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Statistical Combination of Multifrequency Sounder-detected Bottom Lines Reduces Bottom Integrations

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Alaska Fisheries Science Center
7600 Sand Point Way N.E.
Seattle, WA 98115
www.afsc.noaa.gov

U.S. DEPARTMENT OF COMMERCE
Gary F. Locke, Secretary
National Oceanic and Atmospheric Administration
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National Marine Fisheries Service
Eric C. Schwaab, Assistant Administrator for Fisheries

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ABSTRACT

Accurate quantification of biological abundance using acoustics requires complete removal of the sea floor's contribution from the echo. Acoustic-trawl surveys often utilize a single sounder-detected bottom (SDB) line for bottom determination, but combining bottom detections from multiple frequencies could provide a more accurate representation. Using bottom detection lines from five different frequencies, 222 nautical miles of trackline from four distinct acoustic-trawl survey areas were investigated to determine if the mean or median statistical combination of multiple frequency SDB lines resulted in fewer bottom integrations compared to a single frequency SDB. The difference in bottom detection depth between the statistical combination lines and the 38 kHz SDB was also investigated. The mean statistical combination line reduced bottom integrations by an average of 45% and the median produced a 43% reduction in integrations over all areas. Additionally, bottom depth averaged 5.9 and 6.9 cm shallower for the mean and median, respectively, compared to the 38 kHz SDB. Overall the mean tended to be marginally better at reducing the bad bottom integrations while at the same time slightly less divergent from the 38 kHz SDB compared to the median. Based on these results, beginning in 2009, the Alaska Fisheries Science Center's Midwater Assessment and Conservation Engineering Program began using the mean statistical combination line to represent the true bottom, replacing the 38 kHz SDB line historically used.

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INTRODUCTION

Underwater acoustics have been employed since the mid-20th century for determining bottom depth and estimating the density of fish aggregations. Acoustic-trawl surveys are used to estimate abundance of economically important fish stocks worldwide (Misund 1997). To accurately quantify the abundance of fish in the water column, it is crucial to completely remove the contribution of the echo returned from the bottom. If the bottom echo is not properly excluded, the estimated fish density can be grossly inaccurate (Simmonds and MacLennan 2005).

Many fisheries applications utilize a 38 kHz split-beam transducer as a primary source of acoustic data and depth determination (Aglen 1996, Misund 1997). Bottom-detection depends on echo-amplitude measurements and user-defined thresholds for defining bottom discrimination levels (Bourguignon et al. 2009, Ona and Mitson 1996). A vertical offset or backstep from the threshold amplitude is also commonly employed to ensure that the bottom is sufficiently excluded.

Even with an appropriate threshold and backstep, several circumstances can result in unsatisfactory bottom detection. Adverse weather conditions can cause missed or dropped pings and may also result in the bottom appearing rougher or more variable. Additionally, a dense school of fish in close proximity to the bottom may be integrated with the bottom, or a soft, poorly reflecting bottom may be misinterpreted as being deeper (Bourguignon et al. 2009, MacLennan et al. 2004). In these instances it may be helpful to consult bottom detections from additional frequencies to obtain a more accurate determination of the bottom. Using a combination of frequencies would also reduce the random variability of a single sounder in areas of relatively flat seabed.

The rationale underlying multifrequency bottom detection is simple: by averaging simultaneous estimates of the bottom depth made from a cluster of co-located transducers at multiple frequencies, one can arrive at a more precise estimate of the seafloor depth at a particular location. If some portion of the error in estimating the range to the seafloor is uncorrelated across frequencies, using multiple frequencies will produce a less variable estimate of the bottom depth by averaging out stochastic errors. Multifrequency bottom detection will therefore result in fewer cases in which the bottom depth is misidentified. This is likely to be the case with bottom detections in areas of relatively flat bottom, where a single sounder-detected bottom (SDB) line fails to eliminate backscatter from the seafloor, events that are typically uncorrelated across frequencies. In contrast, steep or variable bottom terrain can result in occasional loss of bottom detection or a shadowing effect that could be misinterpreted as fish. Inaccurate bottom detections such as these are caused by interactions of the side lobes of the acoustic beam with the seafloor due to the angle of incidence being too large (Bourguignon et al. 2009). Unfortunately, side-lobe induced errors in areas of high relief are correlated across frequency, and multifrequency combinations of bottom detections are unlikely to eliminate the problem entirely.

A combined bottom detection line could approximate bottom depth more accurately and potentially reduce the amount of time spent on the post-processing step of manually checking bottom integration errors. In addition to reducing bottom integrations, a combined multifrequency bottom detection line could help reduce false bottom detections within dense fish schools where different frequencies detect the bottom at different depths. Both of these errors can significantly impact biomass estimation. Furthermore, a more robust multiple frequency bottom detection method would facilitate efforts to use multifrequency combinations for species identification, where the need to accomplish bottom exclusion at multiple frequencies simultaneously is required (De Robertis et al. 2010).

Scientists from the Alaska Fisheries Science Center's (AFSC) Midwater Assessment and Conservation Engineering (MACE) Program routinely conduct acoustic-trawl stock assessment surveys in the Gulf of Alaska (GOA) and Eastern Bering Sea (EBS). Historically MACE has used the 38 kHz SDB line produced by the 38 kHz EK60 echosounder using a -36 dB threshold to establish the range to the seafloor. In post-processing, a bottom determination line (defined as the SBD with a 0.5 m backstep) is used to remove the contributions of backscatter from the seafloor. The exact algorithm for the EK60 SDB, though proprietary, is known to be amplitude-based over multiple pings. With a desire for greater precision and accuracy of data collection and less user manipulation through manual correction of the SDB line, MACE scientists worked with Myriax, a vendor of echosounder post-processing software, to implement an algorithm for use in their Echoview (Myriax Software Pty, Ltd., Hobart, Australia) post-processing software that would combine SDB lines from multiple frequencies and output either the mean or median as a single statistical combination bottom detection line (see Methods). Similar ideas have also been incorporated into alternate hydroacoustic software packages (Korneliussen et al. 2006) used by other groups performing acoustic-trawl surveys.

During EBS surveys, MACE traditionally estimates biomass to within 3 m of the seafloor, and in the Gulf of Alaska surveys that is extended to within 0.5 m of the seafloor. If the bottom detection depth is altered significantly using a new combination line, the data time series could be biased due to inclusion or exclusion of fish within the bottom few meters. Therefore before implementing a new bottom detection methodology, the potential for biasing the survey time series needed to be considered.

This document describes the use and functionality of combining sounder-detected bottoms from multiple frequencies to generate a more robust estimate of seafloor depth than is possible with a single frequency. Specifically, we test if the mean and median sounder-detected bottom lines across multiple frequencies result in fewer bottom integrations. The occurrence of bottom integrations with the statistical combination lines was compared with that of the 38 kHz SDB. The difference in the bottom detection depth is also investigated between the statistical combination lines and the 38 kHz SDB. A recommendation is made for the statistical combination line that performs best under survey conditions, and it is demonstrated that adopting this new method will not bias survey estimates of fish abundance.

METHODS

All survey data were collected aboard the NOAA ship *Oscar Dyson*, a 64-m stern trawler equipped for fisheries and oceanographic research. Acoustic measurements were collected with a calibrated Simrad EK60 scientific echo sounding system (Simrad 2004) with five split-beam transducers (18, 38, 70, 120, and 200 kHz) clustered close together on the bottom of the vessel's retractable centerboard. Acoustic measurements were analyzed using Myriax Echoview post-processing software version 4.70. Each frequency transmitted simultaneously at one ping per second, with a 1.024 ms pulse length. Nominal half-power beam widths were 11° for the 18 kHz transducer, and 7° for the 38, 70, 120, and 200 kHz transducers. For each frequency, the echo sounder's amplitude-based bottom detection as implemented in the echosounder software (ER60 version 2.1.2) was used with a backstep minimum level set to -36 dB. For each ping, and for each frequency, an independent estimate of the range to the seabed was obtained.

To ensure performance over a range of bottom types and depths, the statistical combination algorithm was evaluated using data from 2007 and 2008 that was representative of all survey areas currently monitored by MACE (Fig. 1). Within each region, from 30 to 94 nautical miles (nmi) of survey trackline data were analyzed ranging in depth from 62 to 479 m (Table 1). Tracklines to be analyzed were chosen from periods when wind speeds exceeded 20 knots to have the greatest possibility of erroneous or bad bottom integrations.

Several operators are available within the Echoview software for manipulating lines; the current evaluation will focus on the statistical combination and crop options. For higher frequencies at greater range, noise becomes limiting, causing erroneous depth estimations, which if not removed, would be incorporated into the statistical combination operator. We therefore used the crop operator to remove the SDB lines below 500 m for the 120 kHz and 250 m for the 200 kHz frequencies to reduce erroneous depth entries.

The statistical combination operator includes several options for customizing the lines created (Fig. 2). One allows the designation of lines for input into the statistical combination. A minimum of two and a maximum of six SDB or other editable lines are available for input. Another option allows the user to choose which statistic to work with for the combination: mean, median, minimum, or maximum depth. The mean calculates the average bottom detection at each ping from the chosen frequencies. The median chooses the bottom detection line that is in the ordered middle when there are an odd number of lines being evaluated, or computes the average of the two ordered middle lines if the number of lines is even. The minimum and maximum statistics choose the line respective to the name designation at each ping. Also in this operator is an optional function to systematically exclude any lines that exceed a stated divergence limit from the mean. In other words, if an individual sounder-detected bottom line does not fall within the range defined by the divergence limit from the mean, it is excluded, the mean is recalculated, and the remaining lines are re-evaluated against the new mean. Another option allows the user to name the new statistical combination line. The name will display on the Echoview window when the cursor is positioned on the line. Finally there is a notes documentation window to allow the user to input miscellaneous meta-data.

For this study individual pings were scrutinized from the 38 kHz echogram and tallied when the bottom was integrated. To quantify bottom integration, an analysis region was created from 0.5 m to 1.0 m above the SDB. The mean Sv within this region was displayed as a color code, and a visual scan of individual pings was performed. The total number of bottom integrations was compared among the 38 kHz SDB, mean, and median statistical combination lines. All echograms were scrutinized by the same individual to eliminate any selection bias of questionable integrations. Areas of steep relief were not included in counts of bottom integration as bottom detection in these areas was poor at all frequencies and did not improve with SDB combination.

Additionally, the bottom depth detected for each ping was exported and compared among candidate lines. If a ping was dropped at any frequency, that ping was removed from bottom depth analysis for all frequencies. The difference between the 38 kHz SDB depth and the mean and median bottom depths were computed for each ping and an overall average and standard deviation of the differences were calculated for each area. Differences between the bottom depths detected by the 38 kHz SDB and the statistical combination lines and other frequencies were also plotted to examine their distributions.

RESULTS AND DISCUSSION

Results were dependent on the area investigated, but the overall count of bottom integrations was lower for both the mean and median statistical combination lines compared to the 38 kHz SDB line (Table 2). Results for the mean and median statistical combination lines were similar within area but tended to be slightly better for the mean in most cases. Error reduction ranged from 3% to 92% with an average of 45% for the mean, and 3% to 87% with an average of 42% for the median. The difference in detected bottom depth was consistent between the mean and median statistical combination lines compared to the 38 kHz SDB, but the median depth was approximately 1 cm shallower than the mean (Table 2). Overall the mean tends to be better at reducing bad bottom integrations while at the same time being slightly less divergent from the 38 kHz SDB, which has historically been used for the detected bottom depth for MACE acoustic-trawl surveys.

A total of 222 nmi of trackline were investigated from six distinct survey areas (Table 1). Wind speeds ranged from 20 to 40 knots and bottom depth ranged from 62 to 479 m. Wind speed, which results in rough sea conditions and increased vessel movement, and water depth appear to influence the number of bottom integrations and the depth difference between the 38 kHz SDB and statistical combination lines differently. The largest difference (20 cm) between the bottom depths detected by the 38 kHz SDB and the statistical combination lines was in the Bogoslof area where the mean water depth was also greatest (479 m)(Table 2). However, in an area with similar wind speed but shallower depth (Renshaw Point) the difference between the 38 kHz and statistical combination depths was only 1 cm, but the percent reduction in bottom integrations was the highest (92%).

One reason for the increased difference between lines at greater depth is that there are fewer SDB to incorporate into the combination. At depths greater than 500 m, the 120 kHz beam is significantly attenuated, and the same is true at depths of greater than 250 m for the 200 kHz beam. Also, the beams intercepting the seafloor are much larger at depth, and one would expect more variance with increased depth. Furthermore, with the divergence limit set at 1 m, measurements greater than 1 m from the mean were removed and the mean was recalculated, resulting in fewer SDB to incorporate. In several instances the 38 kHz bottom detection was outside the divergence limit so that the mean and median were calculated from the 18 kHz and 70 kHz SDB, increasing the difference of the mean and median from the 38 kHz SDB.

The depth difference between the 38 kHz SDB and statistical combination lines revealed no significant positive or negative bias and data were normally distributed around the mean. Even in the Bogoslof survey area, this difference was only 0.2 m which equates to less than the resolution of one integration cell. Therefore, no bias would be introduced into a survey time series due to differential inclusion/exclusion of near-bottom fish, which is a concern for long-term time series used for fisheries management.

Even though bottom integrations were reduced when using the mean and median statistical combination lines and the time spent performing post-processing integration checks can be substantially reduced, the need for scrutinizing the bottom detection line is still imperative. This is especially true in areas where the errors in bottom detections are correlated across frequencies, for example in areas where a steep slope makes bottom detection difficult. Based on our results, beginning in 2009 the MACE Program began using the mean statistical combination line to represent the true bottom in place of the 38 kHz SDB line used historically.

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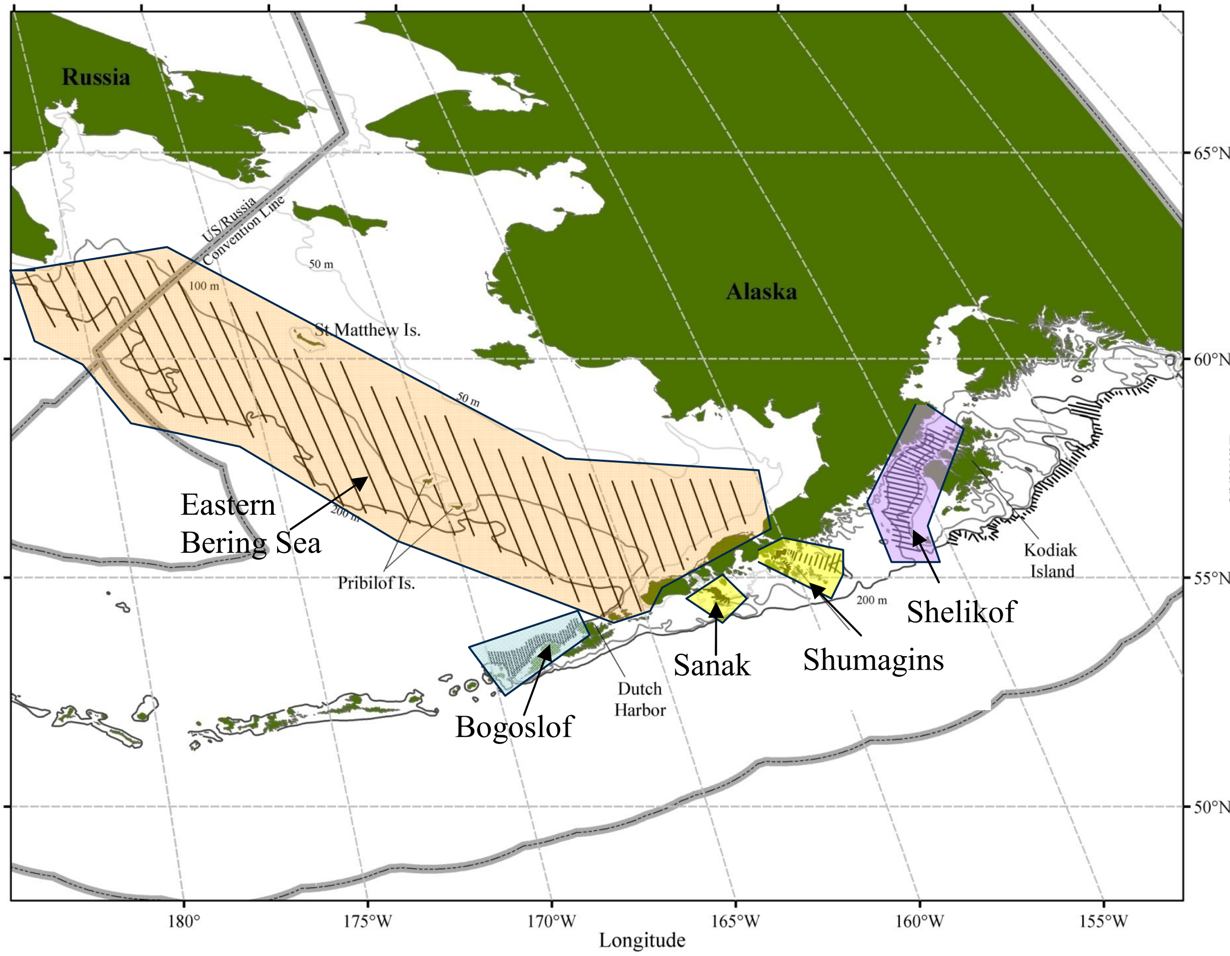

Figure 1. -- The five survey areas from which bottom detection algorithms were tested.

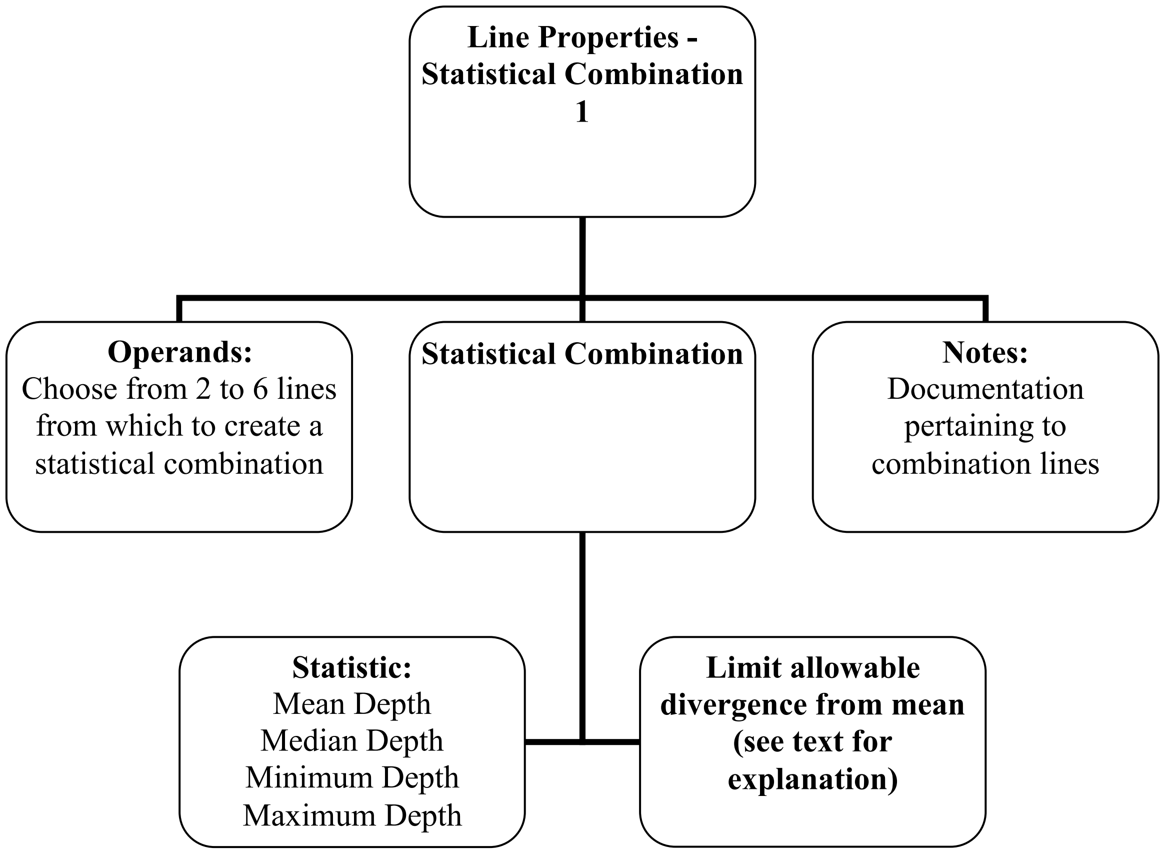

Figure 2. -- Flow diagram of statistical combination selections within the “New Virtual Line” operation in Echoview V.4.70.

Table 1. -- Trackline distance, approximate wind speed, and mean water depth for each survey area used in the evaluation of the statistical combination of sounder detected bottom lines.

Area	Distance (nautical miles)	Wind speed (knots)	Mean water depth
Shumagin trough	15.2	35	161
Renshaw Point	15.7	20	175
Sanak trough	14.6	40	113
Bogoslof T48 and transit	18.5	30-40	135
Bogoslof T25	11.0	20	479
Shelikof Strait	53.0	30-40	218
Eastern Bering Sea	94.0	20-35	62

Table 2. -- Results of bottom integration counts of 38 kHz sounder detected bottom line, and mean and median statistical combination lines. Delta mean or median is the difference in depth determined by the statistical combination line and the 38 kHz SDB line. Negative values indicate shallower depth determination using the mean and median compared to the 38 kHz SDB.

	Bottom integration counts (% reduction from 38 SBD)			Depth difference delta = stat - 38 kHz SDB	
Area	38 SDB	Mean (Statistical combination)	Median (Statistical combination)	Mean +/- s.d.	Median +/- s.d.
Shumagin trough	66	61 (7.6)	64 (3.0)	-3.2 +/- 18 cm	-4.1 +/- 19 cm
Renshaw Point	37	3 (91.9)	5 (86.5)	-0.3 +/- 23 cm	-1.2 +/- 24 cm
Sanak trough	48	16 (66.7)	16 (66.7)	-4.6 +/- 13 cm	-5.3 +/- 13 cm
Shelikof T22	6	4 (33.3)	4 (33.3)	-2.6 +/- 5 cm	-2.9 +/- 6 cm
Shelikof T23	40	8 (80.0)	12 (70.0)	-3.2 +/- 8 cm	-3.9 +/- 8 cm
EBS T4-1	40	25 (40.0)	27 (30.0)	-6.8 +/- 7 cm	-8.4 +/- 8 cm
EBS T4	33	32 (3.0)	27 (18.1)	-6.8 +/- 6 cm	-8.4 +/- 7 cm
Bogoslof T25	45	23 (48.9)	30 (33.3)	-19.7 +/- 140 cm	-20.6 +/- 140 cm
Bogoslof T48 and transit	73	48 (34.2)	45 (38.4)	-6.5 +/- 46 cm	-7.7 +/- 47 cm

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