental unit, the 'tow pair.'

Fishing trials were carried out aboard the F/V Jeanne C, owned and operated by Capt. Pinkham. The vessel is 40 LOA, with a beam of 13.5 feet and a draft of 5.5 feet. It is powered by a 120 hp Volvo engine turning a 36" x 36" 4-bladed propeller. The vessel is shown at harbor in Figure 4.

Figure 4. F/V Jeanne C, owned and operated by Capt. Kelo Pinkham, home ported in Boothbay Harbor, Maine.

Sampling

Catch for all tows was whole-hauled; weights were taken for all finfish species separately, and lengths were obtained for all individuals of species of interest (cod, haddock, American plaice (*Hippoglossoides platessoides*), grey sole (*Glyptocephalus cynoglossus*), hake spp (*Urophycis* *spp*), pollock (*Pollachius virens*), and redfish (*Sebastes marinus*), 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:
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 were 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. Note that all tow pairs were included in the F- and t-Tests, even those tow pairs where zero catch was observed for both the Control and Experimental tow.

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:

Tow Tank Results:
Three days of trials with the model trawl were sufficient to gauge the flotation and weight necessary, that would permit the net to achieve the desired heights off bottom, for both the Cod Rig (approximately 1.5 feet) and the Haddock Rig (approximately 3.0 feet). Chain was used at each wing end was used (53 lbs/24 kg), which could be lengthened or shortened to achieve the different heights desired. Nine floats on the lower leg of the ground gear were used, 21 floats on the headrope, and three floats on the footrope. Floats were simulated as 8-in, center hole trawl floats. A full catalog of photo images and the model data sheets accompany this report on a separate CD.

Fieldwork aboard F/V Ocean Explorer
<u>Net Geometry</u>:
Work with the NetMind sensors aboard the trawl revealed that averages for doorspread, wingspread and headline height were 31.90m (104.6 ft), 10.08m (33.0 ft) and 3.25 m (10.7ft), respectively. The data are displayed graphically in Figures X, X and X. As described above, the data from the NetMind reflected the net in its Control position, with weights tied up tightly. Sections below will describe the sweep height off bottom via photographs, in cases where the chains were allowed to drop into their Experimental positions.

Figure 5. Doorspread of the trawl in the Control position, aboard F/V Ocean Observer, Ipswich Bay, MA.

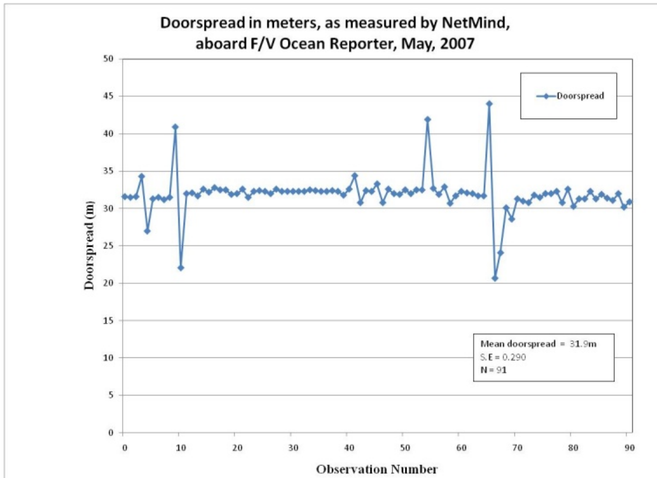


Figure 6. Wingspread of the trawl in the Control position, aboard F/V Ocean Observer, Ipswich Bay, MA.

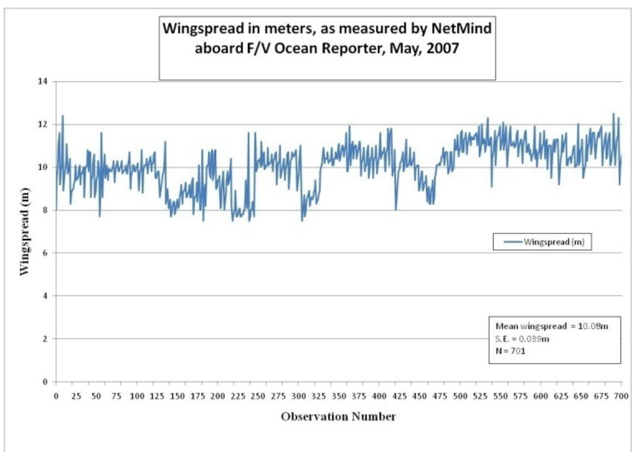
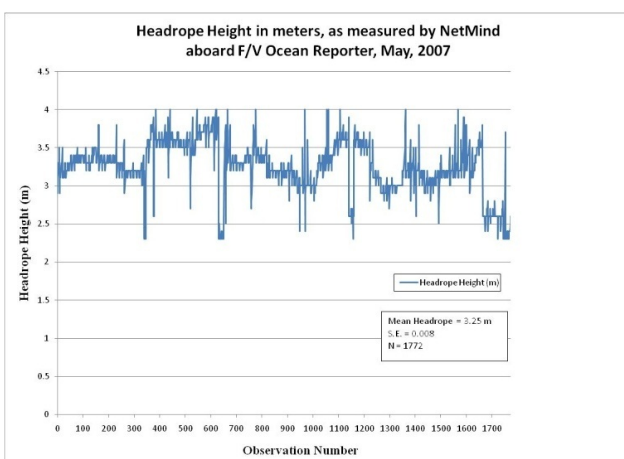


Figure 7. Headrope height of the trawl in the Control position, aboard F/V Ocean Observer, Ipswich Bay, MA.



Height of the Sweep:
A variety of photographs and video clips showed the net to 'fly' well off the bottom, and in various configurations, the height appeared to vary between roughly 30cm (1 foot) and 80-90 cm (2.5 feet). Determining the exact height of the sweep off bottom proved to be somewhat difficult, due to the position of the camera, speed, tow direction or turning, and other factors. Therefore, our estimations are based on the best observations we could obtain, given these limitations. By contrast, we are able to use the size of various trawl components such as float and rubber disk diameters to make some reasonable estimates.

Except for Figure 10, Figures 8-11 below show the trawl in one experimental phase or other, not the Control rig. Our estimates lead us to believe that the in the Cod rig, the wing ends were travelling between 1 and 2 feet off the bottom, with the bosum of the sweep slightly higher; and in the Haddock rig arrangements, the wing ends were travelling between 2 and 3 feet off the seabed. A full catalog of photographs accompanies this report on a separate CD. Enclosed with this report is a second CD, produced by Capt. Lee, showing extensive video of the trawl in action, clearly travelling in a stable state above the seabed.

Figure 8. Starboard side wing end, with wing end weight in the doubled position. Estimated height of the sweep off bottom is 1.5 ft. (45 cm)

Figure 9. Port side wing end, with wing end weight in the extended position. Estimated height of sweep off off bottom is 22" (55.9 cm)

Figure 10. Sweep of the net in the Control position, demonstrating bottom contact.

Figure 11. Center section of the sweep in the Experimental position, showing the sweep 'flying' off bottom. Estimated height off bottom is 2 feet (50.8 cm).

Bottom Impact:
During the fishing activities in Ipswich Bay, tows were made with the experimental gear, followed by passes with the video camera at right angles to the original tow track. In this manner, project partners could document to some degree the interaction between the seabed and the fishing gear. Figures 12 and 13 show the marks left by the passage wing-end weights, or doors. One can see that the tracks themselves are quite narrow, indicating that the remainder of the gear - including the lower leg and nearly the entire sweep - was not in contact with the seabed. Virtually no other seabed from the trawl was observed, confirming in our minds that the points of contact had been reduced to the doors, or the wing end weights.

Figure 12 Close view of marks made in sandy seabed by the Experimental rig.

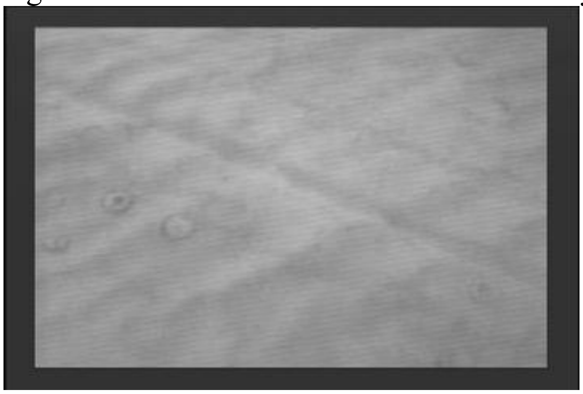


Figure 13. Wider view of marks made in sandy seabed by the passing Experimental rig, aboard F/V Ocean Explorer, Ipswich Bay, MA. Note undisturbed areas outside of the thin track.

Fishing Trials:

Data Review:

Review of the data revealed two pairs of tows in the Cod Rig fishing trials with errors, missing or incomplete data, yielding 18 pairs of tows for all subsequent analyses. All 20 pairs of tows undertaken during the testing of the Haddock Rig were accepted for analysis.

Tow Times:

In the 18 tow pairs using the Cod Rig, mean tow times for the Control and Experimental nets were 120.1 minutes (Std. Error = 0.076) and 120.4 minutes (S.E. = 0.283) respectively, and were not significantly different as evaluated by a paired two-sample t-Test for means. With respect to the Haddock Rig, tow times for the Control and Experimental were 120.3 minutes (S.E. = 0.576) and 120.0 (S.E. = 0.0) respectively, and these times were not significantly different from one another.

Cod Rig - Weight Data:

Weight data for the fishing trials examining the Cod Rig are presented as Catch per Unit Effort (CPUE), in this case, pounds per hour. The species predominately captured during this experiment include monkfish, skate species, dogfish (*Squalus acanthius* and *Mustela canis*), cod and lumpfish (*Cyclopterus lumpus*), as shown in Table 1. In aggregate, catch rates for all species were much lower with the Experimental trawl, though statistical tests were performed only on separate species, indicated below.

Table 1. Summary of catches during trials of the Cod Rig, expressed in pounds per hour.

Mean Catch per Hour in Pounds - 'Cod Rig'

	Control	Exp.	# Obs. Cont.	# Obs. Cont.
Cod	28.45	26.25	18	18
Crab	1.32	0.01	7	1
Dabs	4.96	1.54	17	18
Dogfish	29.87	23.71	18	17
Eelpout	0.00	0.00	0	0
Grey Sole	3.78	1.30	18	9
Haddock	3.44	3.30	10	8
Hake sp.	3.62	0.83	9	6
Halibut	0.00	0.00	0	0
Herring	0.00	0.00	0	0
Lobster	0.60	0.43	4	3
Lumpfish	13.06	10.92	16	16
Monkfish	58.30	8.99	18	15
Pollock	4.54	9.03	7	8
Redfish	0.62	0.62	11	9
Sculpin	0.00	0.00	0	0
Sea Robin	0.04	0.11	1	2
Skate	55.55	8.14	18	13
Whiting	0.00	0.00	0	0
Other	2.40	0.98		
TOTAL	210.57	98.80		

An F-test was performed as an initial review of the catch data, to determine the similarity or dissimilarity of variances from the two samples, by species. Of the six species of interest in this study, samples from Am. plaice, monkfish, skates and pollock had dissimilar variances (heteroscedasticity), shown as red entries in Table 2. Subsequent t-Tests - two sample tests for samples having either similar or dissimilar variances - on the catch rates for these species were done in accord with the results of the F-Test. Overall, catch rates of most species was low, a problem that affect all fishing trials.

Table 2. Results of F-Tests on Cod Rig data, examining differences in variance. Significant differences in F-Test results are shown in red.

Results of F-tests on CPUE data - Cod Rig

	Cod		Haddock		Am. Plaice		Grey Sole		Monkfish		Skate spp.		Pollock	
	Cont.	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp*
Mean	28.452	26.246	3.439	3.298	4.956	1.542	3.777	1.298	58.304	8.994	55.550	8.137	4.54407713	9.03248393
Variance	1444.942	983.898	17.857	24.461	15.683	5.660	18.077	18.247	952.293	181.080	1557.835	124.072	63.8699804	403.325966
Observations	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	18
df	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	17
F	1.469		0.730		2.771		0.991		5.259		12.556		0.15835822	
P(F<=f) one-tail	0.218		0.262		0.021		0.492		0.001		0.000		0.00021307	
F Critical one-tail	2.272		0.440		2.272		0.440		2.272		2.272		0.4401616	

t-Tests on the catch rate data detected no differences for cod, haddock, pollock or grey sole, but did detect differences with respect to catch rates for plaice, monkfish and skate (Tables 3 and 4).

It should be noted that the t-Tests counted zeroes as observations, in contrast to the listing of species in Table 1, which does not count a zero catch in the number of observations.

Table 3. t-Test results for samples having similar variance, in the Cod Rig.

Summary of t-Tests on CPUE by species for the Cod Rig, for Samples Having Similar Variance

	Cod		Haddock		Grey Sole	
	Cont.	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*
Mean	28.462	20.246	3.439	3.298	3.777	1.298
Variance	1444.947	983.898	17.867	24.461	18.077	18.247
Observations	18.000	18.000	18.000	18.000	18.000	18.000
Pooled Variance	1214.420		21.169		18.162	
Hypothesized Mean Diff.	0.0		0.0		0.0	
df	34.000		34.000		34.000	
t Stat	0.190		0.092		1.745	
P(T<=t) one-tail	0.425		0.464		0.045	
t Critical one-tail	1.691		1.691		1.691	
P(T<=t) two-tail	0.851		0.927		0.090	
t Critical two-tail	2.032		2.032		2.032	

Table 4. t-Test results for samples having dissimilar variances, in the Cod Rig.

Summary of t-Tests on CPUE by species for the Cod Rig, for Samples Having Dissimilar Variance

	Am. Plaice		**Monkfish**		**Skate**		**Pollock**	
	Cont.	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*
Mean	4.956	1.542	58.304	8.994	55.550	8.137	4.54407713	9.03248393
Variance	15.683	5.660	952.293	181.080	1557.835	124.072	63.8699804	403.325966
Observations	18.000	18.000	18.000	18.000	18.000	18.000	18	18
Hypothesized Mean Diff.	0.0		0.0		0.0		0	
df	28.000		23.000		20.000		22	
t Stat	3.135		6.214		4.905		-0.88100613	
P(T<=t) one-tail	0.002		<0.001		<0.001		0.19391912	
t Critical one-tail	1.701		1.714		1.725		1.71714434	
P(T<=t) two-tail	0.004		<0.001		<0.001		0.38783825	
t Critical two-tail	2.048		2.069		2.086		2.07387306	

<u>Cod Rig - Length Data</u>:
Kolmogorov-Smirnov tests, applied to the Control and Experimental length frequency distributions for seven of the species retained in the Cod Rig tests, detected no significant differences. Results are summarized in Table 5. The distributions themselves are shown graphically in Figures 14-20; please note that these are cumulative representations, rather than given as relative numbers. Low sample sizes are factors in limiting the robustness of the K-S test results.

Table 5.

Summarized Results of Kolmogorov-Smirnov Test for Length Frequency Comparison - 'Cod Rig'

SPECIES	Control N	Experimental N	D-Statistic Predicted	D-Statistic Observed	Length at Max. Difference	Significant Difference?
Cod	167	140	15.984	7.707	60 cm	No
Haddock	27	30	36.077	25.556	60 cm	No
Am. Plaice	205	43	22.811	18.003	46 cm	No
Grey Sole	150	11	42.482	20.364	30 cm	No
Skate spp.	26	10	50.606	44.614	52 cm	No
Pollock	16	39	40.376	22.724	73 cm	No
Redfish	25	22	39.756	28.364	15 cm	No

Figure 14. Cumulative length frequency curves for cod, in the Cod Rig field tests.

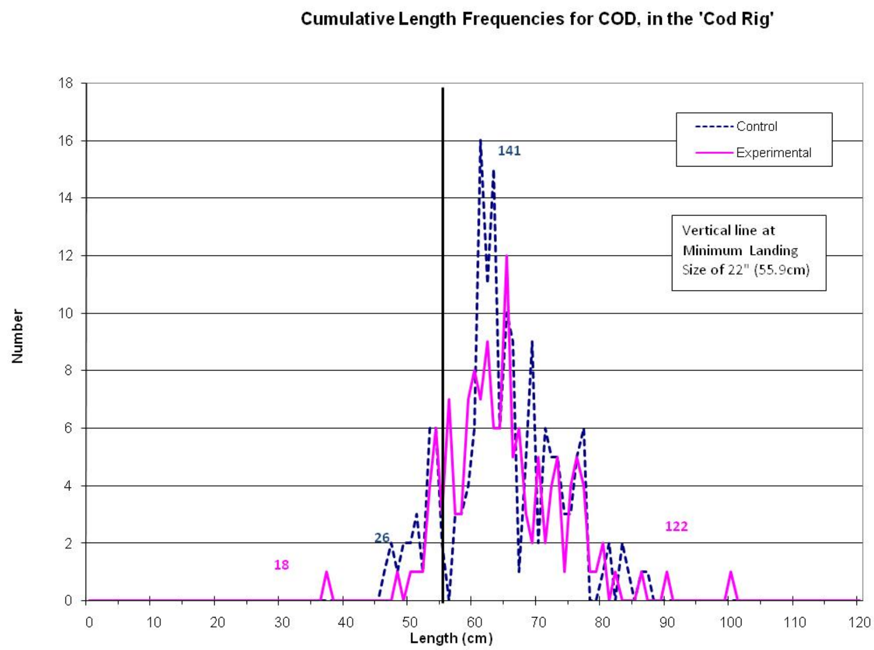


Figure 15. Cumulative length frequency curves for haddock, in the Cod Rig field tests.

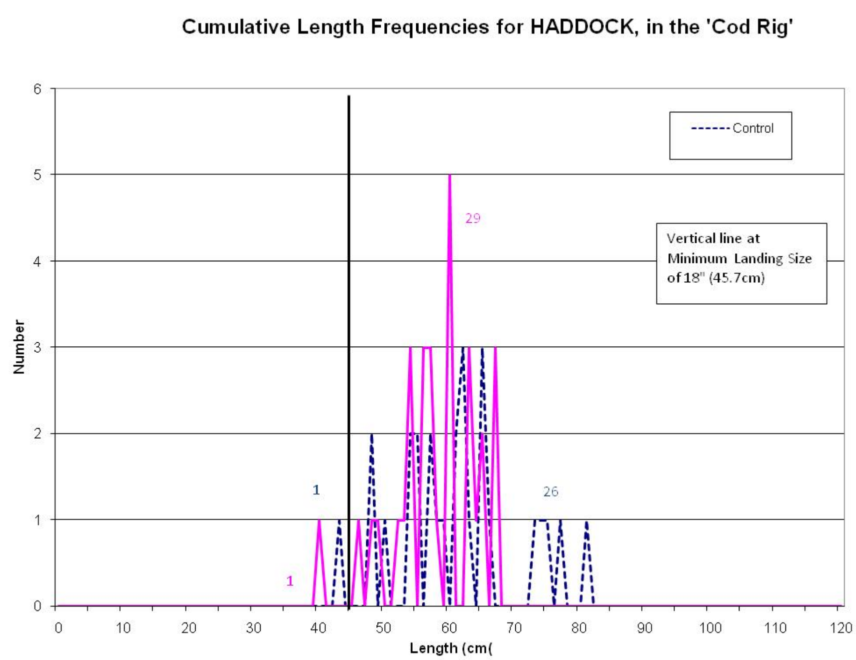


Figure 16. Cumulative length frequency curves for Am. Plaice, in the Cod Rig field tests.

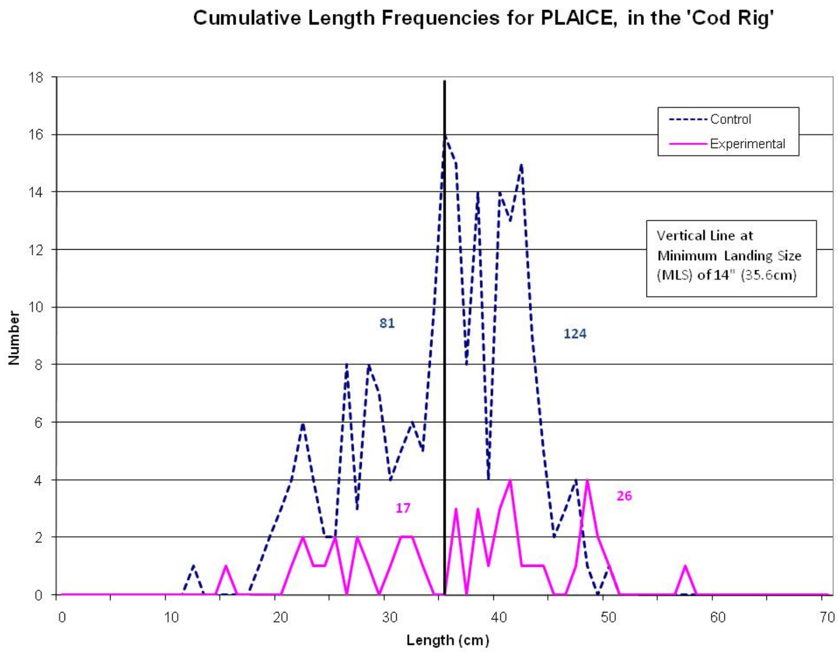


Figure 17. Cumulative length frequency curves for grey sole, in the Cod Rig field tests.

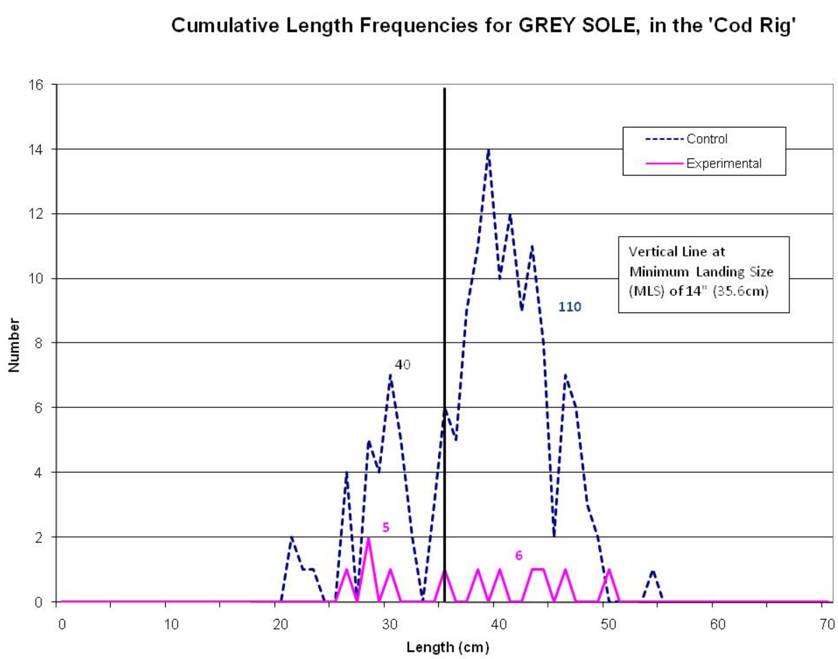


Figure 18. Cumulative length frequency curves for hake species (red and white), in the Cod Rig field tests.

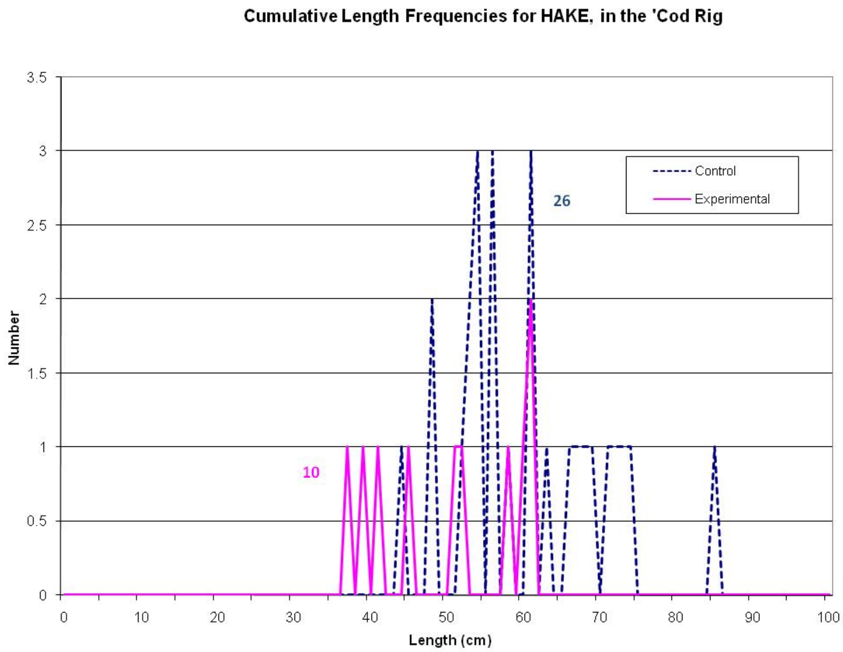


Figure 19. Cumulative length frequency curves for pollock, in the Cod Rig field tests.

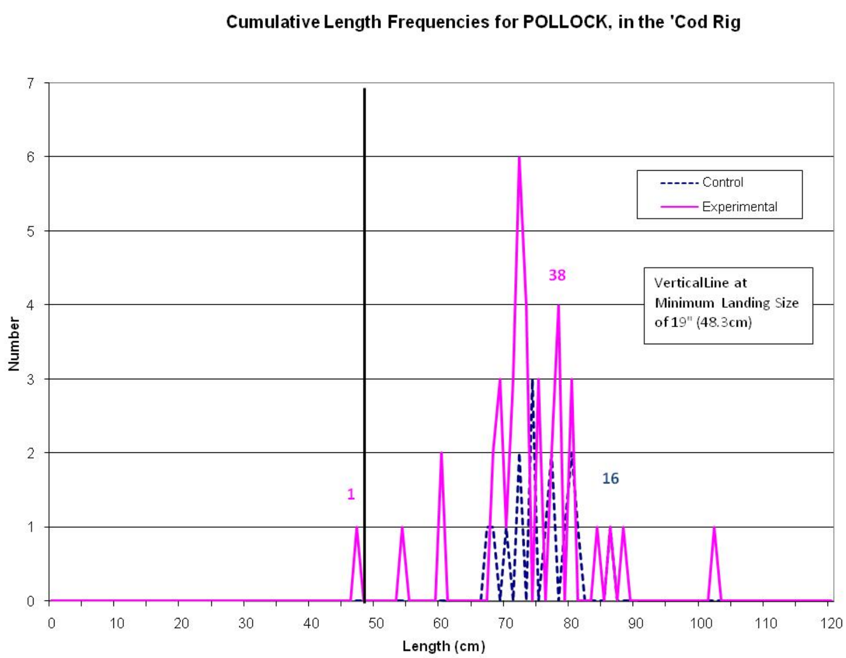
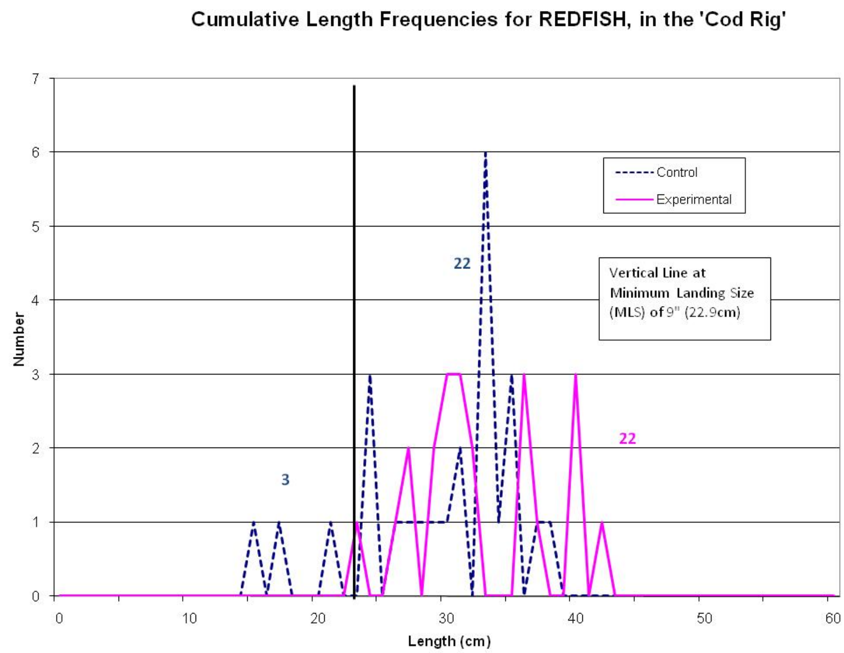


Figure 20. Cumulative length frequency curves for redfish, in the Cod Rig field tests.



<u>Haddock Rig - Weight Data</u>:
Catch rates for several species - notably haddock, Am. plaice and grey sole - were once again low in the tests of the Haddock Rig. Mean catch rates were lower with the Experimental, for all species measured, including zero grey sole retained with the Experimental, over all 20 tows. Catch rate data is summarized in Table 6. Most species were relatively abundant, as shown by the high number of encounters with the Control net, except perhaps for Haddock and Lobster.

Table 6. Catch rate data, expressed as pounds per hour, for all species and species groups measured during field testing of the Haddock Rig.

Mean Catch Per Hour In Pounds - 'Haddock Rig'

	Cont	Exp	# Obs. Cont	# Obs. Exp
Cod	78.2312869	18.1375	20	19
Dabs	2.69196089	0.3125	20	8
Dogfish	28.0694664	8.625	20	17
Grey Sole	1.6106309	0	20	0
Haddock	3.22765421	0.5375	14	4
Hake sp.	46.6649112	6.7625	20	16
Lobster	1.90279173	0.3375	8	1
Lumpfish	29.6064013	15.75	20	19
Monkfish	52.2636544	1.2	20	8
Pollock	44.1015709	34.55	19	20
Redfish	2.89947887	0.9125	16	10
Skate	32.5702219	0.525	20	2
Other	3.57477376	0.0625		
TOTAL	334.178091	95.9		

F-tests applied to the catch rate data indicated highly variable data, with dissimilar sample variances between the Control and Experimental nets for all species or species groups examined, except pollock. Given the zero catch of grey sole with the Experimental net, the F-test was unable to return a sensible result. F-test results are given in Table 7.

Table 7. F-test results, as applied to species and species groups of interest, during field tests of the Haddock Rig.

Results of F-tests on CPUE Data - 'Haddock Rig'

	Cod		**Haddock**		**Am Plaice**		**Grey Sole**		**Monkfish**		**Skate**		Pollock	
	Cont.	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*	*Cont.*	*Exp.*
Mean	78.231	18.138	3.228	0.538	2.592	0.313	1.611	0.000	52.264	1.200	32.570	0.525	44.1015709	34.55
Variance	3419.424	538.687	9.655	1.818	1.657	0.354	0.682	0.000	452.444	3.905	228.254	4.513	1161.73694	954.451316
Observations	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20	20
df	19.000	19.000	19.000	19.000	19.000	19.000	19.000	19.000	19.000	19.000	19.000	19.000	19	19
F	6.348		5.312		4.675		65535.000		115.855		50.583		1.21717778	
P(F<=f) one-tail	<0.001		<0.001		0.001		N/A		<0.001		<0.001		0.33636419	
F Critical one-tail	2.168		2.168		2.168		2.168		2.168		2.168		2.1682516	

Given the results of the F-tests, a t-test for heteroscedastic data was applied to the catch rate data for cod, haddock, plaice, monkfish and skate, again with the exception of pollock, and for that species, a t-test for homoscedastic data was used. Nearly all t-tests returned highly significant results, indicated a strong reduction in catch rates when using the Experimental as compared to the Control trawl (Table 8). Again, the exception was the t-test for Pollock, which returned a non-significant result (Table 9).

Table 8. t-Test results, as applied to species and species groups of interest, during field tests of the Haddock Rig. All tests based on heteroscedastic data, as determine by a prior F-test.

Results of t-Tests on CPUE Data - 'Haddock Rig'

	Cod		Haddock		Am Plaice		Monkfish		Skate	
	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.	Exp.
Mean	78.2312869	18.1375	3.22765421	0.6375	2.69198089	0.3125	62.2838544	1.2	32.8702219	1.525
Variance	3419.42448	638.697336	9.66514909	1.81769808	1.66709289	0.35444079	452.444126	3.90526316	228.264414	4.8125
Observations	20	20	20	20	20	20	20	20	20	20
Hypothesized Mean Diff.	0		0		0		0		0	
df	25		26		27		19		20	
t Stat	4.27169658		3.55189136		7.16759329		10.6899901		9.36328842	
P(T<=t) one-tail	0.00012296		0.00074321		4.9614E-08		8.8891E-10		4.4836E-09	
t Critical one-tail	1.70814019		1.70561634		1.70328804		1.72913133		1.724718	
P(T<=t) two-tail	0.00024596		0.00148641		9.9228E-08		1.7778E-09		8.9672E-09	
t Critical two-tail	2.05953711		2.05553079		2.05182914		2.0930247		2.08596248	

Table 9. t-Test result as applied to Pollock during tests of the Haddock Rig.

Results of t-Test on Pollock - 'Haddock Rig'
Assumes equal variance based on F-test

	Variable 1	Variable 2
Mean	44.1015709	34.55
Variance	1161.73694	954.451316
Observations	20	20
Pooled Variance	1058.09413	
Hypothesized Mean Differe	0	
df	38	
t Stat	0.92856573	
P(T<=t) one-tail	0.17948764	
t Critical one-tail	1.68595446	
P(T<=t) two-tail	0.35897528	
t Critical two-tail	2.02439415	

No significant differences were observed between the length-frequency curves for Control and Experimental catch rates, for species and species groups examined during tests of the Haddock Rig. Numbers of observations were particularly low for haddock, plaice, grey sole, hake and redfish, limiting the robustness of the K-S determination (Table 10).

Table 10.
Haddock Rig - Length Data:
Summarized Results of Kolmogorov-Smirnov Test for Length Frequency Comparison - 'Haddock Rig'

SPECIES	Control N	Experimental N	D-Statistic Predicted	D-Statistic Observed	Length at Max. Difference	Significant Difference?
Cod	422	102	15.005	14.162	61 cm	No
Haddock	31	5	65.542	21.935	57 cm	No
Am. Plaice	146	14	38.050	15.558	33 cm	No
Grey Sole	87	0	--	--	--	--
Hake spp.	314	37	23.639	13.875	67 cm	No
Pollock	129	169	15.900	10.040	70 cm	No
Redfish	107	18	34.647	26.428	30 cm	No

Cumulative length frequency graphs are given for our species of interest in Figures 21 through 27.

Figure 21. Cumulative length frequency curves for cod, as observed in field tests of the Haddock Rig.

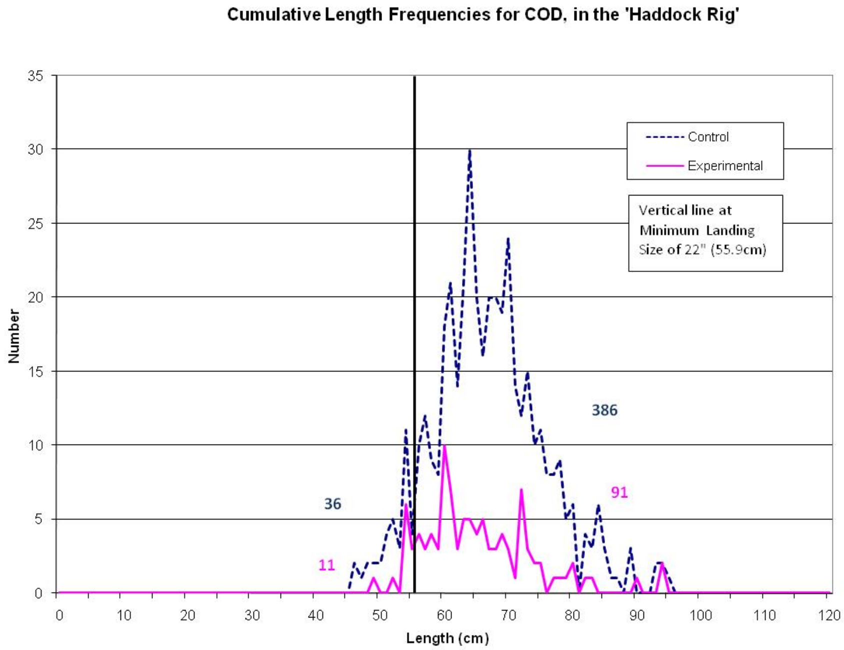


Figure 22. Cumulative length frequency curves for haddock, as observed in field tests of the Haddock Rig.

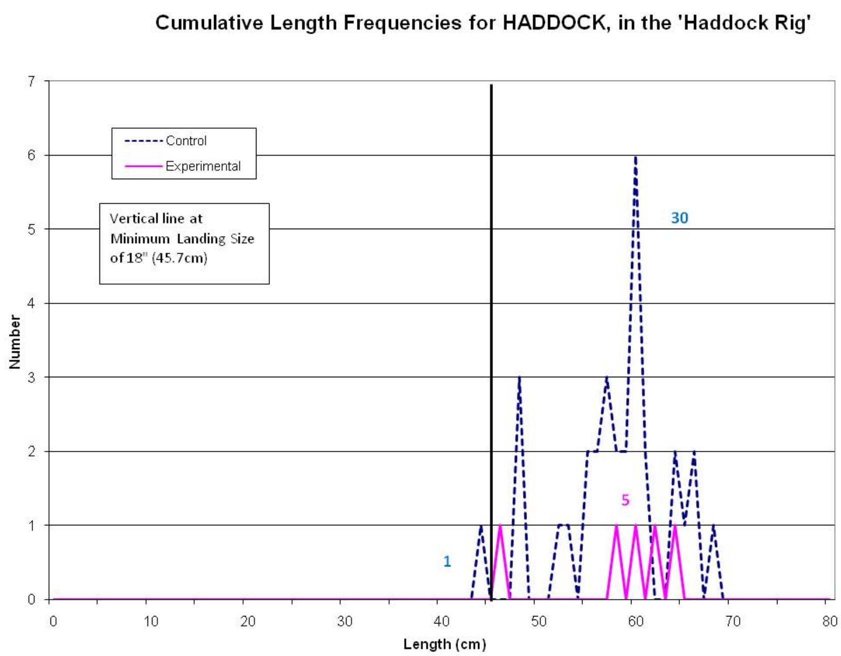


Figure 23. Cumulative length frequency curves for plaice, as observed in field tests of the Haddock Rig.

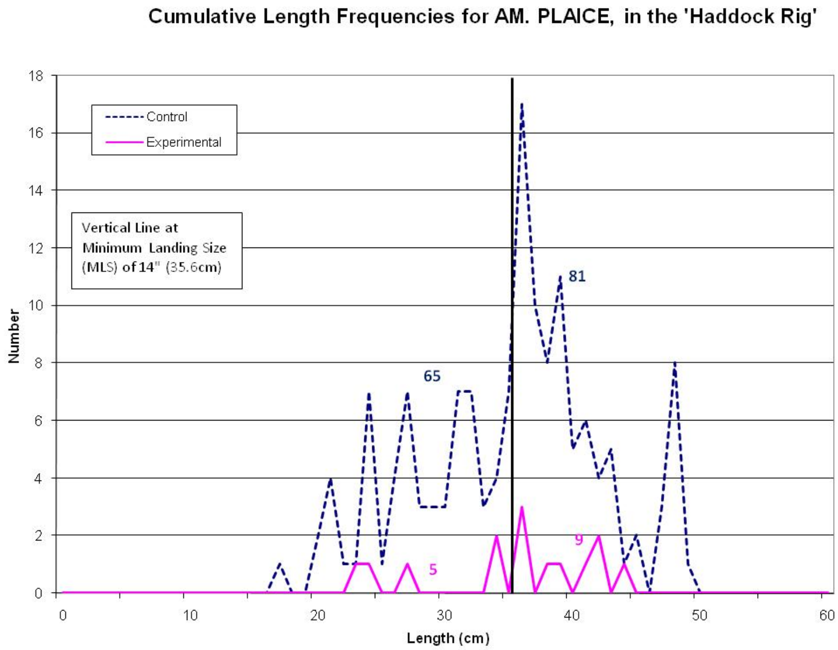


Figure 24. Cumulative length frequency curves for grey sole, as observed in field tests of the Haddock Rig.

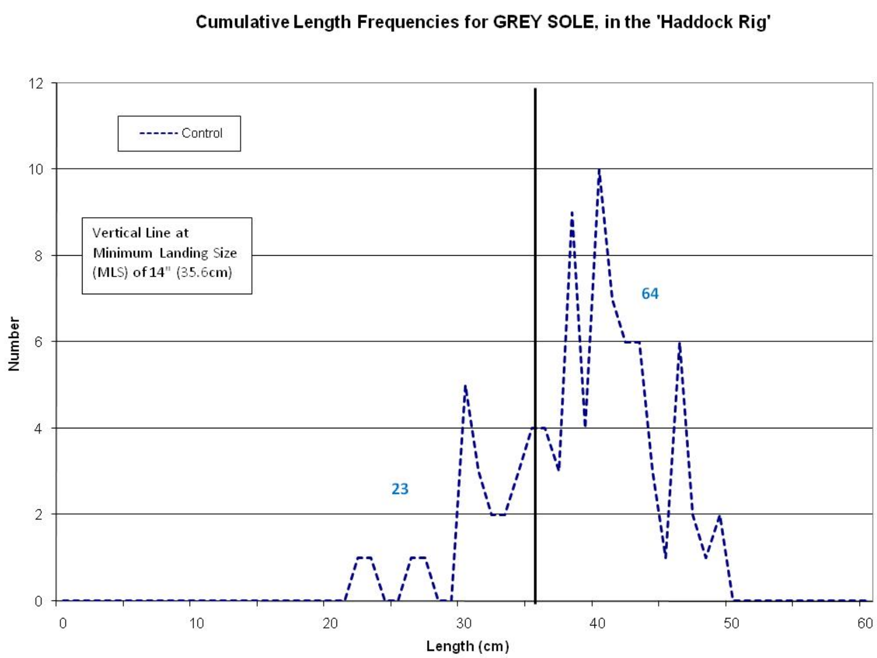


Figure 25. Cumulative length frequency curves for red and white hake combined, as observed in field tests of the Haddock Rig.

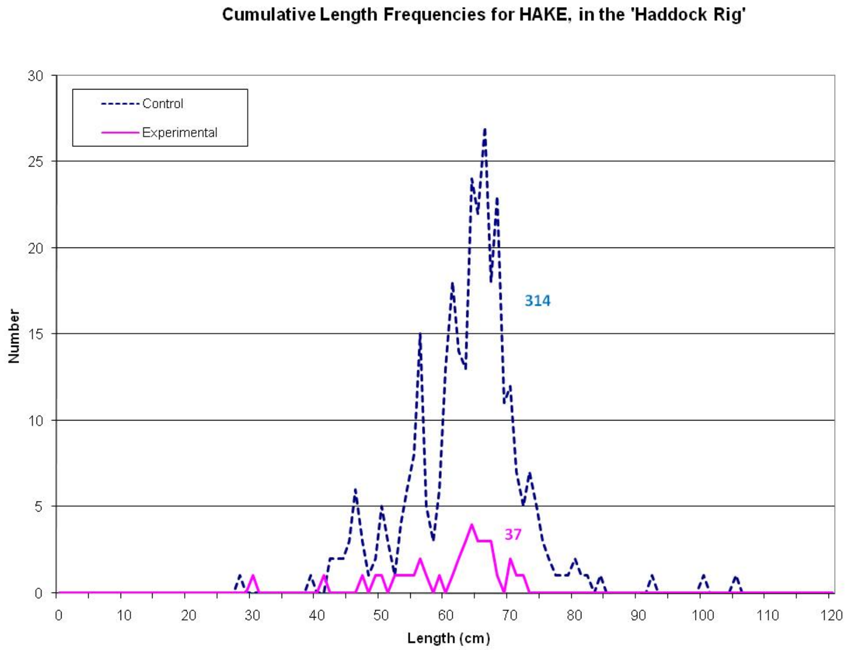


Figure 26. Cumulative length frequency curves for pollock, as observed in field tests of the Haddock Rig.

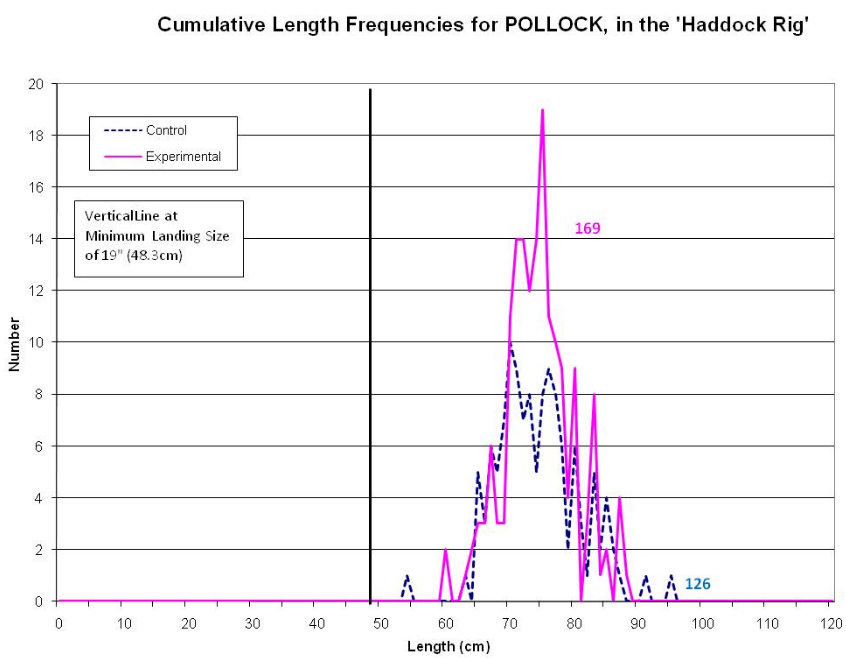
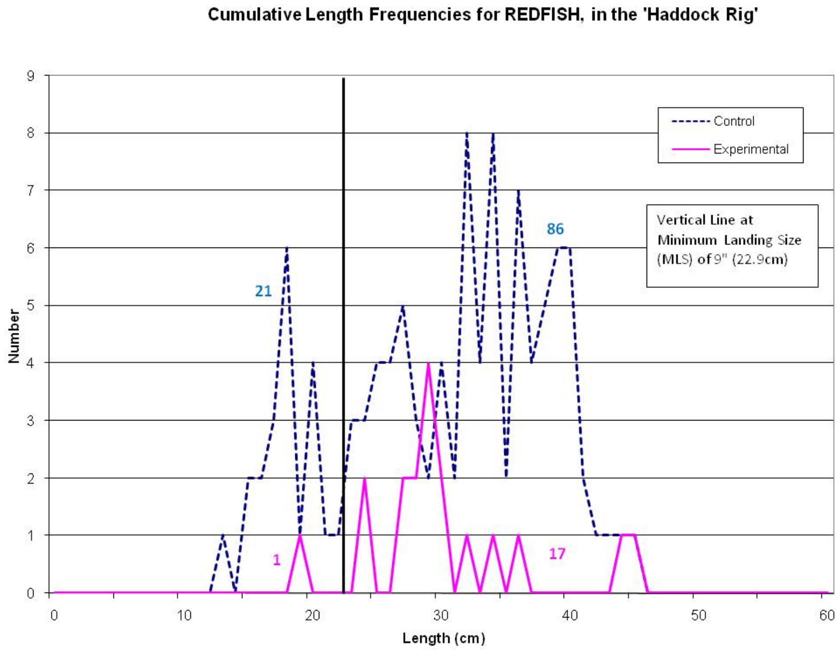


Figure 27. Cumulative length frequency curves for redfish, as observed in field tests of the Haddock Rig.



Partnerships:
All parties in this project have a long history of collaborative research, and so it came as no surprise that there was a high level of participation and information-sharing during this project. Agencies and individuals represented in the project include two fishermen (Pinkham and Lee), two universities (Univ. of Maine and Memorial University), two countries (US and Canada) and three agencies (Maine Sea Grant, Univ. of Maine Cooperative Extension, Mass. Division of Marine Fisheries).

Impacts and applications:
To date, this project appears to be a work in progress in terms of evaluating a full-sweep off-bottom trawl, and a partial success. The need for such a trawl is still evident in the desire for more bottom-friendly gear, one that can successfully separate bottom-tending species from others, and which is robust enough to withstand the frequent changes in direction and depth over rocky bottom, such as found in the Gulf of Maine.

Beyond the rationale given earlier in this report, an additional anecdote supports this view. During testing of the model trawl at the flume tank at Memorial University, the initial response to our model gear was somewhat quizzical; having an off-bottom trawl combined with a complete sweep appeared contradictory. However, once the purpose and reason was explained to the staff there, they speculated that shrimp fishermen along the Newfoundland and Labrador coast might be interested in a similar arrangement: it would allow them to reduce bycatch, be easier over the bottom, and still allow them some measure of protection from the rough seabed. A photo from this project is now the cover of FAO Fisheries Technical Paper #506: Options to

Mitigate Bottom Habitat Impact of Dragged Gears. With those as background, we are still of the mind that the concept is worthy.

Having said that, our biggest obstacle was the overall lack of fish, especially haddock during tests of the Haddock Rig. There are bright spots however, including the following:

- Our work aboard the F/V Ocean Reporter showed that the trawl was operating within the general parameters that we had set, with the sweep riding approximately 1.5' off the bottom, and with other aspects such as wingspread and headrope height being within anticipated limits. This was a welcome confirmation, as were the observations of the 'bottom friendliness' of the gear, via the marks left by the doors or wing end weights.
- Weights of cod and haddock caught by the 'Cod Rig' were not significantly different from one another, and catches of several projected bycatch species were significantly reduced.
- Weights of cod and other bycatch species were significantly reduced while using the Haddock Rig.

The last two points above were principal goals of the original proposal: either to retain good amounts of cod and haddock while letting the bycatch species escape; or allowing cod to escape with the other bycatch, while retaining haddock. In that light, the gear failed only in allowing too many haddock to escape from the Haddock Rig, but again the lack of haddock overall makes this observation possibly subject to change if larger schools could be fished.

Related projects:
Positively Buoyant Ground Cables and Sweep to Reduce Seabed Contact and Enhance Species Selectivity - Northeast Consortium, 2006.

Presentations:
Maine Fishermen's Forum, 2008
UNH Haddock Workshop, April, 2007

Images:
A number of images from this project are included with this report. Most relate to the lab work at Memorial University, though some are from the field as well.

Future Research:
We feel that the performance of this net could be better evaluated, and it's value demonstrated, if fished in areas of higher fish concentration.

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.*, 93(2), 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, C. (1992). Cod and haddock separator trawl. DFO Scotia-Fundy Region, Industry Service and Native Fisheries. Project Summary. No. 38. 4 pp

Main, J. and G.I. Sangster. 1981a. A study of the sand clouds produced by trawl boards and their possible effect on fish capture. Scottish Fisheries Resources Report No. 20. 20p.

Main, J. and G.I. Sangster. 1981b. A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle. Scottish Fisheries Resources Report No. 23. 24p.

Main, J. and G.I. Sangster. 1982. A study of a multi-level bottom trawl for species separation using direct observation techniques. Scottish Fisheries Resources Report No. 26. 17p.

Morse, D.L. 1994. The effects of sweep design on the species selectivity of trawls in the silver hake fishery of New England. M.S. Thesis, University of Rhode Island. 127p.

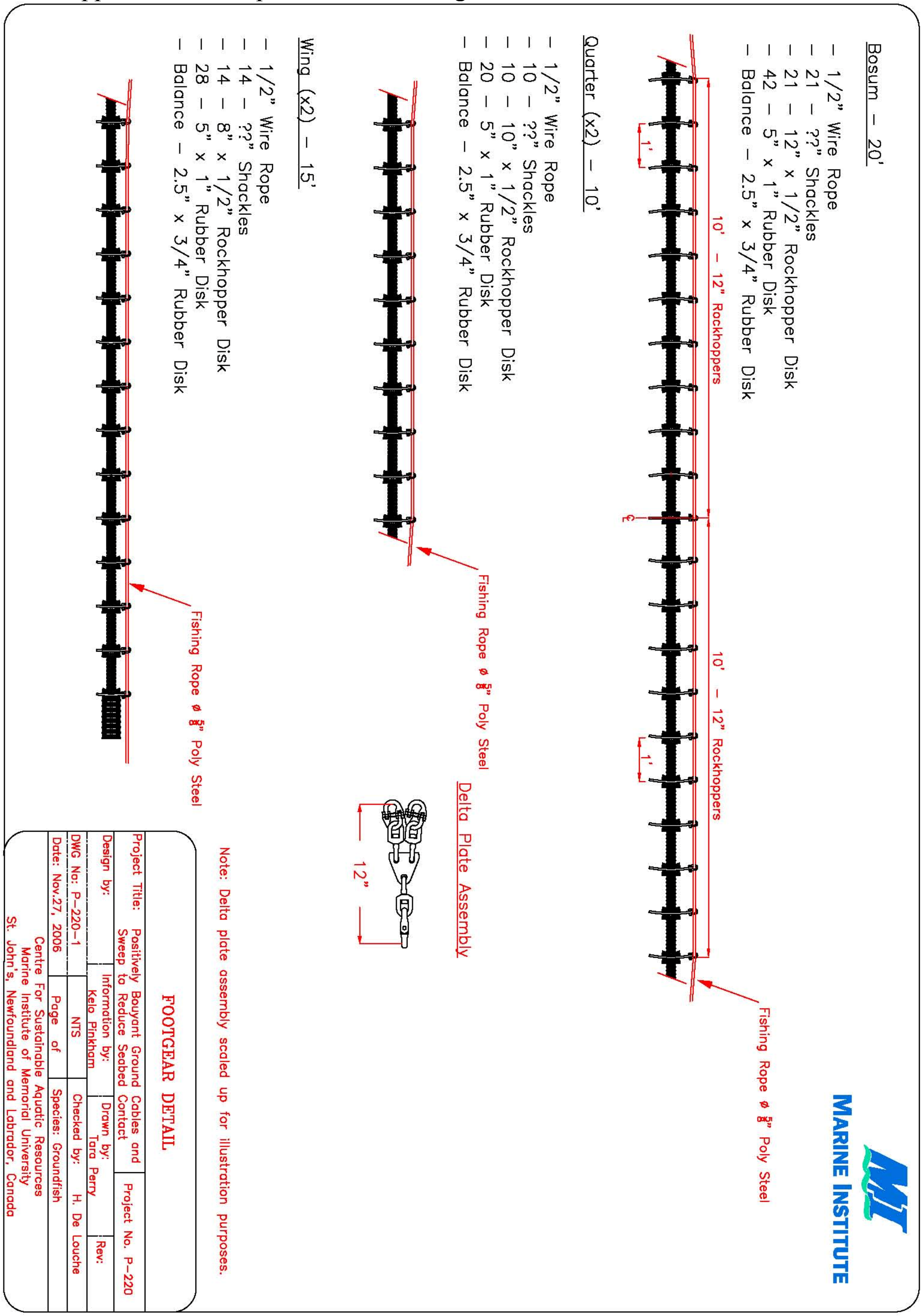
Pol, M. and McKiernan, D. 2004. Expanding the use of the sweepless raised footrope trawl in small-mesh whiting fisheries. *NOAA/NMFS Cooperative Research Partners Initiative, Unallied Science Grant NA16FL2261*. 43pp.

Valdemarsen, J.W., Jorgensen, T., and Engas, E. Options to mitigate bottom habitat impact of dragged gears. FAO Fisheries Technical Paper No. 506, 43p.

Wardle, C.S. 1983. Fish reactions to towed gears. IN: Experimental Biology at Sea. A. Macdonald and I.G. Priede (eds.). Academic Press, NY, pp. 167-195

Wardle, C.S. 1986. Fish behavior and fishing gear. IN: The behavior of teleost fishes. TJ Pitcher, Ed. Croom Helm, London and Sydney, pp. 463-495

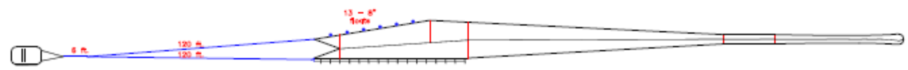
Appendices: Appendix I. Sweep Construction Diagrams



Appen!

Appendis II: Tow Tank Data Sheets

MARINE INSTITUTE



FULL SCALE VALUES (Imperial units)

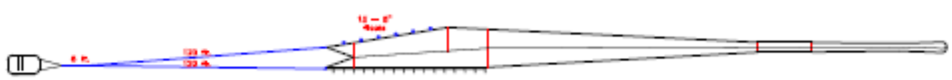
MARINE INSTITUTE FLUME TANK
TRAWL MODEL TEST DATA
DATE: January 3-5, 2007

Company	Pinkham, Morse & Lee
Trawl	Floaty Trawl
Rig 1	

Door type	Door area (m2)	Backstr. length (ft)	U.bridle length (ft)	M.bridle length (ft)	L.bridle length (ft)	M.bridle ext. (ft)	L.bridle ext. (ft)	Tail Chain (ft)	Wingend weight (lbs)	1 Float bouy. (lbs)	Float no.	Total bouy. (lbs)	Kite area (sqm)
Morgere	2.00	15.0	120.0	0.0	120.0			6.0	0.0	6.0	13.0	77.4	

Towing speed (kts)	SPREAD Door (ft)	U.wing (ft)	L.wing (ft)	Mean w/e (ft)	Transp. (ft)	OPENING Wing (ft)	Headline (ft)	HL fr Bottom (ft)	TENSION Port (tonnes)	Stbd (tonnes)	Total (tonnes)	Mouth area (sqft)	Mouth drag lbs/sqft	Bridle angle (deg)
1.75	95.3	27.1	31.5	29.3	0.0	4.9	8.3	8.3	0.34	0.32	0.66	242.6	0.0	13.5
2.00	99.7	27.5	31.8	29.7	0.0	4.7	7.5	7.5	0.40	0.38	0.78	222.0	0.0	14.4
2.25	100.1	27.7	31.4	29.5	0.0	4.5	7.3	7.3	0.48	0.46	0.93	215.2	0.0	14.5
2.50	103.8	28.2	32.4	30.3	0.0	4.5	6.7	6.7	0.55	0.54	1.09	202.8	0.0	15.1
2.75	105.7	28.7	32.9	30.8	0.0	4.3	6.1	6.1	0.66	0.63	1.29	188.0	0.0	15.4
3.00	107.8	29.3	33.9	31.6	0.0	4.1	5.7	5.7	0.75	0.74	1.50	180.6	0.0	15.7

MARINE INSTITUTE



FULL SCALE VALUES (Imperial units)

MARINE INSTITUTE FLUME TANK
TRAWL MODEL TEST DATA
DATE: January 3-5, 2007

Company	Pinkham, Morse & Lee
Trawl	Floaty Trawl
Rig 2	

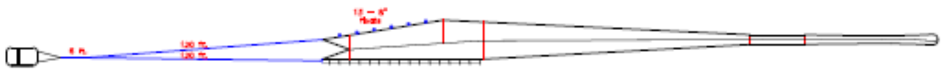
Door type	Door area (m2)	Backstr. length (ft)	U.bridle length (ft)	M.bridle length (ft)	L.bridle length (ft)	M.bridle ext. (ft)	L.bridle ext. (ft)	Tail Chain (ft)	Wingend weight (lbs)	1 Float bouy. (lbs)	Float no.	Total bouy. (lbs)	Kite area (sqm)
Morgere	2.00	15.0	120.0		120.0			6.0		6.0	13.0	77.4	

Towing speed (kts)	SPREAD Door (ft)	U.wing (ft)	L.wing (ft)	Mean w/e (ft)	Transp. (ft)	OPENING Wing (ft)	Headline (ft)	HL fr Bottom (ft)	TENSION Port (tonnes)	Stbd (tonnes)	Total (tonnes)	Mouth area (sqft)	Mouth drag lbs/sqft	Bridle angle (deg)
2.25	101.1	27.2	31.3	29.2		4.9	7.5	7.5	0.47	0.46	0.93	218.7		14.8
2.50	105.8	28.0	32.0	30.0		4.9	7.1	7.1	0.56	0.54	1.10	212.5		15.6
2.75	105.4	28.3	32.1	30.2		4.9	6.5	6.5	0.65	0.64	1.29	196.2		15.5

Rig 2 - Added 11 floats per side (port & stbd) to ground cables

Ground Cable Height off Seabed

Towing Speed (kts)	Forward Grou/cable (ft)	Mid Grou/cable (ft)	Delta Plate (ft)
2.25	1.57	0.98	0.98
2.50	1.57	1.18	0.98
2.75	1.97	1.18	1.18



FULL SCALE VALUES (Imperial units)

MARINE INSTITUTE FLUME TANK
TRAWL MODEL TEST DATA
DATE: January 3-5, 2007

Company	Pinkham, Morse, & Lee
Trawl	Floaty Trawl
Rig 2a-d	

Door type	Door area (m2)	Backstr. length (ft)	U.bridle length (ft)	M.bridle length (ft)	L.bridle length (ft)	M.bridle ext. (ft)	L.bridle ext. (ft)	Tail Chain (ft)	Wingend weight (lbs)	1 Float bouy. (lbs)	Float no.	Total bouy. (lbs)	Kite area (sqm)
Morgere	2.00	15.0	120.0	0.0	120.0			6.0		6.0	13.0	77.4	

	Towing speed (kts)	SPREAD					OPENING			TENSION			Mouth area (sqft)	Mouth drag lbs/sqft	Bridle angle (deg)
		Door (ft)	U.wing (ft)	L.wing (ft)	Mean w/e (ft)	Transp. (ft)	Wing (ft)	Headline (ft)	HL fr Bottom (ft)	Port (tonnes)	Stbd (tonnes)	Total (tonnes)			
Rig 2a	2.25						5.1	7.0	8.3	0.47	0.46	0.94			

Rig 2a - Added 5 floats to frame
Rig 2b - Attached 53 lbs (clump) to delta plate
Rig 2c - Removed 53 lbs and attached 26.5 lbs (clump) to delta plate
Rig 2d - 26.5 lbs hanging free

Ground Cable Height off Seabed

	Towing Speed (kts)	Forward Grou/cable (ft)	Mid Grou/cable (ft)	Delta Plate (ft)
Rig 2c	2.25			0.59
Rig 2d	2.25			0.98

FULL SCALE VALUES (Imperial units)

MARINE INSTITUTE FLUME TANK
TRAWL MODEL TEST DATA
DATE: January 3-5, 2007

Company	Pinkham, Morse & Lee
Trawl	Floaty Trawl
Rig 3 - 7	

Door type	Door area (m2)	Backstr. length (ft)	U.bridle length (ft)	M.bridle length (ft)	L.bridle length (ft)	M.bridle ext. (ft)	L.bridle ext. (ft)	Tail Chain (ft)	Wingend weight (lbs)	1 Float bouy. (lbs)	Float no.	Total bouy. (lbs)	Kite area (sqm)
Morgere	2.00	15.0	120.0		120.0			6.0		6.0	13.0	77.4	

	Towing speed (kts)	SPREAD					OPENING			TENSION			Mouth area (sqft)	Mouth drag lbs/sqft	Bridle angle (deg)
		Door (ft)	U.wing (ft)	L.wing (ft)	Mean w/e (ft)	Transp. (ft)	Wing (ft)	Headline (ft)	HL fr Bottom (ft)	Port (tonnes)	Stbd (tonnes)	Total (tonnes)			
Rig 3	2.25	101.7	27.6	31.9	29.8		6.5	6.7	8.9	0.44	0.44	0.88	199.2		14.8
Rig 4	2.25	100.6	27.5	31.4	29.5		9.6	8.3	12.6	0.49	0.47	0.96	243.6		14.6
Rig 5	2.25						8.3	7.7	11.4						
Rig 6	2.25						6.9	8.3	10.4	0.47	0.46	0.93			
Rig 7	2.25						5.7								

Rig 3 - 13 floats added to fishingline, 26.5 lbs on delta plate

Rig 4 - Added 7 floats to headline, 26.5 lbs on delta plate

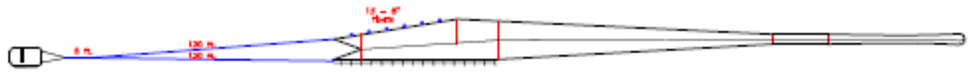
Rig 5 - Total weight at delta plate 53 lbs - 5 ft chain (hanging free); Note 1 float missing on h/line and f/line

Rig 6 - Bare wire ground cable

Rig 7 - 5 Floats removed from fishingline

	Height (ft.)					
	Speed	Fwd End Ground Cable	Mid Ground Cable	@ Delta Plate	Leading 10" Disk	Bosum
Rig 3	2.25	1.57	1.57	2.36	2.36	2.16
Rig 4	2.25	2.16	3.54	4.72	4.72	4.53
Rig 5	2.25	1.77	2.36	3.15	3.54	3.74
Rig 6	2.25	1.77	0.39	1.77	2.16	2.36
Rig 7	2.25			0.79		0.79

MARINE INSTITUTE



FULL SCALE VALUES (Imperial units)

MARINE INSTITUTE FLUME TANK
TRAWL MODEL TEST DATA
DATE: January 3-5, 2007

Company	Pinkham, Morse, & Lee
Trawl	Floaty Trawl
Rig 8 - 10	

Door type	Door area (m2)	Backstr. length (ft)	U.bridle length (ft)	M.bridle length (ft)	L.bridle length (ft)	M.bridle ext. (ft)	L.bridle ext. (ft)	Tail Chain (ft)	Wingend weight (lbs)	1 Float bouy. (lbs)	Float no.	Total bouy. (lbs)	Kite area (sqm)
Morgere	2.00	15.0	120.0		120.0			6.0		6.0	13.0	77.4	

	Towing speed (kts)	SPREAD Door (ft)	SPREAD U.wing (ft)	SPREAD L.wing (ft)	SPREAD Mean w/e (ft)	SPREAD Transp. (ft)	OPENING Wing (ft)	OPENING Headline (ft)	OPENING HL fr Bottom (ft)	TENSION Port (tonnes)	TENSION Stbd (tonnes)	TENSION Total (tonnes)	Mouth area (sqft)	Mouth drag lbs/sqft	Bridle angle (deg)
Rig 8	2.25						8.3	8.5	11.4	0.48	0.47	0.94			
Rig 9	2.25						7.9	8.5	10.8	0.47	0.49	0.96			
Rig 10	2.25	100.0	27.9	30.7	29.3		8.3	8.9	11.4	0.49	0.49	0.99	259.6		14.5
	2.25														
	2.25														
	2.25														

Rig 8 - Ground Cables with Floats re-attached
Rig 9 - Moved 5 floats from fishingline to headline
Rig 10 - Same as Rig 9, Replaced Leaky Float

	Height (ft.)					
	Speed	Fwd End Ground Cable	Mid Ground Cable	@ Delta Plate	Leading 10" Disk	Bosum
Rig 8	2.25	1.97	2.56	3.15	2.76	3.74
Rig 9	2.25	1.97	2.36	2.76	2.36	2.76
Rig 10	2.25	1.97	2.36	2.95	2.56	2.95