Continental Shelf Research 61–62 (2013) 12–22

Contents lists available at SciVerse ScienceDirect

Continental Shelf Research

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

Research papers

Predictive mapping of seabed cover types using angular response curves of multibeam backscatter data: Testing different feature analysis approaches

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ARTICLE INFO

Article history:
Received 15 December 2011
Received in revised form
10 April 2013
Accepted 12 April 2013
Available online 21 April 2013

Keywords:
Angular response curves
Multibeam backscatter
Feature analysis
Prediction
Seabed mapping

ABSTRACT

Angular response curves of multibeam backscatter data are used to predict the distributions of seven seabed cover types in an acoustically-complex area of the continental shelf of Western Australia. Several feature analysis approaches on the angular response curves are examined. A Probability Neural Network model was chosen for the predictive mapping, which accuracy measurement is given by a statistical coefficient Kappa. The prediction results have demonstrated the value of angular response curves for seabed mapping with Kappa=0.59 and a reasonable spatial prediction based on a visual assessment. This study also demonstrates the potential of various feature analysis approaches to improve seabed mapping. The approach to derive statistical parameters from the curves achieved significant feature reduction and some gain in statistical performance (e.g., Kappa=0.62). Its prediction map also represents a notable improvement. The first derivative analysis approach achieved the best overall statistical performance (e.g., Kappa=0.84); while the approach to remove the global slope produced the best overall prediction map as well as a significant gain in statistical performance (e.g., Kappa=0.74). We therefore recommend these three feature analysis approaches, along with the original angular response curves, for future seabed classification studies.

1. Introduction

Cost-effective exploration of the marine environment, sustainable use of marine resources and better management of marine ecosystems are key challenges facing marine scientists and policy makers alike. These issues are particularly urgent given increased human impact and the threat of climate change (e.g., Harley et al., 2006; Halpern et al., 2008; Brierley and Kingsford, 2009). Mapping the seabed and monitoring changes over management-related timescales are important to tackling these challenges. To facilitate such work, accurate maps of seabed cover types are a key dataset because they form the basis for benthic habitat maps (e.g., Lanier et al., 2007; Erdey-Heydorn, 2008; Brown et al., 2011), the prediction of benthic biota (e.g., Brown et al., 2002; Holmes et al., 2008; McGonigle et al., 2009, 2011; Huang et al., 2012a), and provide baseline information for the monitoring of marine protected areas (MPAs).

Remote sensing plays an important role in the investigation of marine environments (Andréfouët et al., 2008). For instance, optical and radar remote sensing technologies are usually used to map the seabed of very shallow and clear coastal waters (e.g., Mishra et al., 2006). The LIDAR (LIght Detection And Ranging) allows better penetration in water, but still limited to clear water shallower than 50 m (e.g., Wedding et al., 2008; Pittman et al., 2009). To map seabeds in deeper waters, acoustic remote sensing techniques such as multibeam echo-sounders are required and remain the most cost-effective ways of mapping large seabed areas (Brown et al., 2011). Depending on the signal frequency they can emit, multibeam echo-sounders are capable of accurately mapping large areas of seabed from water depths of a few metres to thousands of metres (Mitchell, 1996). They transmit pulses and receive backscatter signals from hundreds of narrow beams (angles). Therefore, they can provide high-resolution and near-complete coverage of bathymetry and acoustic backscatter data. The potential of multibeam bathymetry and backscatter (mosaic) data in mapping seabed cover types has been widely demonstrated in recent years (e.g., Kostylev et al., 2001; Dartnell and Gardner, 2004; Zhou and Chen, 2005; Wilson et al., 2007; McGonigle et al., 2009; Preston, 2009; Huang et al., 2012b).

This study investigates new approaches of using multibeam backscatter data for accurate mapping of seabed cover types. Acoustic backscatter data, derived from either multibeam or side-scan sonar, record backscatter intensity returned from the seabed and thus use the similar principle as radar remote sensing. The proportion of acoustic returns scattered from a seabed surface is governed by the acoustic impedance contrast (“hardness”), the apparent surface roughness (relative to sonar frequency) and

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0278-4343/$ - see front matter
http://dx.doi.org/10.1016/j.csr.2013.04.024

volume inhomogeneity (Goff et al., 2000; Kloser et al., 2001; Parnum et al., 2006; Siwabessy et al., 2006; Fonseca et al., 2009). These three parameters are seabed-type dependent.

After processing of raw data, backscatter data are often represented in two forms: angular response curves and backscatter mosaics. Angular response curves are backscatter returns as a function of incidence angles. They are required for the removal of angular dependence to produce an angularly equalised backscatter mosaic. Backscatter mosaic data is an accurately registered spatial layer from normalising backscatter intensity at a chosen incidence angle (or average of several angles). Because the choice of the normalisation angle is subjective, the fully equalised backscatter mosaic normalised to one angle is not a unique representation of the spatial distribution of backscatter intensity (Fonseca et al., 2009). Angular response curves, however, maintain backscatter information at a full range of incidence angles for individual patches of the seabed.

A number of studies have shown the potential of using angular response curves for remote seabed classification (e.g., De Moustier and Matsumoto, 1993; Hughes-Clarke, 1994; Hughes-Clarke et al., 1997; Keeton and Searle, 1996; Fonseca and Mayer, 2007; Hamilton and Parnum, 2011). Although the implication of these studies is very exciting, they did not use a robust predictive modelling approach to produce a seabed cover map as a final product. For example, Hamilton and Parnum (2011) used an unsupervised approach to produce acoustic clusters which need to be further examined to transform into actual seabed cover types. In this study, we adopt a supervised classification approach to map seabed cover types, as in a most recently study of Hasan et al. (2012). This predictive mapping technique builds models between explanatory variables and a limited number of ground samples (as target variable) which is then used to predict a map of the whole study area.

This study has two objectives. First, we investigate the full potential of backscatter angular response curves for the predictive mapping of seven seabed cover types. Second and more importantly, we examine different approaches of extracting useful features from backscatter angular response curves and compare the classification performance of these feature analysis approaches.

The study area has complex seabed bedforms with combinations of rocky substrate and various sediment types. A neural network model was employed under a robust model selection framework to develop predictive models of seabed cover types with the help of 97 ground truth samples. The modelling results were evaluated through the classification statistics of the user's and producer's accuracies, the overall accuracy, and the Kappa coefficient from an error matrix (Cohen, 1960; Congalton, 1991). In addition, the prediction maps were judged using visual assessment.

Hughes-Clarke (1994), Hughes-Clarke et al. (1997) and Fonseca and Mayer (2007) derived several statistical parameters from the angular response curves for seabed classification. They argued that these parameters, based on the shape, variance and magnitude of the curve, adequately describe the important features of the angular response curves without being sensitive to small systematic biases. We develop this approach further in this study. In addition, we also examine several feature analysis approaches being used to enhance the signal to noise ratio of hyperspectral remotely sensed data because the shapes of backscatter angular response curves bear an obvious similarity to hyperspectral data. These feature analysis approaches include the first and second derivative analyses, and the continuum removal analysis (e.g., Curran et al., 2001; Huang et al., 2004). The derivative analysis enhances small fluctuations (local minima and maxima) in the data and is able to reduce background noise. The continuum or trend removal (detrending) from the data enables more effective identification of fluctuations in the data.

2. Multibeam data and seabed cover types

2.1. Study area and survey information

The study area covers the width of the continental shelf offshore from Point Cloates, central Western Australia (Fig. 1). Here the shelf extends ~25 km from Ningaloo Reef and lagoon, a World Heritage-listed area with significant biodiversity valueproviding benthic habitats for a large number of epifauna and infauna species (Brooke et al., 2009). A marine survey was conducted in the area in 2008 (Brooke et al., 2009) to collect sediment samples and towed-video transects.

During the survey, an EM 3002 multibeam echo-sounder was used to collect both bathymetry and backscatter data in shallow waters, from 5 to 200 m depth with vertical resolution of 1 cm. The swath covers an angle of 130° in a single head configuration (this study) with 160 narrow beams. The maximum ping rate is 40 Hz with maximum 254 soundings per ping in shallow water.

The raw bathymetry data were processed using the *Caris Hips and Sips V6.1* software. The motion sensor, Differential GPS and heading data were cleaned using a filter that averaged adjacent data points. Different sound velocity profiles were used to correct the changes in the speed of sound through the water column. The remaining artefacts were filtered automatically but also manually through visual inspection. The tidal variations, obtained from WXTide32 software (http://www.wxtide32.com) with reference

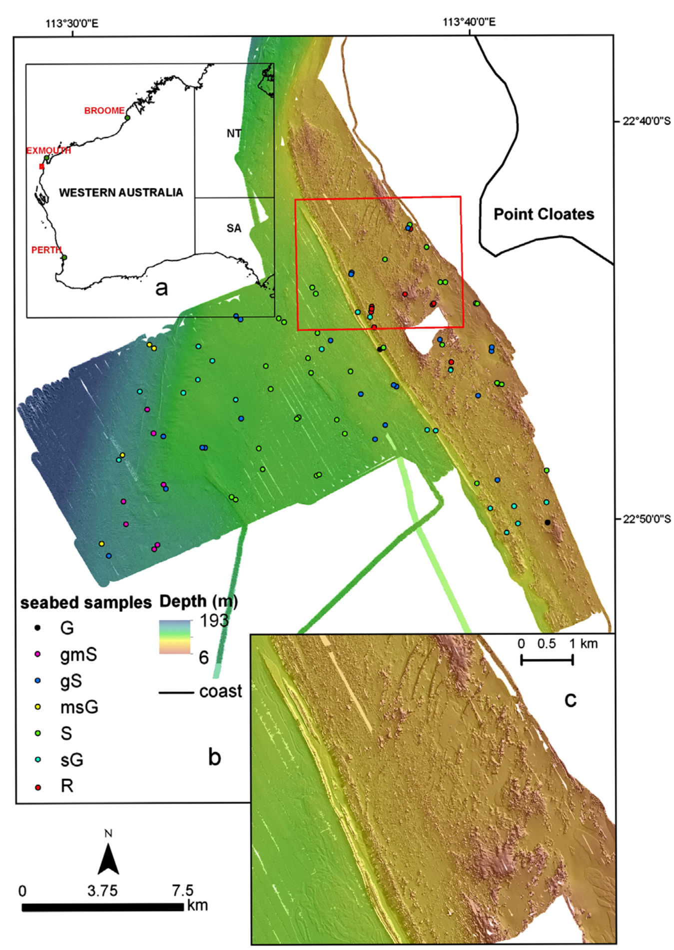

Fig. 1. The study area ((a) and (b)) and the sample locations overlayed on the sun-shaded bathymetry data; the enlarged area (c) illustrates the complexity of the seabed features including ridges, reefs and mounds; the legends of the seabed samples: G: Gravel, gmS: gravelly muddy Sand, gS: gravelly Sand, msG: muddy sandy Gravel, S: Sand, sG: sandy Gravel, R: Rock.