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Factors Affecting Bottom Trawl Behavior: Results of Experiments with 83/112 Eastern Trawls Towed from the NOAA ship *Miller Freeman*

Charles William West

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U.S. DEPARTMENT OF COMMERCE
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Results of Experiments with 83/112 Eastern Trawls Towed from the NOAA Ship *Miller Freeman*

by

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ABSTRACT

Catch results from bottom trawl surveys conducted by the Northwest and Alaska Fisheries Center (NWAFC), National Marine Fisheries Service, are used to estimate the abundance of demersal fishery resources in the northeast Pacific Ocean and the Bering Sea. The magnitude and composition of bottom trawl catches is influenced, among other factors, by the physical performance of the trawl. Observations of the vertical and horizontal dimensions of the mouth opening of 83/112 Eastern bottom trawls (a type of trawl commonly used by NWAFC) were made during routine survey operations aboard the NOAA ship *Miller Freeman*. This paper describes the results of these observations and identifies some of the physical factors of the towing situation that were found to affect trawl performance. Under identical towing conditions, different trawls, even though built to identical specifications, had different characteristic vertical openings. Vertical openings were also found to respond to changes in the physical structure of the trawls, or their rigging, and vertical openings increased about one foot when a third-wire netsonde was deployed. No single variable was found to cause changes in vertical opening greater than two feet, and almost all of the observed vertical openings were between 4.5 ft and 7.5 ft. The horizontal opening of these trawls fell between 60 and 66 ft and was found to increase with increased depth (from 61 to 64 ft), with reduced wingspread when the towing warps were let out in excess of the standard scope ratios for the depths where the tows were made. Other factors found to influence trawl performance were the use of roller gear, which increased the vertical opening, and the presence of following currents, which caused poor horizontal spreading (to as low as 40 ft).

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INTRODUCTION

Results from bottom trawl surveys conducted by the Resource Assessment and Conservation Engineering (RACE) Division of the Northwest and Alaska Fisheries Center (NWAFC), National Marine Fisheries Service (NMFS), are used to estimate the abundance of fishery resources in the northeast Pacific Ocean and the Bering Sea. The catch per unit of effort (CPUE) in these surveys is affected by the density of bottom organisms in the area sampled and the catchability of those organisms with the gear used. To accurately estimate abundance from trawl survey catch data, it is important to understand the physical behavior of trawls used in the survey. This includes such considerations as the vertical and horizontal dimensions of the trawl opening and the extent and force of contact between the footrope and the bottom. Since it has been demonstrated that there can be considerable variability in these trawl performance characteristics from tow to tow (Wathne 1977), it is particularly important to know what factors affect this variability. Considering the bottom trawl as a sampling tool, it is also necessary to understand all the performance characteristics of the trawl in order to evaluate the bias and precision of abundance estimates derived from samples taken with that tool. Constant, unchanging performance is the ideal (though probably unattainable) goal; understanding the causes and the extent of variability is a desirable alternative.

Although on both cruises the object of study was the 83/112 as fished from the Miller Freeman, there are a number of differences between the two cruises that suggest that they should be considered separately. The October 1979 cruise was devoted solely to gear experiments, while in March 1980 the gear observations were made incidental to survey fishing operations, with no attempt to conduct controlled towing experiments. This difference alone necessitated a different approach to each data set. The data from the October 1979 experiments were subjected to an analysis of variance in order to examine the significance levels of factors suspected of influencing trawl performance. The March 1980 data were acquired in such a way that preparation of descriptive statistics was permissible, but examinations for statistical significance were inappropriate. In addition to these differences in methodology and analytical approach, the parameters observed during the two cruises were not identical. For these reasons, it was felt that the methodology and results for the two cruises should be described separately, in two parallel and independent subdivisions of this paper, followed by a unifying discussion section where results from the two cruises are compared.

The purpose of this paper is to describe the results of observations of the performance of one of the trawl types frequently used by NWAFC, the 83/112 Eastern bottom trawl, while being fished from the NOAA ship Miller Freeman. These observations were made during a cruise dedicated to trawl performance studies (Cruise MF-79-05) conducted during October 17-26, 1979, off the Washington coast and during a bottomfish survey off southeast Alaska during March 1980 (Leg III, MF-80-01).

MATERIALS COMMON TO BOTH CRUISES

The Miller Freeman (length overall - 215 feet, 1,515 tons gross, and 2,200 horsepower), in addition to conventional deck gear for bottom and midwater trawling, is equipped with warp tension meters, which measure the amount of resistance to forward motion exerted by the warps, doors, other rigging, and the trawl itself.

The 83/112 Eastern trawl (Figure l), so named because the headrope is 83 ft long and the footrope is 112 ft long, is used frequently on NWAFC groundfish

83/112 EASTERN

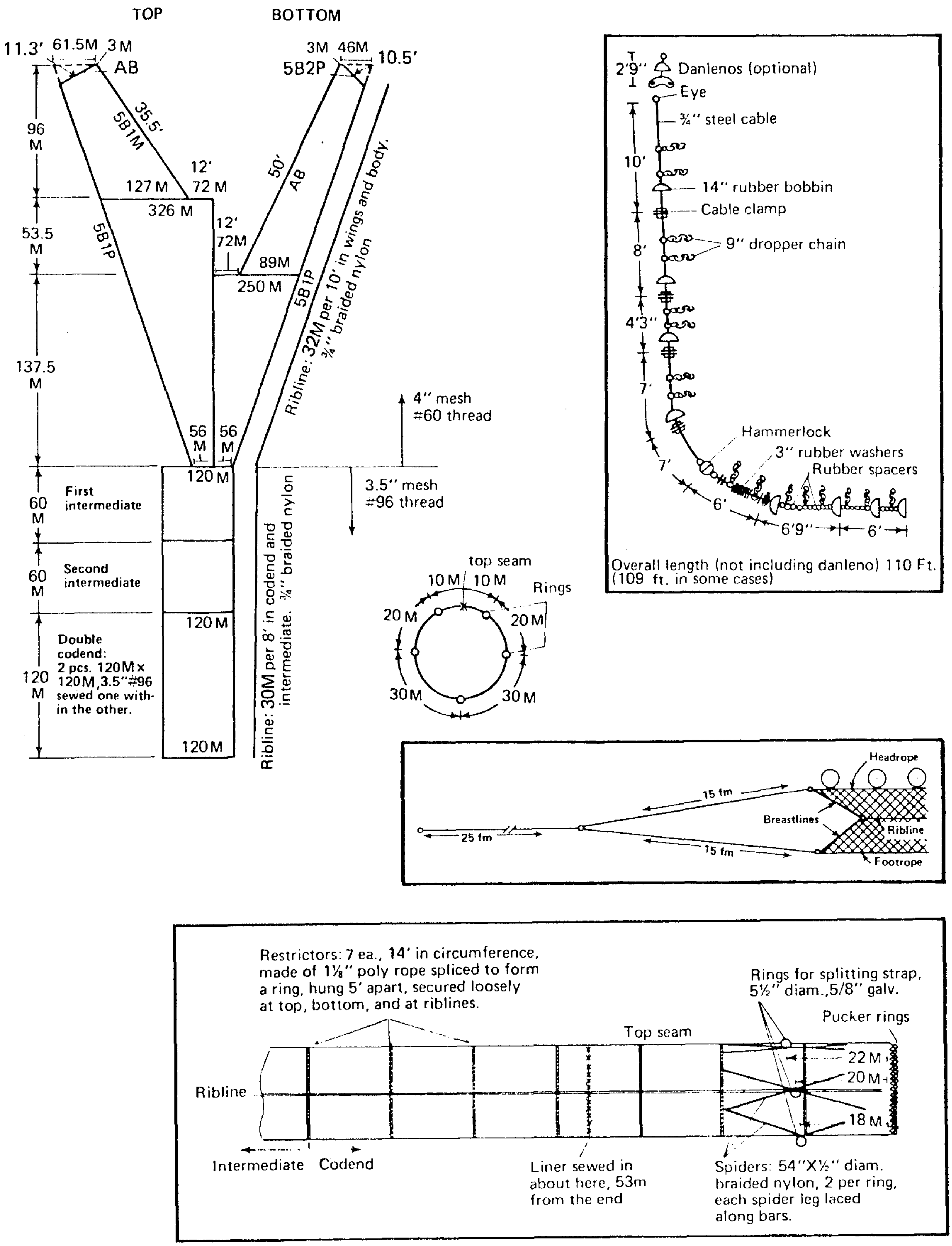

Figure 1.--Plan and specifications for the construction and rigging of the 83/112 Eastern bottom trawl.

83/112 Eastern

Netting - nylon, preshrunk, and dyed green

Headrope - 83.9 ft, 1/2 in diam. 6 x 19 galv. wire rope, wrapped with 5/16 in polypropylene rope,

Footrope - 111.9 ft, 5/8 in diam. 6 x 19 galv. wire rope wrapped with 5/16 in polypropylene rope, the whole wrapped with split pieces of heavy rubber hose; 172 ft of 5/16 in galv. chain hung to footrope, every tenth link seized to the footrope at 8-in intervals, the lower edges of the wings and throat hung to the loops of chain thus formed.

Roller gear - optional

Breastlines - 11.3 ft upper and 10.5 ft lower sections, joined with a "hammer-lock," made of 1/2 in diam. galv. wire rope, wrapped with 1/4 in poly rope. Breastline lengths may vary slightly.

Riblines - 3/4 in diam. braided nylon or equivalent extending the length of the first intermediate or beyond on some trawls.

Flotation - 17 8-in aluminum floats along each wing. In the bosom, 3 16-in alum. floats, one in each corner and one in the middle, plus 4 8-in alum. floats, all 7 floats spaced equally. Total = 41 floats.

Codend liner - 1-1/4 in mesh, No. 18 nylon, 360 meshes around, 200 meshes deep, laced to inner bag 63 meshes from the end, 3 liner meshes to each bag mesh. Actual mesh counts of liners encountered in the field may vary; but when the bag is empty, the codend untied and the bag and liner stretched out, the liner should protrude some 2-3 ft beyond the end of the codend.

Chafing gear - varies, may be 3/8 in diam. poly rope, hog-ringed to form 9-1/2 in meshes, each piece 46 meshes deep x 55 meshes around. Alternatively may be 1/2 in diam. poly rope, interwoven into g-in meshes, 18 meshes deep x 36 meshes around. In either case, chafing gear should be laced to the bag with 2 ft of bag protruding.

Sideseams - upper and lower wing panels and body panels laced together gathering 21 meshes (3 knots) from each panel. These plans allow for this, giving mesh counts for each panel as it should be cut out; mesh counts on panels in finished trawls will be reduced accordingly.

Rigging - dandylines: 25 fm single, 15 fm double, all wires 5/8 in galv.

Boors - 6 ft x 9 ft V-doors, 2,000 lb.

Figure 1 (Continued)

cruises. It is a conventional two-seam bottom trawl (see Figure l), although in contrast to standard commercial trawls, which have the side seam webbing hung into slack riblines, the 83/112 design calls for riblines that are shorter than the stretched mesh length of the webbing, the rationale being that these short riblines will relieve some of the longitudinal strain on the webbing in the forward parts of the trawl, theoretically facilitating an increase in the vertical opening of the trawl mouth. The trawls were fished with 7 ft by 10 ft steel V-doors, weighing 3,000 lb each, on 1 inch diameter warps. Dandylines were 40 fathoms (fm) overall, with a single 25 fm length coming back from each door, branching into two 15 fm legs, one going to the headrope and one to the footrope.

THE OCTOBER 1979 GEAR EXPERIMENTS

Experiment Design

Experiments conducted with several 83/112 trawls were designed to examine the relationship between headrope height (vertical distance from the center of the headrope to the bottom) and wingspread (horizontal distance between the wingtips) to towing speed, scope ratio, and water depth. In addition, differences between nets were evaluated, as were the effects of "hanging in" the side seam webbing to riblines shorter than the stretched mesh length of the webbing.

Materials Employed

Three 83/112's were tested: an unused net (Net #l); a net that had been used for some time with the consequent stretching of webbing, repaired damage, etc. (Net #2); and an 83/112 rigged with roller gear (Net #3). Except for the presence or absence of roller gear, all three trawls were built to the same specifications. They were fished with the same doors and rigging as described above. The dimensions of the trawl openings during the experimental tows were measured with the NWAFC trawl mensuration system (Wathne 1977). The net mensuration instruments (NMI) measured headrope height (HH) and wingspread (WS) hydroacoustically at 3.3 second intervals and recorded these measurements on a magnetic tape within one of the units.

Experimental Methods

The experimental tows were made on trawling grounds between Cape Flattery and Cape Alava, Washington, along the 50 fm and 100 fm contours.

All three nets were tested originally with riblines hung-in to the side seams, after which the riblines were removed and the test sequence repeated. Nets 1 and 2 were tested at 50 and 100 fms; but due to time constraints, net #3 was tested at 50 fms only. At the 50 fm depth, a scope ratio of 3:l was defined as "normal" and 3.75:1 as "high". At 100 fm 2.5:l was normal and 3:l was high. Scope ratio was defined as the amount of warp let out in fathoms divided by the depth in fathoms.

The testing procedure was carried out as follows: codends were left untied during all experimental tows to avert possible changes in net geometry caused by the accumulation of fish in the bag. After the NM1 were attached and the gear was set, the vessel moved ahead at slow speed for 5 minutes to allow the gear to settle to the bottom. Speed (using speed over the ground determined from position fixes) was then increased to 3 knots (kn) and the tow continued for 10 minutes, when speed was increased to 3.5 kn. After another 5-minute stabilization period, the tow continued for 10 minutes. Warp length was then increased to the higher scope ratio and the net was tested again at the two speeds, as described above. The gear was then hauled, the vessel turned 180°, the gear set again, and the test series was repeated in the opposite direction. These steps were taken in an effort to allow measurement of the effects of currents, which were assumed to remain constant in speed and direction during the time required for completion of a pair of north and south tows. After completion of the paired tows, a new net was rigged and was tested at 50 fm. When all three nets had been tested at 50 fm, the ship moved out to the 100 fm contour and the cycle was repeated. Upon completion of that cycle of tests, the riblines were removed from the three nets and they were put through the full test sequence at both depths, except for net #3, as noted above. During the tests, an observer recorded the tow number, depth, speed, direction of tow, scope ratio, and towing tension as recorded on the tension meters. Any unusual events that might affect or reflect gear behavior were recorded and the time noted (for example, a sudden drastic change in towing tension).

Method of Analysis

After the experimental tows had been conducted, it was decided that the average warp tension (simple mean of the readings from the port and starboard tension meters, recorded during each tow) was a better indicator of the speed at which the gear passed through the water during a particular tow than the variables "towing speed" and "direction of tow". In the original experimental design the effect of changes in towing speed on HH and WS was the relationship of interest, with the direction variable included to allow for the effect of currents. However, during preliminary analysis of the data, neither towing speed nor direction had any apparent relationship to either headrope height or wingspread, so all further analyses were performed on the relationship between HH and WS and tension, instead of towing speed and direction.

Even though tension was considered a better predictor of gear performance than the towing speed-direction combinations, in some ways the recorded tension measurements were less than ideal as raw material for statistical analysis. The port tension meter consistently indicated a lower tension value than the starboard instrument, often showing a false discrepancy of as much as 5,000 lb of line pull. Compounding this problem, the tension meters had not been calibrated for some time, either against each other or against any absolute standard. Although these circumstances precluded the use of tension as an absolute measurement, it was felt that the average towing tension was useful as an index of differences in speed through the water from tow to tow.

At one stage of the analysis, it was necessary to code tension scores into one of two categories: "high" or "low". To do this, the simple mean of the average tension values for all tows was calculated; then average tension values that exceeded this value were classified as high, while average tension values that were less than this value were categorized as low.

For the sake of convenience, each lo-minute experimental towing period will be referred to hereafter as a "tow," although in reality each of these tows was nothing more than a lo-minute span characterized by a particular combination of experimental factor levels during a much longer tow.

In all, 84 tows were completed, with usable data recorded from 75 tows. Data from a tow were considered usable if there were 30 or more pairs of simultaneously recorded HH and WS measurements, indicating that the NMI were functioning properly during that tow. Data from the other nine tows were not used in the analysis.

In the laboratory, the tapes were subjected to preliminary processing, using a program developed by the RACE Division. The program considered each set of measurements and rejected any sets where HH or WS values were missing or lay outside preset upper and lower limits. From the values that were retained, the program computed the following statistics for each tow: mean headrope height and standard deviation, mean and standard deviation of wingspread, and the coefficient of correlation between headrope height and wingspread.

Once these statistics had been computed, further analysis was performed to determine which of the factors had a significant effect on headrope height and/or wingspread. To reiterate, the factors being considered in this analysis were: "net" (three different nets consisting of one new (No. 1), one old (No. 2), and one with roller gear (No. 3)); "riblines" (present or absent); towing tension (high or low); depth of tow (50 or 100 fm), and "scope ratio" (normal or high).

Mean headrope height and wingspread values were computed for all the different experimental conditions using the SPSS "CROSSTABS" procedure (Nie et al. 1975). In order to determine whether or not the various factors had a significant effect, an analysis of variance was performed on the coded data. A packaged program, BMD 10V, was used, which assumes a multiple linear regression model:

$$\text{(or WS)} = \mu + a_N N + a_{RL} RL + a_T T + a_D D + a_{SR} SR + \text{interaction effects} + E$$

where u = mean HH (or WS) over all tows

N = net effect

RL = riblines effect

T = tension effect

D = depth effect

SR = scope ratio effect

E is a normally distributed error term

ai is the regression coefficient associated with effect i

Each tow was treated as a single observation using the mean HH or WS obtained for that tow as the dependent variable and assigning appropriate values to the various dummy variables representing the independent variables. The procedure was first run with all pairwise interactions represented; those that were not found to be significant were eliminated from the equation for subsequent runs (Dunn and Clark 1974).

Higher-order interactions were not considered because it is difficult to interpret the results if any higher-order interactions are found to be significant. Consequently, the values associated with the variables found to be significant should be approached with some caution, since the multiple regression technique averages across all factors not named in the regression equation, I.e., the higher-order interactions. It was necessary to choose some compromise between a comprehensive analysis and comprehensible results, and it was felt that the balance should be tipped towards the latter.

Results

In the early stage of analyzing the data, it became apparent that something unusual had been occurring during 12 of the 75 tows analyzed. During these 12 tows, mean HH values were greater than 7 ft and mean WS values were around 40 ft or less, while during the 63 other tows, mean HH values were 6.5 ft or less, with WS measurements of at least 55 ft. These combinations of high HH and low WS values were similar to readings that had been obtained during other net observations when the trawls were not fully contacting the bottom or the doors were not spreading properly.

The following factors were observed and measurements obtained with the variables shown.

Considering the 63 on-bottom tows only, mean headrope height was 5.75 ft, SkD$ = 0.635. It was found that, holding all other factors constant, each net had a significantly (P<.OOl) different headrope height:

	New net	Old net	Net with rollergear
Mean headrope height over all tows, all other conditions combined	5.31 ft	5.99 ft	6.16 ft

The presence or absence of riblines was found to be significant (P = 0.003):

	Riblines present	Riblines absent
Mean headrope height	5.55 ft	5.96 ft

There was a significant (P = 0.001) interaction between the riblines factor and the net ID factor:

		Net		
	Riblines	1	2	3
Mean headrope height	Present	4.9 ft	5.92 ft	5.98 ft
	Absent	5.73 ft	6.05 ft	6.47 ft

There was a significant (P = 0.009) interaction between the net ID factor and the tension factor.

	Net		
Tension	1	2	3
Low	5.35 ft	6.11 ft	6.4 ft
High	5.29 ft	5.76 ft	5.77 ft

Other factors tested and found to be not significant were the tension, depth, and scope ratio variables. No other pairwise interactions were found to have a significant effect on headrope height.

Still considering only the 63 on-bottom tows (mean WS = 62.25 ft, S.D. = 4.711, several factors were found to have a significant effect on wingspread.

Depth was found to be a significant factor (P < .00l):

	Depth	
	50 fm	100 fm
Mean wingspread (ft)	60.8 ft	64.06 ft

Scope ratio was found to have a significant effect (P = 0.023):

	Scone Ratio	
	Normal	High
Mean wingspread (ft)	63.13 ft	61.34 ft

The level of towing tension was found to have a marginally significant effect (P = 0.046):

	Tension	
	Low	High
Mean wingspread (ft)	61.46 ft	63.23 ft

The interaction between depth and scope ratio was found to be significant (P = .026).

		Scope Ratio	
	Depth	Normal	High
Mean wingspread (ft)	50 fm	60.61 ft	60.94 ft
	100 fm	66.3 ft	61.83 ft

The other primary factors (net ID and riblines) were not found to be significant, nor were any of the other pairwise interactions.

An abbreviated version of the same analysis was performed on all 75 tows, including the 12 off-bottom tows. Mean HH was 6.19 ft, S.D. = 1.23, and mean WS was 59.55 ft, S.D.) = 7.77. It was found that towing tension and the depth of the tow had a significant effect on headrope height and on wingspread but not the other factors. Interaction effects were not examined.

Coefficients of correlation were computed for the correlation between mean headrope heights and mean wingspreads: considering all 75 tows, $R = -0.737$, $P < 0.001$; excluding the off-bottom tows, $R = -0.093$, $P = 0.235$.

Discussion

One of the most important factors influencing trawl behavior is the amount of spreading force generated by the doors which in turn is related to the speed at which the doors pass through the water and the degree of door contact with bottom. The speed of passage through the water is affected by the interaction between the speed of the ship over the ground and water currents. In this analysis, towing tension was used as an index of the speed at which the gear passed through the water. Not surprisingly, towing tension was found to have a significant effect on wingspread when all tows were considered, as well as when off-bottom tows were excluded. After this experiment was conducted, discussions with oceanographers familiar with local current patterns revealed that during October there is a net flow of water from north to south at speeds of up to 1 knot along the bottom in the towing area. It is interesting to note that all of the off-bottom tows occurred while towing from north to south, possibly the result of strong following currents.

Two interrelated factors govern the amount of warp deployed during a tow: the depth of the tow and the scope ratio chosen. For any given depth, there is some particular scope ratio that will permit optimum trawl performance in terms of horizontal spread, vertical opening, good bottom contact along the footrope, etc. For strictly on-bottom tows, both the depth and scope ratio variables had a significant effect on wingspread but not on headrope height.

During deeper tows the nets spread farther, and the high scope ratio condition had an apparent constricting effect on wingspread. However, a significant interaction between depth and scope ratio was observed, since in the shallow tows the constricting effect of the high scope ratio was diminished. When off-bottom tows were included, depth (but not scope ratio) had a significant effect on wingspread.

Possibly the most surprising result to emerge from these observations was the absence of any significant correlation between headrope height and wing-spread, when only the on-bottom tows were *considered.* In all other studies of trawl behavior, this relationship has been demonstrated repeatedly. One possible explanation hinges on the trawl doors used during these experiments. The 7 ft by 10 ft doors used by the Miller Freeman may generate so much spreading force that they cause the net to spread to its maximum horizontal opening for any particular set of towing conditions. Other forces then acting independently to cause changes in headrope height were dominated by this spreading force, thus influencing headrope height only within a narrow range of openings.

The original purpose for hanging-in the webbing along the side seams to riblines shorter than the stretched mesh length of that webbing was to take some of the strain off of the webbing, allowing the trawl to open higher and wider. In contrast, standard commercial practice is to hang the webbing to slack riblines, so that the riblines do not take any strain unless there is a load on the trawl, stretching the webbing. Consequently, the observed (and statistically significant) increase in headrope height when the nets were towed with their riblines removed (off-bottom tows excluded) was noteworthy. The mechanism underlying this increase in vertical opening is not known.

The fact that in the analysis of variance the net factor had a significant effect on headrope height indicated that each of the three nets responded in a different way to changes in the other towing influences. Although this effect was significant in statistical terms, in operation the magnitude of these differences is so small that it can probably be ignored.

When off-bottom tows were included in the analysis, both headrope height and wingspread responded significantly to the same two factors: towing tension and depth of tow. At higher towing tensions wingspreads were greater and headrope heights were less than at lower tension levels. When making deeper tows, the trawls spread farther and headrope heights were lower than for the shallower tows.

Further research is needed to determine exactly what is occurring during the off-bottom tows. It appears that off-bottom excursions occur when the speed of the gear through the water has been reduced due to following currents. Further study might try to determine what minimum speed is needed to achieve full spread. While changes in headrope height and wingspread were recorded, no observations were made on the extent and/or force of bottom contact by the footrope, and this should be examined.

THE MARCH 1980 GEAR OBSERVATIONS

Format of the Cruise

Gear specialists from the RACE Division of NWAFC accompanied the Miller Freeman during Leg III of the MARMAP Bering Sea and Gulf of Alaska bottom fish study, Cruise MF-80-01. Trawl performance was observed during 80 sampling tows.

Unlike the October 1979 gear experiments described above, these observations were recorded incidental to standard trawling operations. Any variations in towing procedures that may have occurred were strictly in response to local weather and/or bottom conditions encountered at the individual stations and not according to any kind of experimental framework. Consequently, it was felt that the results of these observations should be considered descriptive only.

Materials and Methods Employed During this Cruise

Five bottom trawls were observed during this leg: three 83/112 Eastern trawls without roller gear, an 83/112 rigged with roller gear, and a 90/105 Nor-Eastern trawl fitted with roller gear (Figure 2). During the survey, several tows were made with a Diamond midwater trawl, but systematic observations of this net's performance were not made. This discussion will be restricted to observations of the 83/112 Eastern's performance.

Two of the 83/112s without roller gear were fished at different times with headrope setbacks (short lengths of cable with an eye at each end) inserted between the upper bridles at each end of the headrope.

Information on vertical opening (distance from the center of the headrope to the sea bottom) was acquired during each observed tow with one or more of the following systems: an ELAC LAZ-72 Netsonde System, a Simrad FE4 Trawl Eye Netsonde System, or the self-contained Hydroacoustic Net Mensuration System developed by the RACE Division (Wathne 1977). Data on the horizontal opening of the trawl (from wing to wing) were acquired on a few tows, but malfunctions in the net mensuration system precluded further observations of this dimension.

On most tows either the RACE Division net mensuration instruments or one of the two off-the-shelf netsonde systems used aboard the Miller Freeman (ELAC I-AZ-72 and Simrad Trawl Eye) were attached to the net. However, on a few tows, both the NM1 package and one or the other of the netsonde systems were attached to the nets simultaneously to facilitate comparisons of headrope height measurements made by the two systems.

Other performance-related characteristics observed were the weight and species composition of the catch and the settling time, or the amount of time required for the net to reach the bottom after the warps were out and the brakes set.

Data on net performance were recorded on magnetic tapes in the case of the NMI, and on paper recordings in the case of the netsonde systems. In the laboratory, the tapes from the NM1 were subjected to preliminary processing using a program developed by the RACE Division. The program considered each set of measurements (measurements of HH and WS and other characteristics were automatically recorded every 3.3 seconds) and rejected any sets where HH or WS values lay outside of preset upper and lower limits. From the values that were retained, the program computed the following statistics for each tow: mean headrope height and standard deviation, mean and standard deviation of wingspread, and the coefficient of correlation between headrope height and wingspread. Average headrope height values for tows where the NM1 were not used were estimated from the netsonde paper recordings, using the range marks printed onto the paper as a scale.

To eliminate biases due to a lack of calibration between the NM1 and the netsondes, headrope height data from tows where both the NM1 and the netsonde had been deployed together were used to prepare formulae for converting netsonde HH readings into NMI-equivalent units ("NMI-feet"). When the netsonde data and the NM1 data were compared from any of those tows where both systems had been used simultaneously, the two systems gave slightly different readings for headrope height throughout the tow. Since both systems gave essentially continuous measurements of trawl performance, it was possible to overlay the two records for a particular tow by matching the records of events such as setting or hauling the gear, which generated distinctive land marks in the records. Pairs of measurements were then selected from the two records of a particular tow, one from the NMI record and one from the netsonde trace, each pair consisting of measurements taken by the two systems at the same instant. Due to noise in the data, it was necessary at times to shift the two records somewhat relative to each other to approximate simultaneity, so a certain subjective element entered the pair selection procedure at this step. More pairs were arbitrarily selected during the settling and hauling phases of the tows in question than from the relatively steady state observations during the bulk of the tow to provide a wider range of values for the regression analysis. The sample pairs from the two tows (Tows 95 and 112) where the ELAC and NM1 had been used were pooled, as were the data from the three tows (Tows 151, 155, and 156) employing the Simrad netsonde system and the NMI. The two sets of sample pairs thus obtained were subjected to a least-squares linear regression analysis, using the SPSS "REGRESSION" subprogram (Nie et al. 1975). In both cases, HH values from the NM1 were regressed onto HH values from the netsonde recordings.

Table 1.--Parameters obtained by regressing headrope heights obtained from Net Measurement Instrument recordings onto headrope heights from netsonde traces.

Netsonde	Tows	a	b	Correlation coefficient (r)	Number of pairs
ELAC	45 & 112	1.6063	.7932	.96362	47
Simrad	151,155,156	-.4604	.9435	.99188	74

These results indicated that netsonde readings are a fairly good predictor of NM1 measurements.

Using the regression parameters listed in Table 1, correction formulas were prepared (see Table 2) for converting headrope heights obtained by netsonde measurements into NMI-feet to permit comparisons of headrope heights observed during tows when a netsonde was used without the NMI, and vice versa. In essence, these formulas predict what the NMI would have measured if it had been attached during tows where only one or the other netsonde was deployed.

Table 2.--Formulas for converting netsonde HH observations into NMI-feet.

ELAC-ft to NMI-ft:	$y = .7932X + 1.6063$
Simrad-ft to NMI-ft:	$y = .9435X - .4604$

(Note : The term NMI-ft is used instead of feet because the net measurement instruments have not been calibrated in some time. Such calibration will be done as performed as soon as possible by the RACE Division.)

For all tows where a netsonde was used and not the NMI, the observed headrope heights were converted into NMI-ft using the appropriate formula from Table 2. Using the corrected HH measurements and the NMI-obtained measurements, the pooled HH values were analyzed using the SPSS subprogram "BREAKDOWN" (Nie et al. 1975), using the descriptive variables net, rigging, and netsonde. Net refers to which of the four nets was used, rigging is related to the three different rigging conditions (no headrope extensions, 2 ft extensions, 3 ft extensions) , and the netsonde variable refers to whether or not a netsonde was used on a particular tow. Preliminary examination of the data had indicated that the depth of the tow had no effect on headrope height, so depth was not considered in the analysis. Because so many (33 out of 51) of the data points in the analysis were actually predicted values, not direct measurements, it was felt that attempting to analyze the statistical significance of the factors net, rigging, and netsonde was not appropriate.

Results of the Observations

Table 3.--Mean headrope height observation&.

Net	No headrope extensions		2' headrope extensions		3' headrope extensions		Measurement system used
	---------------	---------------	feet	---------------	---------------	---------------	
83/112 #1	7.9	(2)	10.3	(4)	8.3	(1)	Netsonde (ELAC)
(no rollers)	7.9	(2)	9.8	(4)	8.2	(1)	Corrected netsonde 2/
	6.0	(2)	11.0	(1)	6.7	(2)	NMI
	7.0	(4)	10.0	(5)	7.2	(3)	Average
83/112 #2	6.9	(2)	--		11.0	(4)	Netsonde (ELAC)
(no rollers)	7.1	(2)	--		10.5	(4)	Corrected netsonde 2/
	--		--		8.9	(3)	NMI
	7.1	(2)			9.8	(7)	Average
83/112 #3	10.7	(8)	--		--		Netsonde (Simrad)
(no rollers)	9.9	(8)	--		--		Corrected netsonde 2/
	8.6	(3)	--		--		NMI
	9.5	(11)					Average
83/112 #4	11.3	(12)	--		--		Netsonde (Simrad)
(roller gear)	9.9	(12)	--		--		Corrected netsonde 2/
	7.2	(7)	--		--		NMI
	8.9	(19)					Average

Note: Figures in parentheses show the number of tows in each condition.

l/ Averaged over all tows within each condition.
2/ Corrected netsonde values are netsonde headrope height measurements converted to NMI-equivalent feet by using the formulas in Table 2.

Table 3 shows the descriptive statistics provided by the "BBEAKDOWN" analysis of headrope heights. Upon examination of these statistics, several generalizations can be made:

Almost without exception, mean headrope heights in each net and rigging condition were higher when a netsonde was used than when it was not (compare corrected netsonde values with NMI values). These differences (1 to 2 ft) are remarkable both for their magnitude and their consistency.

It appears from these data that different nets may have different characteristic headrope heights, all other factors held constant. Nets #1 and #2 appeared to open about the same in the "No headrope extensions" condition, but Net #3 and Net #4 had mean headrope heights in this condition that differed from Nets #I and #2, and from each other. The relatively high opening of Net #4 is not surprising since that trawl was rigged with roller gear, but Nets #l, #2, and #3 were supposedly identical, and the consistently high opening of Net #3 is harder to explain.

Changes in the rigging of a given net by inserting or removing short headrope extensions also had a marked effect on headrope height, although the response of different nets to the same rigging was variable. For instance, with 2-foot extensions, Net #l showed a considerable increase in headrope height, but with 3-foot extensions, headrope height was reduced to levels comparable with the no extensions case. However, Net #2 responded to the 3-ft extensions with an increase comparable to the opening of Net #l with 2-ft extensions. Unfortunately, net #2 was not measured with 2-ft extensions.

Discussion

Vertical openings of all four 83/112 Eastern trawls were measured while fishing with the netsonde attached and with the NM1 system. In all four cases, even when netsonde HH measurements were converted to NMI-equivalents, the average operating heights of the nets with the netsonde were 1 to 2 ft greater (see Table 3) compared to the mean headrope heights from tows measured with the NM1 when the netsonde was not used. Vertical opening measurements obtained by both netsonde and the NM1 when both systems were used simultaneously during a tow were higher than average, usually in the range of observed heights obtained with the netsonde alone. The implication is that the presence of the netsonde somehow raised the headrope, at least in the vicinity of the netsonde transducer attachment point. Both netsondes operate with a "third wire" system, relying on an auxiliary winch preset to a constant tension to control the amount of netsonde cable out, so this is the most likely candidate for the mechanism causing the increased headrope heights. Since the wingspread measurement function of the NM1 was not operating, it is not known to what extent changes in horizontal opening occurred corresponding with the observed increased vertical openings.

The amount of tension (measured in pounds of line pull) exerted by the third wire winch can be regulated from the trawl control house by adjusting the flow rate and pressure of the hydraulic fluid powering the winch motor. In practice, the tension was adjusted until the winch just held the cable, preventing it from freewheeling off the spool but low enough that the cable could pay out and come in to correspond with motions of the ship (as it rode over the swells, for example) and the trawl (as it passed over changes in bottom topography) relative to each other. Each operator had his own idea as to when this equilibrium tension was reached, particularly when responding to changes in weather and sea conditions, and frequently winch tension was manipulated in attempts to resolve ragged or confusing netsonde displays. In consequence, netsonde winch tension often varied considerably from tow to tow and sometimes within a tow as well. Although quantitative analysis was not performed, measured headrope height appeared to be quite sensitive to winch tension. As might be expected, high winch tensions were accompanied by high vertical openings, and when tension was reduced, headrope heights followed suit, as observed on the netsonde display.

Of the four 83/112s measured, the strongest responses to changes in netsonde winch tension were observed with Net #4, the 83/112 rigged with roller gear, possibly because the greatest magnitude of changes in netsonde tension occurred during tows made with this net. In order to reduce hangups and gear damage due to rough bottom, a great deal of experimentation was done with reduced scope ratios and increased netsonde winch tension in an effort to get the gear to "fish light." Some of the highest headrope height measurements observed on 83/112 nets were obtained during these tows. Several times winch tension was reduced during a tow and headrope height fell with it. Catches from the tows with abnormally high headrope heights were compared to catches from other tows in the same area with the same net, and in many cases the catches were smaller and were unusually low in bottom organisms (crabs, flatfish, sea pens, snails, etc.) and high in larger cod and pollock (often found higher off the bottom than smaller individuals) relative to the tows with lower vertical openings. This suggests that bottom contact was poor during these tows.

On at least two tows (171 and 172) fishing was conducted with a strong following current. During these two tows, headrope heights were unusually high (83/112 #3, no rollers), implying low wingspreads and/or poor bottom contact.

Of the four 83/112 trawls observed, Net #4, rigged with roller gear, had a higher mean headrope height than did two of the other 83/112s (see Table 3). How much of this was due to the presence of roller gear and how much due to differences in the way the gear was fished (lower scope ratios, higher netsonde winch tensions) is not known. This higher headrope height also may have been associated with a reduction in wingspread due to the reduced spreading power of V-doors on hard ground (Main and Sanqster 1979). It is notable that catches with this net were markedly lower than were catches with the other three 83/112s. It may be that this is due to differences in fish density between rough and smooth bottom or due to decreased fishing power of nets fitted with roller gear.

Although the wingspread-measuring circuits in the NM1 package failed early in the cruise, they did function during three tows: one tow on 83/112 #l, a tow with 83/112 #2, and part of a tow with 83/112 #3. The mean wingspread values after the nets were on bottom and fully spread are shown in Table 4.

Table 4.--Mean wingspreads of three 83/112 nets.

Net no.	Mean wingspread	Tow
1	59.7 ft	92
2	58.7 ft	109
3	60 ft	128

From the time the warps were let out to the desired scope and the trawl cable winch brakes were set, 4 to 7 minutes elapsed before the nets reached the bottom during most tows. There were no trends discernible from net to net. There was, at times, fairly high variability of settling times from tow to tow with the same net, requiring as little as 1 minute to as much as 19 minutes for the net to settle down and spread fully. Differences in the way the nets were rigged had no distinguishable effect on settling time due to this inherent high variability.

After the beginning of haulback, from 5 to 7 minutes were needed to bring the nets off bottom. During that 5-to-7-minute interval, headrope heights usually remained fairly stable, i.e., about the same as they had been prior to haulback.

More understanding is needed of the ways in which the presence of a netsonde and its ancillary equipment affect trawl performance. It is particularly important to determine to what extent the abnormally high vertical openings associated with use of a netsonde are accompanied by changes in the horizontal spread of the net. It is also important to examine footrope contact with the bottom under varying circumstances of netsonde use.

The effects of roller gear on the fishing power of a given net design should be studied, as well as the effects of roller gear on the physical operation of trawls. This is particularly important if density estimates are prepared based on the fishing power of a given trawl without roller gear but without knowledge of the extent of any changes in effectiveness caused by rigging that trawl with roller gear.

Further study is needed on the extent to which a net continues fishing during haulback. Questions to be answered include:

1) Does the net keep moving over the bottom and, if so, at what speed?

2) Do wingspread values change? and

3) Are there other unspecified changes in fishing effectiveness?

If it develops that the net is actually fishing during haulback (or losing fish already caught, for that matter), it might be desirable to adjust catch per unit of effort (CPUE) formulas to allow for this effect.

More research is needed to identify factors causing variability in settling times. On hauls where the netsonde was not used, the usual approach was to assume that the net was down, spread, and fishing 5 minutes after the trawl winch brakes were set. This was not always the case, and bias could be introduced into CPUE estimates in this way.

Different regions along the footrope may differ in the degree of bottom contact they encounter. Presumably, if only the center of the footrope is on the bottom, the effective fishing width of the net will be less than its full wingspread for some organisms, such as crab. This should be examined.

The spreading force acting on the doors is partially determined by the speed at which they pass through the water and the drag forces acting on the net are dominated by water speed. In areas of strong bottom currents, the speed at which the gear passes through the water can differ from the speed measurements now available, i.e., ship's speed through the water and ship's speed over the ground. Being able to measure the speed at which the trawl passes through the water would further our understanding of trawl performance, thus fishing power.

Early in the cruise, gear specialists from the RACE Division and ship's officers studied netsonde recordings from hauls made during the preceding leg to identify optimal scope/depth ratios for various depths. From these considerations, a table of scope values versus depth was prepared in l-fm increments. It was felt that this would be an improvement over the previously used system, which specified constant scope ratio values over 50-fm depth intervals. The formula for scope versus depth was as follows: Scope (in fathoms) = Depth (in fathoms) X 1.7365 + 68.5103 fm. All subsequent tows were made using values from the tables thus computed. It was found that the nets tended to maintain bottom contact well using these scope values but that the specified scope values may have been excessive for some conditions. In other circumstances, such as fishing in heavy weather, scope values from the table may have been less than adequate. It appears that the table values are a reasonably good first approximation but further refinement is called for.

Summary of Findings from this Cruise

Each net had a different characteristic headrope height, although differences between nets of the same type rigged the same way were sometimes small. Changing the rigging of the net by extending the effective length of the headrope generally caused an increase of about 2 ft in headrope height, although the way in which particular nets responded to these extensions was not always predictable. Attaching a third-wire netsonde to any net caused an increase of a foot or two in its vertical opening, the amount of increase directly dependent on netsonde winch tension to the point where, in some cases, it appeared that the netsonde cable was actually holding the net off bottom. Strong following currents appear to have caused an increase in headrope height on one of the nets and an apparent loss of bottom contact. It appeared that the presence of roller gear caused an increase of about 1 foot in vertical opening, although other factors (described above) could have caused the observed differences. Depending on the net and other towing conditions, headrope heights from 6 ft to 10.5 ft were observed, with wingspreads of about 59 ft.

DISCUSSION OF THE FINDINGS FROM THE TWO CRUISES

Although the philosophies underlying the trawl observations during the two cruises differed (planned experiments versus passive observations), upon ccm-paring the results, some interesting trends emerged (see Table 5). In both cases, it appeared that each net had its own characteristic headrope height, other factors being held constant, and that headrope height was quite sensitive to any changes in the physical structure of the net components (e.q., removal of riblines or the insertion of headrope extensions).

Table 5.--Factors found to have a significant effect on trawl performance.

Dependent variable	Tows considered	Important factors
Cruise MF-79-5		
Headrope height	All tows	Towing tension, depth
	No off-bottom tows	Net identity, presence or absence of riblines
Wingspread	All tows	Towing tension, depth
	No off-bottom tows	Towing tension, depth, scope ratio
Cruise MF-80-1		
Headrope height	All tows	Net identity, rigging, presence or absence of netsonde

Although headrope heights were found to vary from tow to tow, responding to changes in the physical conditions of the tows, the magnitude of these variations is probably not important in an operational sense. When the gear was set properly with no following currents, no netsonde attached, and no headrope extensions, in most instances the vertical openings of these 83/112s were about 6 feet, with nearly all the observations falling within 4.5-7.5 ft. As long as catch results from tows using this gear are used to estimate abundances of strictly demersal organisms, this kind of variability should not be troublesome.

It is important, however, to get better estimates of the area swept by the trawl during each tow. The area swept during a tow can be formulated as follows: wingspread of the trawl during the tow times the actual distance over which the trawl was dragged while it was in full contact with the bottom. It has been demonstrated that following currents can have a severe adverse impact on both wingspread and bottom contact, causing the true area swept to be much less than what might have reasonably been estimated, using the usual assumed values for wingspread, time on bottom, and tow duration and speed. Other factors that were shown to influence area-swept values were depth of tow, the scope ratio employed, and towing tension (which can be interpreted as an index of the relative velocity of the trawl through the water, combining the effects of ship's speed and bottom current effects).

Perhaps the best approach to the area-swept problem is through trawl instrumentation, with first priority going towards development of a simple, reliable system for indicating footrope-bottom contact. Likewise, instrumentation for routinely monitoring trawl wingspread would be most valuable. Failing that, a useful strategy might be to make sure that all tows are made into the current whenever possible to facilitate proper spreading and good bottom contact.

RECOMMENDATIONS

To prepare abundance estimates from trawl survey catches, biologists have been forced, through lack of better information, to assume constant behavior of the gear. In these and other gear studies such as Wathne's report (1977), trawl behavior has been shown to be quite dynamic and sensitive to a number of physical features of the trawling situation. Because this sensitivity can influence the area sampled in ways that are difficult to predict, it is desirable that instrumentation be developed that will permit more realistic estimates of the actual area swept on each tow. In the meantime, strategies should be developed that will reduce this variability, such as towing into any currents (if the local currents are strong enough to cause problems) and to utilize proper scope ratios for the depths involved. Standardization of the gear and its rigging, already accepted practice, should be emphasized even more.

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LITERATURE CITED

Dunn, O. J., and V. A. Clark

1974. Applied statistics: analysis of variance and regression. John Wiley and Sons, New York, Chichester, Brisbane, Toronto, 387 p.

Main, J., and G. I. Sangster

1979. A study of bottom trawling gear on both sand and hard ground. Dep. Agric. Fish. Scotl., Scotl. Fish. Res. Rep. 14, 15 p.

Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrenner, and D. H. Bent

1975. SPSS: statistical package for the social sciences, second edition. McGraw-Hill, New York, 675 p.

Wathne, F.

1977. Performance of trawls used in resource assessment. Mar. Fish. Rev. 39(6):16-23.

Appendix I.--Summary of the physical conditions and the results of the experimental tows conducted from the Miller Freeman Cruise MF-79-5.

HAUL	TOW	NET	RIB-LINES	DEPTH (FM.)	SCOPE RATIO	SCOPE RATIO SCORE	SPEED (KTS.)	DIR.	MEAN TENSION (LBS.)	TENSION SCORE	HEADROPE HEIGHT (FT.)		WINGSPREAD (FT.)		COEFF. CORR.	N
											MEAN	S.D.	MEAN	S.D.		
1	-	MWT	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	MWT	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	MWT	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	MWT	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	1	83/112 #1	W	50	3:1	LOW	3.0	N	5500	HIGH	5.5	.3859	63.1	.8447	-.0891	31
5	2	83/112 #1	W	50	3:1	LOW	3.5	N	8500	HIGH	5.4	.3123	62.1	1.0117	-.1662	25
6	3	83/112 #1	W	50	3.75:1	HIGH	3.0	N	7500	HIGH	5.5	.3051	61.9	.6781	-.2067	57
6	4	83/112 #1	W	50	3.75:1	HIGH	3.5	N	7500	HIGH	5.5	.2288	61.6	.9103	-.2484	29
6.1	5	83/112 #1	W	50	3:1	LOW	3.0	S	3000	LOW	10.9	.8075	42.2	1.4203	.0776	172
6.1	6	83/112 #1	W	50	3:1	LOW	3.5	S	3000	LOW	8.6	.7721	43.0	2.2402	-.4531	171
6.1	7	83/112 #1	W	50	3.75:1	HIGH	3.0	S	3000	LOW	8.5	.6757	41.7	1.9588	-.3236	89
6.1	8	83/112 #1	W	50	3.75:1	HIGH	3.5	S	4500	LOW	8.4	.7994	43.3	2.9401	.0419	118
7	9	83/112 #2	W	50	3.75:1	HIGH	3.5	S	4500	LOW	7.2	1.0516	49.4	3.5667	-.6774	162
7	10	83/112 #2	W	50	3.75:1	HIGH	3.0	S	6000	HIGH	6.0	.4076	61.6	1.6791	.5805	267
7	11	83/112 #2	W	50	3:1	LOW	3.5	S	10000	HIGH	5.6	.3645	62.6	.5587	.2298	193
7	12	83/112 #2	W	50	3:1	LOW	3.0	S	8000	HIGH	6.1	.3402	61.9	.6460	.2158	168
8	13	83/112 #2	W	50	3:1	LOW	3.0	N	7000	HIGH	4.9	.4656	64.2	.7275	-.4240	140
8	14	83/112 #2	W	50	3:1	LOW	3.5	N	9000	HIGH	5.3	.4294	61.8	.6265	-.1905	108
8	15	83/112 #2	W	50	3.75:1	HIGH	3.5	N	9000	HIGH	5.9	.6774	63.0	4.1750	.2593	69
8	16	83/112 #2	W	50	3.75:1	HIGH	3.0	N	8000	HIGH	5.4	.3366	63.2	.6534	.0066	70
8.1	17	83/112 #1	W	100	2.5:1	LOW	3.0	N	6000	HIGH	4.5	.1019	67.1	2.3280	-.0198	162
8.1	18	83/112 #1	W	100	2.5:1	LOW	3.5	N	6000	HIGH	4.6	.2266	63.1	1.9466	.6702	177
8.1	19	83/112 #1	W	100	3:1	HIGH	3.0	N	6250	HIGH	4.5	0.0	64.5	1.1361	0.0	184
9.1	20	83/112 #1	W	100	2.5:1	LOW	3.0	S	2500	LOW	4.5	.1019	67.6	1.3049	-.1233	162
9.1	21	83/112 #1	W	100	2.5:1	LOW	3.5	S	3750	LOW	4.5	0.0	63.9	1.1754	0.0	180
9.1	22	83/112 #1	W	100	3:1	HIGH	3.0	S	3250	LOW	4.5	0.0	65.9	.9957	0.0	184
9.1	23	83/112 #1	W	100	3:1	HIGH	3.5	S	5500	HIGH	4.8	.6384	64.5	2.1345	.5816	167
9.2	24	83/112 #1	W	100	3:1	HIGH	3.5	N	5500	HIGH	5.0	.4510	66.3	3.8070	.0246	108
10	25	83/112 #2	W	100	2.5:1	LOW	3.0	S	3500	LOW	6.9	.7701	58.4	2.5050	-.2446	142
10	26	83/112 #2	W	100	2.5:1	LOW	3.5	S	3500	LOW	6.2	.7642	66.2	3.8346	-.5441	118
10	27	83/112 #2	W	100	3:1	HIGH	3.0	S	2500	LOW	6.7	.7858	52.9	2.2240	-.1642	170
10	28	83/112 #2	W	100	3:1	HIGH	3.5	S	4000	LOW	5.7	.6840	61.8	5.6627	-.3554	161
11	29	83/112 #2	W	100	2.5:1	LOW	3.0	N	5500	HIGH	6.4	.5072	68.0	1.0864	.2169	62
11	30	83/112 #2	W	100	2.5:1	LOW	3.5	N	3500	LOW	5.9	.4636	66.0	1.1202	-.2708	33
11	31	83/112 #2	W	100	3:1	HIGH	3.5	N	4500	LOW	6.0	.6201	66.6	1.3110	.8620	12
11	32	83/112 #2	W	100	3:1	HIGH	3.0	N	3500	LOW	5.8	.4520	57.3	1.3400	-.1285	79
12	33	83/112 #1	W/O	50	3:1	LOW	3.0	N	5000	LOW	5.6	.3269	58.4	.9419	.1342	171
12	34	83/112 #1	W/O	50	3:1	LOW	3.5	N	7000	HIGH	5.4	.5831	57.3	.9770	-.0565	129
12	35	83/112 #1	W/O	50	3.5:1	HIGH	3.5	N	8000	HIGH	5.6	.9119	57.9	1.5461	-.0924	136
12	36	83/112 #1	W/O	50	3.5:1	HIGH	3.0	N	4250	LOW	5.7	.4599	56.8	1.1916	.2047	169
13	37	83/112 #2	W/O	50	3:1	LOW	3.0	S	5000	LOW	6.1	.3721	60.3	.6409	.2640	167

Appendix I.--Continued.

HAUL	TOW	NET	RIB-LINES	DEPTH (FM.)	SCOPE RATIO	SCOPE RATIO SCORE	SPEED (KTS.)	DIR.	MEAN TENSION (LBS.)	TENSION SCORE	HEADROPE HEIGHT (FT.) MEAN	HEADROPE HEIGHT (FT.) S.D.	WINGSPREAD (FT.) MEAN	WINGSPREAD (FT.) S.D.	COEFF. CORR.	N
13	38	83/112 #2	W/O	50	3:1	LOW	3.5	S	5000	LOW	5.6	.6387	59.9	.6657	.2428	128
13	39	83/112 #2	W/O	50	3.75:1	HIGH	3.5	S	5000	LOW	5.6	.4493	62.0	.7832	.1026	66
13	40	83/112 #2	W/O	50	3.75:1	HIGH	3.0	S	4000	LOW	6.1	.3808	52.2	.8728	.2135	172
14	41	83/112 #2	W/O	50	3:1	LOW	3.0	N	4000	LOW	6.4	.3508	58.9	.6917	.0236	169
14	42	83/112 #2	W/O	50	3:1	LOW	3.5	N	5500	HIGH	6.0	.4593	58.7	.5793	.1082	158
14	43	83/112 #2	W/O	50	3.75:1	HIGH	3.5	N	5000	LOW	5.8	.4777	60.8	.8246	-.0778	118
14	44	83/112 #2	W/O	50	3.75:1	HIGH	3.0	N	4000	LOW	5.8	.4013	58.0	.6552	.0677	137
15	45	83/112 #1	W/O	50	3:1	LOW	3.0	S	4500	LOW	9.5	.6478	42.4	3.3186	-	148
15	46	83/112 #1	W/O	50	3:1	LOW	3.5	S	5500	HIGH	7.2	.5609	52.7	4.2812	-.3883	170
15	47	83/112 #1	W/O	50	3.75:1	HIGH	3.0	S	3000	LOW	-	-	-	-	-	0
15	48	83/112 #1	W/O	50	3.75:1	HIGH	3.5	S	3250	LOW	7.2	.5653	47.6	4.0360	-	163
16	49	83/112 #1	W/O	50	3:1	LOW	3.0	N	4000	LOW	5.8	.3515	61.3	1.2460	.0461	133
16	50	83/112 #1	W/O	50	3:1	LOW	3.5	N	4250	LOW	5.4	.4102	60.2	.9851	-.0704	69
16	51	83/112 #1	W/O	50	3.75:1	HIGH	3.0	N	7000	HIGH	5.5	.3797	61.9	.7677	.4593	79
16	52	83/112 #1	W/O	50	3.75:1	HIGH	3.5	N	6000	HIGH	5.4	.4116	61.3	.9943	-.0275	49
17	53	83/112 #2	W/O	100	2.5:1	LOW	3.0	S	3500	LOW	6.9	.8792	63.6	8.2763	-.8084	122
17	54	83/112 #2	W/O	100	2.5:1	LOW	3.5	S	4500	LOW	6.4	.5262	66.2	3.3972	-.4559	78
17	55	83/112 #2	W/O	100	3:1	HIGH	3.0	S	3500	LOW	6.8	.7001	53.1	5.8682	-.5537	117
17	56	83/112 #2	W/O	100	3:1	HIGH	3.5	S	5500	HIGH	5.8	.3585	58.3	4.8277	.2366	36
18	57	83/112 #2	W/O	100	2.5:1	LOW	3.0	N	4000	LOW	6.1	.5179	69.5	3.2947	-.1783	31
18	58	83/112 #2	W/O	100	2.5:1	LOW	3.5	N	5000	LOW	5.8	.3615	63.6	.7965	-.1139	31
18	59	83/112 #2	W/O	100	3:1	HIGH	3.5	N	4500	LOW	5.6	.3131	64.7	.8720	.0425	34
18	60	83/112 #2	W/O	100	3:1	HIGH	3.0	N	7000	HIGH	6.0	.4722	66.5	3.5466	-.0236	20
19	61	83/112 #1	W/O	100	2.5:1	LOW	3.0	S	3750	LOW	6.6	.6617	69.2	2.9182	-.5468	35
19	62	83/112 #1	W/O	100	2.5:1	LOW	3.5	S	5500	HIGH	6.8	1.3280	75.8	5.6883	.8490	11
19	63	83/112 #1	W/O	100	3:1	HIGH	3.5	S	4500	LOW	5.8	.2886	74.3	5.8596	-.9855	3
19	64	83/112 #1	W/O	100	3:1	HIGH	3.0	S	4000	LOW	5.1	.8305	48.9	7.3267	.8563	40
20	-	83/112 #1	W/O	100	-	-	-	N	-	-	-	-	-	-	-	0
21	65	83/112 #3	W	50	3:1	LOW	3.0	N	4000	LOW	6.0	.2757	60.8	.5295	.1358	170
21	66	83/112 #3	W	50	3:1	LOW	3.5	N	4500	LOW	5.7	.2677	60.0	.9568	-.4204	165
21	67	83/112 #3	W	50	3.75:1	HIGH	3.5	N	5500	HIGH	5.6	.2890	62.8	.9916	-.1134	136
21	68	83/112 #3	W	50	3.75:1	HIGH	3.0	N	7000	HIGH	5.7	.3430	62.7	.7736	-.3156	156
22	69	83/112 #3	W	50	3:1	LOW	3.0	S	2000	LOW	9.2	.9469	41.9	2.1063	-.6026	46
22	70	83/112 #3	W	50	3:1	LOW	3.5	S	3500	LOW	6.9	.4676	56.7	2.8609	-.4711	162
22	71	83/112 #3	W	50	3.75:1	HIGH	3.5	S	2500	LOW	7.1	.3882	53.9	2.2683	-.2324	161
22	72	83/112 #3	W	50	3.75:1	HIGH	3.0	S	4500	LOW	9.6	.6009	41.0	.7071	-.2942	9
23	73	83/112 #3	W/O	50	3:1	LOW	3.0	S	1750	LOW	8.6	.5554	45.4	3.0730	-.0541	168
23	74	83/112 #3	W/O	50	3:1	LOW	3.5	S	4875	LOW	6.8	.2837	63.7	1.3677	-.2121	171
23	75	83/112 #3	W/O	50	3.75:1	HIGH	3.5	S	5500	HIGH	6.0	.2482	66.8	.9162	-.1576	143
23	76	83/112 #3	W/O	50	3.75:1	HIGH	3.0	S	4500	LOW	6.6	.2765	61.5	2.2848	-.4027	184
24	-	83/112 #3	W/O	50	3:1	LOW	3.0	N	5000	LOW	6.1	.2490	-	-	-	182
24	-	83/112 #3	W/O	50	3:1	LOW	3.5	N	5000	LOW	6.1	.3157	-	-	-	184
24	-	83/112 #3	W/O	50	3.75:1	HIGH	3.5	N	5500	HIGH	5.6	.1924	-	-	-	184
24	-	83/112 #3	W/O	50	3.75:1	HIGH	3.0	N	5500	HIGH	5.7	.2932	-	-	-	182

Appendix II.--Summary of the physical conditions and the results of the bottom trawl hauls conducted from the MILLER FREEMAN, Cruise MF-80-1, Leg III.

							Mean observed headrope height (HH)				
Tow no.	Net used	Net rigging	Depth (fm)	Scope (fm)	Settling time	Netsonde used	HH Measured (ft)	HH Corrected to NMI-ft	HH Measured by NMI	Catch	Comments
91	83/112 #1(no rollers)	2 ft headrope extensions	160	320	12	ELAC	9.8	9.4	8.8	4,000 lb benthic	--
92	"	"	150	300	--	No	--	--		19,000 lb benthic	Wingspread = 59/7 ft.
93	"	"	124	240	12	ELAC	13.5	12.3	--	500 " "	Bottom contact poor.
94	"	"	110	270	6	ELAC	7.2	7.3	--	1,200 " "	--
95	"	"	107	270	5	ELAC	10.7	10.1	10.9	600 " "	HH declined when netsonde winch tension reduced.
96	"	"	108	268	--	No	--	--	--	600 " "	--
97	"	"	127	250	--	No	--	--	--	1,000 " "	--
98	"	"	95	250	--	No	--	--	--	900 " "	--
99	"	"	85	220	13	No	--	--	11.0	1,400 " "	--
100	"	"	121	250	--	No	--	--	--	1,200 " "	Stbd. bridles twisted
101	"	2 ft headrope extensions	147	300	--	No	--	--	--	5,700 " "	--
102	"	No headrope extensions	126	310	3	No	--	--	6.1	1,300 " "	
103	"	"	115	285	8	ELAC	7.5	7.6	--	1,600 " "	
104	"	"	111	275	3	ELAC	8.3	8.2	--	2,300 " "	
105	"	No headrope extensions	120	290	3	No	--	--	5.9	3,600 " "	
106	"	3-ft headrope extensions	100	250	6	ELAC	8.3	8.2	--	900 lb benthic	--
107	"	"	85	210	4	No	--	--	6.4	--	Hung up
108	83/112 #1	"	85	210	3	No	--	--	7.0	--	Hung up net, badly damaged, changed nets
109	83/112 #2 (no rollers)	"	100	250	5	No	--	--	9.1	1,300 lb benthic	Wingspread = 58.7 ft
110	"	"	110	275	4	No	--	--	8.4	2,500 lb benthic	--
111	"	"	118	295	19	ELAC	bad trace	--	10.3	1,700 " "	
112	"	"	131	265	9	ELAC	9	8.8	9.3	1,100 " "	At first, ELAC showed HH = 17 ft,then netsonde winch tension was reduced & ELAC HH went to 9 ft.
113	83/112 #2	3-ft headrope extensions	149	296	5	No	--	--	9.1	1,200 " "	
114	Diamond midwater trawl	"	148	300	--	ELAC	8 fm vertical opening	--		7,200 lb epi-benthic	This catch was characterized by larger cod and pollock,no crab, flatfish,small pollock, etc.
115	83/112 #2 (no rollers)	3-ft headrope extensions	169	340	--	No	--	--	--	8,300 lb benthic	
116	"	"	149	300	--	No	--	--	--	200 lb benthic	

Appendix II (continued).

Tow no.	Net used	Net rigging	Depth (fm)	Scope (fm)	Settling time	Net-sonde used	Mean observed headrope height (HH): HH Measured (ft)	HH Corrected to NMI-ft	HH Measured by NMI	Catch	Comments
117	"	"	97	242	6	ELAC	11.3	10.6	--	500 lb benthic	--
118	"	"	120	274	5	ELAC	12.8	11.8	--	1,000 " "	--
119	"	"	124	284	--	No --	--	--	--	1,500 " "	--
120	"	3-ft headrope extensions	130	299	--	ELAC	no trace	--	--	2,500 " "	--
121	"	No headrope extensions	150	326	7	ELAC	5.25	5.8	--	22,000 " "	Mostly pollock
122	83/112 #2	"	170	364	5	ELAC	8.6	8.4	--	31,000 " "	Mostly pollock
123	Diamond midwater trawl	"	165	248	--	ELAC	8 fm-12-14 fm	--	--	--	Trawl aborted. Vertical opening inversely related to towing speed.
124	83/112 #4 (roller gear)	"	125	286	--	No	--	--	--	200 " "	Bad tow, trawl hung up
125	83/112 #3 (no rollers)		160	346	6	No	--	--	8.4	1,300 " "	--
126	"	"	165	368	--	No	--	--	--	1,800 " "	--
127	"	"	140	313	--	No	--	--	--	400 " "	--
128	"	"	129	293	5	No	--	--	8.4	2,300 " "	--
129	"	"	101	246	--	Simrad	12	10.9	--	1,600 " "	
130	"	"	130	varied throughout tow	5	Simrad	10.6	9.5	--	1,800 " "	Gear expt. Unequal amts of warp out from side to side(approx.3fm diff @ max) little change in HH
131	"	"	152	331	6	Simrad	10.5	9.5	--	1,000 lb benthic	--
132	83/112 # 3	"	126	varied during tow	--	Simrad	12	10.9	--	--	Tore up gear.
133	Nor'eastern 90/105 (roller gear)	"	133	varied	7	Simrad	19	17.5	--	1,600 " "	Unequal amts of warp out from side to side little effect on HH
134	"	"	141	varied	4	Simrad	27	25.0	--	600 " "	(same as above#133)
135	"	"	122	280	4	Simrad	--	--	--	--	Net fouled, bad tow.
136	"	"	120	277	5	"	32.5	30.2	--	500 " "	--
137	"	"	86	216	4	"	22.3	20.6	--	900 " "	--
138	"	"	83	214	4	"	--	--	--	100 " "	Net fouled during set
139	Nor'eastern	"	100	242	--	"	19.4	17.8	--	--	Net torn up
140	83/112 #4 (roller gear)	"	167	360	--	"	10.7	9.6	--	31,000 " "	--
141	"	"	150	332	2	"	bad trace	--	--	300 " "	HH very high, about 18 ft, net may be off-bottom.
142	"	"	164	353 stbd. 353,358 port	4	"	14.6	13.3	--	1,300 " "	HH appeared to increase slightly when more port warp put out.
143	"	"	143	317	5	No	--	--	8.2	1,100 lb benthic	--
144	"	"	118	282 stbd. 289 "	4	No	--	--	7.9	900 lb benthic	HH constant in spite of change in port warp length.
145	"	"	150	332	1	No	--	--	7.4	1,300 lb benthic	--
146	"	"	131	296	5	Simrad	12	10.9	--	600 " "	--
147	"	"	155	333	4	No	--	--	--	500 " "	--

Appendix II (continued).

Tow no.	Net used	Net rigging	Depth (fm)	Scope (fm)	Settling time	Net-sonde used	Mean observed headrope height (HH): HH Measured (ft)	HH Corrected to NMI-ft	HH Measured by NMI	Catch	Comments
148	"	"	165	355	4	No	--	--	6.0	800 lb benthic	--
149	"	"	119	275	2	No	--	--	7.3	600 lb benthic	--
150	"	"	130	294 stbd 294,291 port	4	No	--	--	6.7	1,900 " "	No change in HH when port warp pulled in halfway thru tow.
151	"	"	150	329	7	Simrad	8.1	6.6	6.6	700 lb benthic	--
152	"	"	138	312	4	Simrad	11.2	9.6	--	1,100 " "	--
153	"	"	133	305	3	Simrad	9.6	8.1	--	2,400 " "	HH declined when netsonde winch tension reduced.
154	"	"	123	289	9	No	--	--	6.8	1,400 lb benthic	--
155	"	"	127	291	5	Simrad	11.0	9.4	10.4	1,500 " "	--
156	"	"	120	277	4	Simrad	11.6	10.0	9.3	500 lb epi-benthic	Mostly large pollock & cod. High HH recorded-poor bottom contact?
157	"	"	111	263	--	Simrad	--	--	--	400 lb benthic	Simrad turned sideways, mounted on wing.
158	"	"	87	216	--	No	--	--	--	300 lb benthic	--
159	"	"	138	312	--	No	--	--	--	--	--
160	"	"	144	313	7	Simrad	13.2	11.5	--	300 lb benthic	--
161	"	"	108	varied less than 200	5	Simrad	8.9-11.4	--	--	500 lb benthic	Gear expt...very low scope ratio, high netsonde winch tension, high HH.
162	"	"	89	223	--	Simrad	9.8	8.3	--	300 lb benthic	--
163	"	"	107	220	6	Simrad	8.5	7.6	--	700 " "	
164	"	"	150	varied 280-300	5	Simrad	8.9-12.2	7.9-11.1	--	2,100 " "	Gear expt. HH responded more to changes in netsonde winch tension than to gross changes in scope.
165	83/112 #4 (roller gear)	"	275	495	8	Simrad	13.4	12.2	--	4,100 " "	HH declined when netsonde winch tension reduced.
166	83/112 #3 (no rollers)	"	162	310	9	Simrad	11.0	9.9	--	400 " "	--
167	"	"	154	331	8	Simrad	9.8	8.8	--	3,000 " "	--
168	"	"	167	368	6	Simrad	9.0	8.0	--	31,000 " "	100% pollock.
169	83/112 #3	No headrope extensions	162	350	6	Simrad	13.0	11.8	--	16,000 lb benthic	100% pollock
170	Diamond midwater trawl	"	--	--	--	Simrad	--	--	--	--(bad tow)	--
171	83/112 #3 (no rollers)	"	155	338	5	No	--	--	9.1	2,400 lb benthic	--
172	"	"	151	338	--	--	--	--	--	--	--
173	"	"	150	324	--	--	--	--	--	--	--
174	"	"	--	--	6	No	--	--	8.3	--	--