Setting the Stage for Multi-Spectral Acoustic Backscatter Research

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Abstract:
The establishment of multibeam echosounders (MBES) as a mainstream tool in ocean mapping has facilitated integrative approaches towards nautical charting, benthic habitat mapping, and seafloor geotechnical surveys. The combined acoustic response of the seabed and the subsurface can vary with MBES operating frequency. At worst, this can make for difficulties in merging results from different mapping systems or mapping campaigns. At best, however, having observations of the same seafloor at different acoustic wavelengths allows for increased discriminatory power in seabed classification and characterization efforts. Here, we present results from early trials of a multispectral multibeam system (R2Sonic 2026 MBES) in the Bedford Basin, Nova Scotia. In this system, the frequency can be modified on a ping-by-ping basis, which can provide multi-spectral acoustic measurements with a single pass of the survey platform. We demonstrate how this capability provides improved seafloor discrimination at this site based on the different frequency responses and seafloor sediment characteristics. These innovations offer tremendous potential for application in the area of seafloor geological and benthic habitat mapping.

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Craig J. Brown is an NSERC Industrial Research Chair in Integrated Ocean Mapping Technologies at the Nova Scotia Community College (NSCC), based in Dartmouth, Nova Scotia. Over the past two decades, his research has focused on the application of seafloor acoustics for studying, mapping and monitoring benthic ecosystems.

Introduction

Effective management of the earth's natural resources requires knowledge of the extent, geographical range, and ecological characteristics of the resource of interest — and maps are the pre-eminent means of recording and communicating this information. By combining these maps with spatial information on human activities, it is possible to accurately assess compatibilities and conflicts between human use and the environment, and implement effective management strategies to mitigate any impacts (Ehler and Douvere, 2009). On land, the development of aerial and satellite remote sensing technologies over the past few decades has increased the availability and affordability of optical remote sensed data for broad-scale terrestrial mapping, which in turn has dramatically improved our understanding of the spatial patterns and complexities of terrestrial ecosystems (Franklin, 2009). Multispectral satellite remote sensing, acquiring data from reflected light across a wide spectrum of electromagnetic wavelengths, has enabled scientists to develop classification routines to objectively map patterns of land cover and features (i.e. vegetation type, surface geology, man-made structures etc.) (Lu and Weng, 2007). Furthermore, by integrating this information with terrestrial digital elevation models (DEMs), along with other environmental data sets (e.g. climate and surficial geology) sophisticated modelling of species distributions can be achieved (Franklin, 2009).

The limited penetration of electromagnetic radiation through seawater renders satellite and airborne remote sensing impractical for mapping the seafloor in all but the shallowest of waters. To map the ocean floor at a similar resolution to that achieved in terrestrial environments we need to use other techniques, namely acoustic remote sensing. Multibeam echo sounders (MBES), have advanced to a level where we can now achieve high-resolution mapping of the seafloor at a similar spatial resolution as witnessed through the application of satellite and airborne optical remote sensing for mapping land (Lecours et al. 2015; Brown, 2015; Brown et al, 2011). Multibeam sonars have therefore become a valuable tool for ocean floor mapping, and in addition to their wide scale use in the acquisition of bathymetric data for hydrographic charting, they are now commonly used for geological and benthic habitat mapping applications.

The modus operandi for producing surficial geology or benthic habitat maps has evolved in recent years, and now routinely adopts the same types of objective segmentation/classification methods used for generating terrestrial maps from satellite remote sensed data sets. Typically, the acoustic remote sensing data (e.g. MBES) are segmented into regions of similar characteristics (e.g. depths, terrain attributes, acoustic reflectance), which are validated through *in situ* observations/sampling (e.g. underwater imagery, grab or core samples) in order to generate a thematic map of the seafloor (Figure 1). A wide variety of spatial integration techniques have been used successfully in recent studies (Diesing et al, 2014), with the choice of method often influenced by the available data sets, spatial scale of the study and the end-use of the map (Figure 1).

Multibeam systems record measurements of water depth (bathymetry) from which a number of secondary data layers providing information of seafloor morphology can be generated (e.g. seafloor slope, aspect, terrain variability etc.). The combination of these terrain metrics are valuable in defining and segmenting seafloor geology and benthic habitat (Lecours et al. 2016). In addition, most MBES today provide a measurement of the received seabed backscatter intensity, which can provide information about the geologic materials on the seabed based on their acoustic properties (Lurton and Lamarche, 2015). Following geometric and radiometric correction of the returning signal, seabed backscatter strength can also be used to segment and classify the seafloor. However, most multibeam systems operate around a single frequency or around a narrow band of a central frequency (i.e. monochromatic) (Hughes Clarke, 2015; Lurton and Lamarche, 2015). This is analogous to collecting data from a single wavelength from an optical satellite system, which would limit the resolvability of terrestrial land cover features compared to collecting data over broad band or multiple, dispersed spectral bands.

Not surprisingly, interest has grown in exploring the value that multispectral backscatter could offer for improved classification of seafloor geological and habitat characteristics. Recent studies to date have explored the use of paired complementary MBES systems deployed simultaneously on the same vessel to collect data at wavelengths separated by more than one octave (Hughes Clarke, 2015), or from surveys conducted at the same time from different platforms over the same area (Brown et al, 2010). Advances in MBES transducer technology have resulted in wider operating bandwidths – with some systems on the market now capable of spanning several hundred kHz to offer improved range resolution for bathymetric data collection (Lurton and Lamarche, 2015). However, to date most of these systems only operate at a single frequency (or around a very narrow band of frequencies) at any one time, and the acquired backscatter is therefore still monochromatic in nature.

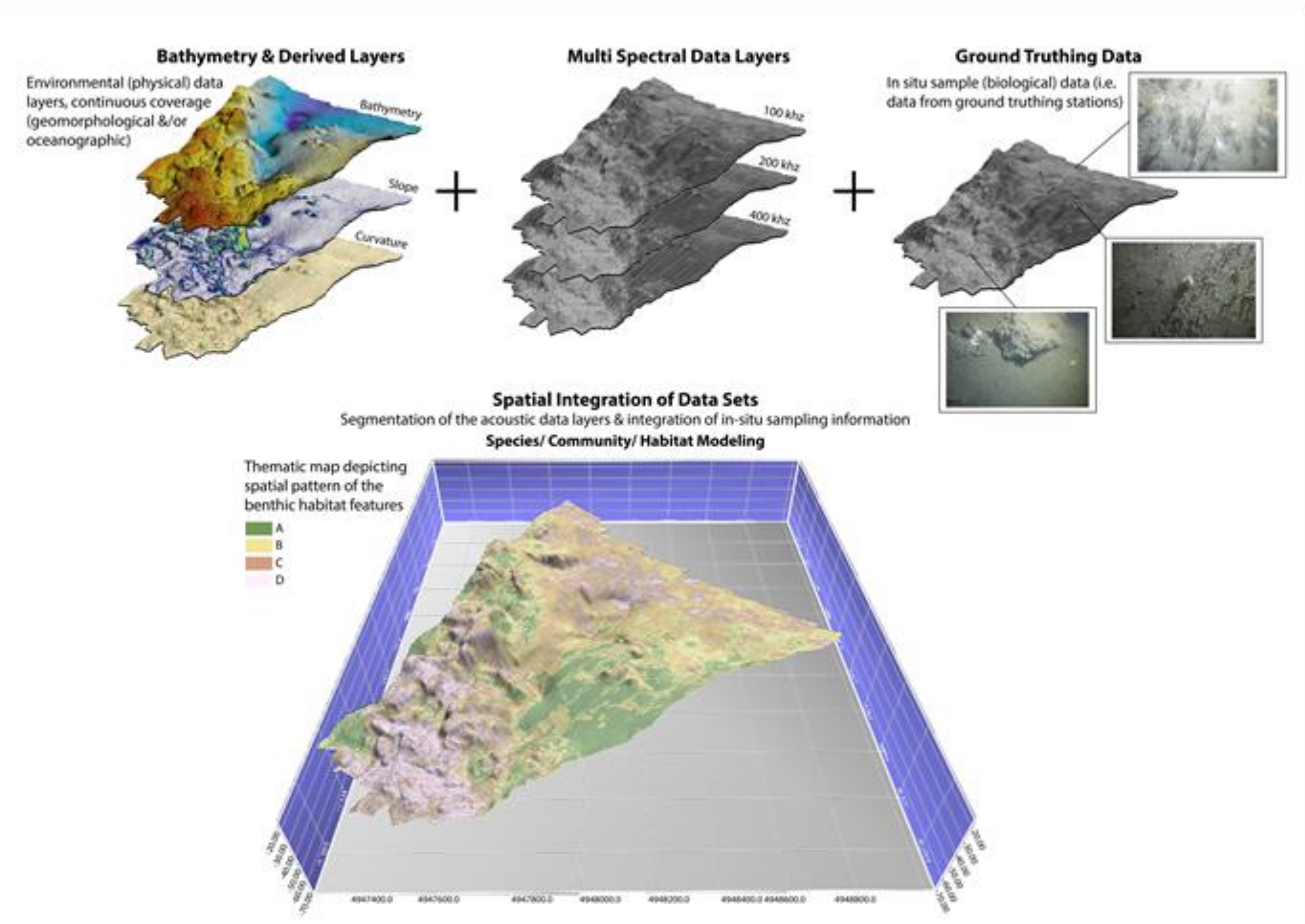

Figure 1: Generalized approach for the production of benthic habitat maps, illustrating typical data sets used for this type of application. The multispectral backscatter layers (i.e. multi-frequency) afforded by the R2Sonic system offer potential advantages over conventional, monochromatic (i.e. single-frequency) systems for improved seafloor characterization.

In 2016, R2Sonic implemented new capabilities in their broadband MBES echosounders allowing the operating frequency to be modified on a ping-by-ping basis. This offered, for the first time, the capability of collecting multispectral backscatter data simultaneously from a single MBES system. In this paper, we present the preliminary results from a field trial of this system in the Bedford Basin, Nova Scotia, Canada, collecting data from three different frequencies (100, 200 and 400 kHz). The operating frequencies were unraveled in post processing, using tools developed in the QPS FMGT software. We demonstrate the significant advantages that this can offer for improved seafloor characterization, and discuss what benefits this may afford the field of seafloor geological and benthic habitat mapping.

Material and Methods

Surveys were conducted on April 20th, 2016 in the Bedford Basin, Halifax, Nova Scotia over a test area at the mouth of the basin (Figure 2). The survey area was selected as it was known from previous multibeam surveys conducted by the Canadian Hydrographic Service (CHS) and the Geological Survey of Canada (GSC) to comprise a range of sediment types ranging from bedrock through to silt with underlying harder substrata (dredge spoil) (Fader and Miller, 2008; Brown et al, 2010). An R2Sonic 2026 MBES was pole-mounted on the port side of the *MV Eastcom*, a 12m fiberglass survey vessel. The transducer mount was fitted with a Valeport sound velocity probe and a POS MV Wave Master Inertial Navigation System (INS). The two Trimble GPS antennas from the INS were mounted on the bow of the survey platform, and all systems integrated through the QPS QINSy software installed on the acquisition PC aboard the wheelhouse of the vessel. SVP casts at the time of survey were conducted using an AML Base X2 fitted with a set of conductivity, temperature and pressure probes.

Figure 2: Overview map of the location of the survey area in the Bedford Basin, Nova Scotia, Canada.

A total of 12 survey lines were run in a NW-SE orientation with ~50% survey line overlap. The R2Sonic multibeam was configured to collect data at 100, 200 and 400 kHz operating frequencies on sequential pings, with operating settings tuned to achieve full coverage across these frequencies. The backscatter signal was monitored throughout acquisition using the R2Sonic saturation-monitoring tool to optimize data quality and avoid signal saturation.

Bathymetry and backscatter data were assessed during data acquisition to ensure data quality. Bathymetry data were processed using QPS Qimera to generate a bathymetric surface of the survey area. Bathymetry data were manually cleaned for erroneous soundings. Tidal corrections were applied using observed tide data from the tide gauge at the Bedford Institute of Oceanography. The multispectral backscatter data was processed using QPS FMGT software. The software enables frequency-specific pings to be unravelled from the multibeam datagram, and separate backscatter mosaics generated for each individual operating frequency (i.e. 100kHz, 200 kHz and 400 kHz) (Figure 3).

A CTD cast from the centre of the Bedford Basin was also conducted on the day of the surveys by Fisheries and Oceans Canada (DFO). The CTD data were used during post-processing to calculate absorption coefficients for frequency dependant attenuation of the transmit pulse to allow correction of the backscatter signal. Processing and signal correction was carried out in QPS FMGT, and resulting corrected mosaics for each frequency exported as 0.5m rasters for subsequent analysis in ARC GIS. This was the only frequency-specific radiometric correction that needed to be applied in FMGT, all other frequency-specific correctors pertaining to beam widths, etc, are applied automatically. At the time of the survey, the receiver and transmitter frequency response was not yet available, these were supplied at a later date and were applied during follow up work as frequency-dependent sonar head dB biases. Surfaces between the three operating frequencies were compared to assess differences in visible features and backscatter intensity levels across the area. Features were also compared with georeferenced seafloor photographs collected within the survey area in March 2016 using a drop-down underwater camera frame fitted with a Sub-C underwater camera and lights. Further extensive ground-truthing of the survey area is planned in the spring/summer of 2017.

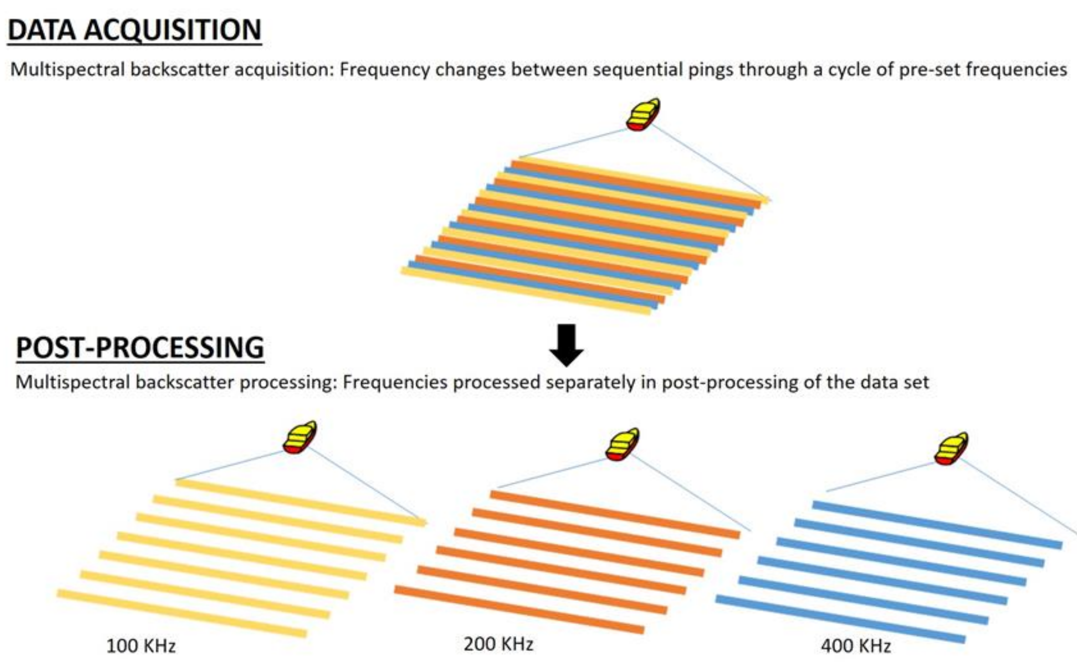

Figure 3: Data acquisition and post-processing of multispectral backscatter data.

Results and Discussion

The Bedford Basin is a bowl-shaped depression approximately 5 km long and 3 km wide, with the physiography extensively described (Fader and Miller, 2008). The multispectral MBES test site covered an area of 1.84 km^2 immediately to the north of the mouth of the basin. Bathymetry in the survey area ranged from a minimum depth of 15 m in the SE of the site, to a maximum depth of 69 m in the centre of the basin (Figure 4). Within the survey area, previously described seabed features are clearly visible. At the mouth of the basin, at the juncture with the Narrows, a shallow water ridge comprising bedrock and gravel including boulder-sized clasts was visible at around 15 m water depth. At all three operating frequencies, this feature was characterized by high backscatter returns of comparable signal strength (Figure 5). A shallow bank (named Sherwood Ridge by Fader and Miller, 2008) is visible running approximately east-west and separates the shallow, hard seafloor in the south of the survey site, from the deeper, softer seafloor in the north of the survey site (Figure 4 and 5).

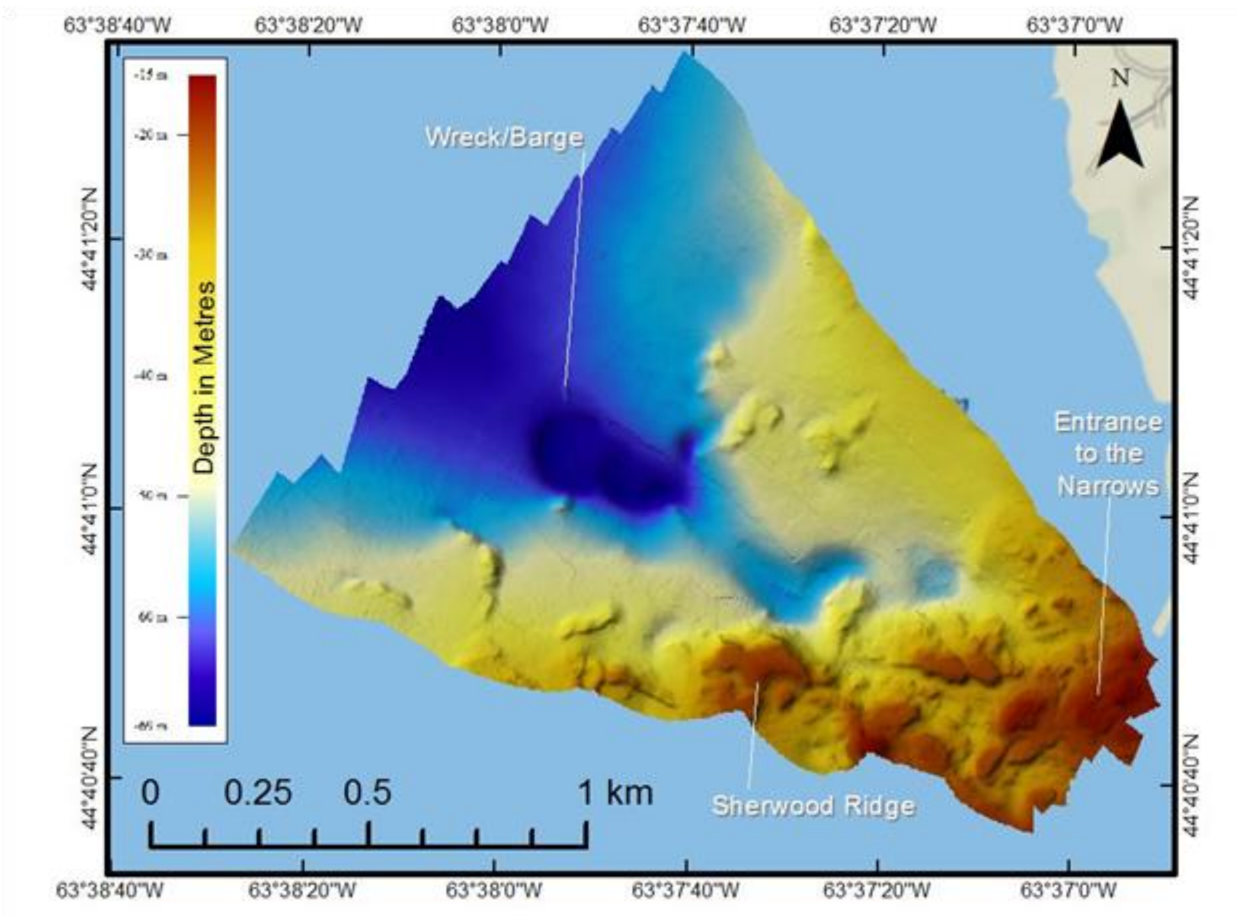

Figure 4: Bathymetry of the Bedford Basin survey area.

The deep sections of the Bedford Basin exhibit curvilinear morphological depressions in a relatively flat seafloor (Figure 4). The oceanography of the Bedford Basin has resulted in the flocculation and settlement of soft sediment deposits, including input of organic material from sewage disposal over recent decades (Fader and Miller, 2008). These deeper sections of the survey site to the north of Sherwood Ridge reveal differences in backscatter intensities between the three operating frequencies. The 400 kHz data set reveals a predominant, relatively low, uniform backscatter return (Figure 5). As the operating frequency decreases, circular patches of higher backscatter become visible in the 200 kHz and 100 kHz mosaics. This is particularly apparent in the 100 kHz mosaic (Figure 5), suggesting a frequency dependant response of the seafloor caused by the surficial sediment characteristics.

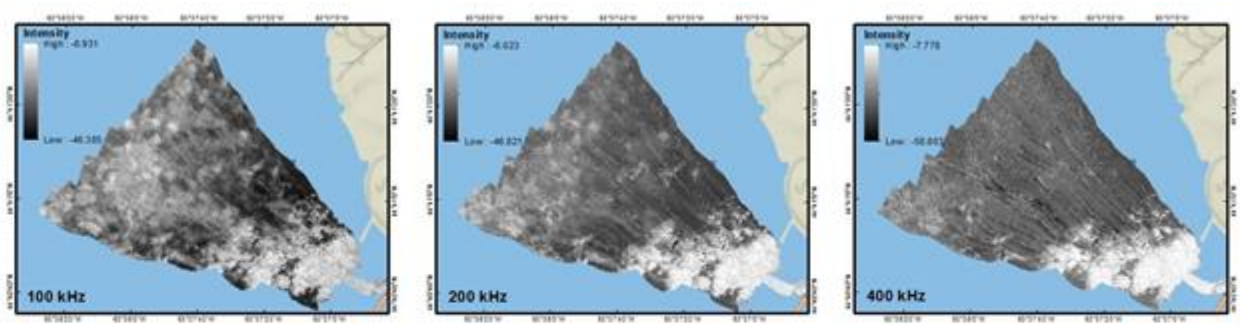

Figure 5: Multispectral Backscatter: 100kHz, 200 kHz and 400 kHz mosaics.

Fader and Miller (2008) describe features in the Bedford Basin caused by disposal of dredge spoil, visible from sidescan sonar data, which are typically characterized by their circular shape and acoustically rough, high-backscatter surfaces, and which are often clustered together. They also describe the presence of biogenic gas within the soft sediments of the Bedford Basin, visible in seismic data sets. In some areas, these seismic data showed an absence of gas within the sediments directly beneath deposited dredge spoil, where the spoil had disturbed and displaced the sediment and vented the gas. These descriptions are in agreement with the features described above from the multispectral multibeam data (Figure 5). We can deduce from these data that the lower-frequency 200 and 100 kHz signals are penetrating through the fine-grained, modern deposits at the seafloor surface (characterized by the uniform, low backscatter intensities of the 400 kHz returns) to reveal the dredge spoil deposits below which have been smothered by more recent sedimentation events.

Improved characterization of these sediment-smothered, dredge spoil features from the multispectral backscatter is also corroborated by preliminary comparison of the three multispectral mosaics with underwater imagery data collected using a drop-down camera system. Over most of the deeper-water regions of the study site the imagery revealed a seafloor comprising soft mud, colonized by various soft sediment biota (e.g. burrowing anemones, polychaete worms etc.) (Figure 6). This corresponds with the uniform low backscatter returns of the 400 kHz mosaic, but not the patches of higher backscatter attributed to the dredge spoil visible in the 100 and 200 kHz mosaics – suggesting that these features are smothered in softer sediments (Figure 5 and 6). In contrast, at the entrance to the Narrows, the seafloor comprised a mixture of coarse substrata (bedrock, boulders and cobbles with attached epifauna) (Figure 6). The backscatter in this region aligned closely between the three multispectral mosaics, as would be expected in coarse, consolidated substrata where signal penetration would be very limited (Figure 5). Comparison of the three multispectral mosaics along a transect from the mouth of the Bedford Basin to the deep water in the centre of the basin, traversing the dredge spoil features, also indicate penetration differences attributed to the frequency response of the transmit signal (Figure 7). Hard substrata, and regions of deep soft sediment deposits display similar backscatter strengths along the transect, with intensities diverging where hard deposits of material are present below soft, surface sediments.

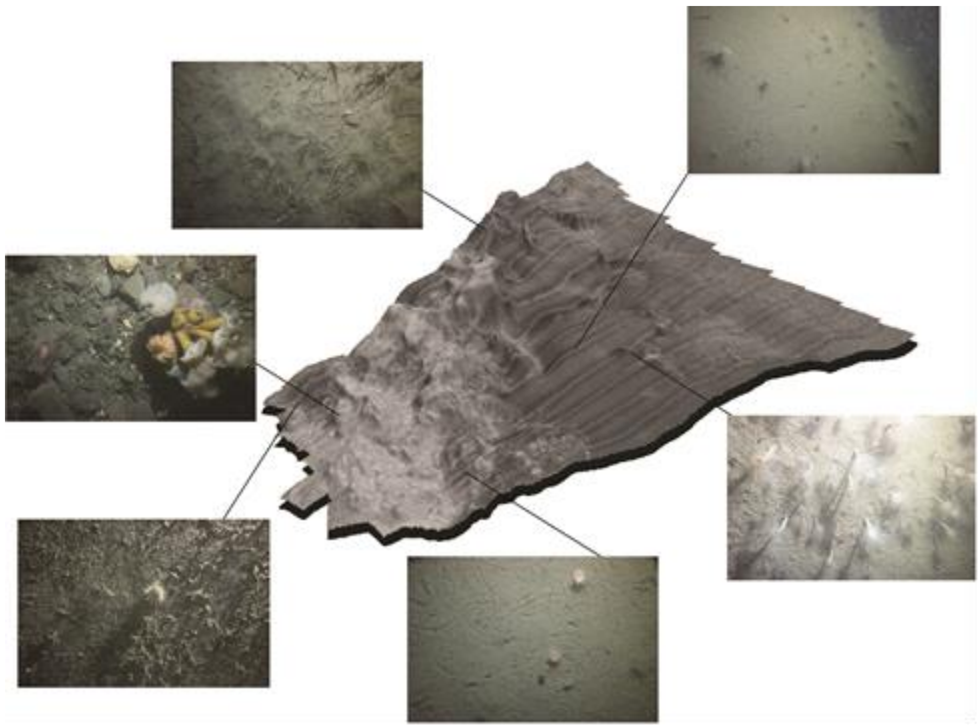

Figure 6: Preliminary ground-truthing underwater imagery from the study site, indicated on the 400 kHz mosaic draped on the bathymetry. Example images shown from different regions of the study site. In the deeper sections of the study site the imagery confirms a soft, muddy seafloor over much of the area, in agreement with the higher frequency backscatter.

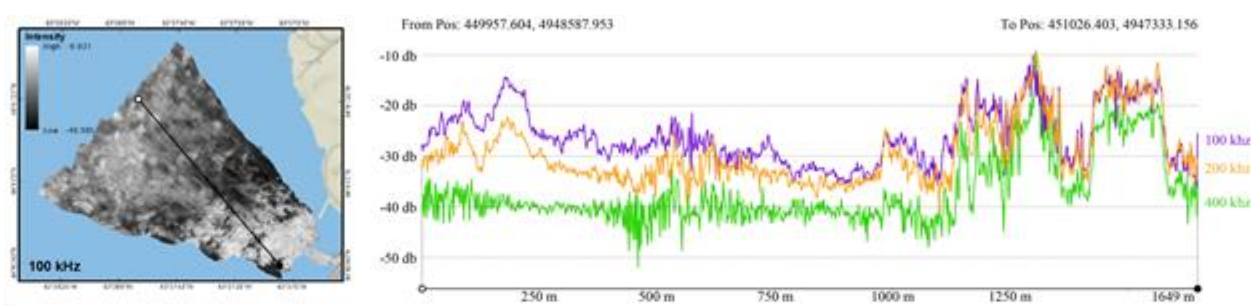

Figure 7: Comparison of differences in backscatter intensities within the survey site between the multispectral mosaics. Backscatter intensities from the three multispectral mosaics are compared along the transect shown on the 100kHz mosaic (left). Backscatter intensities are similar in the hard-substrate region at the mouth of the narrows (SE of the site), and differences are visible in deeper water associated with the dredge spoil deposits.

Next Steps

Extensive ground-truthing of the study site is planned in the spring and summer of 2017. Further collection of underwater imagery will be conducted to thoroughly characterize the surficial sediment over a greater number of stations. Additionally, particle grain size samples will be collected using grabs and shallow cores at the site to confirm surficial and subsurface sediment characteristics. Geotechnical and sub-bottom acoustic profiling surveys are also scheduled in an attempt to measure the thickness of soft sediment veneer above the dredge spoil deposits, and determine the presence of biogenic gas (which would increase signal impedance in the lower frequencies and result in higher backscatter values).

Conclusions

The development of multibeam echosounder systems with multispectral backscatter capabilities is an exciting and innovative opportunity to improve the way that we map seafloor geology and benthic habitat. The preliminary results from this study have demonstrated the benefits that such a system can offer for improved understanding of seafloor geological characteristics. There are many ways in which these data sets can be processed to generate seafloor thematic maps (Figure 1). For example, a false-colour composite image can be generated from the three spectral bands offering an opportunity to discriminate surficial sediment and identify shallow, sub-surface features (Figure 8). Where intensities from all three bands are equally high the resulting composite image appears white (e.g. at the mouth to the narrow where the seafloor is hard). Similarly, where all three bands are consistently low the image appears black (flat areas of the basin where soft sediment deposits are assumed relatively thick). Where there are differences in the relative intensities of the spectral bands the resulting colour will indicate a frequency response of the substrata. This can be seen with the dredge spoil features which appear yellow as a result of detection in the 100 kHz (red) and 200 kHz (green) spectral bands, but not in the 400 kHz (blue) spectral band.

Combining multiple frequencies in this way in habitat mapping studies offers potential opportunities for improved discrimination of habitats. Many recent benthic habitat mapping studies are applying satellite remote sensing classification methods to segment multibeam sonar data objectively within GIS software using a combination of backscatter (monochromatic) and terrain attributes (e.g. Brown et al, 2012; Lucieer et al. 2013; Diesing et al, 2016). Several studies have gone further and have used species distribution modelling approaches to predict habitat suitability for target species with a great deal of success (e.g. Brown et al. 2012; Rengstorf et al, 2013; Young et al., 2016). In such scenarios, defining the ecological niche of the target species based on terrain features and substrate characteristics is the key to success. The application of multispectral backscatter in such studies may offer significant advantages, particularly for soft sediment biota where differences in signal penetration and volume scattering response change by frequency. Careful selection of the best combination of frequencies will be required to optimize the approach, and success will depend on the environmental characteristics of the site. There is still much research needed in this field, with further testing and validation of the methodology required. However, the benefits of this approach to seafloor geological and habitat mapping are potentially ground-breaking in this field of study.

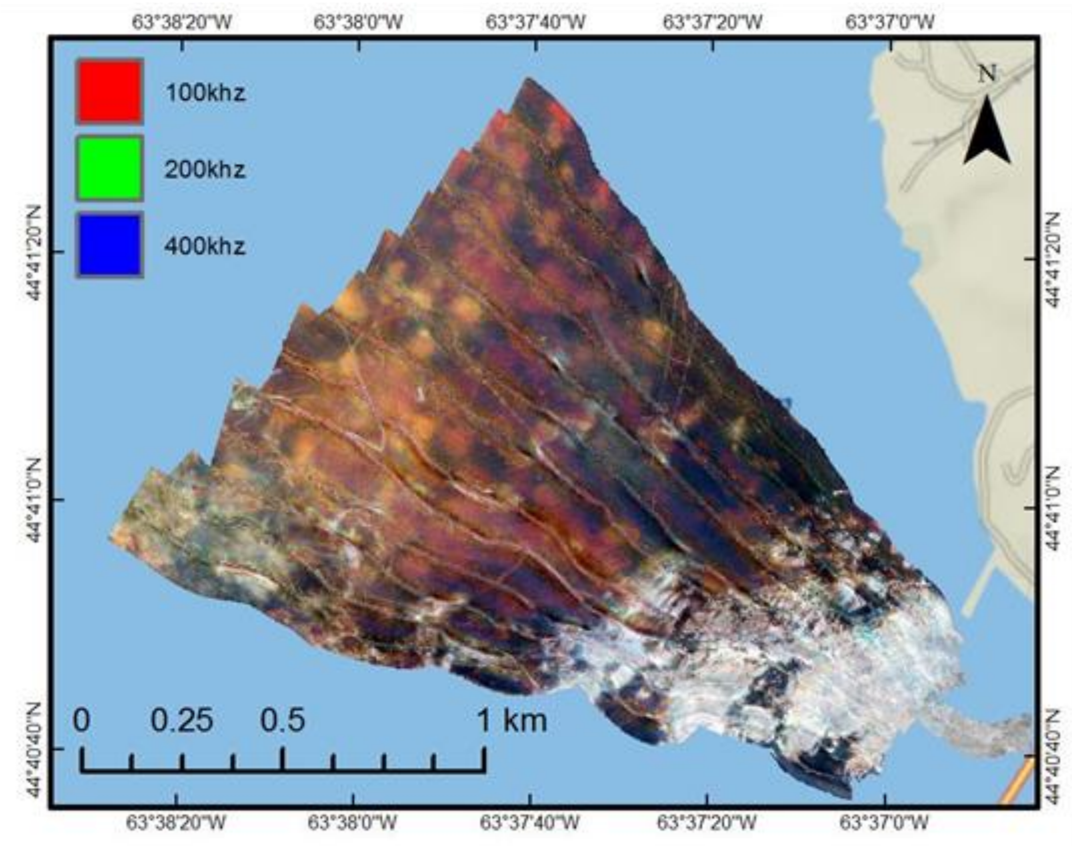

Figure 8: Colour composite image of the multispectral backscatter data.

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