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Measurements of Distance Fished During the Trawl Retrieval Period

by

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Abstract

Observations of sampling trawl performance made during a multi-vessel groundfish trawl survey conducted during 1998 and again in 1999 raised concerns that the trawls might be continuing to fish during the retrieval period, after the end of the sampling period but before coming off bottom. Following the 1998 survey, a simple geometric analysis of times and positions recorded at critical moments during and following each sampling tow was developed to estimate the following parameters: 1) the distance along the bottom that the gear swept during the retrieval period, and 2) the speed at which the trawl moved over the seabed. This analysis suggested that the distances swept were substantial, and systematically increased with the depth of the tow. The effective trawl speed approached or even exceeded the towing speed specified by the sampling protocols, and this varied systematically among the participating vessels. The same analysis was performed for sampling tows conducted during the 1999 survey and compared against trawl positions recorded during the same period by an ultra-short baseline acoustic positioning system. Both techniques yielded similar results, and were in accord with the findings from the 1998 data: distances swept by the trawls during the retrieval period were substantial and the trawls were moving at speeds comparable to fishing speed, and these effects varied systematically from depth to depth and vessel to vessel. Neglect of these effects could increase the impact of depth-related bias and inter-vessel variability on survey results while knowledge of them could help explain the "vessel effect" commonly observed when comparing the fishing performance of two or more vessels.

Introduction

One of the core issues in bottom trawl survey methodology and in other experimental trawling situations is measuring and/or standardizing the fishing effort. Whether survey results will be used to prepare "area swept" estimates of absolute abundance, to compute indices of relative abundance, or to calculate other fishing efficiency statistics, controlling and quantifying tow duration and/or tow distance are typically considered quite important (Gunderson, 1993; Engås, 1994; Godø, 1994; Parsons and Sandeman, 1981; Grosslein, 1971; and Byrne et al. 1981). The significance of these factors is comparable to such others as the construction and rigging of the gear, adherence to a specified towing speed and other operational protocols, and employment of a standardized vessel.

For many surveys tow duration is defined as the period between the time the trawl is determined to be on the bottom and in a stable fishing configuration until the moment when the tow is declared over (usually at the end of some fixed, predetermined sampling period) and the trawl winches are started up to retrieve the gear. In such cases towing distance is similarly defined as equal to the distance transited by the vessel between the starting point and end points of the tow as defined above.

These are oversimplifications of the true situation, as is shown from observations conducted with trawl instruments (e.g. Wathne, 1977). It is quite common for a trawl to remain on the bottom for considerable periods after haulback has begun (see example in Figure 1). Even if the towing vessel's thrust is reduced (as is typically done) it is possible that the trawl continues to advance across the bottom during this period and may continue to catch fish if it remains in its normal fishing configuration and its speed of advance is sufficiently high.

Starting in 1998, every summer the Fishery Resource Analysis and Monitoring Division of the Northwest Fisheries Science Center, U.S. National Marine Fisheries Service, charters four commercial fishing vessels to conduct a bottom trawl survey assessing the distribution and abundance of commercial groundfish resources inhabiting the slope zone (100 to 700 fathoms, or 183 to 1280 m) off the coasts of Washington, Oregon, and California. Each of the four vessels occupies its own unique set of sampling stations distributed along the full length of the survey area, essentially conducting its own complete, independent, coastwide mini-survey. The four sets of stations are interleaved such that all stations combined constitute a full survey at relatively high sampling density. No separate fishing power calibrations are conducted among the four vessels since comparisons among the four mini-surveys can, with the correct analytical approach, contribute information about the relative fishing performance of the four vessels. For this approach to succeed it is necessary to standardize or accurately measure as many as possible of the potential contributors to differences in between-vessel fishing power. Given the known differences among the vessels in such areas as engine horsepower, towing capabilities, and winch characteristics, we had serious concerns about potential differences in fishing performance due to such phenomena as prolonged fishing after the nominal end of the sampling tow as described above. These concerns were heightened by our choice of a relatively short 15-minute standard tow duration, which would increase the relative importance of a few minutes' delay in the gear actually coming off bottom.

Following the 1998 survey, a simple geometric analysis of times and vessel positions recorded at critical moments during and following each sampling tow was developed to estimate the following parameters: 1) the distance along the bottom that the gear swept during the retrieval period, and 2) the speed at which the trawl moved. This analysis (West et al., 1999) suggested that the distances swept were substantial and systematically increased with the depth of the tow, that the effective trawl speed approached or even exceeded the towing speed specified by the sampling protocols, and that these performance parameters varied systematically among the participating vessels.

During the 1999 survey the same data were recorded as in the previous year, making possible the same sort of analysis. In addition, a new data-logging system was employed to automatically and continuously record many significant parameters throughout the tow including trawl positions expressed in latitude and longitude as calculated by one of the instrument systems. Thus two independent means were available for examining trawl performance during the retrieval period, and their results compared.

Methods

The 1999 West Coast slope survey was conducted in the same survey area with the same sampling trawls and according to the same sampling protocols as were used in 1998. Significant operational protocols included a standard target towing speed of 2.2 knots over the ground and a nominal tow duration of 15 minutes between the time the net was properly configured on bottom and fishing, and the time at which heaving was initiated. The four vessels chartered for the 1999 survey were the "Miss Leona," "Blue Horizon," "Captain Jack," and "Sea Eagle."

Simrad ITI trawl instrumentation systems and self-logging bottom contact sensors attached to the 'footrope were used to record various aspects of the trawls' fishing performance including their vertical and horizontal dimensions at the mouth, the time at which the gear contacted the bottom at the beginning of each sampling tow, and the time at which it left the bottom at the end of the tow. Using ultra-short baseline acoustic positioning technology, the ITI systems also calculated and reported the trawls' positions in latitude and longitude throughout each tow. During each tow scientists in the wheelhouse recorded the time and ship's position (using a highly accurate differential GPS system) associated with such critical events as the trawl reaching the bottom, the beginning and nominal end of the tow, the moment at which the trawl actually lifted off bottom during retrieval, and the time at which the trawl doors had been fully heaved. In addition, every few seconds an automated data-logging program linked to the ITI and the GPS recorded the time, vessel position, trawl position, and other parameters throughout each sampling tow.

Two methods were employed to assess the amount of bottom swept while the trawls were still lingering on bottom during retrieval operations and the trawl's speed of advance over the seabed during this period, which we have dubbed "liftoff lag." All tows conducted during the survey were considered unless instrument or datalogger malfunctions made it impossible to use the data, or if the tow had to be aborted due to the trawl hanging up or other operational problems.

We use the term "ITI method' to describe the technique first employed with the 1999 data since it relies on the trawl positions determined by the ITI system. Linking the continuously-logged trawl position data to the time at which retrieval began versus the time at which the IT1 showed the trawls lifting off made it possible to directly calculate the distance the trawl covered and the speed at which it moved. Because the GPS system's ability to correctly compute vessel heading was degraded when vessel speeds were less than half a knot, such as during haulback, the ITI was unable to correctly determine the trawl's geographic position during some of these periods.

However, such phenomena did not affect the ITI's ability to compute the trawl's range and bearing relative to the vessel so by applying the last known good headings to the recorded range and bearing data, then smoothing the results, we were able to obtain sound estimates of the trawl's actual course over the seabed during the liftoff interval.

The other approach, which we have dubbed the "1998 method' since it was originally developed and employed for the 1998 data when trawl positions were not recorded, used various known and interpolated factors to estimate the distance fished and the trawl's speed during the liftoff lag period (Figure 2).

Known factors:

- Time and ship's position at the beginning of haulback
- Time and ship's position at the moment of liftoff
- The scope (length of towing warp deployed) and the fishing depth for the tow
- Duration of the period between the beginning of haulback and the moment of liftoff
- Time required to recover various lengths of towing warp (Figure 3)

The first step was to estimate the trawl's position (actually the position of the trawl doors in this analysis) at the beginning of haulback. This was done by treating the scope as the hypotenuse of a right triangle and the depth as one of the sides, then solving to find the length of the remaining side (Fig.2). This corresponds to the trawl's horizontal distance behind the vessel and this offset distance can then be applied to the vessel's observed position to estimate the trawl's position. For this and subsequent steps some simplifying assumptions were made: 1) that the trawl warps described a straight line between the trawl and the ship without significant sagging or other deflection; 2) that the outward deflection of the warps due to door spread was insignificant relative to the scope; 3) that the trawl was directly behind the ship throughout the towing and haulback periods; 4) that the trawl's fishing depth was the same as the bottom depth displayed by the ship's echosounder; and 5) that the depth did not change substantially during haulback.

The next step was to estimate the amount of warp still deployed at the moment of liftoff. The absence of suitable instrumentation on these vessels made it impossible to directly measure this value. However, the time required to recover varying scopes had been recorded on each vessel and from this it was possible to estimate the recovery speed for each vessel's winches using the data depicted in Figure 3, then use this to predict how much wire had been recovered by the time. liftoff occurred. Subtracting this estimate from the initial scope yielded an estimate of the length of the warps still deployed at the moment of liftoff.

Using this resulting estimate of the scope at liftoff as the straight-line distance (the hypotenuse of the imaginary triangle) between the ship and the trawl, the same approach as described above was used to find the geographic position of the trawl at the moment of liftoff. With estimates of these two positions it was possible to estimate the horizontal distance covered by the trawl, and dividing this distance by the duration of the liftoff lag period yielded an estimate of the trawl's speed of advance.

For each boat, estimates of the liftoff lag distance obtained via the "1998 method" were plotted against those obtained with the "ITI method." Linear regressions were performed on these relationships to determine how well the two techniques corresponded..

Results

During the 1999 West Coast slope survey over 340 sampling tows were carried out. As shown in Table 1 below, valid data from 238 tows were available to analyze by the "ITI method" and from 236 tows by the "1998 method." The trawl performance observations revealed patterns similar to those seen in 1998: there frequently were prolonged intervals during retrieval when the trawls lingered on bottom; the length of such delays tended to increase with depth, and there were systematic differences among the four vessels in this delay/depth relationship (Fig. 1). Records of the trawls' vertical and horizontal openings, confirmed by readings from the bottom contact sensors, showed that during the liftoff lag periods the trawls seemed to remain in roughly the same configuration they had assumed during the actual tow.

Vessel	Length Overall	Rated Horsepower	Number of Tows Analyzed	
			ITI Method	1998 Method
"Miss Leona"	87 ft	850	65	64
"Blue Horizon"	91 ft	675	66	63
"Captain Jack"	75 ft	425	52	51
"Sea Eagle"	88 ft	673	55	58

Table 1. Characteristics of the vessels employed during the survey and number of tows from each vessel's cruise that could be analyzed by the two methods.

Results are graphically depicted in Figures 4, 5, and 6. Figure 4 shows that the distances covered by the trawl during the liftoff lag period were substantial and increased with depth to meet or exceed one kilometer, the approximate "target" tow distance that would be covered in 15 minutes at 2.2 knots, and also shows that this effect varied from vessel to vessel.

A comparison of the distance estimates obtained with the "IT1 method" versus the "1998 method" (Fig. 4) shows that the two techniques yielded similar results. This similarity is further reflected in the plot in Figure 5 and the regression and correlation statistics presented in Table 2 below. Testing the null hypothesis that the two methods would yield exactly the same estimates, (H_0: Slope = 1 .O) it can be seen that they did not exactly agree, although agreement was close.

Vessel	Regression coefficients Slope	Intercept	P-value, H_0: Slope = 1.0	Correlation
"Miss Leona"	0.7950	0.0266	0.0001	0.8825
"Blue Horizon"	0.9289	-0.0366	0.3172	0.8564
"Captain Jack"	1.1444	-0.1226	0.0101	0.9458
"Sea Eagle"	0.7641	0.0261	0.0011	0.8171

Table 2. Results of regression analysis of the distance estimates obtained by the "1998 method" versus those obtained by the "IT1 method," and the coefficient of correlation between the two techniques.

Figure 6 shows that the speed of advance of the trawl during the liftoff lag period was substantial and often exceeded the specified 2.2-knot towing speed. It also demonstrates that these speeds varied systematically from vessel to vessel but that there was no depth-related effect.

Discussion

At the outset it must be noted that these observations were made on a specific set of similar vessels, towing a particular type of trawl under a unique set of circumstances. Different trawl systems operated from other types of vessels under different conditions will perform in a different manner. Nonetheless, while the details of gear performance will doubtless vary it is likely that similar patterns can be observed, or should at least be suspected.

Because the time elapsed during liftoff lag may be a significant portion of the time the net is on bottom, it is important to understand the physical performance of the gear during this interval to facilitate understanding its likely catching performance. If the gear is on bottom, is configured properly, and is moving ahead at or near its normal fishing speed, it is likely to be catching fish. If the net is indeed fishing during this interval then the distance fished during a sampling tow must be adjusted to include this additional time on bottom. Neglecting these effects could lead to serious and systematic overestimates of fish abundance, especially at increasing depths, and the relative impact will increase as the duration of the sampling tows decreases.

This could have contributed to the "catch by surprise" effect postulated by Godø et *al.* (1990). They describe experiments in which it was seen that catch rates during sampling tows for gadoids were at least as high for short tows as for long, and were even higher for the shortest tows. To explain this they proposed that due to fish behavioral responses a trawl's catching efficiency might be highest during the first few minutes of a tow, then drop off to a more steady state as the tow continues. They assumed, based on sonar observations, that the trawl came off bottom immediately at the beginning of haulback, but if this was not the case then the liftoff lag phenomenon described here could have contributed to their observed higher catch rates for shorter tows.

Vessel-to-vessel differences of the magnitude observed here could contribute to an otherwise undetected, but substantial, "vessel effect" which could reduce the accuracy and precision of any survey that ever employs more than one vessel. Alternatively, being able to observe and quantify vessel-specific liftoff lag patterns may prove useful in correcting actual vs. nominal fishing effort and thus help eliminate the impact of vessel effects.

As pointed out above, the impact of liftoff lag on catch quantity and composition depends on the extent to which the trawl is fishing, or is fishing in the same way, during this period. The observed tendency for the gear to traverse the bottom at speeds higher than the standard towing speed has troubling implications for its catching performance. It is possible that the gear's bottom tending characteristics could be affected by these higher speeds, or that its size- and species-specific catching efficiency could otherwise be affected. If any of these possible impacts do actually occur then the impact on survey results will go beyond the difference between actual versus nominal tow duration and/or distance fished. In future efforts we intend to undertake studies of the catching performance of the gear during liftoff lag under various circumstances typical of our survey. These will include more detailed examinations of gear performance during this period as well as ***in situ*** observations of fish behavior and interactions with the gear. If such phenomena are observed and prove to be methodologically or analytically intractable, then it may be necessary to consider other technical measures such as the use of a remotely-operated codend closure system like the "MultiSampler" (Engås et *al.,* 1997) to ensure that the entire sample is captured during a known, discrete sampling period.

There were interesting vessel-to-vessel differences in the relationship between depth and liftoff lag distance. As one might expect, there was a steady increase in distance with increasing depth for the "Miss Leona" and "Captain Jack," but there was a more complex relationship for the "Blue Horizon" and "Sea Eagle." On these vessels, distances increased with increasing depth up to a point, then declined. This can be explained by the dynamics of the towing situation. All four vessels were able to carry just enough towing warp to successfully execute tows at the deepest stations; i.e. the maximum scope the boats could deploy was barely adequate for these depths. During haulback, any increase in the combination of forward thrust applied by the vessel and/or higher trawl winch recovery speed will result in the gear lifting off relatively quickly at these deeper depths. This appears to have taken place with the "Blue Horizon" and "Sea Eagle." On the other hand, the other two boats may not have been applying as much forward thrust and/or their winches were perhaps not as powerful.

There was very good agreement between the estimates of liftoff lag distance obtained by the "ITI method" and the "1998 method." This is particularly remarkable in view of the substantial differences in technology and sophistication and the many assumptions and approximations that had to be employed with the "1998 method." The similarity of the results obtained with these two techniques suggests that a reasonable approximation of the extent of liftoff lag can be obtained without sophisticated trawl positioning systems, so long as a netsounder or other means is available for detecting the moment the trawl comes off bottom. Moving in the other direction, towards increased sophistication and hopefully increased accuracy, we intend in future efforts to fit our ITI system with a flux-gate rate-sensing compass so as to stabilize the heading parameters used by the ITI to calculate trawl position, and thereby obtain better trawl position solutions during haulback and other slow-speed operations.

Liftoff lag is only one of the gear performance issues that can be a potential source of bias or variability in sampling effort. As noted by Wathne (1977) and many others, the gear can arrive on the bottom and potentially start fishing quicker than expected, or alternatively it can fail to settle onto the bottom and into its fishing configuration for substantial periods after it "should" have. Our survey protocols, which relied on real-time observations of the gear's performance to determine the beginning and endpoints of each haul, offered substantial protection from such types of error. However, survey programs that do not employ trawl instrumentation are vulnerable to these effects, and the degree of vulnerability increases as the survey's standard nominal tow duration decreases.

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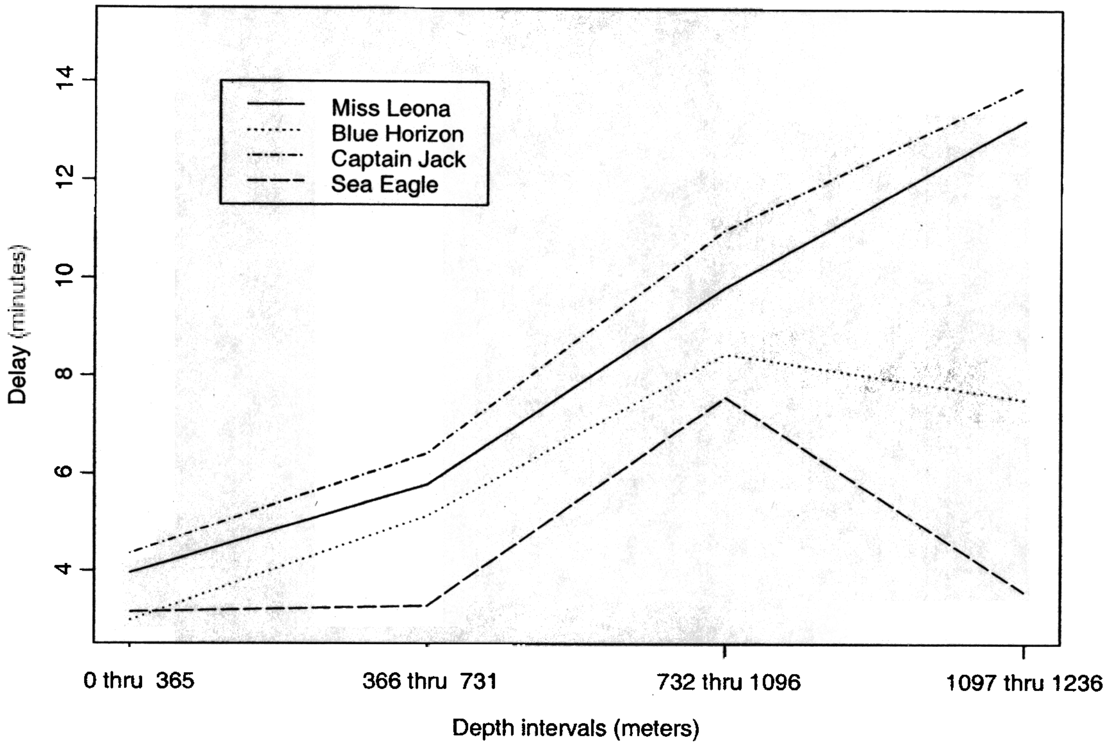

Figure 1. Depth-related mean delay between the initiation of haulback and the moment at which the trawl came off bottom for the four 1999 NWFSC West Coast Slope Survey vessels.

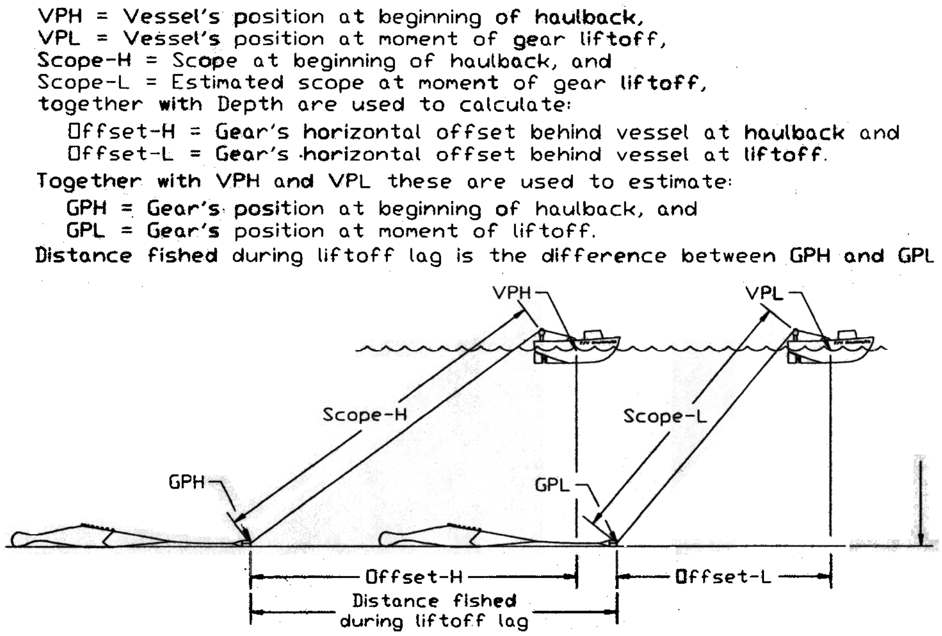

Figure 2. Schematic of the critical geometry and variables used in the "1998 method" (see text) to estimate the trawl's position at haulback and liftoff.

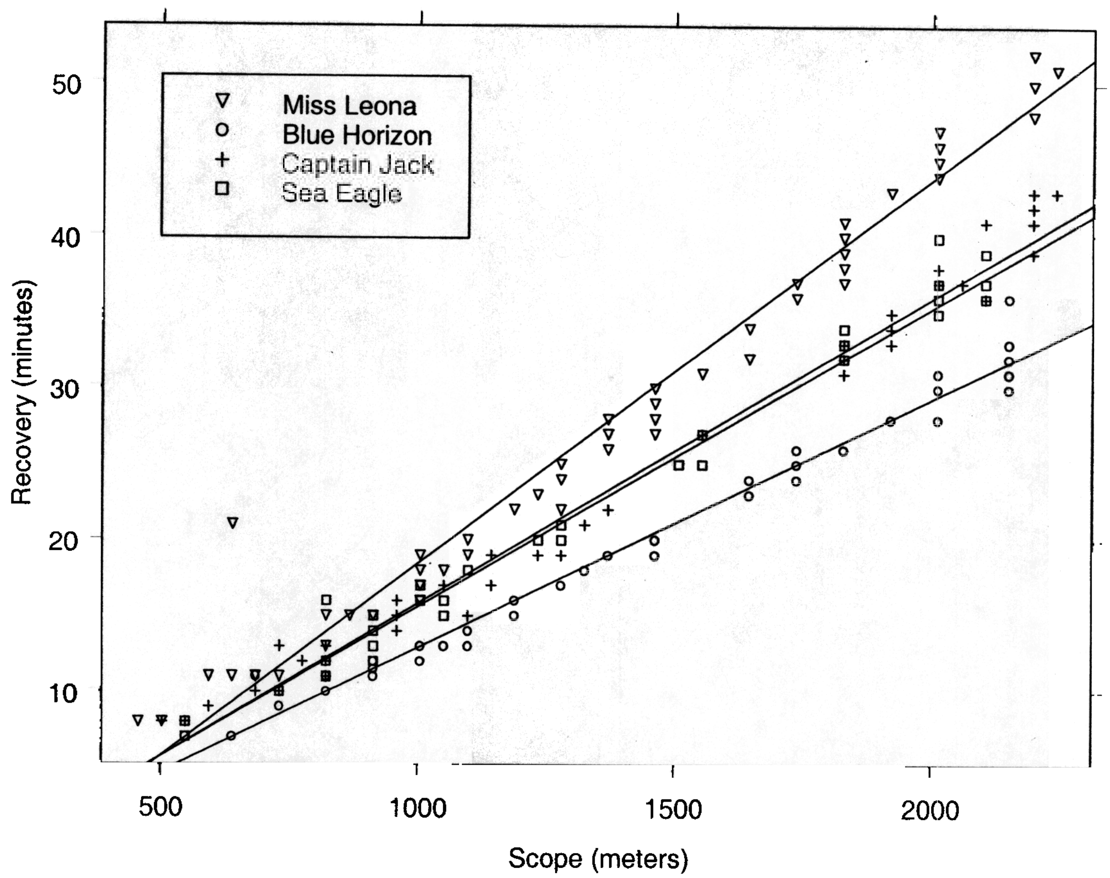

Figure 3. The time required to fully recover the towing warps at varying scopes.

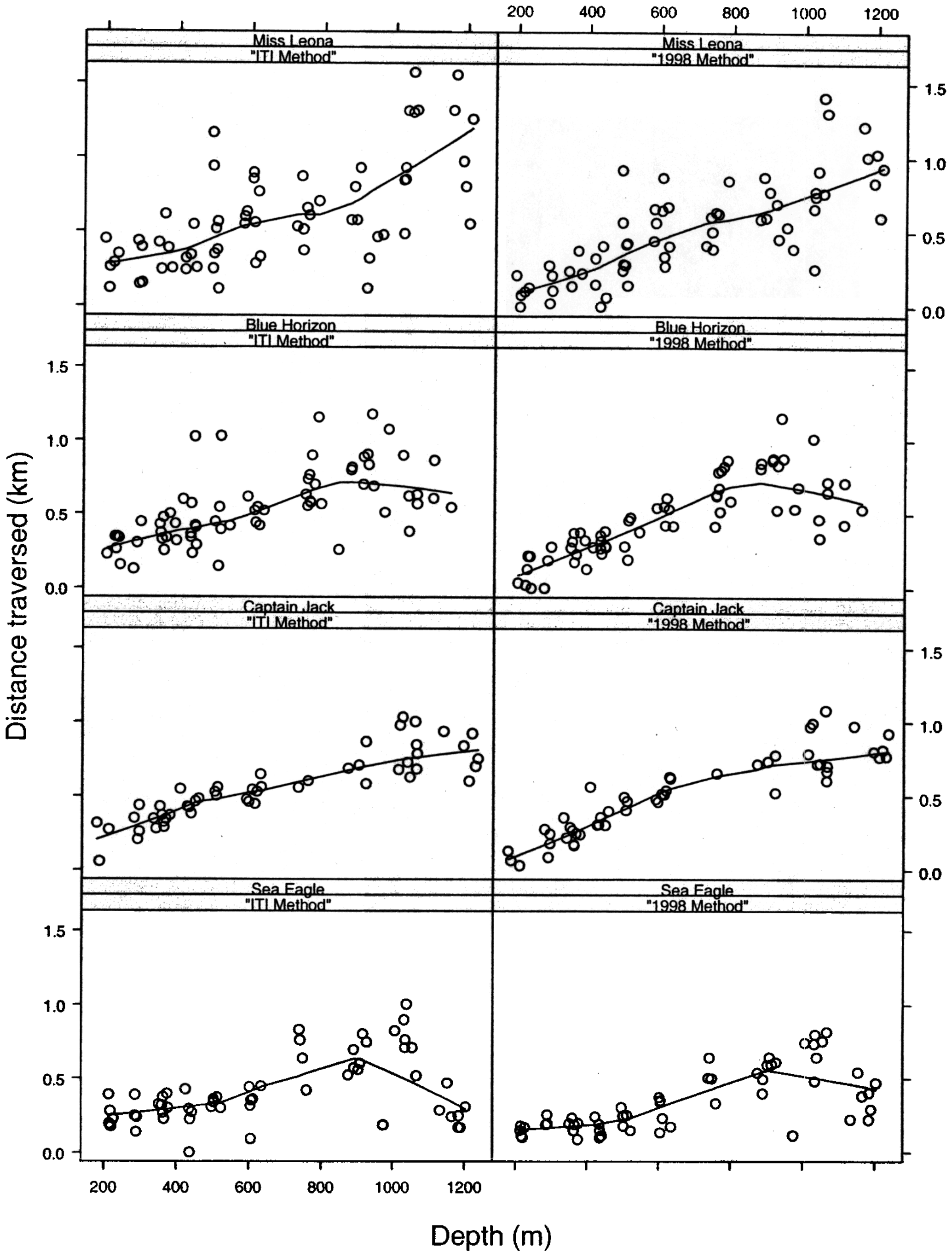

Figure 4. Estimated distance the net moved across the bottom during the liftoff lag period for the four vessels used for the 1999 NWFSC West Coast Slope Survey, calculated by both the "ITI method" and the "1998 method." Lines through the scatterplots were generated by a locally-weighted regression and smoothing procedure (Cleveland, 1979, and Chambers *et al.*, 1983).

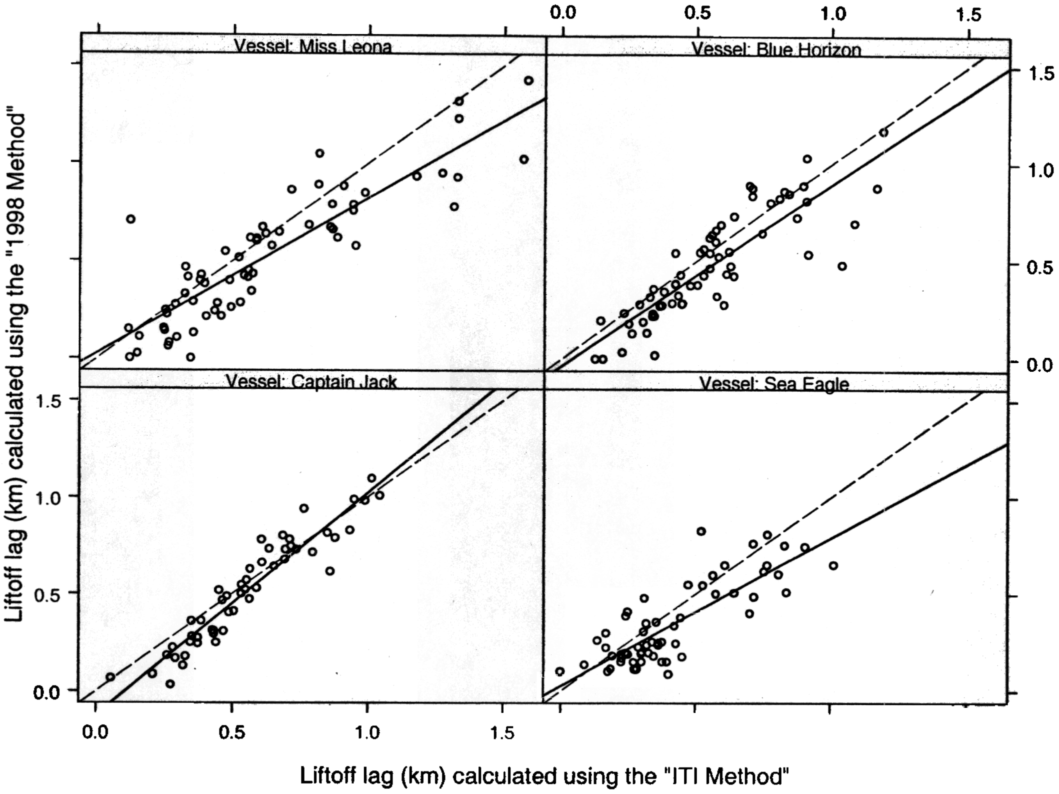

Figure 5. Relationship between the liftoff lag distances estimated with the "ITI method" and the "1998 method." Solid lines represent the linear regression fit to the data while the dashed line represents exact agreement.

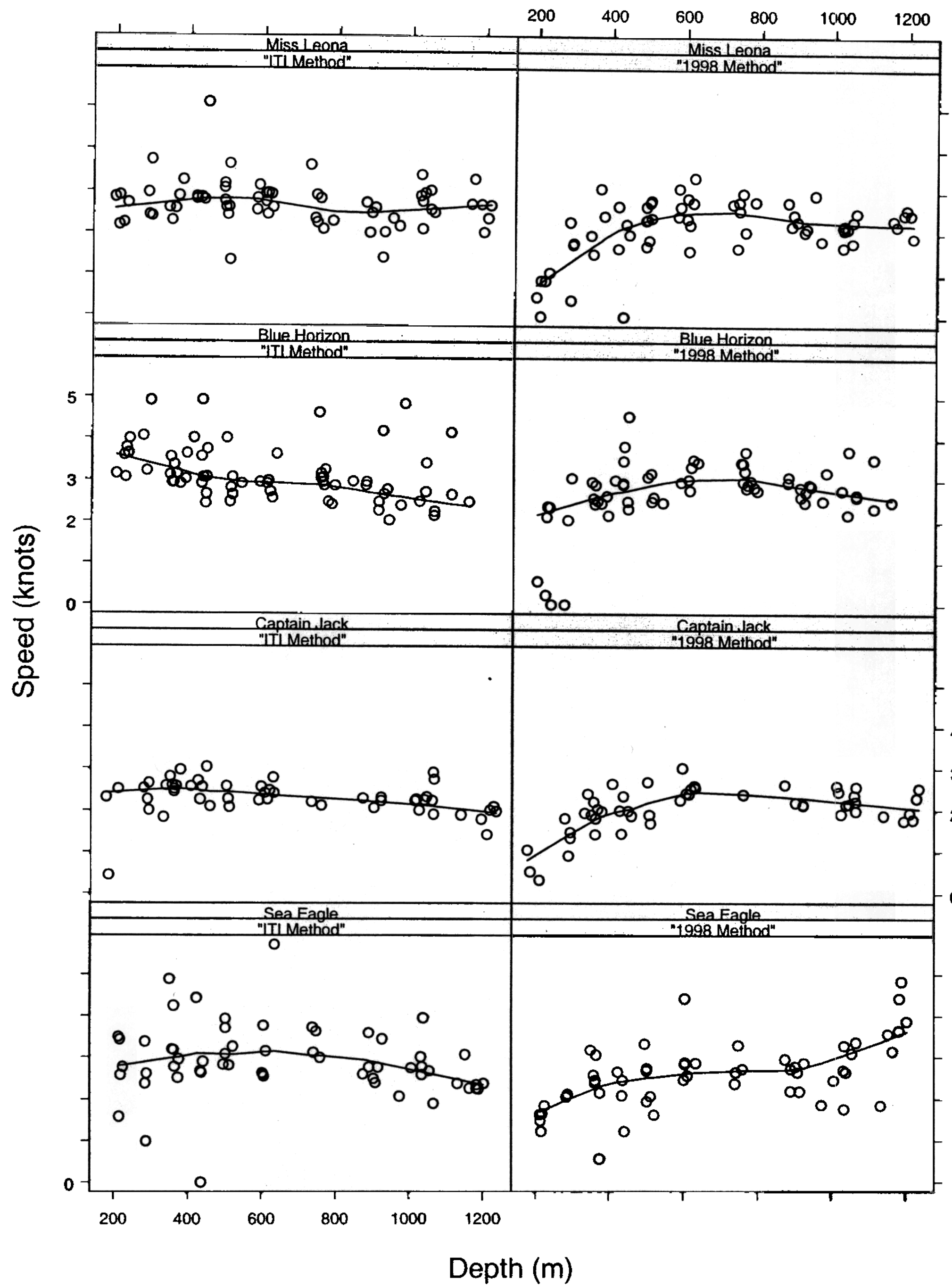

Figure 6. Estimated speed of the trawl's advance across the bottom during the liftoff lag period for the four vessels used for the 1999 NWFSC West Coast Slope Survey, calculated by both the "ITI method" and the "1998 method." The nominal standardized towing speed was 2.2 knots. Lines through the scatterplots were generated by a locally-weighted regression and smoothing procedure (Cleveland, 1979, and Chambers *et al.*, 1983).