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[Article]

Estimation of Bottom Trawl Catch Efficiency for Two Demersal Fishes, the Atlantic Croaker and White Perch, in Chesapeake Bay

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Abstract.—The use of fisheries-independent trawl survey data to estimate fish abundance in shallow coastal systems can present challenges for producing reliable population estimates. We used hydroacoustic and trawl data to estimate the catch efficiency of a demersal trawl that is presently used in surveys to support stock assessments in Chesapeake Bay, USA. Specifically, we determined the efficiency of catching Atlantic croakers *Micropogonias undulatus* and white perch *Morone americana*, two of the most common species captured in the trawl survey. Monotypic hauls (>90% by abundance) from 2003 to 2004 were used to estimate catch efficiency, defined as the ratio of the observed catch to the number of fish encountered by the trawl, which we estimated by deploying a scientific echosounder directly in front of the trawl net. The catch efficiency estimates ranged from 0.18 to 1.26 for Atlantic croakers ($n = 29$ tows) and from 0.11 to 0.60 for white perch ($n = 7$ tows). For Atlantic croakers, Spearman's rank correlation between the total and predicted catch was 0.53. A post hoc analysis of the Atlantic croaker efficiency estimates based on general linear modeling suggests that trawl efficiency is a function of fish behavior, gear geometry, and habitat. Efficiency declined with increasing fish density and increasing trawl width; to lesser extent, an increasing proportion of fines in the sea bed and decreasing depth were also associated with declines in efficiency. We conclude that because catch efficiency is variable, the trawl should be integrated with hydroacoustics to obtain improved population data.

Bottom trawls are commonly used throughout the world to obtain fisheries-independent abundance data for populations that support fisheries of economic importance. However, varying catchability of trawl gear can lead to unreliable population assessments. For example, large between-year variability in abundance estimates of Arctic cod *Boreogadus saida* is in part the result of behavioral differences among year-classes that influence their availability to the trawl gear (Godø and Wespestad 1993). Hydroacoustics is a commonly used tool to identify sources of error and improve abundance estimates from bottom trawl survey data (e.g., Godø and Wespestad 1993; McQuinn et al. 2005). Besides changes in availability to a bottom trawl, the following three additional factors can lead to poor correlation between observed catch and hydroacoustic data (Aglen 1996): (1) boat avoidance reactions by fish (Ona and Godø 1990; Handegard and Tjøstheim 2005); (2) gear avoidance as fish react to the warp and trawl (Doubleday and Rivard 1981; Glass and Wardle 1989); and (3) gear-specific selectivity (Rose and Nunnallee 1998).

The catch per unit effort (CPUE) from the bottom trawl is determined by the catchability (q) and fish abundance (N) in front of the trawl such that CPUE = qN (Jennings et al. 2001). Catchability is a function of both availability of fish to the trawl (q_a), the fraction of the total population available to the trawl, and catch efficiency (q_e), the fraction of the population available to the trawl that are caught, (i.e., $q = q_a q_e$). The q_a is influenced by fish location in the water column (e.g., Godø and Wespestad 1993; Aglen 1996) as well as avoidance of the boat (Ona and Godø 1990) and trawl warp (Handegard and Tjøstheim 2005). The q_e is influenced by herding reactions to the warp and doors (e.g., Glass and Wardle 1989; McQuinn et al. 2005), density of fish in front of the trawl (Godø et al. 1999; O'Driscoll et al. 2002), and gear configuration (e.g., Engås and Godø 1986; Rose and Nunnallee 1998; von Szalay and Somerton 2005). Understanding how fish behavior and trawl gear affect trawl catch data is therefore necessary to generate reliable information for estimating population abundance (Graham et al. 2004).

The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) is a fisheries-independent bottom trawl survey (established in 2002) designed to support single-species and multi-species stock assessment modeling activities for Chesapeake Bay, the largest estuary in the United

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States, and the Mid-Atlantic Bight. This program targets late juvenile and adult fishes in Chesapeake Bay; through the combination of trawl and hydroacoustic methods, ChesMMAP is designed to provide estimates of both relative and absolute abundance. In general, combining hydroacoustic methods with fish sampling in estuaries has the potential to inform sampling by providing improved biomass and size distributions associated with shallow-water habitats (Boswell et al. 2007). The challenges, however, are many and include large areas of very shallow water (<5 m) that prevent down-looking echosounder deployments, variable and speciose fish assemblages, and constantly changing environmental conditions. Chesapeake Bay is relatively long with a narrow central channel flanked by broad, shallow areas. The mean depth of the bay is 6.5 m, and depths exceeding 10 m represent approximately 24% of the bay's surface area (Kemp et al. 2005). The bay is rich in natural resources. Several anadromous, demersal, and pelagic fishes have supported extensive fisheries during the last century. In recent decades, many fish species have experienced heavy exploitation, leading to restricted harvest regulations and in some instances the closing of fisheries. Recent concern about the status of finfish resources in the bay combined with interest in ecosystem management prompted the creation of ChesMMAP.

In this article, we provide analyses of hydroacoustic data collected simultaneously with the ChesMMAP trawl data to obtain an estimate of bottom trawl q_e for two abundant fishes in Chesapeake Bay: the Atlantic croaker *Micropogonias undulatus* and white perch *Morone americana*. We used a scientific echosounder to enumerate fish directly in front of the trawl and then compared this estimate to our trawl catch to calculate q_e. This study is a first step toward improving relative abundance estimates of Atlantic croakers and white perch from bottom trawl data. Although q_a also influences q, this aspect of q was beyond the scope of this study. We identified sources of variability in our q_e estimates via post hoc analyses because q_e is likely to be affected by factors associated with trawl deployment and fish behavior. Collectively, this information contributes to our understanding of Atlantic croaker and white perch abundance in Chesapeake Bay and the variables affecting the performance of bottom trawl survey gear in a shallow, coastal estuary.

Methods

Field collections.—In 2003 and 2004, five bimonthly ChesMMAP cruises were conducted from March to November in the main stem of the Chesapeake Bay. During each cruise, approximately 80 to 90 locations were sampled according to a stratified random design, with strata based on water depth (3–9, 9–15, and >15 m) within five 30′ latitudinal regions of the bay. The locations sampled in each stratum of each region were randomly selected in proportion to the surface area of that stratum. Tows were conducted during the day by using the 19.8-m R/V *Bay Eagle* and were standardized to 20 min in duration. Shorter tows did occur where bottom topography was prohibitive but had to be at least 10 min in duration to be acceptable. Tows during which the net became entangled with hazards on the sea bottom were not acceptable for inclusion. Scope was set at 4:1 and tow speed was set to 6.5 km/h (1.8 m/s), although both these variables were adjusted if necessary based on the real-time net mensuration data to ensure consistent gear geometry (NETMIND trawl monitoring system, Northstar Technical, Inc.).

The trawl net was a four-seam balloon trawl with a 13.7-m headrope and 6.1-m legs connected directly to 1.3- × 0.8-m, steel-V trawl doors (83.9 kg each; Reidar's Manufacturing, Inc., New Bedford, Massachusetts). The wings and body of the net were constructed of number-21 cotton twine (15.2-cm mesh), and the cod end was constructed of number-48 twine (7.6-cm mesh). The trawl net was deployed with a single-warp system (9.5-mm steel cable; 37.6-m bridle of 7.9-mm cable; Figure 1). The NETMIND headline height sensor was located in the center of the net just behind the headrope. The wing spread sensors were located in the wings as far forward as possible. Computer software recorded data from the net mensuration gear and integrated the data with Global Positioning System (GPS) data from the research vessel.

Based on presurvey testing of the trawl gear in Chesapeake Bay by using the R/V *Bay Eagle* in 2001, tow direction was standardized to run with the prevailing tidal current because the trawl height and width were more consistent when the net was deployed with the current rather than against it (the trawl tended to lift off the bottom when towed against the current). Net mensuration gear readings were validated in 2004 by using a Sea Scan PC-based side-scan sonar unit (Marine Sonics Technology, Ltd.) operating with a 900-kHz tow fish deployed from a separate stationary vessel as the R/V *Bay Eagle* towed the trawl gear at the standard scope and speed (Figure 2). Although doorspread may be the best measure for trawl width (Engås and Godø 1986), we used the distance between the wings because the short trawl legs (6.1 m) forced the wings to align nearly directly behind the doors (Figure

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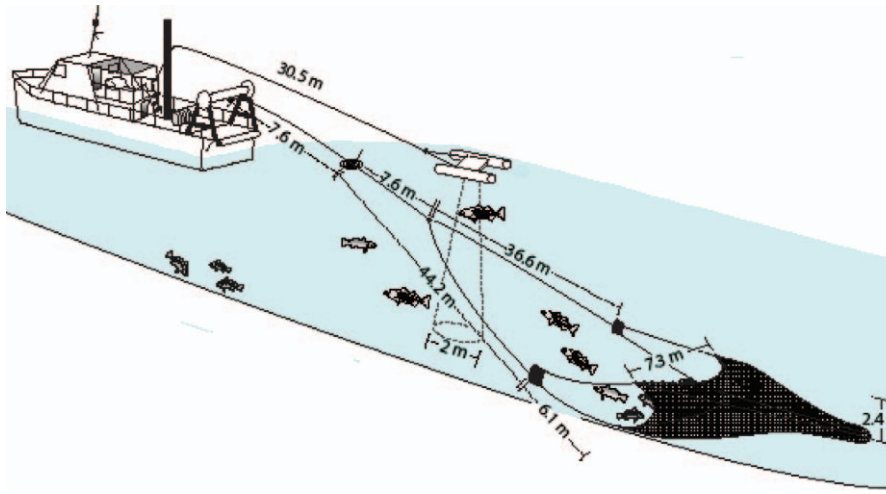

FIGURE 1.—Schematic of bottom trawl with acoustic system deployed in front of the net for a typical tow at 10-m depth in Chesapeake Bay.

2) and because the trawl doors were too small to function correctly with net mensuration gear attached.

A split-beam sonar system was mounted on a tow body that allowed the sonar to sample the water column directly in front of the trawl net (Figure 1). We deployed the transducer to enumerate the fish directly in front of the net because our study goal was to determine q_e. The circular 11.8°, 200-kHz, digital split-beam transducer (BioSonics, Inc.; DE series) was mounted on a catamaran and deployed 0.5 m below the surface (Table 1). The echosounder was calibrated by the manufacturer. Subsequent routine standard target calibrations showed no change from the manufacturer calibration (target strength [TS] within 1 decibel [dB] of its known value). The echosounder was towed directly behind the vessel, approximately 20 m in front of the doors (Figure 1); this distance placed the transducer about 30 m behind the vessel within the warps in an attempt to accurately count fish encountering the net. There was no control for tilt angle; however, the research vessel was operationally limited to light seas (<60-cm wave height). Care was taken to adjust the tow point so that the tow body was pulled horizontally and the catamaran pontoons were spread nearly 2 m across to limit rolling. The transducer was operated concurrently with each tow (Table 1). The acoustic sample volume was limited by the shallow water (<40 m), and thus the acoustic beam width was always less than the net width. At depths of 5, 10, and 20 m, the acoustic beam was only about 1, 2, and 4 m

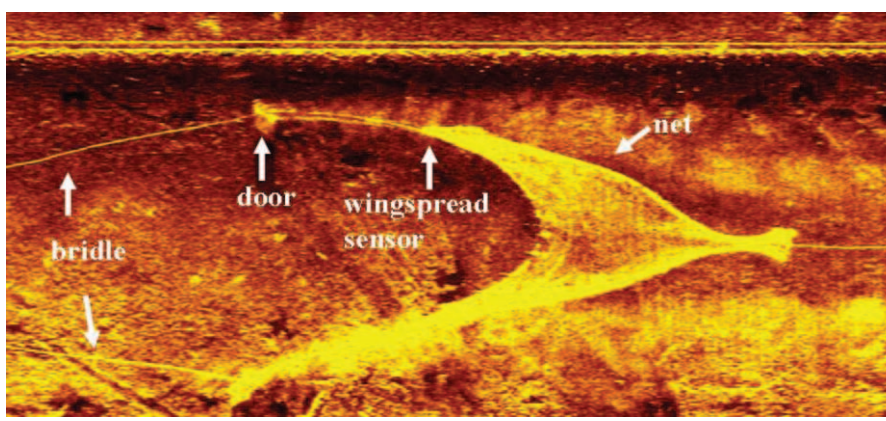

FIGURE 2.—Side-scan image of trawl net deployed from R/V *Bay Eagle* at typical operational conditions (vessel speed = 6.5 km/h, operating with the current; 4:1 scope) in Chesapeake Bay.

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TABLE 1.—Echo sounder (BioSonics, Inc., DE series) specifications and operating parameters.

Parameter (units)	Value
Frequency (kHz)	201
Beam angle (°)	11.8
Ping interval (pings/s)	5
Pulse width (ms)	0.3
Collection threshold (decibels)	−60

wide, respectively, whereas the net generally was about 8 m wide.

Data analysis.—We estimated q_e of Atlantic croakers and white perch from tows at depths greater than 5 m because at shallower depths, the vessel wake interfered with targets in the trawl sweep. Furthermore, only tows where catches were comprised of at least 90% of either species (i.e., monospecific) were used because relationships between down-looking aspect TS and total length (TL), which are needed for hydroacoustic data analysis, are not available for most Chesapeake Bay fishes. During 2003 and 2004, Atlantic croakers comprised 41% of the catch by abundance and white perch made up 19% of the abundance (51% and 14% of the catch by weight). For Atlantic croakers, 38 tows were available, of which nine were excluded due to either faulty net mensuration measurements (two tows) or very few ensonified fish (seven tows). For white perch, eight tows were available, of which one tow was excluded because very few fish were sampled by the echosounder. We believe that the tows used in the analysis are representative of overall gear performance because the catch abundances ranged from low to high, the tows occurred at sampling locations across the Chesapeake Bay main stem, and the fish were caught during a variety of months (Tables 2, 3; Figure 3).

Estimates of q_e were obtained as follows:

$$\hat{q}_e = \frac{\widehat{\text{CPUE}}}{\hat{N}} \tag{1}$$

where $\widehat{\text{CPUE}}$ is the number of fish captured in a tow, estimated when subsampling procedures are used on-deck to process large catches, and $\hat{N}$ is an estimate of the number of fish present in front of the trawl based on the sonar system. The parameter N was estimated as $\hat{N} = \hat{v}\hat{\rho}_v$, where $\hat{v}$ is the estimated tow volume and $\hat{\rho}_v$ is the estimated density of fish in front of the trawl. Tow volumes were estimated by multiplying the tow distance (d) by the mean headrope height (h) and mean wing spread (w) during the tow. Values of h and w were estimated from the readings provided by the net mensuration equipment, and the value of d was obtained from the onboard GPS unit. These data were estimated for fishing time on the bottom and did not include trawl deployment or retrieval. The estimate of ρ_v was based on two measures from the echosounder: (1) the mean volume backscattering strength (S_v), which is the mean acoustic energy scattered from targets per finite volume of water sampled; and (2) the mean cross-sectional backscattering coefficient, $\bar{\sigma}_{bs}$, which is the mean acoustic energy returned from the targets sampled.

Because the acoustic beam width was less than w, we calculated $\hat{\rho}_v$ by assuming 100% detectability along the acoustic sample transect (exception was for near sea bottom detection, as described below). This does not allow for error estimation of $\hat{\rho}_v$ on a tow-by-tow basis (i.e., each tow is an independent sample) because the deployment did not allow us to investigate the spatial distribution of fish in front of the net. We would, however, expect greater uncertainty in $\hat{\rho}_v$ among shallow tows than among deeper tows for a given fish density because the echosounder samples a smaller proportion of the fish.

The acoustic files were subjected to echo integration (EI) to estimate ρ_v by using BioSonics Visual Analyzer software (version 4.1; analysis threshold set to −60 dB). Prior to EI, files were visually inspected to identify potential nontarget species (particularly schools of fish) in the trawl sweep, and none were found. For EI, we divided the water column into 0.5-m vertical depth strata and the tow into along-track regions of equal length. Each along-track region had a depth change of less than 0.5 m to ensure a match between the trawl height and the EI strata (generally, the seabed depth was fairly constant, and only one or two regions were required). Only depth strata within the trawl sweep were included in the estimate (generally, the trawl height was 2.0–2.5 m). For each tow, $\hat{\rho}_v$ was calculated as the weighted mean of the fish density estimates among along-track regions:

$$\hat{\rho}_v = \frac{\sum_i \sum_j \hat{f}_{ij}\hat{\rho}_{ij}}{n}, \tag{2}$$

where $\hat{f}_{ij}$ is the estimated fraction of stratum i region j that was echo integrated, $\hat{\rho}_{ij}$ is the estimated fish density in stratum i region j, and n is the total number of strata. The ρ_{ij} for any cell (stratum × region) is its S_v divided by the $\bar{\sigma}_{bs}$ for that depth stratum. Volume $\bar{\sigma}_{bs}$ values were averaged (linear domain) prior to logarithmic transformation. Bottom tracking was automated by using the Visual Analyzer software; we excluded a narrow zone above the seabed (<0.15 m) to maximize the water column. Bottom tracking was visually inspected and manually edited to ensure that the seabed was excluded from EI.

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TABLE 2.—Catch data from 29 bottom trawl tows used in the analysis of Atlantic croaker catch efficiency (q_e), including location (latitude, longitude) in Chesapeake Bay, tow distance (d), average trawl headrope height (h), average trawl width (w), station depth (z), total trawl catch (catch; all fish), percent of tow composed of Atlantic croakers (% comp.), acoustic density (ρ_v), estimated q_e, average proportion fines (f) from grab samples and associated sample sizes (n), and dissolved oxygen (DO) concentration at the bottom (N/A = data were not available).

Tow	Date	Latitude (°N)	Longitude (°W)	d (m)	h (m)	w (m)	z (m)	Scope	Catch	% comp.	ρ_v (fish/m^3)	q_e	fines, f (n)	DO (mg/L)
S89	28 Mar 2003	37° 18′ 22″	76° 5′ 5″	1,954	2.9	6.8	19.3	5.1	971	98	0.026	0.98	0.24 (13)	11.2
S64	22 May 2003	37° 53′ 32″	76° 8′ 53″	1,835	2.6	7.6	23.0	4.1	323	94	0.011	0.80	0.11 (1)	4.3
S54	10 Jul 2003	37° 40′ 24″	76° 3′ 38″	2,038	2.4	9.0	5.0	4.9	464	98	0.026	0.40	0.14 (3)	4.8
S57	3 Jul 2003	37° 30′ 27″	76° 8′ 38″	2,003	2.3	9.1	12.0	4.5	779	100	0.026	0.71	0.71 (4)	2.4
S63	3 Jul 2003	37° 31′ 26″	76° 8′ 36″	2,243	2.6	9.3	12.0	4.9	405	100	0.021	0.35	0.74 (1)	2.8
S64	2 Jul 2003	37° 51′ 23″	76° 8′ 34″	1,967	2.0	8.4	19.8	4.2	391	98	0.011	1.03	0.15 (2)	2.0
S81	1 Jul 2003	37° 21′ 21″	76° 6′ 3″	2,060	2.0	8.7	13.8	5.1	670	96	0.019	0.99	0.42 (10)	5.5
S83	30 Jun 2003	37° 6′ 35″	76° 8′ 4″	2,045	2.0	9.3	13.3	4.6	1,213	95	0.039	0.81	0.15 (24)	6.5
S85	7 Jul 2003	37° 20′ 28″	76° 9′ 56″	2,040	2.4	8.8	10.0	5.2	392	95	0.026	0.36	0.25 (14)	3.0
S86	7 Jul 2003	37° 18′ 23″	76° 10′ 31″	1,985	2.2	9.2	11.0	5.6	550	91	0.019	0.72	0.48 (20)	4.3
S89	1 Jul 2003	37° 19′ 37″	76° 5′ 6″	2,118	2.1	8.2	19.5	4.8	719	92	0.025	0.81	0.19 (10)	N/A
S90	1 Jul 2003	37° 14′ 47″	76° 5′ 17″	1,859	2.3	8.3	15.5	4.9	950	98	0.035	0.76	0.40 (10)	4.0
S83	24 Mar 2003	37° 4′ 27″	76° 7′ 21″	2,072	2.6	8.1	11.5	5.1	164	92	0.005	0.71	N/A	12.0
S60	3 Jul 2003	37° 41′ 29′	76° 13′ 27″	2,057	2.1	6.7	13.0	4.9	82	91	0.003	1.12	N/A	2.8
S54	18 May 2004	37° 31′ 21″	76° 8′ 28″	1,928	2.3	7.2	11.0	5.1	886	99	0.063	0.44	0.71 (4)	7.1
S55	18 May 2004	37° 26′ 28″	76° 9′ 41″	2,120	2.4	7.0	9.8	5.1	730	97	0.018	1.14	0.15 (1)	7.8
S59	25 May 2004	37° 26′ 35″	76° 2′ 42″	1,030	2.1	8.0	13.7	5.0	299	95	0.023	0.73	0.11 (3)	7.7
S60	19 May 2004	37° 32′ 20″	76° 8′ 39″	1,922	2.1	7.8	11.5	5.1	302	90	0.038	0.25	N/A	6.1
S63	25 May 2004	37° 28′ 42″	76° 2′ 47″	2,171	1.4	7.6	18.1	4.8	866	97	0.037	0.99	0.13 (2)	5.9
S81	18 May 2004	37° 18′ 26″	76° 8′ 19″	1,925	1.9	8.0	11.1	5.9	280	95	0.039	0.24	0.35 (21)	8.7
S82	18 May 2004	37° 25′ 29″	76° 8′ 13″	2,060	2.1	7.2	11.4	5.1	893	98	0.041	0.71	0.73 (1)	7.9
S83	18 May 2004	37° 15′ 34″	76° 10′ 54″	2,170	2.0	7.9	11.5	5.3	593	98	0.050	0.34	0.25 (9)	8.0
S84	17 May 2004	37° 10′ 24″	76° 12′ 2″	2,086	2.2	8.2	10.4	4.5	735	94	0.017	1.15	0.24 (9)	7.6
S86	18 May 2004	37° 16′ 24″	76° 11′ 55″	2,114	2.0	7.9	12.0	4.8	884	95	0.030	0.86	0.01 (1)	8.6
S87	18 May 2004	37° 15′ 30″	76° 12′ 0″	2,076	2.0	7.6	12.0	4.9	738	95	0.065	0.35	0.40 (4)	7.4
S80	1 Jul 2004	37° 18′ 20″	76° 7′ 20″	2,039	1.7	8.3	12.1	4.9	295	90	0.055	0.18	0.40 (22)	6.6
S38	25 May 2004	37° 59′ 14″	76° 11′ 43″	2,177	2.4	8.0	26.0	4.4	428	97	0.008	1.21	N/A	5.2
S39	25 May 2004	38° 3′ 20″	76° 12′ 10″	2,036	2.3	8.3	15.8	5.2	197	94	0.004	1.26	N/A	4.4
S61	2 Jul 2004	37° 43′ 28″	76° 9′ 21″	1,022	2.0	8.2	12.5	5.2	58	98	0.005	0.72	N/A	0.8

Acoustic signal interference with the bottom causes loss of acoustic energy and thereby results in a lower fish density for EI than was encountered near the bottom (the "acoustic dead zone" [ADZ] problem). Before calculating $\hat{\rho}_v$, we applied a theoretical ADZ correction (Ona and Mitson 1996) to the ρ_{ij} value(s) from those depth strata in which the seabed was encountered. The theoretical ADZ correction, which varies in relation to seabed depth, ranged from about 0.3 to 0.6. The actual correction was less because EI was generally performed for less than 100% of the bottom strata. A depth correction was not applied because Chesapeake Bay is shallow; tows were conducted at depths ranging from 5 to 20 m.

Echo integration was scaled by depth strata, with the $\bar{\sigma}_{bs}$ coefficients derived from an in situ TS analysis. Target strength is equivalent to the cross-sectional backscatter for a single target ($TS = 10 \cdot \log_{10}[\sigma_{bs}]$). For analysis of in situ targets, TS values were corrected by using the split-beam technique, and echoes were

TABLE 3.—Catch data from seven bottom trawl tows used in the analysis of white perch catch efficiency (q_e), including location (latitude, longitude) in Chesapeake Bay, tow distance (d), average trawl headrope height (h), average trawl width (w), station depth (z), total trawl catch (catch; all fish), percent of catch composed of white perch (% comp.), acoustic density (ρ_v), and estimated q_e.

Tow	Date	Latitude (°N)	Longitude (°W)	d (m)	h (m)	w (m)	z (m)	Scope	Catch	% comp.	ρ_v (fish/m^3)	q_e
S4	4 Apr 2003	39° 12′ 29″	76° 15′ 52″	1,562	2.9	7.6	6.8	6.7	297	95	0.021	0.41
S1	3 Oct 2003	39° 9′ 26″	76° 17′ 31″	1,175	2.1	8.2	6.4	5.5	542	89	0.043	0.60
S3	3 Oct 2003	39° 9′ 47″	76° 23′ 50″	1,964	2.7	8.7	6.3	6.3	860	95	0.075	0.24
S3	12 Sep 2004	39° 4′ 19″	76° 21′ 47″	2,106	2.1	8.5	8.0	5.2	335	96	0.081	0.11
S18	31 Oct 2004	38° 37′ 28″	76° 27′ 17″	1,839	2.1	8.4	11.5	4.3	544	92	0.096	0.17
S8	1 Nov 2004	39° 4′ 18″	76° 19′ 31″	1,963	2.1	8.4	9.5	5.3	356	95	0.090	0.11
S7	1 Nov 2004	39° 3′ 20″	76° 19′ 53″	2,014	2.1	8.4	11.9	4.9	326	90	0.027	0.34

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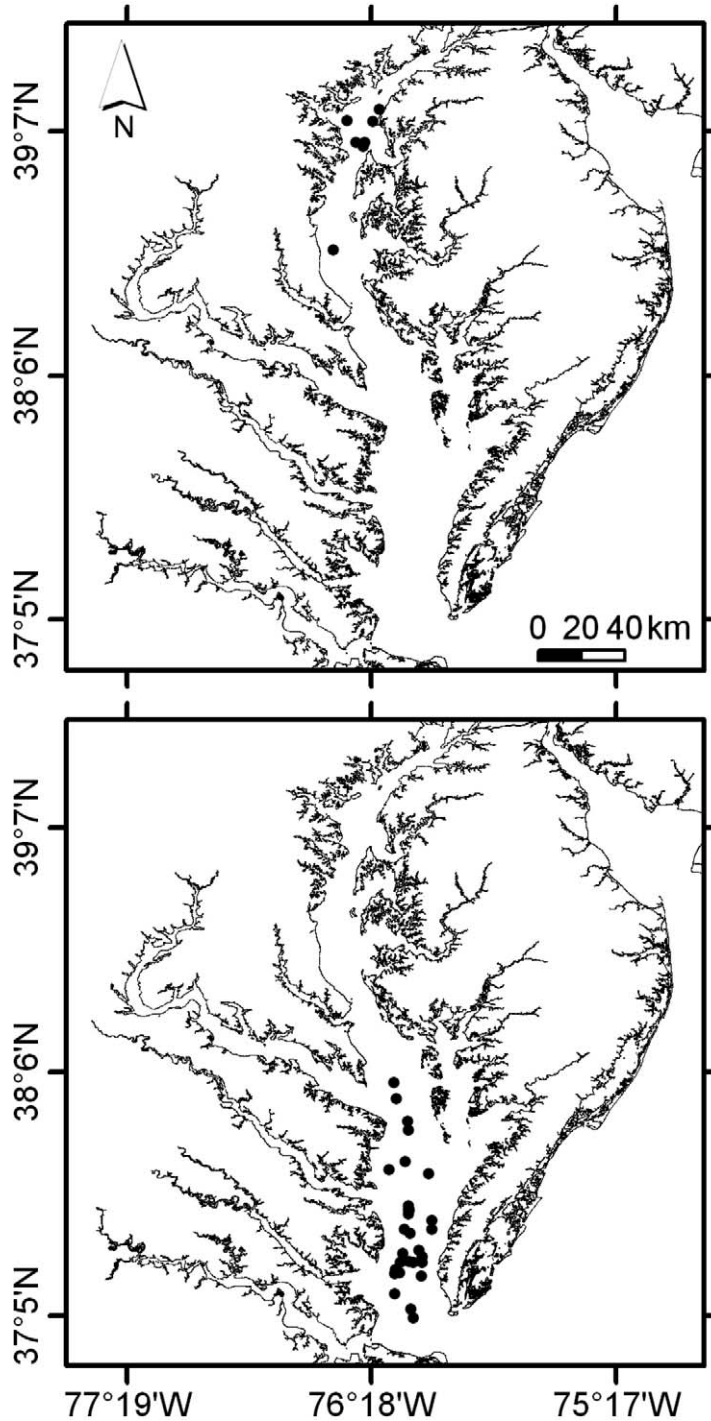

FIGURE 3.—Locations of hauls (black circles) used in analyses of bottom trawl catch efficiency for white perch (top panel) and Atlantic croakers (bottom panel) in Chesapeake Bay during 2003 and 2004.

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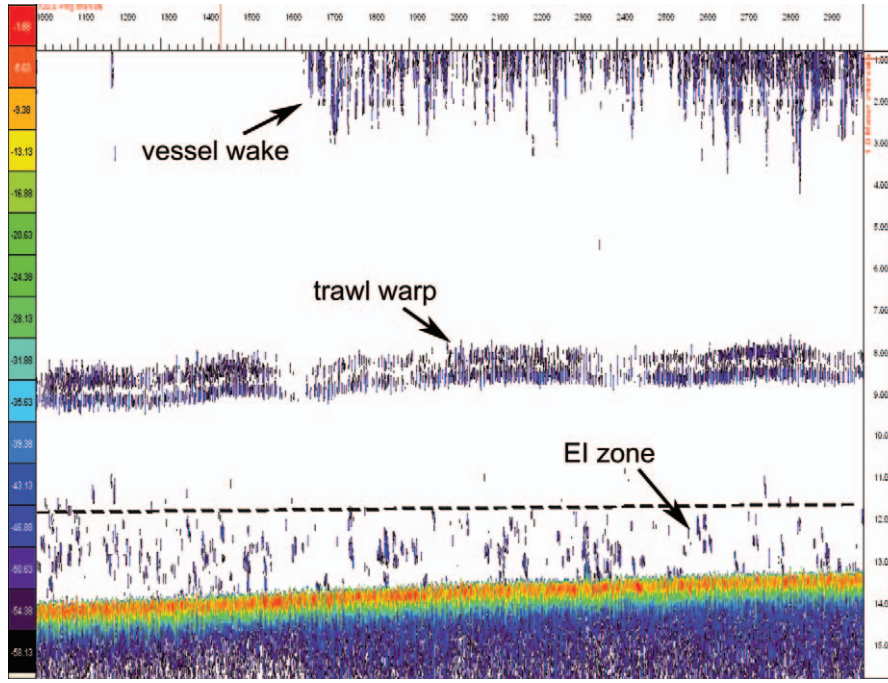

FIGURE 4.—Typical echogram from a bottom trawl haul dominated by Atlantic croakers (tow S81 on 1 July 2003 in Chesapeake Bay); pings 1,000–2,000 of 6,022 total pings are presented. Only the area accessible to the trawl was used for echo integration (EI; water column below dashed line).

classified as single targets based on amplitude and duration criteria. Allowable TS values ranged from −60 to −20 dB. Multiple-target returns were excluded by using an allowable pulse duration factor of 0.75–1.50. Bias against small targets was prevented by including only fish within 4° from the transducer axis. We did not filter by target density because we observed few acoustic targets that spatially overlapped (e.g., high-density target aggregations; Figure 4) in the echograms and the estimated fish density (N_v) was generally lower than the threshold (0.04 fish/acoustic reverberation volume) identified by Gauthier and Rose (2001; maximum N_v for Atlantic croakers = 0.05, maximum N_v for white perch = 0.08). It is possible, however, that for those tows with higher densities, the in situ TS estimate was biased high and the resulting q_e was overestimated.

To assess how well the in situ target analysis characterized demersal fishes, we used the TS distributions derived from targets within the trawl sweep to estimate an in situ dorsal aspect TS–TL relationship for both Atlantic croakers and white perch. Following Mehner (2006), we used a multimodel analysis to develop the TS–TL relationship by decomposing the cumulative frequency distributions of paired TL and TS distributions into cohort-specific normal distributions (CMIX software, www.aad.gov.au; de la Mare et al. 2002). Each cruise was analyzed separately to increase sample sizes and to control for seasonal differences. For Atlantic croakers, four cruises were available (March and July 2003; May and July 2004). For white perch, only two were available (September 2003; November 2004), which produced an insufficient number of pairs for regression analysis. For each cruise, the analysis produced two to four modes representing distinct cohorts. We used linear regression to estimate the dorsal aspect TS–TL relationship by using the TS and TL pairs: $\mathrm{TS} = b + a \cdot \log_{10}(\mathrm{TL})$. The intercept ($b$) was estimated for the postulated quadratic dependence of TS on TL ($\mathrm{TS} = b + 20 \cdot \log_{10}[\mathrm{TL}]$), as originally recommended by Foote (1979). For reference, these results were compared with the relationship estimated by Love (1971): $\mathrm{TS} = 19.1 \cdot \log_{10}(\mathrm{TL, cm}) + 0.9 \cdot \log_{10}(\mathrm{frequency}) - 62$.

We performed a post hoc analysis to evaluate potential causes of variability in q_e estimates associated with Atlantic croakers. The roles of both gear geometry and environmental variables were investigated by using a linear model of the following form:

$$\mathbf{Y} = \mathbf{X\beta} + \boldsymbol{\varepsilon}, \tag{3}$$

where $\mathbf{Y}$ represents the vector of q_e estimates, $\mathbf{X}$ is the design matrix associated with the hypothesized ex-

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planatory variables, $\boldsymbol{\beta}$ is the vector of parameters to be estimated, and $\boldsymbol{\varepsilon}$ is the vector of residuals. The explanatory variables considered were w (m), trawl depth (z; m), fish density in front of the trawl ($\hat{\rho}_v$; fish/m^3), and sediment type (f; proportion fines).

The latter environmental variable, f, was chosen because we were concerned that q_e could change if a large plume of fine sediment was associated with the gear (Wardle 1993). We obtained benthic grab data from a winter (December–March) dredge survey conducted by the Virginia Institute of Marine Science (Montane et al. 1997). Approximately 7,150 grab samples were taken at the randomly selected dredge-tow starting points from 1991 to 1997 and were processed for grain size analysis: gravel (>2.0 mm), sand (0.0625–2.0 mm) and fine (<0.0625 mm). For the post hoc analysis, percent fines data from each grab sample were overlaid onto the ChesMMAP sampling grid (1.852 km^2, or 1 square nautical mile), and an average was calculated for each grid cell to associate it with the corresponding trawl sample. Some grid cells did not have any samples from which the bottom type could be classified.

Six model parameterizations of equation (3) were considered, and all parameters were estimated via maximum likelihood by using R version 2.6.2 (R Development Core Team 2008). A measure often used to compare among models within the candidate set is Akaike's information criterion corrected for small-sample bias (AIC$_c$), calculated as

$$\mathrm{AIC}_c = -2\log_e(\hat{L}) + 2p + \frac{2p(p+1)}{n-p-1}, \qquad (4)$$

where $\hat{L}$ is the estimated maximized likelihood value, p is the number of model parameters, and n is the overall sample size (Burnham and Anderson 2002). In a set of candidate models, the model with the minimum value of AIC$_c$ is considered the best model; the AIC$_c$ difference (ΔAIC$_c$) is calculated as a given model's AIC$_c$ minus the lowest AIC$_c$. In general, models with ΔAIC$_c$ values between 0 and 2 have substantial support, those with ΔAIC$_c$ values between 4 and 7 have considerably less support, and models with ΔAIC$_c$ values greater than 10 have essentially no support (Burnham and Anderson 2002). Given ΔAIC$_c$ values, the Akaike weight of model k relative to the others within the candidate set was computed as follows (Burnham and Anderson 2002):

$$(\text{Akaike weight})_k = \frac{\exp\left(\dfrac{-\Delta\mathrm{AIC}_{c,k}}{2}\right)}{\displaystyle\sum_{i=1}^{M}\exp\left(\dfrac{-\Delta\mathrm{AIC}_{c,i}}{2}\right)}, \qquad (5)$$

where M represents the total number of models in the candidate set.

Results

Catch Data

The Atlantic croaker tows used in the analysis were from March, May, and July cruises in 2003 and May and July cruises in 2004 at bottom depths ranging from 5 to 26 m ($n = 29$ tows; Table 2). The total catch in these tows ranged from 58 to 1,213 fish. The h ranged from 1.4 to 2.9 m (average $h = 2.2$ m), and w ranged from 6.7 to 9.3 m (average $w = 8.1$ m). Bottom salinity for these tows ranged from 18 to 28 practical salinity units (psu), and bottom temperature ranged from 8°C to 24°C. White perch tows used in the analysis were from March and September cruises in 2003 and September and November cruises in 2004 at depths ranging from 6 to 12 m ($n = 7$ tows; Table 3). The total catch ranged from 297 to 860 fish, h ranged from 2.1 to 2.9 m (average $h = 2.3$ m), and w ranged from 7.6 to 8.7 (average $w = 8.3$ m). Bottom salinity for the white perch tows ranged from 6 to 15 psu, and bottom temperature ranged from 8°C to 25°C.

Echo Integration

The value of $\hat{\rho}_v$ was higher for white perch than for Atlantic croakers (Tables 2, 3). For Atlantic croakers, $\hat{\rho}_v$ ranged from 0.003 to 0.065 fish/m^3 (mean ± SD = 0.027 ± 0.017 fish/m^3); for white perch, $\hat{\rho}_v$ ranged from 0.021 to 0.096 fish/m^3 (mean ± SD = 0.062 ± 0.031 fish/m^3). In general, we believe that EI generated a good measure of the target species' densities because acoustic targets were located within 2 m of the bottom and because schools of small targets (probably bay anchovy *Anchoa mitchilli*) were not observed within the trawl sweep (Figure 4). Targets were observed on or near the sea bottom, however, where acoustic detectability is reduced (Figure 4).

In general, there is a good visual match between the cohorts from the TL and TS data identified by using CMIX (Figure 5). The analysis was limited because CMIX software can only identify modes; both the left and right tails of the length distribution were thus excluded from the analysis, reducing the length range analyzed. Although each cruise had few cohort pairs to contribute to the overall analysis, it is clear from the data plots that the TS–TL relationship differed among cruises, particularly for March 2003. When data were pooled and two outliers from March 2003 were excluded, the analysis yielded the following significant relationship: dorsal aspect TS = 31 • $\log_{10}$(TL, cm) – 91 ($n = 10$, $r^2 = 0.46$, $P = 0.03$; Figure 6). When the regression was fitted assuming a quadratic dependence

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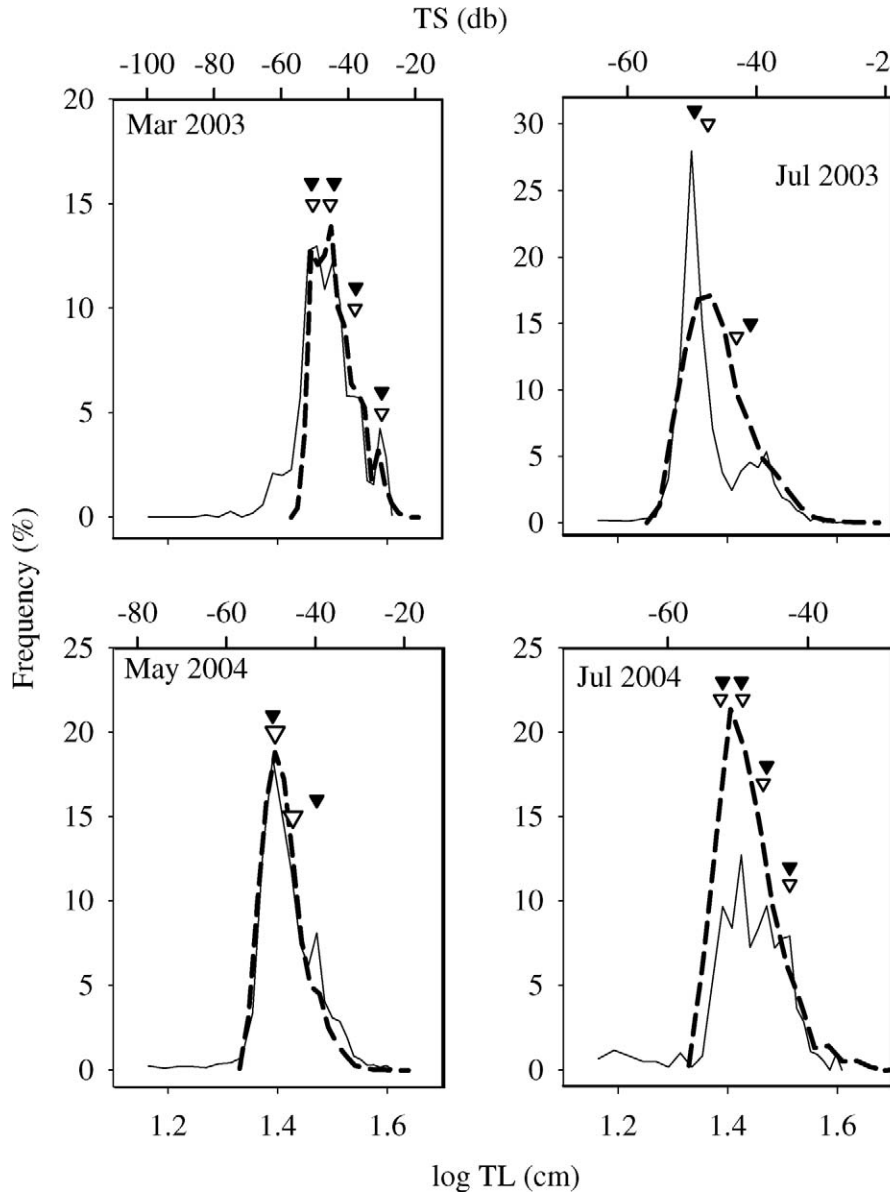

FIGURE 5.—Comparison between Atlantic croaker $\log_{10}$ (total length, TL) distributions (solid line) and target strength (TS) distributions (decibels [dB]; dashed line) for bottom trawl hauls conducted during four research cruises in Chesapeake Bay. Modes identified by CMIX software (see Methods) are shown for both the TL distribution (black triangles) and the TS distribution (open triangles).

of TS and $\log_{10}$(TL), we estimated an intercept of −76.0 (SE = 17.8).

Catch Efficiency

The values of $\hat{q}_e$ ranged from 0.18 to 1.26 for Atlantic croakers (mean ± SD = 0.73 ± 0.32) and from 0.11 to 0.60 for white perch (mean ± SD = 0.29 ± 0.18; Tables 1, 2). The estimates were not constrained; in those tows where $\hat{q}_e$ was greater than 1.0, more fish were captured than were predicted to be available to the gear based on the sonar data (Figure 7). The distribution of the Atlantic croaker q_e estimates appears to be bimodal, whereas that for white perch appears to be unimodal; however, direct comparison

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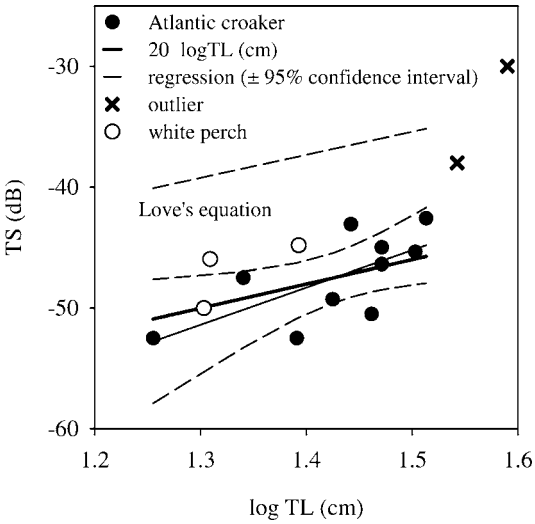

FIGURE 6.—Comparison of three equations depicting the relationship between dorsal aspect total length (TL, cm) and target strength (TS; decibels [dB]) of Atlantic croakers (black circles; × = outliers; CI = confidence interval): (1) least-squares regression ($TS = a \cdot \log_{10}[TL] + b$, where b = intercept and a = slope; thin solid line), (2) regression assuming quadratic dependence ($TS = 20 \cdot \log_{10}[TL] + b$; heavy solid line), and (3) Love's (1971) equation ($TS = 19.1 \cdot \log_{10}[TL] + 0.9 \cdot \log_{10}[\text{frequency}] - 62$; straight dashed line). White perch data (open circles) are also presented but were not subject to regression analysis.

between the species is hindered by the small and unequal sample sizes (Figure 8). For Atlantic croaker data, Spearman's rank correlation coefficient between total catch and predicted catch was 0.53 ($P < 0.01$).

Sediment type data were not available for all of the Atlantic croaker tows used for q_e estimation, and therefore the post hoc analysis of q_e variability was based on a slightly restricted data set ($n = 23$). As indicated by ΔAIC_c, the model that specified w and density of Atlantic croakers as explanatory variables was the best given the data and candidate model set (Table 4). In general, $\hat{q}_e$ decreased with increasing w and increasing fish density (Figure 8). There was appreciable support for models that included either z ($\Delta AIC_c = 2.5$) or f ($\Delta AIC_c = 2.9$) along with w and fish density. Although relationships were not strong, $\hat{q}_e$ increased with z and decreased in relation to f (Table 4). The model probabilities for the three best-fitting models were 0.61, 0.17, and 0.14, respectively. Accordingly, for a given combination of w, fish density, f, and z, the predicted q_e ($q_{e,\text{pred}}$) for Atlantic croakers would be calculated as follows: $q_{e,\text{pred}} = 0.61(\hat{Y}_1) + 0.17(\hat{Y}_2) + 0.14(\hat{Y}_3)$, where $\hat{Y}_k$ represents the linear prediction based on equation (3) for model k (Table 5).

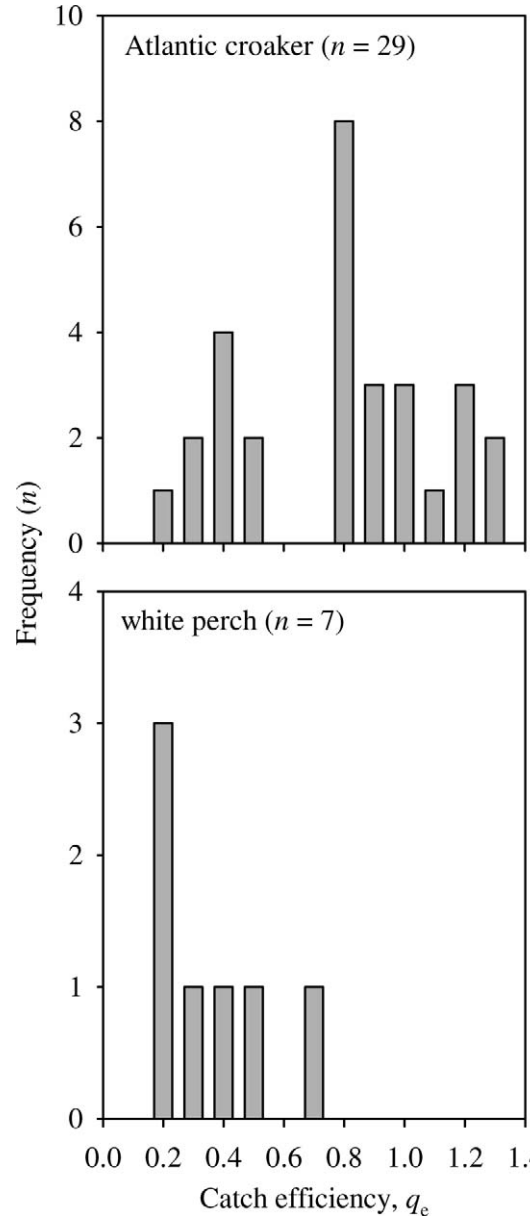

FIGURE 7.—Frequency distribution of bottom trawl catch efficiency (q_e) estimates obtained for Atlantic croakers (top; 29 tows) and white perch (bottom; 7 tows) in Chesapeake Bay.

Discussion

Fisheries-independent monitoring programs have been conducted in Chesapeake Bay for over five decades. The ChesMMAP survey, however, is the first to incorporate routine deployment of technology (area-swept net mensuration gear and hydroacoustics) as a

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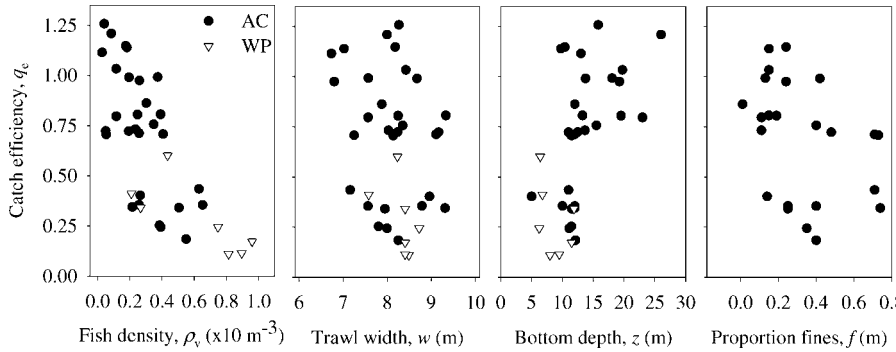

FIGURE 8.—Atlantic croaker (AC; black circles) and white perch (WP; open triangles) bottom trawl catch efficiency (q_e) estimates from Chesapeake Bay plotted in relation to the following model variables: fish density in front of the trawl (ρ_v; from echosounder); average trawl width (w); bottom depth (z); and substrate type (f; proportion fines; not available for stations where white perch were caught).

first step towards characterizing q. These advancements are vital to ongoing regional stock assessment and ecosystem modeling efforts. Here, we discuss the implications of the TS–TL model with respect to the study design; possible sources of error associated with hydroacoustics, net mensuration gear, and fish behavior and their likely effects on q_e estimates; and likely causes for the efficiency losses associated with fish density, w, f, and z.

Target Strength of Atlantic Croakers and White Perch

Our analysis indicated that the acoustical targets had a smaller TS at a given size than has been found when experimentally measuring a fish species' maximum dorsal aspect TS (e.g., Foote 1979; McClatchie et al. 1996a; Frouzova et al. 2005); this result may indicate that EI was subject to bias. When the relationship was fit assuming quadratic dependence, we obtained an intercept (−76 dB) that was lower than expected when compared to the maximum dorsal aspect TS (−59 to −71 dB; McClatchie et al. 1996a). The finding is tentative, however, because the linear regression covered a small length range (Atlantic croakers: 18.0–32.6 cm TL; white perch: 20.4–27.5 cm TL) relative to the maximum sizes of these fish in Chesapeake Bay (Atlantic croakers: 50 cm TL; white perch: 48 cm TL; Murdy et al. 1997). Furthermore, the TS of the two outliers for Atlantic croakers, the two largest modes identified by CMIX (34.9 and 38.9 cm TL), were consistent with the TS predicted by Love's (1971) equation (Figure 6).

Further study is recommended to identify potential sources of bias that might explain the persistently low TS values among size-classes and cruises. For

TABLE 4.—Summary of model fits, as measured by Akaike's information criterion corrected for small-sample bias (AIC_c), for the set of candidate models describing bottom trawl catch efficiency for Atlantic croakers in Chesapeake Bay (ΔAIC_c = difference in AIC_c between the given model and the model with the lowest AIC_c; $\hat{L}$ = estimated maximum likelihood). The explanatory variables associated with the six parameterizations were as follows: trawl width (w), trawl depth (z), acoustic density (ρ_v; fish/m^3), and sediment type (f; proportion fines).

Model	Variables	$-\log_e(\hat{L})$	Number of parameterizations	AIC_c	ΔAIC_c	Model probability
1	w, ρ_v	−4.3	4	1.6	0.0	0.61
2	w, ρ_v, z	−4.7	5	4.1	2.5	0.17
3	w, ρ_v, f	−4.5	5	4.5	2.9	0.14
4	ρ_v, f	−1.6	4	7.0	5.4	0.04
5	w, ρ_v, z, f	−4.9	6	7.5	5.8	0.03
6	w, f	2.1	4	14.4	12.8	0.00

TABLE 5.—Parameter estimates (SE in parentheses) associated with best-fitting models of bottom trawl catch efficiency for Atlantic croakers in Chesapeake Bay. For all models, b_0 is the intercept and b_1, b_2, and b_3 are the coefficients of variables included in the analysis. Model variables were trawl width (w), acoustic density (ρ_v; fish/m^3), trawl depth (z), and proportion of fines in the sediment (f).

Model	Parameter	Variable	Estimate (SE)
1	b_0	Intercept	2.49 (0.52)
	b_1	w	−0.17 (0.06)
	b_2	ρ_v	−14.00 (2.90)
2	b_0	Intercept	2.15 (0.64)
	b_1	w	−0.15 (0.06)
	b_2	ρ_v	−12.91 (3.10)
	b_3	z	0.01 (0.01)
3	b_0	Intercept	2.43 (0.52)
	b_1	w	−0.16 (0.06)
	b_2	ρ_v	−13.22 (3.11)
	b_3	f	−0.13 (0.21)

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example, if the acceptable TS bounds were too conservative, the TS could be consistently biased. There was no evidence for this effect; neither the left-hand tail nor the right-hand tail was truncated in the TS distributions (Figure 5). Furthermore, our result is probably not attributable to morphological differences because neither sciaenids nor moronids have unusually sized swim bladders in proportion to their lengths. Based on experimental results from a 120-kHz echosounder, the relationship between the maximum dorsal aspect TS and TL for white perch and striped bass *Morone saxatilis* in Chesapeake Bay is within the range of that expected for most marine fishes (Hartman and Nagy 2005).

If fish were tilted with respect to the face of the transducer, a systematic reduction in TS at size may have occurred. If the echosounder, when mounted to the tow body, was persistently tilted or rolled by waves (deployment was aft of waves generated by the vessel wake), it could have observed the targets at an angle. Wave and current conditions, however, varied by tow; thus, it is not apparent that wave-generated bias would be consistent among tows. Fish behavior, though complex regarding interactions with trawls, may also have resulted in a lower TS at size if the fish were tilted with respect to the beam (McClatchie et al. 1996b; Hazen and Horne 2004). For example, trawl warps elicit a strong swimming response in gadoids; upon encounter, they will swim down and away from the warp (Handegard and Tjøstheim 2005). The echosounder predominantly sampled near the trawl warp (Figures 1, 4); therefore, if Atlantic croakers and white perch exhibited a similar response, then they would have been tilted downwards, reducing their TS at size. This behavior is also consistent with q_e estimates less than 1.0.

The discrepancy between the TS–TL relationship generated from our data and the experimental measures underscores the difficulty in obtaining a general model for use in EI of acoustic data obtained in situ. Where single species dominate in a fishery, incorporating life history stage and behavior into theoretical models can generate TS–TL relationships that fit in situ observations (Horne 2003). We anticipate that future progress on Chesapeake Bay fisheries assessment will rely on in situ acoustic observations because the bay's fish fauna is both diverse and dynamic, undergoing wide-ranging seasonal assemblage shifts. Such progress will require a better understanding of species-specific behavior so that behavioral differences do not confound analysis of acoustic backscatter distributions. This might be accomplished with imaging sonar technology (e.g., Handegard and Williams 2008).

Trawling Efficiency of Atlantic Croakers and White Perch

We did obtain trawl q_e estimates that were well below 1.0 for both Atlantic croakers and white perch, indicating either that fish routinely avoided the trawl gear or that fish abundance in front of the net was overestimated. There are numerous potential sources of error in the fish density estimates, including accuracy of the ADZ correction, the presence of fish that were undetectable by the acoustics (i.e., lying on the sea bottom or herding near doors), or the presence of small fish in the echogram that were not retained by the trawl.

We do assume adequate compensation for the ADZ based on the theoretical correction. Although we cannot know if detection was 100%, we used a short pulse width and fast repetition rate to observe fish in contact with the sea bottom (Ona and Mitson 1996). Given our pulse width (0.3 ms) and the typical speed of sound (approximately 1,500 m/s), fish had to be about 0.2 m above the sea bottom to be resolvable by our echosounder. This distance is greater than the fish height of either Atlantic croakers or white perch, so it is probable that some fish echoes were unresolved or partially integrated. Targets, however, tended to spread evenly throughout depths occupied by the trawl rather than clustering in the bottom 0.5 m integrated (Figure 4), which is necessary for an accurate ADZ correction (Ona and Mitson 1996).

We do not believe that fish density was overestimated by EI of nontarget species that were sampled by the echosounder but not retained by the trawl. First, all files were visually inspected during EI to identify any potential nontarget species (e.g., large schools) in the trawl sweep, and none were identified. Second, there was a good visual match between the TS distributions and the TL distributions, especially when the length distribution was complex and the distributions were generated from many tows (i.e., March 2003 and July 2004; Figure 2). This is, however, a limited diagnostic because fish physiology, aspect with respect to the echosounder, and behavior are all important factors in influencing TS measurements (e.g., Horne 2003).

It is also possible that q_e estimates are biased high because the effective fishing volume of the net may be underestimated. We know that the short legs cause the trawl wings to align behind the doors (Figure 2); however, the volume estimate is conservative, presuming that the doors are at times spread farther out than the wings and herding fish (Engås and Godø 1986). A relatively small distance between the door and wing, such as 0.5 m, would yield a tow volume underestimate of 9–14% over the range of w measured.

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It is also possible that fish density estimates were not representative of the conditions in front of the entire net. Shipboard personnel observed that the position of the echosounder in relation to the vessel (and presumably the trawl) did at times change through the course of a tow. Thus, we likely obtained readings from different positions relative to the warp and mouth of the trawl. Variation in position of the echosounder might yield different fish density as fish react to the warp (Handegard and Tjøstheim 2005) or vessel (Fréon et al. 1993; Wardle 1993) and could yield bias because the echosounder did not sample the entire area in front of the net. The direction of this bias, if present, is unknown and is not possible to evaluate from our data.

Despite the potential for error, the distribution of q_e estimates suggests that q_e was not underestimated. The larger mode of Atlantic croaker estimates (20 of 29 hauls) is clustered about a $\hat{q}_e$ value of 1.0 (average $\pm$ SD $= 0.91 \pm 0.19$). If there was a systematic bias, then one could equally well conclude that the estimates were too low (i.e., $\hat{q}_e$ was often >1.0). Furthermore, the Spearman's rank correlation had a value of 0.53, which compares favorably with the results of other studies that have related acoustic backscatter to trawl catch data (von Szalay et al. 2007).

Finally, this study does not quantify q ($=q_e q_a$), which is certainly less than q_e if some fish were unavailable to the gear, whether due to vessel avoidance or position in the water column. Vessel effects were outside the scope of this study. Past studies have failed to find a correlation between acoustic backscatter integrated over varying depths and trawl catches, often because it is difficult to identify the depth of the fish that are available to the trawl (e.g., Aglen 1996). Our data set does not allow us to evaluate the assumption that all Atlantic croakers and white perch are demersal during the trawling period (diurnal). The acoustic backscatter in the tows used for this study was highest within 2–3 m of the sea bottom, which corresponds well to the height of the trawl sweep, and few targets were observed in the other areas of the water column. However, in shallow tows, visual inspection was difficult due to interference of vessel wake in the upper water column.

Factors Associated with Varying Efficiency

While the cause of the variable q_e is not known, the post hoc analysis of the Atlantic croaker data indicates that fish density and w are highly significant factors, whereas z and f are slightly less influential factors. It is likely that variation in $\hat{q}_e$ is the result of changes in trawl performance and fish behavior. Our study is a preliminary examination of this trawl gear and was not meant to address these more complex variables but rather to identify aspects of the gear that merit further research.

The observation that $\hat{q}_e$ declined as fish density increased could be the result of net avoidance behavior by Atlantic croakers, catch saturation, or possibly both factors. A similar loss of efficiency at high fish densities was observed in bottom trawls targeting the capelin *Mallotus villosus* (O'Driscoll et al. 2002). Net avoidance would be consistent with the low TS at size if we observed fish swimming down and away from the trawl.

The decline in $\hat{q}_e$ that occurs as w increases is likely due to the fact that the trawl was overspread. When overspread, the leadline on the bottom trawl will reduce its bottom contact and allow fish to escape downward beneath the gear (e.g., Engås and Godø 1986; Rose and Nunnallee 1998; von Szalay and Somerton 2005). To improve q_e, future research should examine the relationship between w, bottom contact time, and potentially relevant operational or oceanographic variables, such as towing speed and current conditions.

Sediment type and z were significant factors relating to $\hat{q}_e$, although these relations were smaller in magnitude than those observed for fish density or w. Catch efficiency decreased in relation to f. Sand plumes, like trawl doors, may effectively herd fish into the net (e.g., Engås and Godø 1986; Wardle 1993). Whether this is due to physical bed structure, fish behavior, or both is unknown. Possibly, the plumes associated with the trawl are smaller or less dense in silty sediment than in sandy sediment. In contrast, dredging efficiency actually declines over firm, sandy sediments compared with soft, muddy sediments because bottom contact is reduced (Currie and Parry 1999). Similarly, it is not known why $\hat{q}_e$ increased with z. Gear avoidance may be prompted by visual stimuli; thus, the higher q_e at depth may be due to reduced light, which is thought to reduce avoidance behavior (Fréon et al. 1993) but may also reduce herding (Glass and Wardle 1989).

Conclusions

Should acoustics be used for long-term fishery-independent monitoring in Chesapeake Bay or other shallow coastal ecosystems? Estimates of q_e provided reasonable results, generally not much higher than 1, and the Spearman's rank correlation of the acoustic estimate and catch data was significant. Thus, the demersal trawl plausibly can be used to provide a relative density index. We recommend that acoustics be integrated into the survey design to address variable q_e. Chesapeake Bay is shallow ($<$45 m), and thus acoustic sampling will routinely sample only a portion of the area in front of the net. However, combining catch data

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and acoustic transects should be able to provide more robust estimates of fish abundance in Chesapeake Bay than are currently obtained. Hydroacoustic transects can be used to obtain density estimates and the trawl can be used for species and size allocation in mixed-species data sets (e.g., Peltonen et al. 1999; McQuinn et al. 2005), or abundance estimates can be obtained from both methods (Godø and Wespestad 1993). Further research on species-specific TS–TL relationships, including the influence of behavior, will be required so that EI can be scaled correctly over the course of dramatic seasonal assemblage shifts.

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References

Aglen, A. 1996. Impact of fish distribution and species composition on the relationship between acoustic and swept-area estimates of fish density. ICES Journal of Marine Science 53:501–505.

Boswell, K. M., M. P. Wilson, and C. A. Wilson. 2007. Hydroacoustics as a tool for assessing fish biomass and size distribution associated with discrete shallow water estuarine habitats in Louisiana. Estuaries and Coasts 30:607–617.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and inference: a practical information-theoretic approach, 2nd edition. Springer-Verlag, New York.

Currie, D. R., and G. D. Parry. 1999. Impacts and efficiency of scallop dredging on different soft substrates. Canadian Journal of Fisheries and Aquatic Sciences 56:539–550.

de la Mare, W., A. Constable, E. van Wijk, T. Lamb, D. Hayes, and B. Ronai. 2002. CMIX: user's manual and specifications. Australian Antarctic Division, Kingston.

Doubleday, W. G., and D. Rivard. 1981. Bottom trawl surveys. Canadian Special Publication of Fisheries and Aquatic Sciences 47:385–394.

Engås, A., and O. R. Godø. 1986. Influence of trawl geometry and vertical distribution of fish on sampling with bottom trawl. Journal of Northwest Atlantic Fishery Science 7:35–42.

Foote, K. G. 1979. On representations of length dependence of acoustic target strengths of fish. Journal of the Fisheries Research Board of Canada 36:1490–1496.

Fréon, P., F. Gerlotto, and O. A. Misund. 1993. Consequences of fish behaviour for stock assessment. ICES Marine Science Symposia 196:190–195.

Frouzova, J., J. Kubecka, H. Balk, and J. Frouz. 2005. Target strength of some European fish species and its dependence on fish body parameters. Fisheries Research 75:86–96.

Gauthier, S., and G. A. Rose. 2001. Diagnostic tools for unbiased in situ target strength estimation. Canadian Journal of Fisheries and Aquatic Sciences 58:2149–2155.

Glass, C. W., and C. S. Wardle. 1989. Comparison of the reactions of fish to a trawl gear, at high and low light intensities. Fisheries Research 7:249–266.

Godø, O. R., S. J. Walsh, and E. Angås. 1999. Investigating density-dependent catchability in bottom trawl surveys. ICES Journal of Marine Science 56:292–298.

Godø, O. R., and V. G. Wespestad. 1993. Monitoring changes in abundance of gadoids with varying availability to trawl and acoustic survey. ICES Journal of Marine Science 50:39–51.

Graham, N., E. G. Jones, and D. G. Reid. 2004. Review of technological advances for the study of fish behaviour in relation to demersal fishing trawls. ICES Journal of Marine Science 61:1036–1043.

Handegard, N. O., and D. Tjøstheim. 2005. When fish meet a trawling vessel: examining the behaviour of gadoids using a free-floating buoy and acoustic split-beam tracking. Canadian Journal of Fisheries and Aquatic Sciences 62:2409–2422.

Handegard, N. O., and K. Williams. 2008. Automated tracking of fish in trawls using the DIDSON (Dual frequency Identification Sonar). ICES Journal of Marine Science 65:636–644.

Hartman, K. J., and B. W. Nagy. 2005. A target strength and length relationship for striped bass and white perch. Transactions of the American Fisheries Society 134:375–380.

Hazen, E. L., and J. K. Horne. 2004. Comparing the modelled and measured target-strength variability of walley pollock, *Theragra chalcogramma*. ICES Journal of Marine Science 61:363–377.

Horne, J. K. 2003. The influence of ontogeny, physiology, and behaviour on the target strength of walleye pollock (*Theragra chalcogramma*). ICES Journal of Marine Science 60:1063–1074.

Jennings, S., M. J. Kaiser, and J. D. Reynolds. 2001. Marine fisheries ecology. Blackwell Scientific Publications, Oxford, UK.

Kemp, W. M., W. R. Boynton, J. E. Adolf, D. F. Boesch, W. C. Boicourt, G. Brush, J. C. Cornwell, T. R. Fisher, P. M. Glibert, J. D. Hagy, L.W. Harding, E. D. Houde, D. G. Kimmel, W. D. Miller, R. I. E. Newell, M. R. Roman, E. M. Smith, and J. C. Stevenson. 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. Marine Ecology Progress Series 303:1–29.

Love, R. H. 1971. Dorsal-aspect target strength of an individual fish. Journal of the Acoustical Society of America 49:816–823.

McClatchie, S., J. Alsop, and R. F. Coombs. 1996a. A re-evaluation of relationships between fish size, acoustic frequency, and target strength. ICES Journal of Marine Science 53:780–791.

McClatchie, S., J. Alsop, Z. Ye, and R. F. Coombs. 1996b. Consequence of swimbladder model choice and fish

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orientation to target strength of three New Zealand fish species. ICES Journal of Marine Science 53:847–362.

McQuinn, I. H., Y. Simard, T. W. F. Stroud, J. L. Beaulieu, and S. J. Walsh. 2005. An adaptive, integrated "acoustic-trawl" survey design for Atlantic cod (*Gadus morhua*) with estimation of the acoustic and trawl dead zones. ICES Journal of Marine Science 62:93–106.

Mehner, T. 2006. Prediction of hydroacoustic target strength of vendace (*Coregonus albula*) from concurrent trawl catches. Fisheries Research 79:162–169.

Montane, M., R. N. Lipcius, and M. S. Seebo. 1997. Crustacean Ecology Program, Technical Report Number 1997(3), submitted to the Chesapeake Bay Stock Assessment Committee, National Oceanic and Atmospheric Administration, Annapolis, Maryland.

Murdy, E. O., R. S. Birdsong, and J. A. Musick. 1997. Fishes of Chesapeake Bay. Smithsonian Institution Press, Washington, D.C.

O'Driscoll, R. L., G. A. Rose, and J. T. Anderson. 2002. Counting capelin: a comparison of acoustic density and trawl catchability. ICES Journal of Marine Science 59:1062–1071.

Ona, E., and O. R. Godø. 1990. Fish reaction to trawling noise: the significance for trawl sampling. Rapports et Proces-Verbaux Des Reunions Conseil International Pour l'Exploration de la Mer 189:159–166.

Ona, E., and R. B. Mitson. 1996. Acoustic sampling and signal processing near the seabed: the deadzone revisited. ICES Journal of Marine Science 53:677–690.

Peltonen, H., J. Ruuhijarvi, T. Malinen, and J. Horppila. 1999. Estimation of roach (*Rutilus rutilus* (L.)) and smelt (*Osmerus eperlanus* (L.)) stocks with virtual population analysis, hydroacoustics and gillnet CPUE. Fisheries Research 44:25–36.

R Development Core Team. 2008. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.

Rose, C. S., and E. P. Nunnallee. 1998. A study in changes in groundfish trawl catching efficiency due to differences in operating width, and measures to reduce width variation. Fisheries Research 36:139–147.

von Szalay, P. G., and D. A. Somerton. 2005. The effect of net spread on the capture efficiency of a demersal survey trawl used in the eastern Bering Sea. Fisheries Research 74:86–95.

von Szalay, P. G., D. A. Somerton, and S. Kotwicki. 2007. Correlating trawl and acoustic data in the eastern Bering Sea: a first step toward improving estimates of walleye pollock (*Theragra chalcogramma*) and Pacific cod (*Gadus macrocephalus*)? Fisheries Research 86:77–83.

Wardle, C. S. 1993. Fish behaviour and fishing gear. Pages 609–644 *in* T. J. Pitcher, editor. Behaviour of teleost fishes. Chapman and Hall, London.

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