Fisheries Research 185 (2017) 14–16

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Technical note

# Evaluating the use of acoustic bottom typing to inform models of bottom trawl sampling efficiency

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ARTICLE INFO

*Article history:*
Received 26 July 2016
Received in revised form
21 September 2016
Accepted 26 September 2016
Handled by Prof. George A. Rose

*Keywords:*
Acoustic bottom typing
Trawl selectivity
Snow crabs

ABSTRACT

The sampling efficiency of survey bottom trawls can vary in response to a variety of biotic and abiotic factors. In a previously published model of the sampling efficiency of snow crab (*Chionoecetes opilo*), based on a trawl comparison experiment, the efficiency of the bottom trawl used in the eastern Bering Sea varied with water depth and sediment size. The sediment size used in the model, however, was not directly sampled at the trawl locations but instead was interpolated from an existing sediment data base. We examine whether bottom type attributes estimated with commercially available software applied to acoustic data collected by the vessels during the experiment was more informative to the model than the interpolated estimates of sediment size. Based on increases in explained deviance, the model fits for males (6% higher) and females (35% higher) were both improved using the acoustically derived estimates of bottom type.



## 1. Introduction

Bottom trawl surveys often encompass large geographic areas with spatially variable biotic and abiotic conditions. The sampling efficiency of a survey trawl (i.e. proportion of individuals within the trawl swept-area that is captured for a given species) can be affected by this variability because sampling efficiency is a function of body size (Wileman et al., 1996), and potentially influenced by bottom type (Dawe et al., 2010), current speed (Weinberg et al., 2002), water depth (Weinberg and Kotwicki, 2008), wave height (Stewart et al., 2010) and perhaps other factors that vary over the survey area. In a study of the sampling efficiency of the bottom trawl used in the eastern Bering Sea (EBS) survey (EBS survey and trawl described in Lauth and Conner, 2014) for snow crab (*Chionoecetes opilio*), Somerton et al. (2013) conducted a side-by-side fishing experiment in which a vessel equipped with an experimental trawl designed to capture nearly all crabs was paired with the survey vessel equipped with the standard trawl during normal operations. The resulting data were used to build a model of sampling efficiency as a function of the sex and carapace widths of the crabs, as well as the water depth and mean sediment diameter at the trawling locations (Somerton et al., 2013). However, the sediment size data used in the model were not directly measured at each trawling site, but instead were estimated using geospatial interpolation (kriging) of data from historical collections of EBS sediment samples (Smith and McConnaughey, 1999). Although the number of sediment samples was quite large, the sampling locations were spatially clumped and more concentrated near land, with the consequence that some of the estimated values of sediment size at trawling locations were the result of interpolations far from the nearest sediment sampling location, which potentially introduced bias to the estimates.

Instead of initiating a program to collect sediment samples at EBS trawling locations to better inform the model, we investigated the approach taken by Dawe et al. (2010), in a similar study of snow crab trawl sampling efficiency in Canadian waters, and measured sediment properties using commercially available acoustic bottom typing software applied to acoustic data collected by the EBS survey vessel while conducting the experiment. In this study, we examine the predictive power of these acoustic estimates of bottom type compared to that of the kriged estimates of mean sediment size originally used in the model. If the acoustically derived estimates of bottom type are as informative to the model of snow crab sampling efficiency as the kriged estimates, it would indicate that the continued collection of acoustic data by trawl survey vessels, and its use in the estimation site-specific trawl sampling efficiency, would be a promising way of reducing among-station variation in trawl

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http://dx.doi.org/10.1016/j.fishres.2016.09.029
0165-7836/© 2016 Published by Elsevier B.V.

sampling efficiency and, thereby, reducing the variance of trawl survey estimates of abundance.

## 2. Methods

### 2.1. Collection and processing of acoustic data

Acoustic backscatter data were collected continuously by the EBS bottom trawl survey vessels used in the original experiment (Somerton et al., 2013) with Simrad ES-60 echosounders (38 kHz) that had been calibrated with tungsten-carbide spheres at the beginning of the survey. The acoustic data for each trawl haul were extracted from the Simrad output (RAW files; Simrad, 2000) from the time of the first contact of the trawl footrope with the bottom to the time of last contact, offset by the time required to traverse the trawl lay-back distance to ensure that the acoustic backscatter from the seafloor were representative of the actual tow path. These data have a systematic error (i.e., "triangle wave") embedded in the transmit pulse, which was removed using the ES60 adjust utility detailed in Ryan and Kloser (2004). The corrected acoustic data were then analyzed using a new version of QTC Impact[1] (renamed IMPULSE 15.0 by Maritime Way Scientific Ltd; http://www.maritimeway.ca/seabed-classification/impulse15/) bottom typing software that measures a variety of characteristics of the returning bottom echo (Biffard et al., 2007) and computes three principal components ($Q_1$, $Q_2$, $Q_3$) of these measures for each acoustic ping. The Q values were subsequently averaged over the ~2.7 km length of each haul.

### 2.2. Modeling sampling efficiency

The original sampling efficiency model (Eq. (5)) in Somerton et al., 2013) is

$$logit\left(\frac{C_a}{C_a + C_b}\right) = S(W) + S(D, \phi) \quad ,$$

where $C_a$ and $C_b$ are the number of snow crab, by sex and 5 mm width interval, caught by the EBS trawl survey vessel (subscript a) and by the vessel with the experimental trawl (b), S(W) is a smooth function of carapace width and S(D,Φ) is a bivariate smooth function of water depth at a trawl station and the sediment size expressed in units of Φ (-$\log_2$(diameter in mm)). The equation was fit to the data using Generalized Additive Modeling (function gam in the R package mgcv; R Development Core Team, 2008), then back-transformed to a linear scale to produce estimates of capture probability. To examine the information content of the $Q_1$, $Q_2$, and $Q_3$ values, they were substituted for Φ in the above equation but were entered into the model both as single smooth functions and as bivariate smooth functions with each other and with depth. The best-fitting model was chosen as the one that minimized the value of AIC (Akaike, 1974). To show the impact of including the Q-values into the model, relative to the inclusion of no bottom substrate information and relative to the inclusion of kriged values of Φ, we also fit models that included: 1) S(W) and S(D) alone (i.e., no bottom type data), and 2) S(W) and S(D,Φ) (i.e., the original model in Somerton et al., 2013). The model results, expressed as AIC and the percent of the total deviance explained by the model, is presented in Table 1 for each sex and model formulation.

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

**Table 1**
Four models are shown for each sex of snow crab: 1) a model without bottom type information, 2) a model with bottom sediment size expressed as mean Φ, 3) a model with bottom type expressed as independent smooth functions of the three Q-values and 4) a model with bivariate smooth functions of the Q-values and depth. For each model, the values of AIC and the percent of the deviance explained by the model are shown. The sample size (N) is the sum of the number of 5 mm carapace width categories over all sampling stations where each sex was encountered. The notation "S" indicates a smooth function of arguments.

| Sex | Model | AIC | % Dev. exp. | N |
|---|---|---|---|---|
| female | S(W)+S(D) | 5032 | 41 | 699 |
| female | S(W)+S(D,Φ) | 4312 | 54 | |
| female | S(W)+S(D)+S($Q_1$)+S($Q_2$)+S($Q_3$) | 3873 | 61 | |
| female | S(W)+S($Q_3$,D)+S($Q_1$,$Q_2$) | 3173 | 73 | |
| male | S(W)+S(D) | 6134 | 40 | 1407 |
| male | S(W)+S(D,Φ) | 5837 | 49 | |
| male | S(W)+S(D)+S($Q_1$)+S($Q_2$)+S($Q_3$) | 5545 | 49 | |
| male | S(W)+S($Q_3$,D)+S($Q_1$,$Q_2$) | 5415 | 52 | |

## 3. Results

The best-fitting model utilizing Q-values to represent bottom characteristics, for both male and female snow crab, included a bivariate smooth of $Q_3$ and depth and a bivariate smooth of $Q_1$ and $Q_2$ (Table 1). In all models tested, those that included all three Q variables had a lower value of AIC than those with less, but models with bivariate terms had still lower values. Relative to the model reported in Somerton et al. (2013), the best model using Q-values increased the percent deviance explained by 6% for males and by 35% for females (Table 1). Relative to the model including no bottom type information, the percent deviance explained increased by 29% for males and by 75.5% for females. This indicates that the bottom type information was an important explanatory variable in the models and that the Q-values derived from acoustic analysis of data collected for each haul in the original experiment were more informative to the model than the kriged estimates of sediment size.

## 4. Discussion

In the original study (Somerton et al., 2013), inclusion of the kriged values of sediment size in the model of trawl sampling efficiency clearly resulted in a better fit (i.e., smaller value of AIC) than models without this variable, indicating that the sediment size significantly influenced the sampling efficiency of snow crab by the EBS survey trawl. Previous research on the sampling efficiency of the EBS survey trawl for snow crab, using an auxiliary trawl attached underneath the survey trawl (Somerton and Otto, 1999), indicated that the primary cause of reduced snow crab sampling efficiency is escapement under the footrope. Thus our model predictions on the influence on bottom type on sampling efficiency is consistent with the study on the same trawl by Weinberg and Kotwicki (2008) which demonstrated that the distance of the footrope from the bottom also varied with water depth and sediment size. It follows that sampling efficiency should be lower when the footrope was farther from the bottom.

The inclusion of the Q-values, instead of sediment size, produced still better fits to the efficiency data, implying that the Q-values provided more information to the model. This may be the result of either of two possibilities. First, in the original study the sediment size values were interpolated (kriged) to the locations of the trawl stations, which may have introduced error and possibly bias, but the Q-values were estimated as an average over each trawl path from data collected during the trawl efficiency experiment. Second, the sediment size values are based on the mean particle diameter of the sediment, which ignores sediment characteristics such as sorting and compaction which also may affect

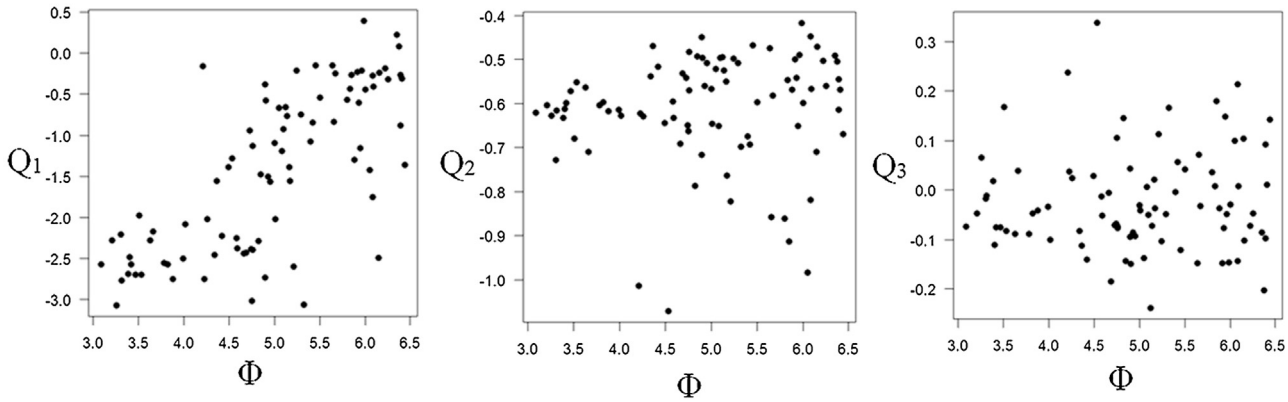


**Fig. 1.** Plots of each of the three Q variables and the sediment size expressed in units of Φ (-$\log_2$(sediment diameter in mm)). $Q_1$ is strongly correlated with Φ, but $Q_2$ and $Q_3$ are either not correlated or only weakly correlated with Φ but likely represent other influential substrate characteristics.

trawl performance. However, because the Q values are principal components derived from many measured attributes of the acoustic data, their exact physical interpretation is vague. $Q_1$ is strongly correlated to Φ (Pearson correlation, r = 0.76, p < 2.2e-16) indicating that it is related to sediment grain size; but $Q_2$ is uncorrelated (r = 0.02, p = 0.56) and $Q_3$ is weakly correlated (r = 0.10, p = 0.01) to Φ (Fig. 1) and perhaps reflect some of these other sediment properties (Holliday, 2007). Regardless of their physical interpretation, the Q values are three independent, continuous-valued descriptors of the bottom that are informative for trawl efficiency modeling.

As seen in Somerton et al. (2013), the improvement in model fit resulting from the inclusion of bottom type data was much greater for females than males (Table 1). One possible reason for this is that adult female snow crabs are considerably smaller than males (Daly et al., 2015) and have noticeably shorter legs. Consequently, the bodies of females tend to be closer to the seabed than those of males and, therefore, their probability of capture may be less than males and more influenced by variation in the footrope clearance distance and, consequently, by the properties of bottom sediments.

The use of acoustically derived bottom type information in species habitat modeling is well established (McConnaughey and Syrjala, 2009). However, this study and that of Dawe et al. (2010) may be unique in their linkage of acoustically derived bottom type information to trawl performance and sampling efficiency. The importance of this linkage is especially important when conducting bottom trawl surveys. The variance of abundance indices from surveys depends not only on among-station variation in species density but also on among-station variation in trawl sampling efficiency. In cases where the benthic properties of a survey area are not well mapped, such information could be obtained relatively cheaply by collecting acoustic data while collecting the trawl samples. Once a trawl experiment has been conducted to provide data to model sampling efficiency, the model could be used to correct subsequent trawl samples for spatial variation in efficiency, thereby reducing one component contributing to the variance of trawl survey estimates of abundance.

## Acknowledgements

This work was supported by a grant from the National Marine Fisheries Service, NOAA, Office of Science and Technology in support of the Habitat Information in Stock Assessments initiative (Project # 13-016). In addition, we thank Jon Preston for technical support and Suzanne Romain for her diligent work using QTC Impact to analyze the acoustic data.

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