Using multibeam angular range analysis coupled with "underway" in-situ ground-truthing technology for benthic habitat mapping

Derrick R. Peyton[1], Craig J. Brown[2], Glen King[3], Gerard Costello[3], Patrick Potter[4]

[1] Rolls-Royce Naval Undersea Systems, Dartmouth, Nova Scotia.

[2] Fisheries and Oceans Canada, Bedford Institute of Oceanography, Dartmouth, NS

[3] Canadian Hydrographic Service, Bedford Institute of Oceanography, Dartmouth, NS

[4] Natural Resources Canada, Bedford Institute of Oceanography, Dartmouth, NS

Abstract

Multibeam surveys have facilitated an integrated approach towards nautical charting, benthic habitat mapping, and seafloor geotechnical surveys. This synergy is presently being evaluated by DFO/CHS through the analysis of automated classification of backscatter data using angular range analysis techniques coupled with in-situ ground-truthing techniques. The evaluation process involves the automated classification of multibeam backscatter data using angular range analysis (using CARIS HIPS/SIPS embedded Geocoder) and the "underway" in-situ ground-truthing technology of the FFCPT™ (Free Fall Cone Penetrometer). The approach offers the potential for objective classification of seafloor geological and biological features, and a robust method for seafloor habitat mapping. This paper provides an overview to the approach taken, data collection, and preliminary results in working towards the goal of developing a standardized methodology for the production of benthic habitat maps.

Introduction

Estimates indicate that 40% of the world's population live within 100 kilometres of the coast [1]. This results in enormous pressure being placed on the marine environment resulting from land based discharge, coastal development for human habitat and recreational facilities, and economic based activities such as commercial shipping, resource exploration, fisheries, and marine structural development. In particular, for Canada, the realization of depleting oil reserves has pushed exploration into the remote, harsh, and yet environmentally and ecologically sensitive Arctic region, which is estimated to contain nearly 20 percent of the earth's oil and gas reserves [2]. In order for these activities to be environmentally sustainable, Canada has legislation which lays the framework for sustainable management of offshore lands which encapsulates the principles of conservation and ecosystem-based management [3].

One of the key components of an effective marine management program is the spatial mapping of the marine system that includes the interrelationship of bathymetry, seafloor and sub-seafloor geology, and benthic habitat [4]. The most commonly applied method of mapping seabed environments is to acoustically survey an area of seabed, define boundaries between different seabed structures, and then identify biological features and assemblages within each region via ground-truth, point-source sampling [5, 6].

There remain some persistent challenges in the collection, processing, and analysis of multibeam and sidescan backscatter data when it comes to establishing a complete benthic habitat mapping system. This paper discusses some of these challenges and provides a description of an initiative by DFO/CHS and NRCAN to address them in working towards an optimization of processes for benthic habitat mapping.

Acquiring sub-bottom information and ground-truth spatial resolution

<u>Sub-bottom Information</u>

The extent of interest of acoustic seabed classification, as it pertains to benthic habitat mapping, ranges from 1m (or less) below the seabed to 1m (or more) above the seabed [7]. Sub-surface information is desirable to more fully understand the benthic habitat environment, in particular infaunal community characteristics, and to allow us to examine the interactions between fauna and sediments [8, 9].

This being said, the extent to which sub-surface sediment information is obtained during habitat surveys is limited. Grab samples are sparse and seldom go beyond a couple of decimetres beneath the seafloor. The use of sub-bottom profiling and chirp sonar systems are often confined to marine surveys in the cable or oil and gas industry, and usually do not have the fine (cm) resolution within the upper most strata of the seafloor of importance to infaunal communities.

Ground-truth Spatial Resolution

Seabed mapping for the purpose of establishing benthic habitat has, for the most part, been undertaken using three principal marine acoustic technologies: sidescan sonar, acoustic ground discrimination systems based on normal incidence single-beam echo sounders, and multibeam echo sounders [6].

It is understood that details about the character of the seabed, (e.g. roughness, sediment type, grain size distribution porosity, material density, and tortuosity), are embedded in the acoustic echoes from the seabed [7]. Sediment grain size, porosity or shear strength, and sediment dynamics are considered particularly important for habitat classification in relation to benthic faunal assemblages of marine sands and gravels [9].

Verification of acoustic sediment classification is normally established through grab samples, sediment cores, and seafloor photography. These processes involve halting normal ship survey operations and thus place considerable time and economic demands on the overall survey program. In essence, these sampling methods become inefficient over large areas [10]. Because of the low spatial resolution of ground-truthing due to ship time, weather, and subsequent costs, many programs are forced to rely heavily on interpolation and assumption techniques.

One way to expedite the collection of seafloor sub-surface information and as an attempt to establish an efficient means of ground-truthing is the use of an FFCPT™ (Free Fall Cone Penetrometer). The FFCPT measures acceleration and pore pressure as a function of depth penetration into the seafloor. It also records hydrostatic pressure and optical backscatter for detection of water-sediment interface. This combination of sensors provides two independent means of calculation of undrained shear strength, as well as engineering variables that are used to identify sediment grain size characteristics [11]. A comparison of the FFCPT measurements with independent information from sediment cores reveals that the FFCPT is making accurate determination of sediment type and porosity for a wide range of marine sediments [12]. There have been previous experiences in the use of the FFCPT for benthic habitat mapping that have shown positive results [13]. Figure 1a and 1b shows an example of an MVP™200 with an FFCPT™ and a Ponar Grab respectively.

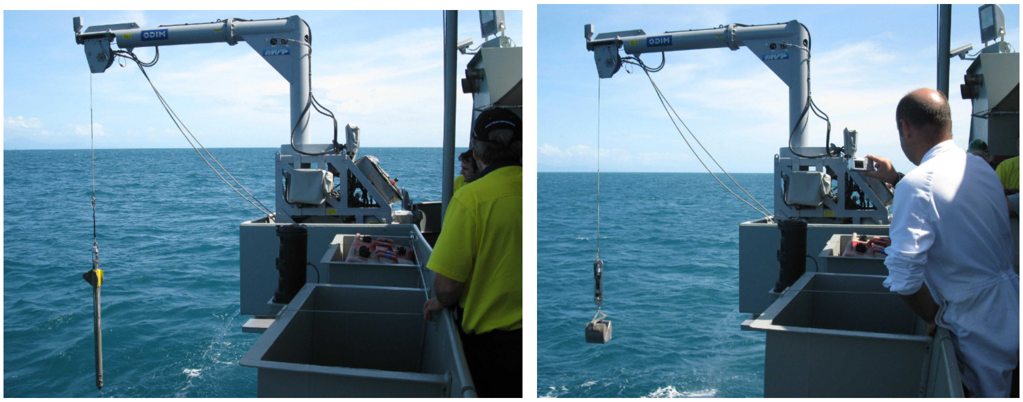

Figure 1: a) FFCPT™ with MVP™200; b) Ponar Grab with MVP™200
(photos courtesy of Royal Australian Navy)

Linking Benthic Habitat to Backscatter

There is a requirement to more closely map the relationship between the seafloor acoustic properties and surficial/sub-surficial geology to that of the biological characteristics of the seabed. The purpose would be to further study species distribution patterns observed across different seafloor environments [13]. Habitat mapping can be described ideally as the complete description of a particular physical environment both in space, which includes not only the seabed but also the sub-surface, and time, encompassing either the tide cycle or the seasons [6].

Habitat mapping traditionally involved an interpretation of bottom response images of seafloor surveys utilizing sidescan sonar. A mosaic of individual sidescan sonar tracks was produced, and segmented into acoustic facies by-eye (using expert interpretation of the sonargraphs). Groundtruthing was established by grab samples and photographs of the seafloor targeting the various acoustic facies. Near shore positioning techniques involved range-range technology and was for the most part relatively accurate for the purpose. However, further offshore positioning was much less accurate as frequencies were lower and accurate positioning techniques were expensive. Quality of interpretation was based on the experience and knowledge of the interpreter.

Although more modern techniques in positioning (e.g. differential GPS) facilitated the extension of habitat mapping further offshore with near shore positional accuracy, the interpretation process was still much left to the experience and knowledge of the interpreter rather then an analytical approach. With the commercial introduction and subsequent advancement of multibeam echosounders, coupled with technological advancements in acoustic backscatter processing, marine scientists began to rely more on an objective analysis of the acoustic returns of the ocean mapping system for acoustic seabed classification [3, 7, 14]. As an extension to this, there have been surveys linking benthic biology to acoustic response signal from sidescan sonar and multibeam echosounders [5, 8, 10, 15, 16].

Research in clustering acoustic backscatter in the angular response space offers potential for the remote discrimination and delineation of benthic habitats, combining automated image segmentation with informed and targeted ground-truthing [17, 18]. Commercialization of this process has been established through *Geocoder*; a software tool that radiometricaly corrects the backscatter intensities registered by multibeam to geometrically correct and position each acoustic sample and to interpolate properly the intensity values into a final backscatter mosaic [19]. This offers a great deal of potential for improved seafloor mapping from a biological/habitat perspective.

Inter-calibration of Backscatter Data

Large area seafloor mapping programs face a number of technical challenges when it comes to the integration of various surveys conducted over time and with different multibeam systems. Often, acoustic classification is unique to only one survey. Differences in backscatter intensity during acquisition can lead to incompatibility between different adjacent data sets. There is a requirement to address backscatter calibration issues in order to normalize results over multi-source data sets [20].

For the most part, the bathymetric component of the MBES has undergone significant standardization for data collection and processing such that all resultant data is correct in both accuracy and precision [21]. This is not the case when using backscatter information for seafloor interpretation and subsequent benthic habitat mapping. Unlike the bathymetric component, multibeam backscatter is rarely calibrated which poses a huge technical problem when combining data from hydrographic surveys spanning several campaigns and from varying multibeam systems. In this situation, backscatter data from adjacent areas from different sources can often be significantly different in terms of absolute decibel (dB) value of the signal with knock-on implications relating to data interpretation and map production [20]. To rectify this issue, it is necessary to develop methods to correct for the uncalibrated nature of extant data sets, and to provide guidelines on best practice for future surveys to minimize or eradicate this issue.

To rectify this issue, it is necessary to develop methods to correct for the uncalibrated nature of extant data sets, and to provide guidelines on best practice for future surveys to minimize or eradicate this issue.

Meeting the Challenge: Inter-calibration of multi-source, multibeam sonar backscatter data

Fisheries and Oceans Canada (DFO), though the Canadian Hydrographic Service (CHS), is addressing the challenges described in the previous sections; in essence, how to optimally utilize and process the vast amount of multibeam echosounder data it has collected and generate a production process for benthic habitat mapping.

In working towards a resolve, DFO/CHS is embarking upon a strategy of evaluating commercial available technology combined with on-going research and development. The approach undertakes to perform an analysis of automated classification of multibeam backscatter data using angular range analysis techniques coupled with in-situ ground-truthing techniques (FFCPT and grab sampling for grain-size analysis).

<u>Project Aims</u>

The aim of the project is to evaluate and develop methods to compensate and correct for differences in backscatter intensity between multi-source data sets, focusing on possible solutions using the *Geocoder* suite of tools within *CARIS HIPS and SIPS.*

Specific objectives:

1. Use patch test data sets collected over several years from the same test site in Bedford Basin (Figure 2) and in situ sediment samples and FFCPT data to compare and calibrate the Angular Range Analysis (ARA) performed by Geocoder

2. Investigate the effects of MBES data acquisition parameters (e.g. pulse length, gain settings, mode of operation etc.) on seafloor feature recognition using the *Geocoder* post-processing backscatter classification methods

3. Test the performance of the Geocoder analysis/classification between data sets collected at small-area test sites (Figure 2) using different acquisition parameters and

different sonar systems (e.g. EM710 vs EM3002) to identify the most robust method of classification

4. Compare the performance of the Geocoder backscatter processing with the results from other processing methods

<u>Data sets</u>

Data from two areas within Bedford Basin, Halifax, Nova Scotia will be used to address the above objectives: 1) a patch test area which has been used for over a decade by CHS to calibrate various MBES systems; 2) a case study area selected encompassing a range of seafloor substrate types and water depths (Figure 2).

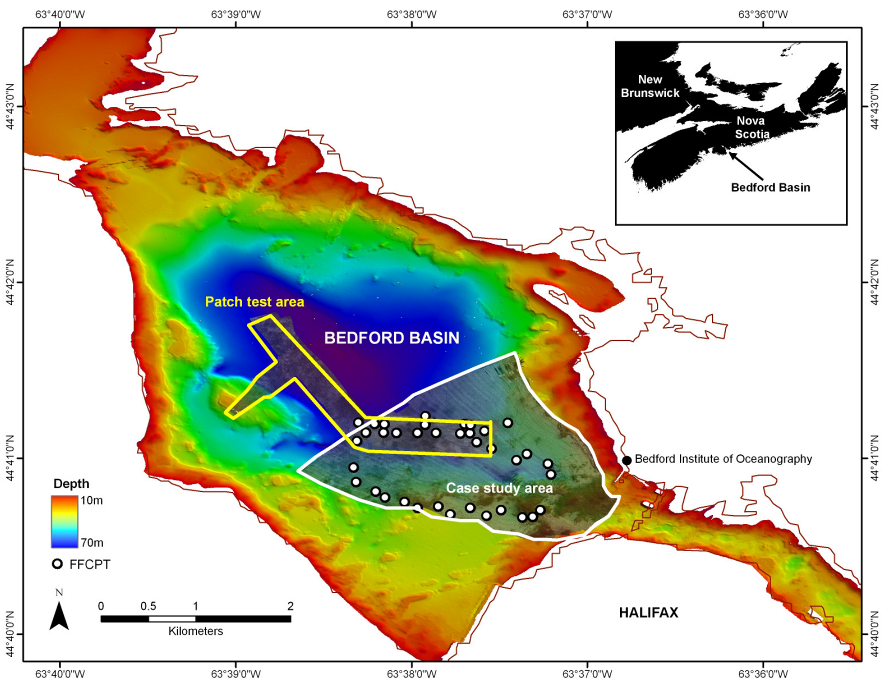

Figure 2: Study sites within Bedford Basin, Halifax, Nova Scotia. 1) Patch test area used by CHS for MBES calibration (highlighted in yellow); 2) a case study area selected encompassing a range of seafloor substrate types and water depths (highlighted in white).

CHS hold numerous MBES data sets spanning several years, collected from different vessels using various Kongsberg MBES systems, from the patch test survey area highlighted in Figure 2. This offers the opportunity to compare the backscatter data sets between systems, platforms and years over exactly the same area of seafloor (Figure 3).

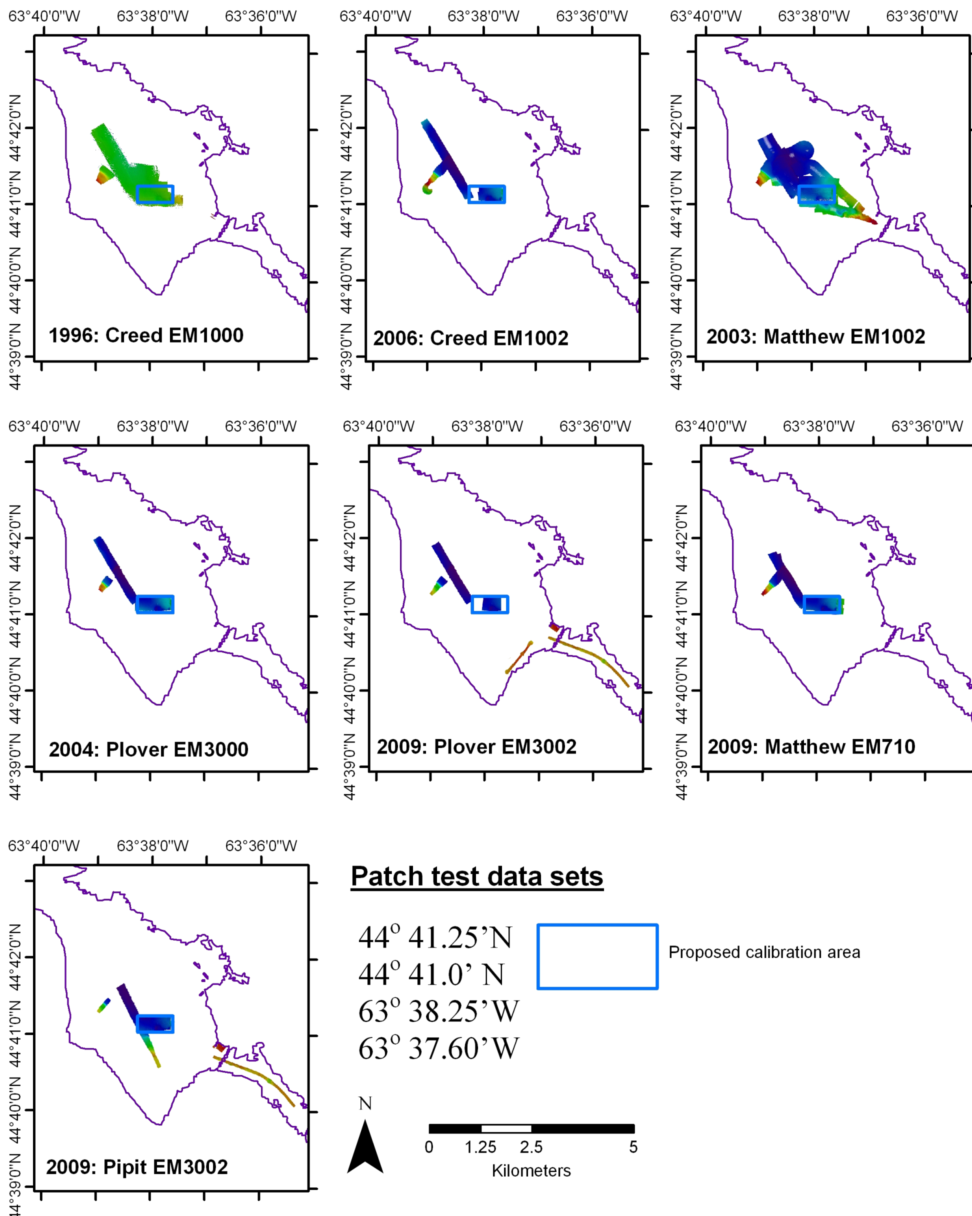

Figure 3: Calibration/test site in Bedford Basin. The figure shows a selection of the available data sets which will be analyzed as part of the study. CHS hold data from a wide range of multibeam sonars data sets from this site, collected over several years and from a number of different vessels.

New data from three CHS platforms were also collected in May 2010 over this site. The CCGS Matthew is a dedicated hydrographic platforms used by the Canadian Hydrographic Service (CHS), and is outfitted with the Kongsberg EM710 as well as an MVP™200 and an FFCPT™. Two CHS survey launches, the CSL Plover and the

CSL Pipit, are both fitted with EM3002 MBES systems. Data was collected from these three platforms from the patch test area and case study area using a number of different data acquisitions parameters (i.e. pulse length, beam configuration etc). FFCPT data was also collected at these sites in May 2010 (Figure 2), and future grab sampling surveys are planned in the summer of 2010 to ground-truth this area.

These data will be used to:

1. Compare backscatter data between MBES systems, survey years and survey platforms.
2. Compare predicted angular range analysis outputs from *Geocoder* (grain size, impedance and roughness) from the different backscatter data sets with the in-situ ground truthing data (FFCPT and grab samples)
3. Explore methods for inter-calibration of the various backscatter data sets using the *Geocoder* tools within Caris HIPS and SIPS

Preliminary results

MBES backscatter data were processed using methods outlined in Brown *et al* [22]. Preliminary analysis of the data from the case study area for the three systems/platforms (CCGS Matthew – EM710; CSL Plover – EM3002; CSL Pipit – EM3002) is shown in Figure 4. Backscatter mosaics from the two EM3002 systems are very similar, revealing high backscatter returns in the south east of the study area, and homogenous, low backscatter returns over the majority of the area. In contrast, the backscatter mosaic from the EM710 MBES reveals a more heterogeneous backscatter signal across the area, which may be indicative of the different operating frequencies between the MBES (EM3002 – 300 kHz; EM710 – 71-97 kHz). The backscatter signal from the lower frequency EM710 (i.e. greater acoustic penetration) may be detecting harder sub-surface geological material compared to the higher frequency EM3002 systems.

This trend is also reflected in the angular range analysis (ARA) outputs showing predicted sediment grain size results (Figure 4). ARA grain size (10m resolution grids) is similar for the two EM3002 data sets, predicting a range of sediments over the case study area ranging from +0.6 phi (very coarse sands) to +9 phi (silt/clay). In contrast, predicted grain sizes from the EM710 data ranged from -1 phi (very coarse sand and gravel) to +5 phi (silt). Whilst these results are preliminary, and require further detailed analysis and comparison with the in situ ground truthing data, they do indicate that the different sounders, perhaps as a result of the different operational frequencies, are leading to coarser sediment predictions by the lower frequency system. Further analyses of these data sets are planned for later in 2010 and 2011.

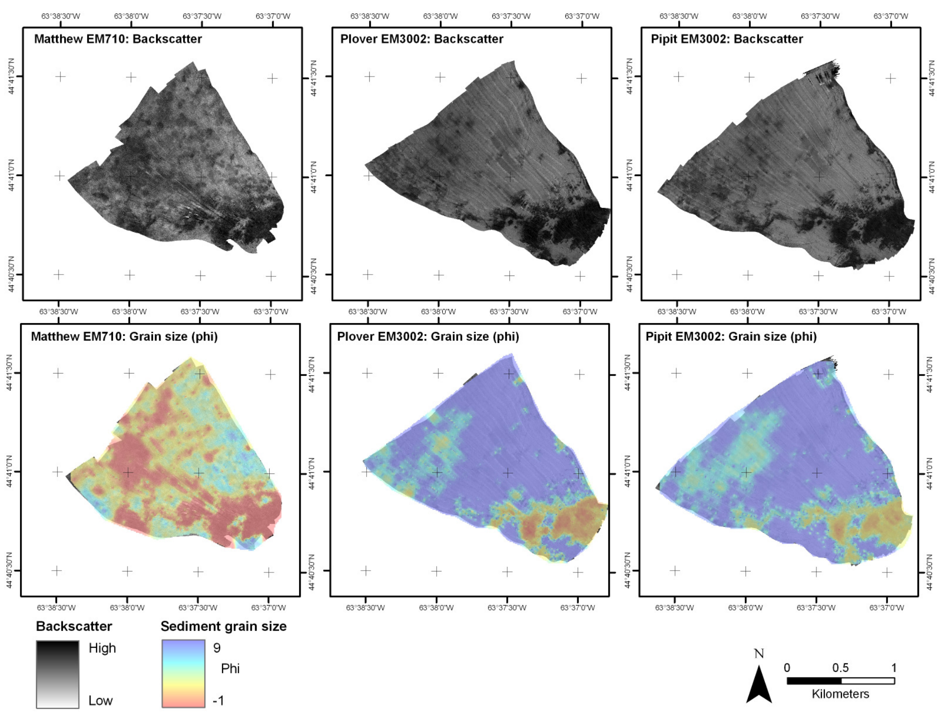

Figure 4: Preliminary *Geocoder* outputs. Top, left to right: MBES backscatter mosaic from the Matthew EM710, Plover EM3002 and Pipit EM3002. Bottom, left to right: Predicted sediment grain size from the Angular Range Analysis from the Matthew EM710, Plover EM3002 and Pipit EM3002.

Acknowledgements

We thank: The crew of the CCGS Matthew, CSL Plover, CSL Pipit; CHS and NRCan personnel involved in MBES data acquisition and processing; Natural Resources Canada for provision of sediment grain size data; The support of the MVP/FFCPT team at Rolls-Royce Naval Undersea Systems. For input and suggestions we thank: Stephen Smith, Peter Lawton, Ellen Kenchington and Alain Vezina (DFO); Stephen Parsons, Herman Varma, Mike Lamplugh, Chris LeBlanc (CHS). This program of research is supported by the Ecosystem Research Initiative for the Gulf of Maine.

References

[1] Data are distributed by the Socioeconomic Data and Applications Center (SEDAC), located at the Center for International Earth Science Information Network (CIESIN) of Columbia University, NY. http://sedac.ciesin.columbia.edu

[2] National Petroleum Council, Global Access to Oil and Gas, Topic Paper #7, Working Document of the NPC Global Oil & Gas Study, 2007, July.

[3] Pickrill RA, Kostylev VE, Habitat Mapping and National Seafloor Mapping Strategies in Canada, In Todd, B.J., and Greene, H.G., eds., Mapping the Seafloor for Habitat Characterization: Geological Association of Canada, 2007, Special Paper 47, p. 483-495.

[4] Kostylev VE, Todd BJ, Shaw J, Benthic habitat mapping in Canada – a perspective, Journal of Ocean Technology, 2008, Volume 3, Number 2.

[5] Eastwood PD, Souissi S, Rogers SI, Coggan RA, Brown CJ, Mapping seabed assemblages using comparative top-down and bottom-up classification approaches, Canadian Journal of Fisheries and Aquatic Science, 63, page 1536-1548, 2006.

[6] Brown, CJ, Blondel P, Developments in the application of multibeam sonar backscatter for seafloor habitat mapping. *Applied Acoustics*, 2009, 70, page 1242-1247.

[7] Anderson JT, Holiday DV, Kloser R, Reid DG, Simard Y, Acoustic seabed classification: current practice and future directions, ICES Journal of Marine Science, 65: 2008, page 1004-1011.

[8] Brown CJ, Collier JS, Mapping benthic habitat in regions of gradational substrata: An automated approach utilizing geophysical, geological, and biological relationships, Estuarine Coastal and Shelf Science, 2008, 28, page 203-214.

[9] Kenny AJ, Cato I, Desprez M, Fader G, Schuttenhelm RTE, Side J, An overview of seabed-mapping technologies in the context of marine habitat classification, ICES Journal of Marine Science, 2003, 60, page 411-418.

[10] McConnaughey B, Yeung C, Smith K, Amend M, Hydrography through the Eyes of a Fish – Can Acoustic Backscatter be used to classify Benthic Fish Habitat?, Proceedings of the US Hydrographic Conference, 2007, Norfolk, Virginia, May 14-17.

[11] Mosher DC, Christian H, Cunningham D, MacKillop K, Furlong A, Jarret K, The Harpoon Free Fall Cone Penetrometer for Rapid Offshore Geotechnical Assessment, Proceedings of the 6th International Offshore Site Investigation and Geotechnics Conference, London, UK, September 11-13, 2007.

[12] Osler J, Furlong A, Christian H, A sediment probe for the rapid assessment of seabed characteristics, in: Acoustic Inversion Methods and Experiments for Assessment of the Shallow Water Environment, eds. Caiti A, Chapman NR, Hermand JP, Jesus SM, Springer, New York, 171-182, 2005.

[13] Cruise Reports for 2008/9 FISHPAC Project, Prepared by the Resource Assessment and Conservation Engineering (RACE) Division, Alaska Fisheries Science Center, National Marine Fisheries Service (NMFS).

[14] Collier JS, Brown CJ, Correlation of sidescan backscatter with grain size distribution of surficial seabed sediments, International Journal of Marine Geology, Geochemistry and Geophysics, 214, page 431 – 449, 2005

[15] Yeung C, McConnaughey RA, Using acoustic backscatter from a sidescan sonar to explain fish and invertebrate distributions: a case study in Bristol Bay, Alaska, ICES Journal of Marine Science, 2008, 65: 242–254.

[16] Amend M, Lomnicky J, Smith K, McConnaughey B, Yeung C, McGillicuddy G, Rzhanov Y, Adding Ecological Context to EFH Models Using Groundtruthing Technologies, Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering (RACE) Division, National Marine Fisheries Service, NOAA Fisheries, FISHPAC Multi-disciplinary Habitat and Hydroacoustic Research Project Poster, 2008

[17] Luciano F, Brown C, Calder B, Mayer L, Rzhanov Y, Angular range analysis of acoustic themes from Stanton Banks Ireland: A link between visual interpretation and multibeam echosounder angular signatures, Applied Acoustics, 70, 2009, page 1298-1304.

[18] Fonseca L, Calder B, Clustering Acoustic Backscatter in the Angular Response Space, U.S. Hydrographic Conference, 2007, Norfolk, VA.

[19] Fonseca L, Calder B, Geocoder: An Efficient Backscatter Map Constructor, Proceedings of the U.S. Hydrographic Conference, 2005, San Diego, CA.

[20] Hughes Clarke JE, Iwanowska KK, Parrott R, Duffy G, Lamplugh M, Griffin J, Inter-calibrating multi-source, multi-platform backscatter data sets to assist in compiling regional sediment type maps: Bay of Fundy, Proceedings of the Canadian Hydrographic Conference and National Surveyors Conference, Victoria, BC, 2008

[21] IHO Standards for Hydrographic Surveys, International Hydrographic Organization Special Publication No. 44, 5th Edition, published by the International Hydrographic Bureau, Monaco, February, 2008.

[22] Brown, C.J., King, G., Varma, H., Costello, G., Parsons, S., Smith, S. and Lawton, P. Advances in seafloor habitat mapping: The application of multibeam backscatter data using Caris tools for habitat discrimination. Caris 2010, Miami, USA. 24-25 March, 2010.