# Change in the Performance of a Bering Sea Survey Trawl Due to Varied Trawl Speed

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# Change in the Performance of a Bering Sea Survey Trawl Due to Varied Trawl Speed

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ABSTRACT: An experiment was conducted by the Alaska Fisheries Science Center to study the effect of trawl speed through the water on the footrope bottom-tending performance, and other measures of trawl geometry, of the 83/112 Eastern flatfish trawl used annually in surveys of commercially important eastern Bering Sea crab and groundfish resources. A series of tows was made in one eastern Bering Sea location at vessel speeds (speed over ground) ranging from 2.0 to 5.0 knots at 0.5 knot intervals while simultaneously measuring the speed of the trawl moving through the water. The distance of the center of the footrope above the bottom was measured using an electronic bottom contact sensor. The flatfish trawl gear remained relatively stable as evidenced by only minor increases in measured footrope distances off the bottom with increasing trawl speed. Predicted heights were 1.1 cm at 3 knots, 2.5 cm at 4 knots, and 4.9 cm at 5 knots speed through the water. Footrope distances off the bottom were relatively minor at trawl speeds through waters typically encountered during a Bering Sea survey and likely would have a nominal effect on the capture rates of most commercially targeted semi-benthic fish species. However, variable footrope contact caused by variable trawl speed through the water could potentially introduce unwanted variability in estimates of catch per unit of effort for bottom dwelling fauna such as sculpins, skates, flatfish, red king crab *Paralithodes camtschaticus*, snow crab *Chionoecetes opilio*, and Tanner crab *C. bairdi*. Survey scientists might better control the variability in catch per unit of effort estimates caused by varying trawl efficiency by lending attention to local current conditions. One improvement to surveys may well be standardizing towing speed to trawl speed through the water.

## INTRODUCTION

The eastern Bering Sea (EBS) supports several of the largest and most valuable fisheries in the United States. Recommended annual guideline harvest levels for EBS flatfish and crab resources are influenced by the previous summer's catch per unit effort (CPUE) estimates of relative abundance obtained from the annual Alaska Fisheries Science Center (AFSC) bottom trawl survey (Otto 1986). The precision of these estimates is a function of not only the variability in animal density between sampling sites, but also the variability in the sampling efficiency of the trawl (Dickson 1993).

Clearly, standardization of survey methodologies, fishing gear, and fishing protocol help to improve the precision of CPUE estimates by reducing some of the variability associated with the sampling efficiency of the trawl. However, the effect of uncontrollable environmental variables such as changing substrate, sea surface conditions, and local currents on trawl efficiency is less understood. For example, prevailing currents and tidal flows impact the speed of a trawl passing through the water (trawl speed through the water) which can lead to fluctuations in fishing efficiency by varying the trawl geometry (Fridman 1986), footrope contact (Somerton and Weinberg 2001), capture retention (Dahm et al. 2002), and fish swimming speed and endurance (Winger et al. 1999). Of these, inconsistent footrope contact, which provides animals with an opportunity for escape, is likely to most affect EBS crab and flatfish assessments, because survey trawl geometry is measured acoustically and mathematically accounted for; a fine-mesh liner retains catch in the cod end (codend); and the 3.0 knot (1.5 m/sec) target vessel towing speed (speed measured over ground by global positioning system, GPS) used by the AFSC is sufficient to overtake flatfish and crabs of all sizes.

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Previous studies conducted on snow crab *Chionoecetes opilio*, Tanner crab *C. bairdi* (Somerton and Otto 1999) and several flatfish species from the EBS (Munro and Somerton 2002) have shown that escapement underneath the footrope of the 83/112 Eastern bottom trawl, the AFSC trawl used in EBS groundfish assessment surveys, can vary by species, size, and sex. Although avoidance behavior in response to stimuli produced by the footrope is a primary determinant of escapement, for strict bottom dwellers such as sculpins, skates, crabs, and flatfishes, a major contributing factor is the continuity of bottom contact or the distance of the footrope from the bottom (Weinberg et al. 2002).

The effect of varying trawl speed through the water on trawl performance is likely to be gear specific. The bottom-tending characteristics of a different survey bottom trawl, the poly Nor'eastern, used by the AFSC for Gulf of Alaska (GOA) groundfish assessment surveys, was studied by Somerton and Weinberg (2001). They concluded that the footrope of the poly Nor'eastern trawl best tended the bottom at a trawl speed through the water just under 3.0 knots, and as trawl speed increased the center of that footrope lifted off the bottom. At speeds through the water in excess of 4.5 knots, the equivalent of towing into a strong current, the footrope was estimated to have lifted off the bottom by as much as a meter. These findings prompted a concern that the footrope of the EBS survey trawl may also be negatively impacted by increasing trawl speed through the water, thus affecting sampling efficiency and the precision of EBS survey estimates.

The 83/112 Eastern bottom trawl used in the soft substrate surveys of the EBS is constructed very differently than the poly Nor'eastern trawl used in the hard substrate GOA surveys. The 83/112 Eastern bottom trawl is a low-rise flatfish trawl equipped with a bobbin-less footrope designed to exert downward pressure, making it resistant to the environmental influences on bottom contact (see Nebenzahl 2001 for net plan). However, because relatively strong tidal currents are common throughout the EBS shelf and vessel operators can potentially exceed the standard 3 knot, speed over ground, vessel towing speed, there exists a potential for the footrope to lift. I report the findings of an experiment conducted to determine whether bottom contact of the EBS bottom trawl footrope varied sufficiently with trawl speed through the water to warrant consideration to standardizing survey towing speed over ground to trawl speed through the water as a means to reduce between-sample variability.

## MATERIALS AND METHODS

### Description of trawl gear

The 83/112 Eastern trawl used in AFSC's annual crab and groundfish assessment surveys of the EBS is a two-seam flatfish trawl with a 25.3-m (83-ft) long headrope and a 34.1-m (112-ft) long footrope designed without rollers or bobbins, thus enabling 100% contact with the bottom. The footrope is approximately 5.2 cm in diameter, and consists of 34 kg of 1.6-cm diameter, fiber-core galvanized wire that has been wrapped for protection with a layer each of polypropylene rope and split rubber hose (Figure 1). A 52.4-m long, 0.8-cm galvanized chain weighing 75 kg is hung in loops to the footrope by seizing every 10$^{th}$ link (roughly every 30.5 cm) at 20.3 cm intervals from which the lower edges of the wing and throat webbing are hung. The trawl is constructed of 10.2-cm (stretched-mesh) nylon mesh netting throughout the wings and throat, and 8.9-cm nylon mesh in the intermediate and codend. An additional 3.2-cm nylon mesh netting lines the codend. Each side of the trawl is attached to a 1.8 m by 2.7 m steel V-door, which weighs 816 kg, by a pair of 54.9-m long, 1.6-cm diameter, galvanized wire dandylines. A 0.6-m long chain extension is inserted between the lower dandyline and the footrope as set-back to facilitate bottom contact.

### Experimental design

The experiment was conducted May 21–25 prior to the onset of the 2001 annual Bering Sea bottom trawl survey aboard the 40-m long stern trawler F/V *Aldebaran*. The F/V *Aldebaran* has been used on this survey since 1993. Trawling operations were located in the EBS in the vicinity of lat 55° 05' N, long 165° 08' W at a depth of 113 m. This region is characterized by a smooth, mildly sloping sea floor consisting of mud and sand. During each tow, vessel speed over ground and position were measured at 2 s intervals with GPS. Trawl wing spread (wingtip to wingtip) and headrope height were measured at 5 s intervals with a Netmind acoustic net mensuration system. Most tows were made in either a northerly or southerly direction, similar to most standard survey tows. All tows were made with the winches locked using 366 m of warp, consistent with survey standards for tows at this depth. Also, all tows were made with the codend open to eliminate any effect due to catch.

Trawling operations commenced with several trial tows in which the vessel operator set the trawl on the bottom and focused on stabilizing vessel speed over

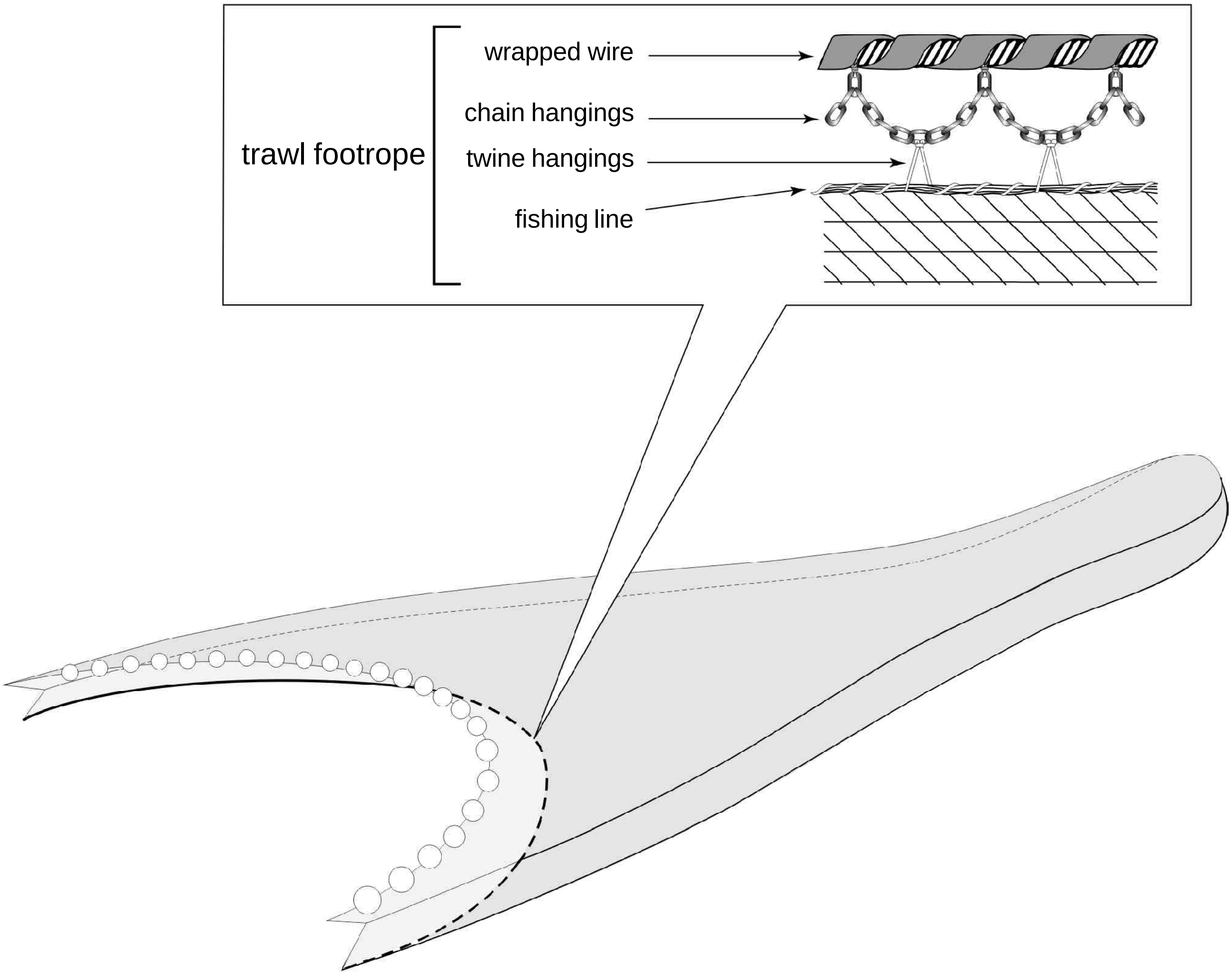


Figure 1. The 83/112 Eastern bottom trawl with small diameter footrope.

ground for several minutes at 0.5 knot increments. The actual experiment commenced once the vessel operator was familiar with the necessary engine speed and variable pitch propeller settings required to achieve the planned experimental tow speeds. Experimental tows consisted of repetitive towing whereby vessel speed was maintained constant for a 10 min period at each of up to seven GPS-determined target speeds (2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 5.0 knots, speed over ground). Most experimental tows spanned the 2.5 to 4.5 knot range, speed over ground; a few included the 2.0 or 5.0 knot limit. Shifting between stable speed increments often required several minutes of throttle adjustment by the vessel operator.

Trawl speed through the water was measured at the center of the headrope with two instruments: a NOBSKA, 3-axis, self-recording modular acoustic velocity oceanographic current meter (model MAVS-2; henceforth referred to as MAVS) and a Scanmar, 2-axis, acoustically-linked grid sensor designed for commercial fishery use. The MAVS, with rated accuracy to 0.006 knots, was placed outside the trawl and was programmed to sample trawl speed at 3 s intervals. The grid sensor, with rated accuracy to 0.1 knot, was mounted just inside the trawl and sampled trawl speed at 24 s intervals. Both units were mounted on identical 0.9 m by 0.6 m plastic plates that attached directly to the headrope. Headrope floats normally positioned in front of the current meters were moved aside to reduce interference caused by water turbulence.

Measuring the distance of the center of the footrope to the sea floor was achieved using a self-contained bottom contact sensor developed at the AFSC, which consisted of a watertight, stainless steel container housing an inclinometer, and a digital logger set to measure and record tilt angles from 0° to 90° in roughly 0.5° increments at 1 s intervals (Somerton and Weinberg 2001). The bottom contact sensor was sheathed in a protective 10.2-cm diameter, stainless steel pipe. For this study, attachment to the trawl footrope required the fabrication of a metal collar welded to the forward end of the bottom contact sensor that clamped around the center of the 5.2-cm diameter footrope so that the unit was oriented perpendicular to the footrope and pivoted freely about its horizontal axis. Bottom contact of the trailing end of the sensor was visually determined using a trawl-mounted, underwater video camera system. The overall length and dry weight of the bottom contact sensor unit was 40 cm and 8.0 kg. Changes in recorded tilt angles corresponded directly to variations in footrope distance from the bottom. The calibration of tilt angle to distance off the bottom was performed on land by first obtaining the tilt angle when the bottom of the collar was in contact with a hard level surface, representing contact with the sea floor (Figure 2). Subsequent tilt readings were obtained by raising the collar, representing loss of contact with the sea floor, and measuring its distance to the hard surface. The calibration data was then fit with a regression-based model.

## Data analysis

Measured values of net height, wing spread, MAVS trawl speed, grid sensor trawl speed, and tilt angle were averaged over the time interval of each target speed.

Figure 2. Calibration experiment for determining footrope distances off the bottom based on the electronic bottom contact sensor tilt angle readings.

The relationship between the measured distance of the footrope off the bottom and the tilt angle measured by the bottom contact sensor was estimated using regression from the calibration experiment data. The average value of the distance off the bottom for each time interval was determined by applying the estimated function to the mean value of tilt angle.

The MAVS oceanographic current meter was primarily used to estimate the trawl speed through the water. For trial tows lacking MAVS speed data, MAVS speed was predicted from grid sensor speed with a linear function determined by regressing MAVS speeds on grid sensor speeds for all tows where both types of data were collected.

Analyses of the footrope distance off the bottom as a function of trawl speed through the water commenced with a visual examination of the data. The error associated with the data appeared to be multiplicative, necessitating log transformation to linearize the model. A functional relationship between footrope distance off the bottom and trawl speed through the water was estimated with regression. In order to increase sample size at target speed intervals in which there were few data points, I examined the feasibility of combining the initial trial tow data, in which trawl speed through the water had to be estimated from the Scanmar grid sensor, into the analyses. To determine if the functional relationships differed between trial and experimental tows, the following test was performed. First, separate regressions were performed on both the log-transformed trial tow data and the log-transformed experimental tow data. Second, the residual sum of squares from the combined model was compared to that of the sum of the individual models using an F-test (p. 304, Zar 1984). Significance of this test indicates that the two data sets are different and can not be combined.

Additional information was analyzed for continuity in bottom contact from 69 standard survey tows from the 2001 annual Bering Sea survey, and for trawl speed through the water from 40 tows made in the EBS where the vessel operator was instructed to tow at the survey standard 3 knot speed over ground. These 40 tows were a combination of experimental tows and tows from a resample exercise for red king crab *Paralithodes camtschaticus* performed during 2000 in which either the MAVS or the grid sensor were deployed. For cases in which only the grid sensor was used, grid sensor speeds were converted to MAVS speed in the manner described above. Proper functioning of the bottom contact sensor during the resample of red king crab stations was ascertained through direct observations using a video camera attached to the trawl.

Table 1. Summary of the number of tows that produced valid trawl mensuration data by vessel target towing speed (speed over ground).

| | Target towing speed (knots) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 |
| Footrope contact | 2 | 18 | 16 | 15 | 15 | 12 | 4 |
| Wing spread | 2 | 11 | 12 | 9 | 8 | 8 | 1 |
| Headrope height | 2 | 12 | 12 | 10 | 10 | 9 | 3 |

## RESULTS

Six trial tows and 16 experimental tows were completed in which footrope contact, wing spread, and headrope height data were collected for one or more target speed intervals (Table 1). Video camera observations of the bottom contact sensor were obtained on all but three tows. However, on many of these tows, particularly at higher towing speeds, the field of view shifted slightly to portside of center, losing the image of the bottom contact sensor. In these instances, contact of the bottom sensor with the sea bed was inferred from visual estimation of the footrope height within the new field of view, and the comparison of observed tilt angles to tilt angles from other tows when the video camera confirmed sensor contact. During five tows, when sampling the 2.0 or 2.5 knot target speed, thick mud clouds obscured the video camera's field of view. Mud clouds coupled with lower than expected wing spreads and higher than expected headrope heights suggests that one or both trawl doors may have fallen over.

Tilt angles measured at sea ranged from 52.0° to 82.6°. Estimated distances off the bottom were predicted from these angles by the quadratic function:

$$\text{distance}=32.805-0.5836(\text{angle})+0.0023(\text{angle}^2);\ (n=18,\ R^2=0.999;\ \text{Figure 3}).$$

To determine whether trial tow and experimental tow data sets could be combined for use in predicting the functional relationship of footrope distance off the bottom as a function of trawl speed through the water, MAVS speed was estimated from grid sensor data during trial tows when the MAVS was not deployed. The functional relationship between MAVS and grid sensor speed was estimated linearly as:

$$\text{speed}_M=0.3165+1.1057(\text{speed}_{GS});\ (n=57,\ R^2=0.992),$$

and the parameters applied to mean grid sensor data to estimate MAVS speed (Figure 4).

The relationship of footrope distance off the bottom to trawl speed through the water was determined by first fitting separate parabolas to both the trial and the experimental tow log-transformed data sets, then using an F-test to determine if the models differed. Results of the F-test were non-significant ($F$=0.99, $P$=0.62, df=2, 78) allowing for the pooling of the separate data sets which were subsequently fit with the model:

$$\text{distance}=0.0432\ (\text{speed}^{2.94});\ (n=82,\ R^2=0.86)$$

to describe footrope distance off the bottom as a function of trawl speed through the water. Footrope distances off the bottom increased at an accelerating rate with trawl speed through the water (Figure 5). Measured footrope distances off the bottom ranged from 0.3 to 8.7 cm over a 2.4 to 5.7 knot range of trawl speeds through the water. Predicted footrope distance from the bottom was 1.1, 2.5, and 4.9 cm at trawl

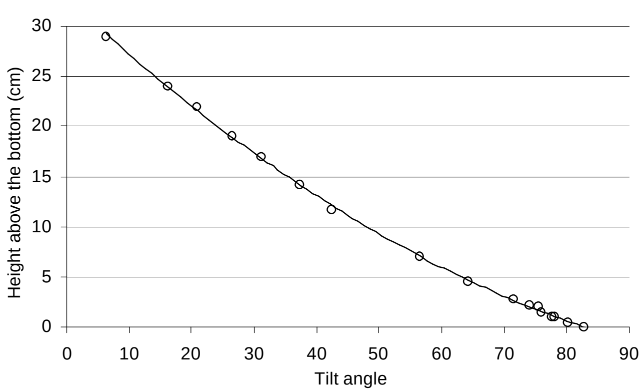


Figure 3. Calibration curve describing the functional relationship between the bottom contact sensor tilt angle and the estimated footrope height above the bottom.

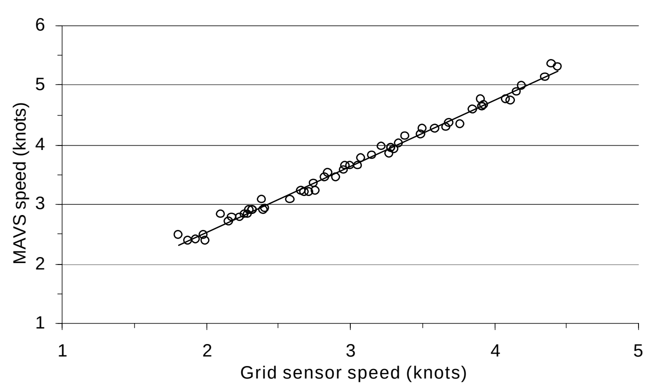


Figure 4. Regression analysis of trawl speed through the water as measured by the modular acoustic velocity (MAVS) oceanographic current meter and the Scanmar grid sensor.

speeds through the water of 3, 4, and 5 knots, respectively.

Trawl aperture also varied as a function of trawl speed through the water. Wing spread measurements were generally lowest at trawl speeds under 2.8 knots, highest around 3 knots, then narrowed with increasing speeds through the water (Figure 6). One or both trawl doors falling over was suspected of causing wing spreads under 13 m and excessive mud clouds suggesting a low-end trawl speed threshold for the 83/112 Eastern trawl. High headrope height measurements ranging between 2.9 and 3.8 m were also observed at trawl speeds through the water under 2.8 knots before stabilizing at about 2.2 m in height for all faster trawl speeds (Figure 7).

## DISCUSSION

Using an underwater video camera and a bottom contact sensor, adapted to measure footrope departures from the seabed, shows that changes in trawl speed through the water produce small changes in the bottom-tending performance of the 83/112 Eastern trawl which is used by the AFSC Bering Sea crab and groundfish surveys. Footrope contact was best at trawl speeds through the water just under 3 knots, when the estimated mean footrope distance off the bottom was a nominal 1.1 cm. At greater trawl speeds through the water, the footrope increasingly rose off the bottom. The model predicted a 7.2-cm footrope distance off the bottom for the experiment's maximum 5.7 knot trawl speed through the water, a speed comparable to towing at a 3 knot vessel speed over ground into a 2.7 knot current. Most EBS survey stations are subjected to current velocities under 1 knot, but Kowalik (1999) reports stronger currents, in excess of 2 knots, do occur in isolated nearshore areas.

Unfortunately, trawl speed through the water and bottom contact sensor data have not been collected simultaneously during standard EBS survey tows, negating direct comparison of experimental results to observed survey conditions. However, I reviewed data

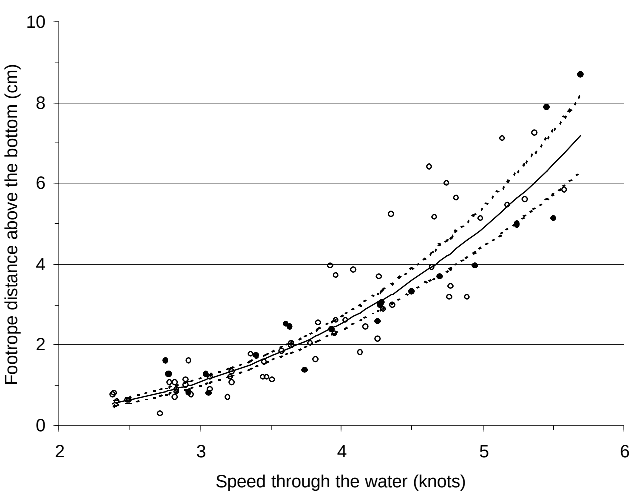


Figure 5. Estimated distance of the center of the 83/112 Eastern trawl footrope above the bottom as a function of trawl speed through the water. Circles represent experimental tows in which the trawl speed through the water was measured by the modular acoustic velocity (MAVS) oceanographic current meter. Dots represent trial tows in which the MAVS trawl speed through the water was estimated from the Scanmar grid sensor. Dashed lines represent the 95% confidence bounds about the mean.

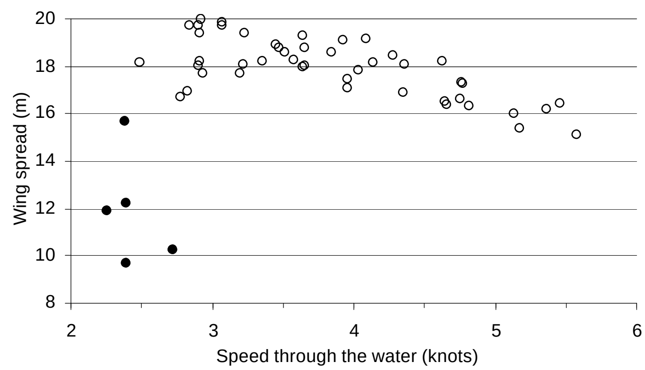


Figure 6. Trawl wing spread as a function of trawl speed through the water. Circles represent good performance tows, dots represent tows in which a trawl door was suspected to have fallen over.

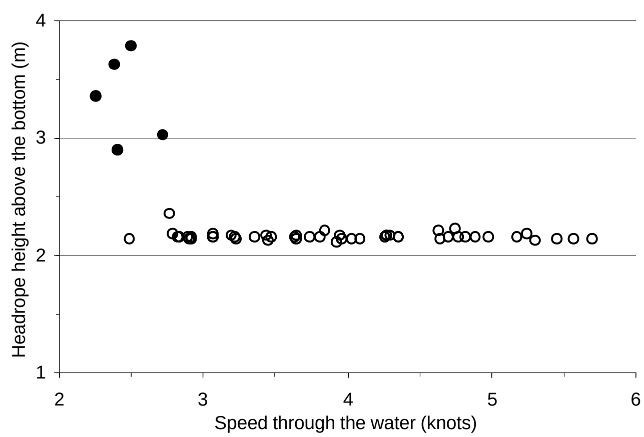


Figure 7. Trawl headrope height above the bottom as a function of trawl speed through the water. Circles represent good performance tows, dots represent tows in which a trawl door was suspected to have fallen over.

from 40 tows in which trawl speed through the water data were collected during AFSC experiments conducted in the EBS. Although the experienced vessel operator was instructed to maintain a 3 knot, speed over ground, vessel towing speed, mean trawl speeds through the water ranged from 2.8 to 3.7 knots. This information suggests that during standard survey tows, trawl speeds through the water will vary as a result of how the vessel is operated or the influence of currents, or both, and cause the center of the trawl footrope to lift. My findings also help to interpret the data collected during the first leg of the 2001 EBS survey. The same bottom contact sensor, attached to the footrope in nearly the same manner, was deployed in 69 standard survey tows made without the benefit of a current meter or video camera on the trawl. Based on the calibration experiment, the bottom contact sensor tilt angles indicated that 20 of the 69 tows (29%) had mean footrope distances off the bottom of 1 cm or less, 32 tows (46%) ranged from 2 to 3 cm, 15 tows (22%) ranged from 4 to 7 cm, and 2 tows (3%) had mean distances off the bottom greater than 7 cm (Figure 8). Several, but not all of the tows with greater recorded distances off the bottom, occurred in areas exposed to higher current levels (Kowalik 1999; Pearson et al. 1981). For those tows made in areas not known for high current, yet bottom contact sensor tilt angles suggested appreciably high footrope distances off the bottom, I suspect normal operation of the bottom contact sensor had been altered, perhaps by entanglement in benthic debris or invertebrate fauna, as sometimes observed in videotape segments. Studies on factors other than changes in speed through the water and their effect on the bottom contact sensor are still in progress.

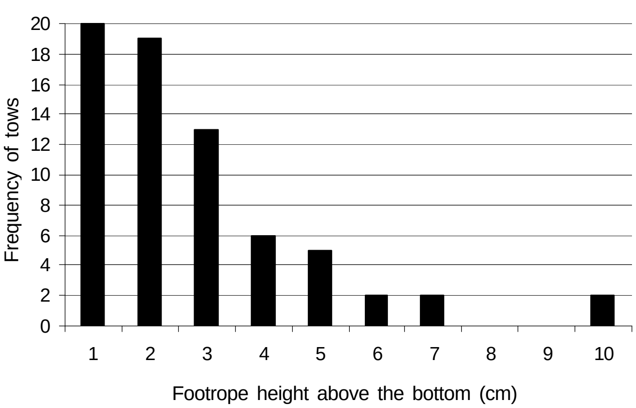


Figure 8. Frequency of estimated footrope center distances off the bottom from 69 standard survey tows made in Bristol Bay during the 2001 annual Alaska Fisheries Science Center bottom trawl survey of Bering Sea resources.

The annual EBS survey of crab and groundfish resources has been conducted since 1971 by the AFSC. In 1982, the survey switched sampling trawls from a smaller 400-mesh Eastern to the standardized 83/112 Eastern trawl. This changeover was preceded by a series of tows used to adapt the trawl gear to "best" tend bottom as defined by the presence of benthic fauna in the trawl catch (Bakkala 1993). The trawl gear adaptations were performed in the absence of trawl mensuration or underwater video camera observations. Since then, no further changes have been made to the survey trawl gear, and for stock assessment purposes, the trawl was considered to catch 100% of the invertebrates and bottom-dwelling fish species within its path.

Although the footrope distances off the bottom found in this experiment appear slight, for bottom-dwelling animals such as crab and flatfish, they are sufficient enough to afford escape opportunities and partially explain the lower than 100% capture probabilities reported by Somerton and Otto (1999) and Munro and Somerton (2002). Video camera observations made during a station resampling exercise in 2000 showed significant escapement for both sexes of adult red king crab occurring beneath the 83/112 Eastern trawl during tows when the footrope distances off the bottom were visually estimated to be comparable to those obtained in the present experiment. For this large, commercially important crab species, as well as for other benthic organisms, the relationship between footrope height and point of contact with the body could be crucial in the catch process.

Environmentally-induced changes in survey trawl speed through the water are difficult to control when monitoring only vessel speed (speed over ground). Since changes in trawl speed through the water affect both trawl geometry and footrope contact with the seabed, survey precision is likely to be negatively impacted. While variable path width is monitored with trawl mensuration gear and mathematically accounted for in the computation of survey effort, variable footrope lift caused by the trawl moving through the water at variable speeds is not. Weinberg et al. (2002) has demonstrated a trawl's catchability of benthic fish species is reduced as increasing trawl speeds through the water lifts the footrope off the bottom. Reduced catches of Bering Sea crab species is also likely to occur as the distance of the footrope from the bottom increases. It therefore follows that standardizing survey towing speed to a trawl speed through the water in which bottom contact is optimized would help to reduce variability in CPUE estimates due to variability in trawl catch efficiency at the footrope.

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