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Comparing surficial sediments maps interpreted by experts with dual-frequency acoustic backscatter on the Scotian Shelf, Canada

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ABSTRACT

Understanding seabed properties is increasingly important to support policy in the marine environment. Such knowledge can be gained from diverse methods, ranging from more traditional expert-interpretations of acoustic and ground-truth data, to maps resulting from fully quantitative analyses of acoustic data. This study directly compares surficial geology maps created through expert-interpretations to near-nadir acoustic backscatter data from two frequencies (38 kHz and 120 kHz) collected using single beam echosounders (SBES) for two 5 × 1 km study areas on the Scotian Shelf, Canada. Statistical methods were used to analyze and classify both single and dual-frequency acoustic backscatter for comparisons. In particular, spatial scaling of acoustic backscatter responses and acoustic classes created using acoustic seabed classification (ASC) is compared between frequencies and to interpreted sediment units (ISUs) which make up surficial geology maps produced by experts. Seabed morphology layers were included in an ASC approach to reflect the morphological components included in the interpreted geological maps. Results confirmed that higher frequencies and coarser grain sizes generally produced higher backscatter, while more heterogeneous and rougher seabeds produced variable backscatter. Differing acoustic responses within similar substrate units suggest fundamental seabed variations not reflected in the geological interpretations. Spatial scaling of sand and gravel substrates from 38 kHz frequency were closer than the 120 kHz frequency to the spatial scaling of the interpreted geological map. Variable grain size in the sediment volume and surface morphology are both presented as possible reasons for frequency differences. While both frequencies had similar general responses, differences in frequency responses of backscatter occurred at scales of tens to hundreds of meters. Results presented here emphasize the importance of multi-scale seabed mapping and additional information available from multi-frequency approaches.

1. Introduction

Mapping of marine benthic habitats is necessary as nation states assume responsibilities for the management of their coastal resources (UNCLOS, 1982). Seabed mapping efforts are giving way to approaches that integrate multiple techniques and increasingly rely on advanced technologies (Brown et al., 2011a). Some of those approaches strongly rely on expert interpretations of acoustic and ground-truthing data, while others favor more automated quantitative methods (Anderson et al., 2002; Fader, 2007). Acoustic remote sensing and classification of the seabed from spatial scales of meters to kilometers now allows scientists to apply the theory and practice of landscape ecology to the seabed for the first time (Lanier et al., 2007). Common acoustic mapping technologies include single beam echosounders (SBES), sidescan sonars (SSS) and multibeam echosounders (MBES) (Anderson et al., 2008). MBES have gained popularity in the benthic habitat mapping community due to their ability to provide continuous maps of the seafloor (Brown et al., 2011b). While MBES can generally provide accurate bathymetry, there are challenges associated with processing seabed backscatter data (Lurton and Lamarche, 2015). Despite recent progress with the processing of MBES acoustic backscatter data (Fonseca et al., 2009), SBES often remains a more effective system for accurately classifying seabed sediments due to the normal incidence of the backscatter signal and the relative ease of calibration and data processing and understanding (Anderson et al., 2008; Lurton and Lamarche, 2015). In their comparison of how SBES and MBES backscatter relate to sediments, Haris et al. (2012) conclude that SBES backscatter is more closely correlated to grain size than MBES backscatter. Acoustic backscatter is characterized by acoustic impedance contrasts (product of sediment mass

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density and sound speed), influenced by grain size, porosity, and surface roughness (Jackson and Richardson, 2007). Interpretation of acoustic backscatter differences in association with other factors such as depth, slope and rugosity can be used to classify biotic and abiotic seabed habitats.

Theory relating backscatter to different substrate types is based on models that quantify the relationship between physical seabed properties (e.g. grain size and roughness) and the corresponding backscatter shape and intensity (Jackson and Briggs, 1992; Sternlicht and de Moustier, 2003). These models also consider the frequency a system employs as the amount of absorption, attenuation, and reflectivity of an acoustic signal for various substrate types is also governed by the particular acoustic frequency (Lurton, 2002). Acoustic frequency impacts the ability of the transmitted signal to penetrate the seabed as a function of grain size. Volume scattering and heterogeneities of the substrate volume dominate lower frequency scattering response whereas surface scattering is more influential on higher frequency scattering (Holliday, 2007).

Traditional seabed mapping involves subjective interpretation of a number of data sources (e.g. *in-situ* sampling, seabed photos/videos, and acoustic data) by trained marine geologists. Acoustic seabed classification (ASC) on the other hand utilizes an objective approach whereby classes are statistically determined from acoustic data using specific classification techniques. ASC is typically carried out using a single frequency in the range of 10–300 kHz (Anderson et al., 2008). However, theory predicts that different frequencies can provide different responses as both surface and volume backscatter vary with frequency (Anderson et al., 2008; Lurton and Lamarche, 2015).

Only a few studies have empirically evaluated improvements in seabed classification using more than one frequency. Galloway and Collins (1998) used a commercial classification system (QTC View) to classify surficial geology using 38 kHz and 200 kHz acoustic frequencies. They concluded that dual frequency data, when used in conjunction with single frequency classification results, provided additional insight into surficial geology. The ability of the lower frequency to penetrate deeper into the seabed provided information about the physical properties of the substrate volume. In contrast, the higher frequency detected the immediate water-seabed interface and could detect smaller particles related to sand and mud substrate. Kloser et al. (2002) used commercial seabed classification software (RoxAnn and EchoPlus) to combine the hardness and roughness metrics of single frequency (12 kHz, 38 kHz, and 120 kHz) and dual frequency (12 kHz and 38 kHz) datasets by calculating the first principal component. Classification results were compared to ground-truthing and the combined frequency dataset proved to have lower cross-validation error. Fossa et al. (2005) evaluated four different frequencies (18 kHz, 38 kHz, 120 kHz, and 200 kHz) in their study of deep-water corals (*Lophelia* sp.). They demonstrated a marked increase in the backscatter signal from the 120 kHz frequency over the reefs. Riegl and Purkis (2005) also used the commercial QTC View system and found that a lower frequency (50 kHz) carried more information about the hardness and softness of the substrate. The higher frequency (200 kHz) primarily carried information about the roughness of the seabed and was able to distinguish rough and flat seabeds. Overlaying classification maps from both frequencies resulted in a four class map containing soft, hard, rough, and flat seabeds. Chakraborty et al. (2007) echoed Galloway and Collins (1998) by highlighting how backscatter from a higher frequency (210 kHz) was a function of the immediate water-seabed interface while a lower frequency (33 kHz) penetrated deeper into the seabed and encountered different sub-surface sediment layer compositions resulting in volume scattering. They also concluded that the higher frequency was more effective for discriminating between sediment types as the differences between backscatter values of fine and coarse grain sediment was greater. Finally, Freitas et al. (2008) assessed QTC View classification results using 50 kHz and 200 kHz by comparing them to seabed grab samples in shallow water (5–20 m). The lower frequency was able to distinguish sediment patterns and type whereas the higher frequency failed to do so due to attenuation of the higher frequency signal by macroalgae.

The objective of this study was to compare seabed classifications interpreted by experts on the Scotian Shelf, Canada, to acoustic backscatter values and derived ASC classes obtained using two SBES frequencies for two different study areas. The approach of comparing quantitative backscatter values to interpreted mapped seabed units has been used before (Cutter and Demer, 2013). For consistency, the SBES acoustic data was collected during the same scientific survey as the ground-truth and sidescan acoustic data used by experts to create the surficial geology maps. Emphasis has been placed on the role of acoustic frequency on the ASC results and more particularly how the spatial scaling of backscatter responses from two frequencies compare to each other and to the spatial scaling of dominant substrate types in the two study areas. This paper first presents the data and methods used in this project by describing the study area, data collection and data processing steps, and the analyses conducted. The discussion section summarizes the main results and provides reasoning for the main findings based on previous literature. Finally, conclusions from this research were drawn in the last section and directions for future research paths are discussed.

2. Materials and methods

2.1. Study area

To better capture the diversity of sediment acoustic responses in different contexts, two 5 × 1 km study areas located on Western Bank, Scotian Shelf, Canada, were used in this study (Fig. 1). Western Bank is representative of typical seabed environments on Canada's eastern continental shelf, being primarily composed of sand and gravel substrates (Courtney et al., 2005). This area was selected because of the rich amount of information collected over the years that provided the ground-truthing information necessary for this study. A previous study conducted by Anderson et al. (2005) had identified two study areas on the Western Bank (i.e. the preferred and non-preferred study areas) based on known preferred and non-preferred habitats for juvenile haddock (Fig. 1).

A detailed map of the seabed surficial geology was created by Fader (2007) Fig. 2 for both study areas. These maps are based on expert interpretations of high-resolution (0.25 m) 120 kHz sidescan imagery, combined with ground-truthing information from sediment grain size analysis and underwater imagery (Fader, 2007). The geological and morphological characteristics of each interpreted sediment unit (ISU) are described in Table 1. The datasets used for generating the ISUs were collected during the same scientific survey expedition as the 38 kHz and 120 kHz single beam datasets. Courtney et al. (2005) describe that the ISUs were based on:

a. Comparison and contrast of the relative backscatter of the reflected energy.
b. The presence or absence of shadow-casting features on the seabed.
c. The shape and orientation of features such as bedforms and moraines.
d. The characteristics of boundary relationships between features and patterns of backscatter.