The effect of autotrawl systems on the performance of a survey trawl

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Abstract—Three aspects of a survey bottom trawl performance—1) trawl geometry (i.e., net spread, door spread, and headrope height); 2) footrope distance off-bottom; and 3) bridle distance off-bottom—were compared among hauls by using either of two autotrawl systems (equal tension and net symmetry) and hauls conducted with towing cables of equal length and locked winches. The effects of environmental conditions, vessel heave, crabbing (i.e., the difference between vessel heading and actual vessel course over ground), and bottom current on trawl performance with three trawling modes were investigated. Means and standard deviations of trawl geometry measures were not significantly different between autotrawl and locked-winch systems. Bottom trawls performed better with either autotrawl system as compared to trawling with locked winches by reducing the variance and increasing the symmetry of the footrope contact with the bottom. The equal tension autotrawl system was most effective in counteracting effects of environmental conditions on footrope bottom contact. Footrope bottom contact was most influenced by environmental conditions during tows with locked winches. Both of the autotrawl systems also reduced the variance and increased the symmetry of bridle bottom contact.

Autotrawl systems proved to be effective in decreasing the effects of environmental factors on some aspects of trawl performance and, as a result, have the potential to reduce among-haul variance in catchability of survey trawls. Therefore, by incorporating an autotrawl system into standard survey procedures, precision of survey estimates of relative abundance may be improved.

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Bottom trawl survey operating procedures are standardized in order to reduce the variability of catch per unit of effort (CPUE) estimates. Many of the current standardization procedures address the efficiency of the trawl gear and the maintenance of constant catchability among samples and over time. Despite these efforts, variability in trawl catchability can be exacerbated by uncontrollable environmental conditions. Variables such as surface and bottom currents, sea state, wind direction, varying substrate types and inclinations, and depth of tow may all contribute to differences in gear efficiency by influencing the area swept by the net (Rose and Nunnallee, 1998), the herding efficiency of the bridles (Somerton and Munro, 2001; Somerton, 2003), and escapement beneath the footrope (Weinberg et al., 2002).

Many bottom trawl surveys conducted by the National Marine Fisheries Service, such as the Alaska Fisheries Science Center's (AFSC) eastern Bering Sea (EBS) shelf survey, operate with trawl winch brakes, set or locked, and tows are made with equal amounts of towing cable (warp) on both sides of the vessel. Other than by controlling towing speed and direction, these surveys are unable to compensate for changing environmental conditions. In contrast, autotrawl systems are widely used by the commercial fleet and are purported to improve fishing performance by stabilizing trawl geometry over varying environmental conditions, such as rough weather when vessel heave produces an upward lift on the trawl door resulting in loss of ground shear and wing spread, or over rough bottom when doors and nets have a greater probability of snagging. If autotrawl systems are able to reduce some of the variability in gear efficiency that is due to environmental variability, such as sea state and currents, then including the use of autotrawl systems as a standard survey bottom trawl procedure may improve the precision of survey results.

In simple terms, autotrawls are dynamic systems that operate on the principle of ensuring that the trawl is being towed in a direction perpendicular to the center of the footrope and headrope in order to optimize its performance. We are aware of two styles of autotrawl systems currently marketed. The first is a tension-controlled system that reacts to the difference in warp tension between winches by equalizing hydraulic pressure (equal tension). When the tension on either side exceeds that of the other side (a user-defined threshold) due to factors such as increased drag, currents, sediments, or steep slopes, the system lengthens that warp to equalize the pressure between the two winches. Conversely, when the tension decreases on one warp, the system compensates by shortening that warp to equalize pressure between the two winches. The second autotrawl style is a symmetry-controlled system that actively adjusts warp length in response to cross flow signals from a sensor mounted on the trawl headrope. This system operates on the principle that net skewing can be caused by a crosscurrent. If the net is pulled square to the direction of flow then, its geometry will be symmetrical and trawl performance will be optimized.

In the late summer of 2003, the AFSC conducted an experiment to examine the effect of these two types of autotrawl systems on the geometry of a survey trawl, comparing them to towing with equal amounts of warp on each side with the winches locked. The study considers three aspects of trawl performance: 1) the factors of trawl geometry influencing the area and volume swept by the trawl (door spread, wing spread, and headrope height); 2) the bottom-tending performance of the footrope; and 3) the bottom-tending performance of the lower bridles.

Materials and methods

Operations and instrumentation

The experiment was conducted during 19–25 September 2003 aboard the chartered 38-m-long commercial stern trawler FV *Vesteraalen* on smooth, relatively level bottom in 115 m of water at a site approximately 70 km north of Unimak Pass in the Bering Sea (55°10′N, 166°15′W). The *Vesteraalen* is powered by a single 1725-hp engine and is equipped with split Rapp Hydema (Rapp Hydema AS, Bodø, Norway) trawl winches carrying 2.5 cm (1″) diameter, compacted, solid-core trawl warp. The winches are controlled by a Scantrol 2000 (Scantrol, Bergen, Norway) winch control system capable of quickly switching to different towing modes as requested by the vessel operator. For this experiment towing was performed with the codend open and with three different winch control modes: locked winches with equal amounts of warp on the port and starboard side (locked); a tension-controlled autotrawl, which maintains equal tension on both warps by adjusting warp length based on the drag forces on each side (tension); and a symmetry-controlled autotrawl, which adjusts warp length according to side current forces in order to "optimize" water flow through the net (symmetry). The symmetry-controlled system requires a real-time speed sensor capable of detecting the direction of water flow across the headrope. We used an acoustically linked Scanmar (Scanmar, Asgardstrand, Norway) trawlspeed sensor that transmits flow data at 24-sec intervals both perpendicular and tangential to the headrope at its center. For this experiment and when in symmetry mode, the Scantrol system adjusted warp length at 30-sec intervals in response to changes in tangential velocity.

The experiment was conducted with the AFSC standardized trawl for the EBS shelf survey, the 83-112 Eastern bottom trawl. The 83-112 Eastern is a low-rise, 2-seam flatfish trawl designed to fish on smooth, soft bottom. The nylon net is constructed of 10.1-cm stretch mesh in the wing and body, 8.9-cm mesh in the intermediate, and double 8.9-cm mesh lined with

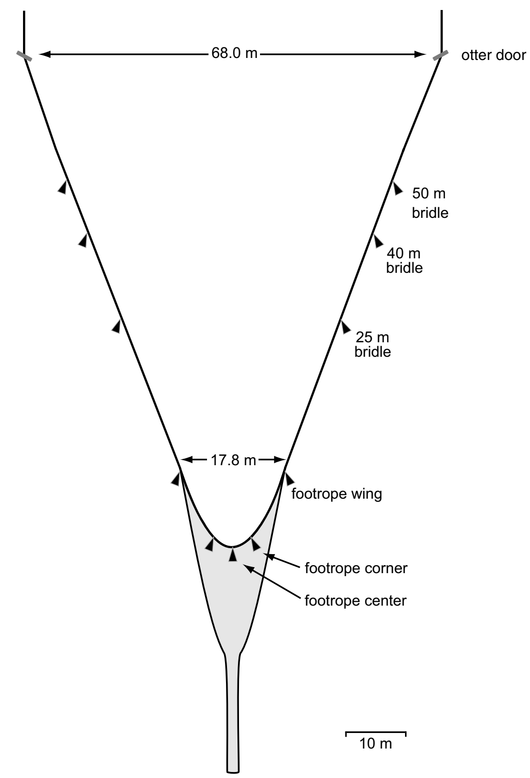


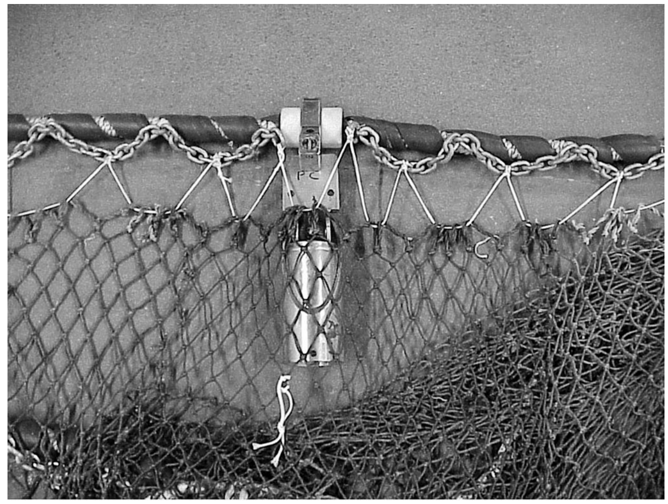
Figure 1
Schematic diagram of the 83-112 Eastern bottom trawl and rigging shown from above. Mean door spread (68.0 m) and mean wing spread (17.8 m) were calculated from experimental tows made at a depth of 115 m with the winches locked and 366 m of trawl warp out on each side. Bottom contact sensor units, shown as oversized triangles along the bridle and footrope, are labeled by position, as discussed in the text.

3.1-cm mesh in the codend. It is towed behind a pair of 1.8×2.7 m steel "V" doors, weighing approximately 816 kg apiece, which are attached to the net by two 3-m-long, 1.6-cm long-link chain door legs, a 12.2-m-long, 1.9-cm diameter stranded-wire door leg extension, and a pair of 55-m-long, 1.6-cm diameter bare stranded-wire bridles on each side (Fig. 1). The 25.5-m-long (83 feet) headrope has forty-one evenly spaced, 20.3-cm diameter floats providing 116.4 kg of total lift. The 34.1-m-long (112 feet), 5.2-cm diameter footrope is constructed of 1.6-cm diameter stranded-wire rope that is protected with a single wrap of both 1.3-cm diameter polypropylene line and split rubber hose. The footrope is weighted with 51.8 m of chain (0.8-cm proof-coil) attached at every tenth link, forming 168 loops to which the netting is hung. An additional 0.6-m-long, 1.3-cm long-link chain extension connects each lower bridle to the trawl wing tips to help keep the footrope close to the bottom.

Prior to experimental towing, trawl warps were measured and marked at 366 m, the amount of warp used on the EBS survey when stations are fished at a depth of 115 m, the depth of our study site. Warps were measured and marked in accordance with AFSC protocol (Stauffer, 2004) by using in-line wire counters (Olympic 750-N, Vashon, WA) while at the same time, calibration of the geometric winch counters associated with the autotrawl system was performed.

A haul consisted of towing at a vessel speed of 3 knots while steering a steady course over ground. Tow direction was selected by attempting to expose the trawl to the maximum amount of side current. Vessel speed and position were measured at 2-sec intervals with satellite navigation. Each haul consisted of two treatment sets in which three 15-min towing treatments (locked winches [locked], tension-controlled autotrawl [tension], symmetry-controlled autotrawl [symmetry]) were conducted, allowing at least two minutes between treatments for the net to equilibrate. Randomizing the order of treatments within each treatment set reduced the influence of treatment order on trawl performance introduced by sea state, wind, and tidal currents. Likewise, towing at the same site for the duration of the experiment eliminated bias that could be attributed to varying substrate.

Wing spread, door spread, and headrope height were measured acoustically with Scanmar sensors at 4-sec intervals to the nearest 0.1 m. Footrope distance from the sea floor (cm) was measured at 0.5-sec intervals and averaged over 1.5-sec periods at five positions along the footrope simultaneously by placing bottom contact sensors (BCS) at the center, at both trawl corners (located 3 m to either side of the center), and on each wing 1 m aft of the wing tips (Fig. 1). These sensors are self-contained units consisting of a tilt meter capable of measuring angle to the nearest 0.5° and a data logger housed in a watertight stainless steel container that fits inside a steel sled (Somerton and Weinberg, 2001). One side of the sled clips into a clamp that pivots freely on the trawl footrope and the other end drags along the bottom (Fig. 2). Changes in the distance of the footrope from the bottom produce changes in the recorded tilt angle. Conversion from tilt angle to distance off-bottom was accomplished with a calibration function determined for each BCS unit by fitting a quadratic function to data derived from a separate calibration experiment in which tilt angles were recorded when the footrope clamp was elevated set distances from a hard surface. The BCS unit extended out from the footrope 44 cm and its combined weight (consisting of BCS, sled, and footrope clamp) was 8.9 kg in seawater. The thickness of the clamp beneath the footrope was 2 cm. Because underwater video equipment was unavailable for this experiment, the extent to which this clamp penetrates into variable substrates was not estimated.



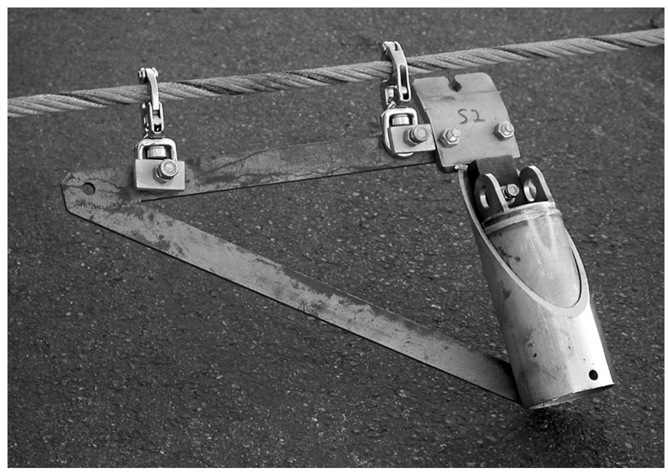


Figure 2

Bottom contact sensors mounted to the footrope (top) and the bridle (bottom).

Bridle distance from the bottom was measured at three positions simultaneously on both port and starboard sides by placing BCS units 25, 40, and 50 m forward of each wing tip. The BCS units and sled were mounted on triangular frames designed to hold them perpendicular to the bridle (Fig. 2, Somerton, 2003). The triangular frame measured 49 cm in its longest dimension. The combined weight of a BCS unit and frame was 8.7 kg in seawater.

In addition to trawl mensuration, data were also collected on certain environmental variables during the different towing modes. Three variables were studied: 1) vessel heave measured at the trawl block; 2) the relative degree of offset of the warps from the heading of the vessel (crabbing); and 3) bottom current velocity both parallel and perpendicular to the direction of the vessel.

The effect of sea state on the vertical displacement and attitude of the vessel is transmitted to the footrope from the trawl blocks through the trawl warps and likely causes variable bridle and footrope contact with the bottom. Vessel heave at the starboard trawl block was used as a proxy for sea state. Heave, pitch, and roll data were collected at 1-sec intervals with a heave sensor (VT TSS, DMS-25, Watford, UK) mounted in the bridge along the centerline of the vessel. Heave data at the starboard block were then predicted, given the *x, y, z* coordinates of the block from the heave sensor, as distance (cm) from its equilibrium position. In the analyses, the standard deviation of the heave was used as the index of sea state.

Net crabbing was subjectively assessed on a four-point scale by a single observer, then numerically coded as follows; 1) none—the net trailed straight behind the vessel; 2) slight—the warp could be seen entering the water between the side rail and the aft gantry; 3) moderate—the point of entry of the warp into the water was blocked from view by the aft gantry; and 4) severe—the warp was observed entering the water behind the stern ramp. Conditions usually remained constant and one observation was made per towing-mode treatment. However, in some instances conditions changed rapidly and warranted more than one code. In such cases the average of the observation codes was used in the analyses.

Bottom current direction and velocity (cm/sec) were measured at 10-sec intervals with an oceanographic current meter (Nobska, MAVS-3, Woods Hole, MA) moored in the vicinity of our trawling activity three meters from the bottom. The current data were partitioned into two directional components, one parallel to the course of the vessel and the other perpendicular, and averaged for each sample treatment.

Data analyses

Comparison of the means and standard deviations among treatments Our null hypothesis, that the three treatments had the same effect, was tested with a Kruskal-Wallis one-way ANOVA for all measures of trawl performance. We selected this test because of the skewed nature of the data. To describe the effect of the three treatments on trawl geometry features the mean and standard deviation (SD) were calculated for the wing spread, door spread, and headrope height off-bottom from each treatment in each haul.

To describe the bottom-tending performance of the footrope we calculated the following statistics for each treatment:

1 mean footrope distance off-bottom—the sum of mean distances off-bottom along the footrope, from five footrope BCS units;
2 standard deviation of the footrope distance off-bottom—the sum of standard deviations along the footrope, from five footrope BCS units; and
3 symmetry of the footrope distance off-bottom—the sum of the absolute difference between the means of the two wing positions and the absolute difference between the means of the two corner positions on the footrope.

To describe the bottom-tending performance of the lower bridle, we considered only the BCS unit positioned 40 m from the wing tip. The variability in bottom-tending performance of the bridles 40 m from the wing tip may have the highest impact on the catchability of the trawl because the BCS at the 25 m position was always on the bottom and the BCS at the 50 m position was always off the bottom. Performance of the bridles at the 40 m position was characterized by

1 mean bridle distance off-bottom—the sum of the mean distances off-bottom from the BCS units located 40 m forward of the wing tip on both lower bridles;
2 standard deviation of the bridle distance off-bottom—the sum of the standard deviations from the BCS units located 40 m forward of the wing tip on both lower bridles; and
3 symmetry of the bridle distance off-bottom—the absolute difference between means from the BCS units located 40 m forward of the wing tip on both lower bridles.

Assessment of the effect of environmental factors If differences among towing mode treatments were found by the ANOVA ($P<0.05$), then the effects of heave, crabbing, and bottom current on gear performance within each treatment were explored. Multiple regression analyses were performed for each of the treatment statistics with environmental variables as dependents. At the start of the analyses, the models included all four dependent variables (heave, crabbing, current parallel, and current perpendicular to the tow direction). Variance inflation factors (VIFs) were calculated for all variables to test for multicollinearity (Neter et al., 1996). Dependent variables in all models had VIFs ranging from 1 to 1.4, indicating that no serious multicollinearity existed among dependent variables. Models were simplified (backward deletion) until all P-values of the individual slopes were lower than 0.05. This procedure enabled us to establish which variables had a statistically significant impact on performance of the trawl within each treatment.

Results

A total of 21 successful hauls were performed during the experiment, yielding 42 possible treatment sets for analyses. The number of successful treatment sets included in the analyses varied for each of our performance statistics as a result of either malfunctions or poor survey trawl performance caused by conflicts with abandoned fishing gear.

Comparison of the means and standard deviations among treatments

Trawl geometry A total of 41 treatment sets were used to analyze the six trawl geometry statistics (means and

Table 1

Means of the trawl geometry statistics (m) and *P*-values of the Kruskal-Wallis test for differences between three towing-mode treatments. Locked=locked winches; symmetry=symmetry-controlled autotrawl; and tension=tension-controlled autotrawl.

Statistic		Locked	Symmetry	Tension	*P*-value
Wing	mean	17.76	17.77	17.85	0.6952
	SD	0.69	0.70	0.73	0.9157
Door	mean	68.03	67.67	67.71	0.8380
	SD	1.87	1.73	2.14	0.0977
Height	mean	1.82	1.81	1.81	0.7618
	SD	0.21	0.20	0.20	0.8618

Table 2

Means of the footrope and bridle statistics (cm) and *P*-values of the Kruskal-Wallis test for differences between three towing-mode treatments. Locked=locked winches; symmetry=symmetry-controlled autotrawl; and tension=tension-controlled autotrawl.

Statistic		Locked	Symmetry	Tension	*P*-value
Footrope	mean	13.98	13.09	12.08	0.0441
	SD	6.39	5.67	5.24	0.0391
	symmetry	1.95	1.44	1.45	0.0554
Bridle	mean	7.50	6.69	6.28	0.0286
	SD	4.91	4.03	3.37	0.0046
	symmetry	1.59	0.93	0.88	0.0030

standard deviations of the wing spread, door spread, and net height). No significant differences were detected among the three towing modes (Table 1); consequently, no environmental variables were tested for their influence on trawl geometry.

Footrope distance off-bottom Analyses based on 33 successful treatment sets produced varying results among the three measures describing the bottom tending performance of the footrope. Mean footrope distance off-bottom differed significantly among the three towing modes (Table 2, Fig. 3). Footrope distance was lowest for the tension treatment followed by the symmetry treatment and locked winches. The greatest observed difference occurred between the locked (13.98 cm) and the tension treatment (12.08 cm). Standard deviation in footrope distance off-bottom also differed significantly among treatments. Differences were similar to those observed for the mean, in that the lowest SD was observed for the tension treatment (5.24 cm) and the highest SD was observed for the locked treatment (6.39 cm). Because the variance equals the square of the standard deviation, this seemingly small reduction in standard deviation corresponds to a fairly large reduction in the variance (~30%). Symmetry in the footrope off-bottom distance did not differ significantly (P=0.0554) among the three towing modes.

Bridle distance off-bottom A total of 34 successful treatment sets were used to analyze the bridle distance off-bottom data. Mean bridle distance off-bottom differed significantly among treatments (Table 2, Fig. 4); it was lowest for the tension treatment (6.28 cm) and highest with the winches locked (7.50 cm). Standard deviation of bridle distance off-bottom also differed significantly among the three towing modes. SD values were significantly lower in the autotrawl towing modes, being lowest in the tension treatment (3.37 cm) and highest in the locked treatment (4.91 cm). Bridle distance off-bottom was most symmetrical in the symmetry and tension towing modes. Symmetry and tension means were similar (0.93 cm and 0.88 cm, respectively) and significantly lower than that observed for the locked-winches treatment (1.59 cm).

Assessment of the effect of environmental factors

Footrope distance off-bottom The effect of environmental factors on our three measures describing the bottom tending performance of the footrope produced varying results. Mean distance off-bottom was significantly affected by heave only, during all treatments (Table 3, Fig. 5). The standard deviation of the footrope distance off-bottom was also significantly affected by heave, crabbing, and bottom current parallel to the direction of the

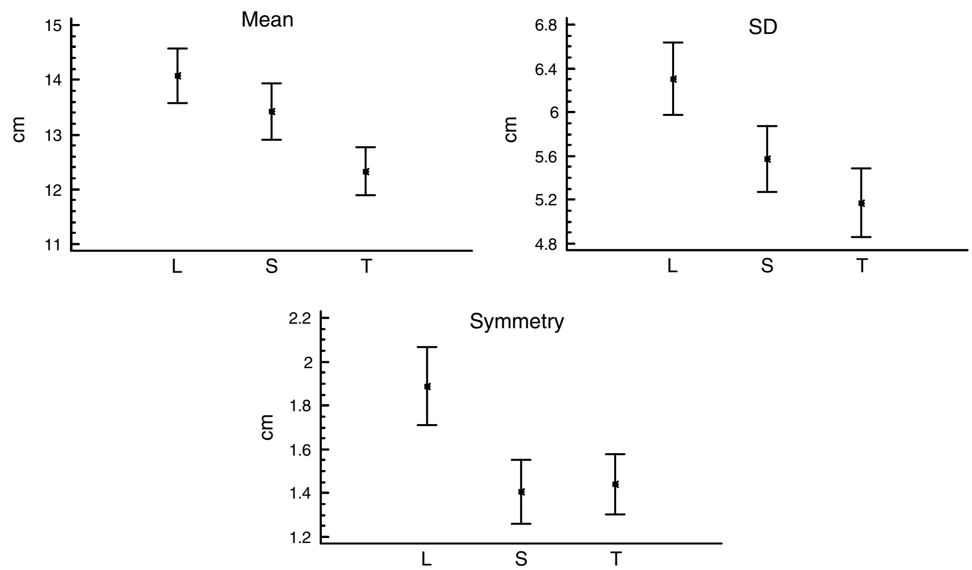


Figure 3

Means and standard errors of the footrope distance off-bottom, standard deviation of the footrope distance off-bottom, and footrope symmetry for the locked winches (L), symmetry (S), and tension (T) treatments.

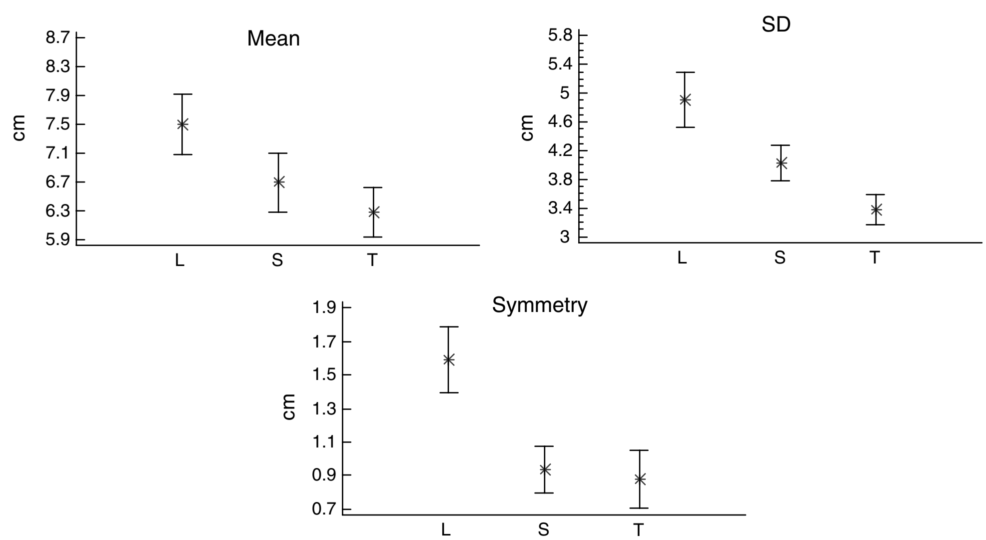


Figure 4

Means and standard errors of the bridle distance off-bottom, standard deviation of the bridle distance off-bottom, and bridle symmetry for the locked winches (L), symmetry (S), and tension (T) treatments.

tow during some treatments (Table 3, Fig. 6). Heave had a greater effect on footrope SD during the locked-winches treatment (slope=0.0610) than during the symmetry treatment (slope=0.0381). Similar effects were also detected for crabbing (slopes=1.2355 and 0.8493, respectively). Current speed in the direction of the tow affected footrope SD only during the symmetry mode. Heave, crabbing, and current velocity had no effect on

Table 3

Multiple regression model slope coefficients with P-value <0.05, for locked winches, symmetry-controlled, and tension-controlled towing modes (Y=bottom current parallel to the direction of the tow, Abs$X$=absolute value of the crosscurrent).

Statistic		Treatment	Heave	Crabbing	Y	Abs$X$	R^2	P-value
Footrope	mean	locked	0.0572	—	—	—	9.04	0.0495
		symmetry	0.0713	—	—	—	15.64	0.0227
		tension	0.0544	—	—	—	16.14	0.0205
	SD	locked	0.0610	1.2355	—	—	58.93	<0.0001
		symmetry	0.0381	0.8493	–0.0446	—	33.96	0.0066
		tension	—	—	—	—	—	>0.05
	symmetry	locked	—	—	0.0255	—	15.42	.0238
		symmetry	—	—	—	—	—	>0.05
		tension	—	—	—	—	—	>0.05
Bridle	mean	locked	0.0680	—	—	—	19.66	0.0086
		symmetry	—	—	—	—	—	>0.05
		tension	0.0491	—	—	—	14.88	0.0242
	SD	locked	0.0796	0.9536	—	—	60.30	<0.0001
		symmetry	—	—	—	—	—	>0.05
		tension	0.0411	0.3023	—	—	33.83	0.0017
	symmetry	locked	—	—	—	0.0556	26.58	0.0018
		symmetry	—	—	—	—	—	>0.05
		tension	—	—	—	0.0361	13.25	0.0343

footrope SD during the tension mode. The symmetry in footrope distance off-bottom was significantly affected by the current parallel to the direction of the tow during the locked-winches treatment only (Table 3, Fig. 7).

Bridle distance off-bottom Mean bridle distance off-bottom was affected by heave only during some of the treatments (Table 3, Fig. 8). Heave had a greater impact on the mean bridle distance off-bottom during the locked-winches treatment (slope=0.0680) than during the tension treatment (slope=0.0491). The standard deviation of the bridle distance off-bottom was affected by heave and crabbing during two of the treatments (Table 3, Fig. 9). Heave had an effect on the SD of the bridle distance off-bottom during both locked (slope=0.0796) and tension (slope=0.0411) treatments. A significant effect due to crabbing was also detected during these same two treatments (slopes 0.9536 and 0.3023, respectively). During the symmetry mode no effect due to any of the environmental conditions was detected, even though SD was almost always higher than that observed in the tension mode, with the exception of extreme heave conditions. Symmetry in the bridle distance off-bottom was affected only by crosscurrent (Table 3, Fig. 10). Crosscurrent had an effect on the symmetry during the locked (slope=0.0556) and tension (slope=0.0361) treatments.

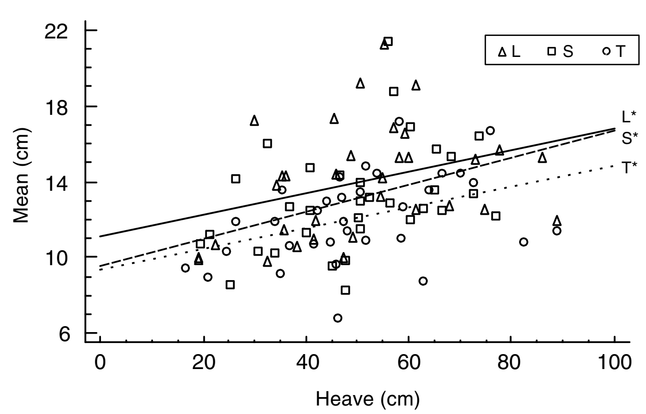


Figure 5

Comparison of regression lines illustrating the relationship between the mean footrope distance off-bottom and heave for locked winches (L), symmetry (S), and tension (T) treatments. Treatments in which heave had a statistically significant effect on the mean are identified with an asterisk (*).

Discussion

The objective of this study was to identify towing modes that could potentially reduce variance in the catchability of the 83-112 Eastern bottom trawl among hauls. Three separate aspects of trawl performance affecting catchability were investigated: trawl geometry, bottom tend-

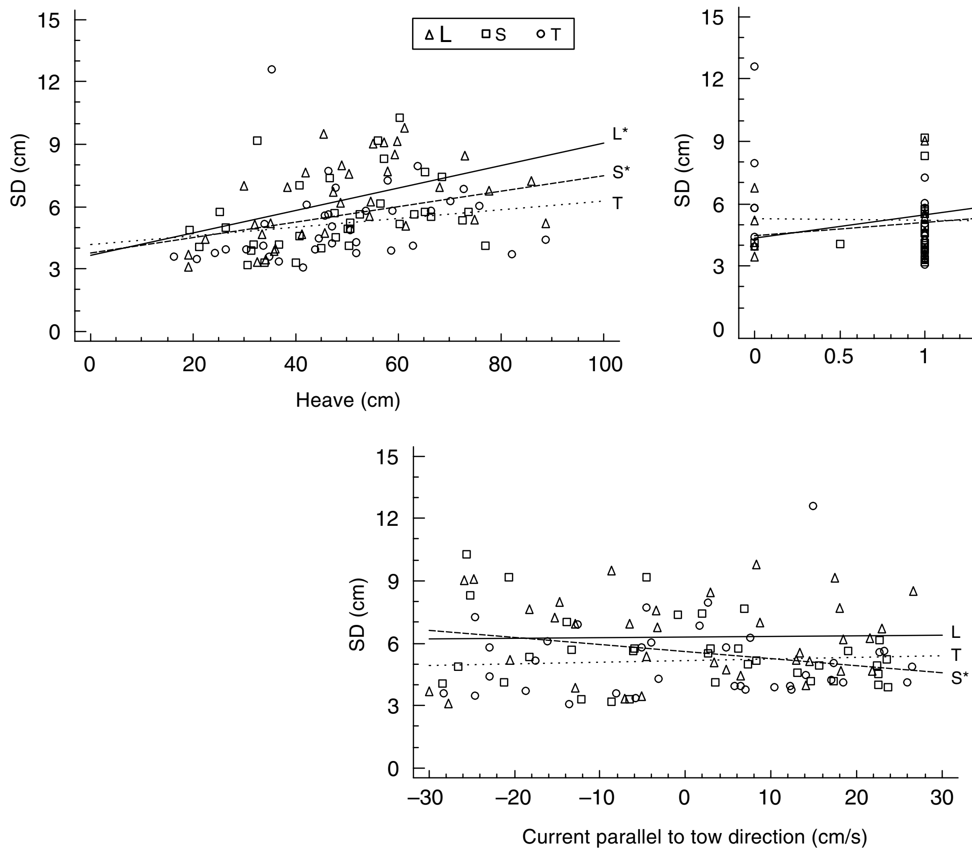


Figure 6

Comparison of regression lines illustrating the relationship between the standard deviation (SD) of the footrope distance off-bottom and environmental variables for locked winches (L), symmetry (S), and tension (T) treatments. Treatments in which the environmental variable had a statistically significant effect on the SD are identified with an asterisk (*).

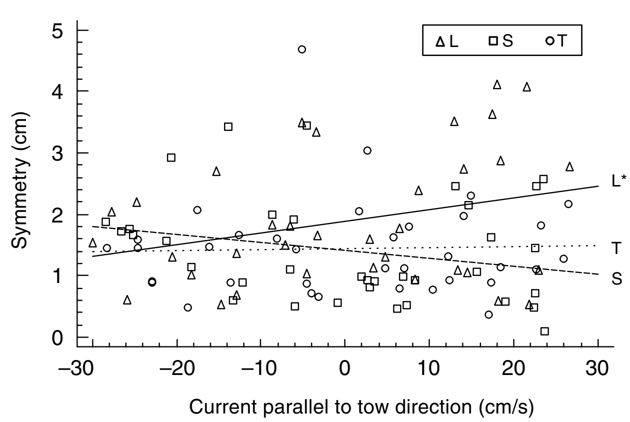


Figure 7

Comparison of regression lines illustrating the relationship between the symmetry of the footrope distance off-bottom and current parallel to the direction of the tow for locked winches (L), symmetry (S), and tension (T) treatments. Treatments in which the current had a statistically significant effect on the symmetry are identified with an asterisk (*).

ing performance of the footrope, and bottom-tending performance of the lower bridles.

Trawl geometry

Because wing and door spread and net height variability all influence catchability of a trawl (Rose and Nunnallee, 1998), surveys would stand to benefit from autotrawl systems if variances in the trawl geometry features were reduced. Our study showed that neither autotrawl system improved trawl geometry over the conventional locked-winches towing mode.

Footrope

Previous studies have demonstrated that escapement under the footrope is an important factor determining the catchability of the 83-112 Eastern survey trawl (Somerton and Otto 1999; Munro and Somerton, 2002; Weinberg et al., 2004). Periodic separation between the footrope and the bottom contribute to variability in catchability and have been shown to be influenced by a variety of factors, such as net speed through the water (Somerton and Weinberg, 2001) that can increase footrope distances off-bottom. Weinberg et al. (2002), using a different survey bottom trawl, found capture probability of some benthic species to decrease as a result of footrope separations with the bottom. These findings likely apply to the 83-112 Eastern trawl as well. Because capture probability is generally size dependent (Munro and Somerton, 2002), an unstable footrope may not only increase the variance of overall biomass estimates, but may bias the size distribution data generated by a survey as well. If autotrawl systems can help maintain footrope contact with the bottom, then the use of an autotrawl during surveys may be warranted.

In our experiment, the tension-controlled autotrawl system provided the best footrope contact overall and the lowest standard deviation (Fig 3). High heave and moderate to strong crabbing were largely responsible for the differences observed in the bottom-tending performance of the footrope among treatments (Figs. 5–7). The tension treatment was most effective in counteracting the effects of environmental conditions, whereas the locked-winches treatment was the least stable of the three treatments given the changing environmental conditions.

We found both autotrawl systems have a potential to improve bottom trawl survey biomass estimates by increasing the dynamic stability of the trawl, thereby reducing the variance in its catchability. The equal-tension system proved better than the symmetry system in improving the overall stability of the footrope bottom-tending performance given the low bottom current velocities observed. Symmetry autotrawl systems, designed to react to crosscurrent conditions at towing depth, could prove to be more effective under stronger current conditions, but during our experiment, current velocities may have been too low (≤35 cm/s) for us to be able to detect a difference between the symmetry and tension towing modes.

Bridles

Flatfish are stimulated to herd by close proximity to or actual contact with the lower bridle (Main and Sangster, 1981a), whereas semipelagic species such as Atlantic cod (*Gadus morhua*) are probably stimulated to herd by the sight of the otter doors and mud clouds created by the doors and lower bridles (Main and Sangster, 1981b). For this reason, the length of the lower bridle in contact with the bottom and the frequency of this contact affect the herding efficiency of the trawl (Somerton, 2003). If the among- and within-tow variability of the bridle bottom-tending distance could be reduced by using an autotrawl system, then standardizing survey

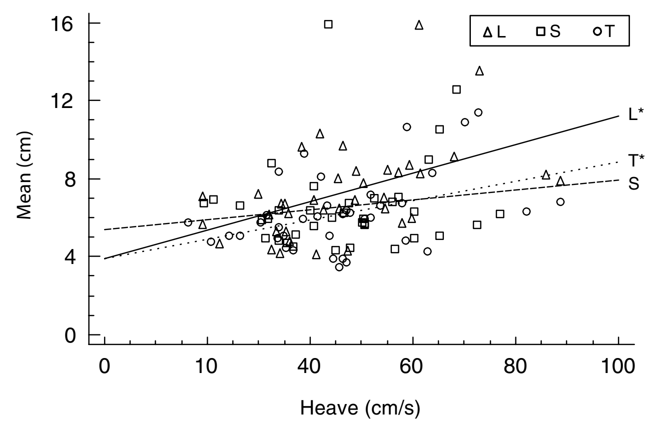


Figure 8

Comparison of regression lines illustrating the relationship between mean bridle distance off-bottom and heave for locked winches (L), symmetry (S), and tension (T) treatments. Treatments in which the heave had a statistically significant effect on the mean are identified with an asterisk (*).

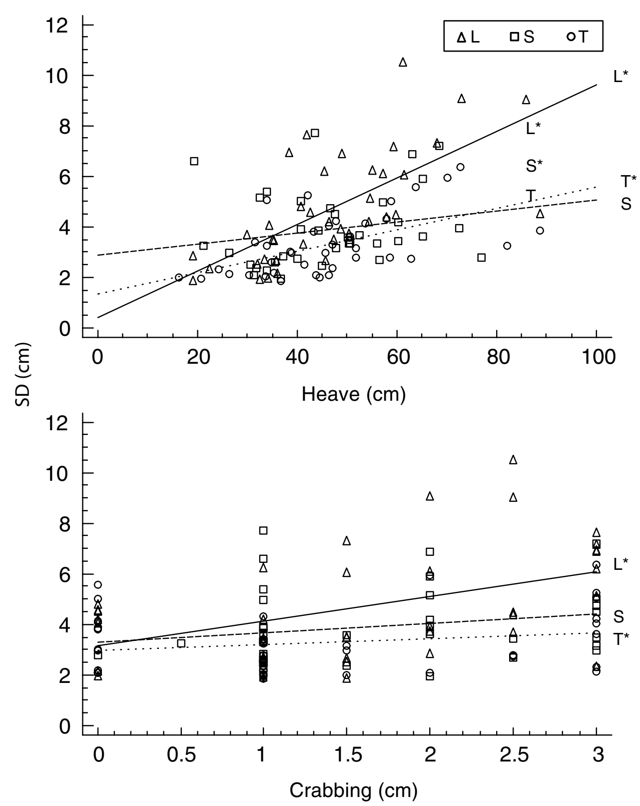


Figure 9

Comparison of regression lines illustrating the relationship between standard deviation (SD) in bridle distance off-bottom and environmental variables for locked winches (L), symmetry (S), and tension (T) treatments. Treatments in which the environmental variable had a statistically significant effect on the SD are identified with an asterisk (*).

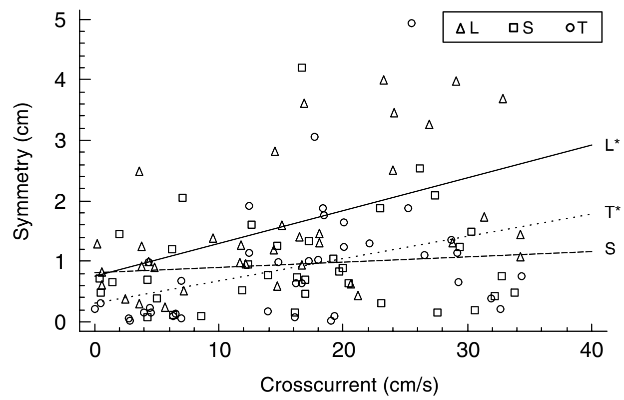


Figure 10

Comparison of regression lines illustrating the relationship between bridle symmetry and crosscurrent for locked winches (L), symmetry (S), and tension (T) treatments. Treatments in which crosscurrent had a statistically significant effect on bridle symmetry are identified with an asterisk (*).

procedures to include towing with an autotrawl system would likely be beneficial.

Our results showed that both autotrawl systems reduced the mean distance of the bridles off-bottom and the standard deviation of this distance and increased the symmetry between bridles (Fig. 4) over the locked-winches treatment. Our experiment also demonstrated that both autotrawl systems increased the stability of lower bridle bottom contact in changing environmental conditions, but we were unable to discern which of the systems was better. The data indicate that bridle bottom-tending performance was the least affected by environmental conditions during the symmetry treatment; however the standard deviation in the bridle distance off-bottom was almost always lower during the tension treatment, the exception being under extreme heave conditions (Fig. 9). The locked-winches treatment had the highest standard deviation and was affected the most by heave, crabbing, and crosscurrent velocity.

Autotrawl systems counteract the effects of warp length differential created by trawl crabbing. During our locked-winches treatment crabbing likely caused unequal tension in the warps similar to that seen while towing straight behind the boat with unequal warp lengths. Weinberg and Somerton (2006) reported that warp tension changes significantly with offset in warp lengths. To compensate for the crabbing angle and to assure that the trawl is pulled square to the direction of the tow during crabbing, one warp should be shorter than the other. Tension-controlled autotrawl systems adjust the length of the warps to equalize the tension on them. Symmetry-controlled autotrawl systems change the length of the warps to minimize crosscurrent and also increase the symmetry of the trawl in relation to the tow direction.

In summary, autotrawl systems proved to be effective in decreasing some of the adverse effects of environmental factors on some aspects of the 83-112 bottom trawl performance and, as a result, have the potential to reduce variance in among-haul catchability of the survey trawl. For this trawl, footrope and bridle distances off-bottom were significantly different among the three towing modes, albeit the differences in actual distances off-bottom were small. Trawls deploying heavier groundgear, thus enabling more constant contact with the bottom, may not be as affected. Further investigations are needed to assess the effects of the two types of autotrawl systems on other types of survey trawl gear, such as high-opening bottom trawls, trawls using different footropes, shrimp trawls, and midwater trawls. The effect of using autotrawls in areas with stronger current and different depths also needs to be investigated for the different types of trawl gear.

For bottom trawl surveys, we are concerned with two potential shortcomings in the symmetry-controlled autotrawl system tested. First, videos of trawling in rough terrain have revealed footrope distortion occurring when the footrope or doors snag on the bottom (Weinberg, unpublished data). Typically, the side opposite the snag is pulled forward while the snagged side remains stationary or is pulled ahead at a slower pace. This uneven pull on the net causes asymmetry in the headrope shape, by skewing it from the general tow direction (Weinberg and Somerton, 2006). Distortion of the headrope introduces error in the current direction and velocity values obtained by the current sensor mounted on the headrope from which warp length is determined, and thus impacts trawl performance. Our second concern involves the overall warp adjustment period required for the trawl to equilibrate to current direction and velocity based on the current sensor input. Because many surveys standardize to a 15-min tow duration, a proportionally large percentage of tow time may be involved with adjusting warp lengths in pursuit of optimal symmetry and therefore vary trawl catchability during the tow. Under commercial trawling conditions, the manufacturer of the symmetry winch control system recommends using a 2-min minimum signal collection and analysis period between warp adjustments. After each adjustment, new sensor signals would be received and evaluated, followed by another warp adjustment, if necessary. We are uncertain as to how many warp adjustments may be necessary to orient the trawl in relation to crosscurrent flow, but based on our experiences and the frequency with which warp lengths changed during our experiment, it is conceivable that several adjustment periods spanning the majority of the survey tow may be necessary, leaving minimal time for the net to actually fish symmetrically. Furthermore, each 2-min warp adjustment would be based on a maximum of only five current flow readings because the current sensor refreshes data at 24-s intervals. Should signal loss occur, then fewer data points would be available.

We recommend taking a cautious approach before switching a trawl survey from locked winches to autotrawl. A change in survey method may require an extensive calibration experiment between the two trawling methods in order to maintain the continuity of a survey time series. Furthermore, autotrawl systems, like other mechanical devices, require service, appropriate inspections and periodic testing to ensure that they are functioning correctly within manufacturer specifications. Autotrawl calibration parameters are dependent upon accurate measurements of the diameter and length of each winch drum, warp diameter, and construction (e.g., compacted vs. traditional or wire core vs. fiber core), layers of warp, and the number of windings per layer on each drum. Hydraulic pumps and lines, electric motors, valves, solenoids, computerized control panels, and geometric counters must all be inspected to assure proper operation. Of course, should surveys operate with a symmetry-style autotrawl system, then all of the above procedures would hold true in addition to the need for accurate calibration of the current sensor and the proper mounting of the sensor to the headrope.

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