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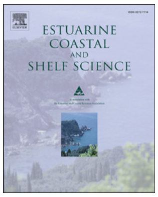

Interlinking backscatter, grain size and benthic community structure

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ABSTRACT

The relationship between acoustic backscatter, sediment grain size and benthic community structure is examined using three different quantitative methods, covering image- and angular response-based approaches. Multibeam time-series backscatter (300 kHz) data acquired in 2008 off the coast of East Anglia (UK) are compared with grain size properties, macrofaunal abundance and biomass from 130 Hamon and 16 Clamshell grab samples. Three predictive methods are used: 1) image-based (mean backscatter intensity); 2) angular response-based (predicted mean grain size), and 3) image-based (1st principal component and classification) from *Quester Tangent Corporation Multiview* software. Relationships between grain size and backscatter are explored using linear regression. Differences in grain size and benthic community structure between acoustically defined groups are examined using ANOVA and PERMANOVA+. Results for the Hamon grab stations indicate significant correlations between measured mean grain size and mean backscatter intensity, angular response predicted mean grain size, and 1st principal component of *QTC* analysis (all $p < 0.001$). Results for the Clamshell grab for two of the methods have stronger positive correlations; mean backscatter intensity ($r^2 = 0.619$; $p < 0.001$) and angular response predicted mean grain size ($r^2 = 0.692$; $p < 0.001$). ANOVA reveals significant differences in mean grain size (Hamon) within acoustic groups for all methods: mean backscatter ($p < 0.001$), angular response predicted grain size ($p < 0.001$), and *QTC* class ($p = 0.009$). Mean grain size (Clamshell) shows a significant difference between groups for mean backscatter ($p = 0.001$); other methods were not significant. PERMANOVA for the Hamon abundance shows benthic community structure was significantly different between acoustic groups for all methods ($p \leq 0.001$). Overall these results show considerable promise in that more than 60% of the variance in the mean grain size of the Clamshell grab samples can be explained by mean backscatter or acoustically-predicted grain size. These results show that there is significant predictive capacity for sediment characteristics from multibeam backscatter and that these acoustic classifications can have ecological validity.

1. Introduction

The marine environment is increasingly threatened by a wide variety of anthropegenic stressors (IPCC, 2007; Rahmstorf et al., 2007; Widdicombe and Spicer, 2008; Jackson, 2008; Hoegh-Guldberg and Bruno, 2010). Various estimates predict that no area of the ocean remains unaffected by some form of anthropogenic degradation (Halpern et al., 2008; Ramirez-Llodra et al., 2011). Against this backdrop, there is consensus about the need for effective management to mitigate these effects; however there is no agreement about how this will be best achieved. In terms of marine spatial planning and regulation of activities involving the benthic resource, the science that underpins and informs management is benthic habitat mapping. This area has seen a recent sharpening of focus at an international level, as evidenced through the wide range of initiatives: eg. Mapping European Seabed Habitats (MESH) (http://www.searchmesh.net/); MESH Atlantic (http://www.meshatlantic.eu/); MAREANO (http://mareano.no/en); Gulf of Maine Mapping Initiative (http://www.gulfofmaine.org/gommi/); UKSeaMap (McBreen et al., 2011) and EU Seamap (http://jncc.defra.gov.uk/page-5040).

A common feature of these initiatives is the widespread use of multibeam echosounder (MBES) as one of the fundamental tools with which to interrogate this environment. Despite this increasing incidence, more work is required to better understand the nature of the relationship between acoustics, sediment properties and benthic community structure, as it has direct bearings on our ability to understand the processes controlling and regulating the distribution of biodiversity on the ocean floor.

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1.1. *Mapping the seafloor*

Remote sensing of the seafloor using marine geophysical techniques is a common approach in benthic habitat mapping and has been well described in the literature (deMoustier, 1986; Anderson et al., 2008a,b; Brown et al., 2011a). Methods used include side scan sonar (SSS), single beam echosounders (SBES) and MBES, each with their own relative merits for different applications (Lurton, 2010). Information about the shape of the seafloor can be determined from the timing of the returning signal corrected for the speed of sound through the water column (bathymetric data), whilst the strength of returning signal can be used to differentiate relative hardness or softness of seafloor material at near-normal angles of incidence or relative roughness or smoothness at wider-angles of incidence (backscatter data) (Jackson and Richardson, 2007; Lurton, 2010). Swath systems (SSS and MBES) have the broadest level of coverage and the greatest capacity for high resolution backscatter imagery. The data generated is of significant value to end users for describing material properties that cannot be determined from the shape of the seafloor alone. Here we analyse the backscattered signal, specifically the ability to use it to predict the nature of the physical sediments, and secondly to explore the interrelationship with benthic community structure. The strength of the returning signal is not a simple measure of a single physical property of the seafloor; it is a product of the transmit signal less the energy lost through interface scattering at the boundary between the sediment and the water column and volume scattering and absorption within the sediment volume (Lurton, 2010). The depth of penetration into the sediment is also a function the frequency of the sonar and the grazing angle, which further complicates the comparability of results when using different acoustic sources (eg. Hughes-Clarke et al., 2008). The science behind the prediction of seafloor properties from acoustic backscatter is relatively mature (eg. Urick, 1954; Hamilton, 1971), although several different scattering models are in use ranging from the simple Lambertian model to more complex, such as the composite roughness model. The complex models give a more accurate description of backscatter from the seafloor at the expense of being difficult to compute and use (Mourad and Jackson, 1989). A further, and arguably bigger challenge, is applying this theoretical knowledge to realistic field data. As a result practical approaches are increasingly being modified with changes in technology, from the hardware acquisition side to the software on the processing end of the spectrum (Mayer, 2006). There are now a variety of different software packages available to do all or various different components of a typical workflow relating to backscatter data processing and analysis (*CARIS HIPS* and *SIPS*, *ESRI ArcGIS*, *QPS Fledermaus*, *Quester Tangent Corporation* [*QTC*] *Multiview*). Here we test the performance of three current approaches applied to a typical MBES dataset.

1.2. *Predicting seafloor properties from acoustic backscatter*

Broadly speaking, analysis of backscatter data from MBES is divisible into image- and signal-based approaches. Image-based analysis and classification of multibeam backscatter has its origins in techniques for satellite remote sensing data (Haralick et al., 1973). Once suitably corrected for radiometric and geometric distortions related to acquisition, backscatter data can offer an insight into the relative hardness and softness of the seafloor environment using geospatial image processing techniques (eg. *ArcGIS, GRASS, ERDAS Imagine, ENVI, IDRISI*). Image-based analysis of MBES backscatter occurs through several existing platforms, including: developmental versions within some academic institutions, eg: *Texan* (Blondel et al., 1998); *PRISM* (LeBas and Hühnerbach, 1999); the mosaicing element of *Geocoder* (Fonseca and Mayer, 2007), among others using similarly novel approaches (eg. Lucieer and Lamarche, 2011; Lucieer et al., 2013). *Quester Tangent Corporation* (*QTC*) had marketed and released several products over the last decade which were based around the classification of acoustic imagery, most notably *Sideview*, *Multiview* and most recently *Swathview* (Preston et al., 2001; Preston, 2004; 2009). The principles followed in the software are well detailed in Brown et al. (2011), McGonigle et al. (2009) and Preston (2009).

Signal-based approaches for MBES backscatter data analysis discussed here are related to angular-response based methods. The relationship between the acoustic response of the sediment at varying grazing angles and the sediment properties has been well studied since the 1960's (eg. Li and Taylor-Smith, 1969; Hamilton, 1971; Williams, 2001). Recent attention has returned to this area of research because of its potential to provide more accurate seabed properties than image-based methods which simply average the angular-response of a given dataset during processing (Hughes-Clarke, 1994, 1997; Fonseca et al., 2009; Schimel et al., 2010; Lamarche et al., 2011; Hasan et al., 2012; Rzhanov et al., 2012; Huang et al., 2012, 2013).

Recently a commercial version of angular response analysis element has been assimilated into both the *CARIS* and *QPS Fledermaus* analysis environments, developed from the academic development version of *Geocoder* (Fonseca and Calder, 2005; Fonseca and Mayer, 2007). This software functions in two respects; initially it can allow for the production of radiometric and geometrically corrected backscatter imagery, and secondly it allows for analysis of the angular response of the MBES to be examined in respect to anticipated modelled responses. The actual methods used in the current implementation are not fully explained due to the commercial nature of the product. However, Fonseca and Mayer (2007) describe how the development version of the software was based on an effective density fluid model derived from Biot theory, subject to several modifications (after Williams, 2001).

There are increasing precedents for using combinations of the image- and signal based approaches (eg. Fonseca et al., 2009; Hasan et al., 2012; Rhzanov et al., 2012).

1.3. *Qualifying the interpretation of acoustic data*

Obtaining ground measurements is necessary to qualify interpretation of remotely sensed observations (Curran and Williamson, 1986). With an appropriate degree of directed ground truth acquisition and processing observed values can be related to remotely sensed data. This is a common approach to geological and geomorphological mapping of the seafloor and is widely reported in the literature (eg. Blondel and Murton, 1997; Collier and Brown, 2005; Cutter et al., 2003). In this manner, many existing studies have described physical properties of marine sediments (eg. Collier and Brown, 2005), and others by extension benthic community structure (eg. Kostylev et al., 2001; Cochrane and Lafferty, 2002; Brown and Collier, 2008; Rattray et al., 2013). The close association between functional assemblages and substratum (Snelgrove, 1999; Anderson, 2008; Clarke et al., 2008; Gray and Elliott, 2009; Anderson et al., 2012) has given way to much existing research equating geological classifications to equivalences in terms of benthic community structure (eg. McBreen et al., 2008). Kostlyev (2012) presents a critical evaluation of this type of approach, exploring these fundamental assumptions of geological and ecological interpretations of remotely sensed acoustic data.

As an aspiration, the ability to reliably predict sediment properties and benthic assemblage structure from marine geophysical data would transform the way we can understand, monitor and ultimately manage the marine environment. In this context, this research attempts to examine the relevance of these comparisons in terms of a 300 kHz source, sediment grain size properties and