Examining the relationship between acoustic backscatter and physical properties of the seabed

FINAL REPORT
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Background to the fund
In 2002 the Government imposed a levy on all primary aggregates production (including marine aggregates) to reflect the environmental costs of winning these materials. A proportion of the revenue generated was used to provide a source of funding for research aimed at minimising the effects of aggregate production. This fund, delivered through Defra, is known as the Aggregate Levy Sustainability Fund.
(ALSF); marine is one element of the fund.

**Governance**

The Defra-chaired MALSF Steering Group develops the commissioning strategy and oversees the delivery arrangements of the Fund.

**Delivery Partners**

The Marine ALSF is currently administered by two Delivery partners - the MEPF (based at Cefas, Lowestoft) and English Heritage. MEPF reports are available from [www.alsf-mepf.org.uk](http://www.alsf-mepf.org.uk). Where applicable, MEPF source data (e.g. survey data) is available from the Marine GIS secure data storage facility at [www.marinealsf.org.uk](http://www.marinealsf.org.uk). Project reports are also available from here. For more information on English Heritage please visit [www.english-heritage.org.uk](http://www.english-heritage.org.uk).
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The relationship between backscatter imagery, sediment grain size and measures of biological community diversity are investigated using a quantitative approach at two aggregate extraction sites; one in the Southern North Sea (East Coast) and another in the English Channel, UK (South Coast). Previous work conducted at Oban in Scotland (Collier and Brown, 2005) showed the potential for estimating sediment grain size from first order backscatter statistics. In particular this study reported $r^2$ correlation values of 0.531 between mean backscatter and mean sediment grain size, with $r^2=0.351$ between standard deviation backscatter and sediment grain size sorting (n=19). Here we test these simple linear relationships in different environments with a considerably larger number of samples where the sediments are coarser and the degree of sorting is lower. We present the analysis of two datasets; the South Coast data were collected in 2007 as part of MEPF REC 07/02 (Gardline Geosurvey Ltd., 2007), the East Coast data between 2008 and 2009 as part of MEPF REC 08/04 (CEFAS, 2009a; 2009b). In both instances, the acoustic data was collected using two sources; 100 kHz mosaiced imagery collected by side scan sonar (Edgetech 4200) and beam-time series backscatter imagery from a 300 kHz multibeam echosounder (Kongsberg Simard EM3000D and EM3002D). Ground-truth data were obtained from a series of Hamon and Clamshell grabs which were processed for particle size analysis. The Hamon grabs were also processed for benthic faunal biomass and abundance. There were a significantly different number of samples in each of the study areas, with 26 Clamshell and Hamon grabs in the South Coast, as compared with 16 Clamshell and 106 Hamon in the East Coast. The methodology for ground-truth site selection was different, based on a regularly spaced grid in the South Coast and a directed approach in the East Coast informed by manual interpretation of the acoustic data. The latter approach meant that there was a significant time lag between the remote sensing and ground truth acquisition, which has implications for the results.

The analysis presented in this report was based on the extraction of pixels from 8-bit backscatter imagery for all the acoustic data, and where the raw data was available, 32-bit backscatter imagery was generated. This allowed for sampling at a range of scales (20, 50 and 100 m$^2$ windows) based on the ground-truth data locations in an attempt to define an optimum size. The effect of ship track orientation and image pixel bit-depth on the analysis were also considered. The results from the analysis in
the East Coast were significantly more convincing than the South. This was largely attributed to the poor weather conditions at the time of the South Coast survey and the lack of availability of the raw multibeam data for in-house processing.

Our work shows that the first order statistics of backscatter imagery have the predictive capacity for mean sediment grain size. First order statistics of multibeam imagery have exhibited a positive correlation with the observed grain size in the East Coast, with $r^2$ values of 0.623 for the Clamshell grab (n=16) and 0.266 for the Hamon grab (n=106). Particle size analysis results from the Clamshell grab produced a more significant correlation than the Hamon grab, despite there being a smaller number of samples (n=16). The success of this correlation was attributed to the more effective retention of the coarse fraction due to the hydraulic mechanism and the larger volume of the Clamshell grab and processed sample. The size of the backscatter window (20, 50 and 100 m$^2$) did not significantly affect the correlations. The level of significance between the observed grain size and the first order statistics of backscatter imagery are very encouraging, taking into account the highly complex local bedforms coupled with the temporal disparity between the geophysical and ground-truth data acquisition. Standard deviation was demonstrated to be more sensitive to variance, particularly when using the larger analysis window (100 m$^2$). Ship-track orientation was demonstrated to be significant in terms of the mean values recorded for the South Coast, but neither orientation produced statistically significant results. Comparison of faunal analysis on the East Coast Hamon grab samples revealed a uniformly low level of significance ($r^2 < 0.1$) for all measures explored.

The results of our study reinforce the idea that simple first order backscatter statistics can be used to predict seabed sediment properties. In this instance, the first order statistics from the multibeam backscatter imagery in the East Coast could be used to explain 63% of the variance observed in the Clamshell grab samples. These results were achieved despite issues such as poor survey conditions, a highly dynamic energetic environment and significant temporal disparity between the collection of the acoustic and grab samples. This most promising evidence of a relationship between these variables, slightly betters the existing work in the peer-review literature, and therefore contributes significantly towards the ultimate goal of direct translation of remotely sensed data into seabed properties.
Chapter 1: Preface

1 Project overview
This project was commissioned under the MEPF Call theme:

   Innovative ways of improving methods for the multi-use interpretation of marine sonar and bathymetric data

1.1 Rationale
A major challenge for marine environment characterisation is to recognise and delineate benthic habitats with a high degree of accuracy. Typically this is done by a combination of geophysical surveying and collection of seabed samples and/or photography. Usually the acoustic data comes from side scan sonar (SSS), although recently backscatter data from multibeam echosounder (MBES) is being tested. The interpretation of seabed classes is then done by visual inspection of a processed backscatter mosaic that is guided in a qualitative way by the seabed observations. Such an approach has been used in the MEPF funded REC projects so-far.

Clearly in the future it is desirable to move to automated methods to remove human subjectivity (and the reliance on skilled geological interpreters) and extract additional quantitative constraints from the sonar imagery. However the physics of acoustic backscatter is complex and establishing robust relationships between measured instrument response and seabed properties is an outstanding research question. A quantitative link between acoustic data and marine species is even less well tested. Understanding these links is critical for effective environmental resource management within marine aggregate licensed areas in the future.

In this project we investigate relationships between acoustic backscatter, seabed physical properties and biological indices from data previously collected in the South and East Coast RECs. The work establishes the potential of current archived data to automatically predict the spatial distribution of facies and biological attributes. Based on our research we make recommendations for the future collection and analysis of MEPF backscatter imagery.
1.2 Background to the REC surveys

The Regional Environmental Characterisation (REC) projects were commissioned by the Marine Aggregate Levy Sustainability Fund as a means of defining the character of the benthic habitat and the cultural value of marine landscape in four areas of active aggregate extraction around the coast of England; the South and East Coasts, and the Humber and Thames areas. Data acquisition was conducted by various different partner organizations between 2007 and 2009. At the time of writing, the data processing has been completed and the final reports for the South Coast and Thames areas have been published; (James et al., 2007, Emu Ltd and University of Southampton, 2009, James et al., 2010). The final reports and maps from the East Coast and Humber areas are due for completion in February 2011 (URL: http://www.alsf-mepf.org.uk/projects/rec-projects.aspx [accessed January-June 2010]. Here we analyse data from the South and East Coast RECs, the location of which is shown in Figure 1.1.

![Figure 1.1: Location map of Oban (site of Collier and Brown, 2005) and the South and East Coast REC areas (studied here) relative to the coastline of Britain and Ireland.](image-url)
Chapter 1: Preface

The evolution of the South Coast REC began in 2004 with the MEPF commissioned “The Eastern English Channel Marine Habitat Map” (EECMHM) study: Project code 04/01 (James et al., 2007). The objective of the study was to create a broad-scale habitat map based on the available geological and biological information for the area. This methodology was similarly adopted in the approach to the South Coast REC: Project code MEPF 07/02 (James et al., 2010). The approach in the East Coast area represented a diversification of the original South Coast work (James et al., 2007, James et al., 2010).

Owing to the fact that the acoustic and ground-truth acquisition was conducted by several different partner institutions and collaborators, there are marked differences in the way the data have been acquired, processed and archived. Each of these factors may influence the validity of comparative analysis. This project evaluates the acoustic backscatter data types, in particular investigates the relationships between the various parameters to determine the optimum conditioning of these data for quantitative analysis. The project is therefore an example of the “collect once – use many times” principal adopted by the MEPF steering committee. An aspect of the project therefore involves the assessment of the REC archive for future multi-use analysis.

The scientific aim of project MEPF 09/P80 is to analyse the REC data to investigate quantitative links between backscatter imagery, sediment grain size and benthic community data. This study uses methods developed by the Project Leader in a previous study at Oban, in Scotland (Collier and Brown, 2005, Brown and Collier, 2008).

1.3 Specific objectives

The project objectives are as follows. Please note that these have been slightly modified from those given in the original project tender due to data availability/quality problems. In the original tender the aim was to analyse the EECMHM area, but in end we used data from the South and East Coast RECs.

**Objective 1. Is multibeam backscatter suitable for direct translation into seabed parameters?**

Multibeam echosounders produce high quality bathymetric data, however, for acoustic imaging their along-track beamwidth is much wider than what is used on
conventional side scan sonar. As such the backscatter imagery produced by side scan sonar is usually of better quality and is often preferred for acoustic mapping projects (Brown and Blondel, 2009). Side scan has the disadvantage that it is not co-registered with bathymetry (limiting angular-range processing), is not motion compensated and can suffer from tow-related noise. In the REC study areas we are fortunate to have both data types, allowing a direct comparison of their ability to correctly predict known seabed properties. Clearly there will be no need to collect, process, analyse and archive additional side scan sonar datasets in future MEPF REC’s if the backscatter data from multibeam echosounder can be shown to be sufficient to quantify seabed parameters.

Objective 2. Are first-order statistics sufficient for predicting mean sediment grain size and sediment sorting?

In a previous study off the west coast of Scotland we found first order statistics of backscatter pixels around each grab-sample site to be sufficient to predict sediment grain size characteristics (Collier and Brown, 2005). We test these relationships off the South and East Coasts of England to see if such an approach is also suitable here. In more complex marine environments, such as tropical reefs, it has been suggested that more sophisticated textural analysis methods are needed to extract seabed properties, but these may not be necessary on continental shelves in temperate regions such as the UK. Establishing the best mathematical basis for automated sediment classification is a long-term research goal.

Objective 3. Is there a direct relationship between acoustic data and assigned infaunal biotope class?

Sonar instruments measure both seabed surface scattering and volume scattering (within the upper few cm of sediment for high-frequency sonar used here). Although in some situations biological organisms may directly affect the physics of sediments (eg. shells as scatters, bioturbation altering vertical stratification, gas bubbles from biological decay processes), it is more likely that there is an indirect and multi-factor link between biological community and sediment properties. Given the advanced level of infaunal analysis of the grab samples from the study area we investigate the links between the acoustic data and diversity indices and univariate measures of abundance such as; number of species, number of individuals and biomass.
1.4 Report Structure

This report is structured in the following manner:

- Chapter 2 gives an introduction to the principal methods for acquiring remotely sensed and ground-truth data in the marine environment. The differences and similarities between methods are explained, and what implications this might have for their subsequent comparison. This is followed by a brief summary of the main physical characteristics of each of the study areas from the perspective of the MEPF 09/P80 project, specifically for contemporary seabed sediments and the physical energetic environment.

- Chapter 3 is a description of the processing flow and methodology followed in this project for the extraction of imagery around the sediment grab locations. The statistical approach used to examine correlations between parameters is also reviewed.

- Chapter 4 examines the backscatter imagery (side scan sonar [SSS] and multibeam echosounder [MBES]) and ground-truth data (particle size analysis [PSA] and benthic faunal data) in the South Coast REC archive.

- Chapter 5 presents the results for the analysis and correlations between the variables in the South Coast REC.

- Chapter 6 examines the backscatter imagery and ground-truth data in the East Coast REC archive.

- Chapter 7 presents the results for the analysis and correlations between the variables in the East Coast REC.

- Chapter 8 discusses the principal findings, which are then examined in terms of some of the problems which may have presented obstacles/ confounding variables to the analysis conducted.

- Chapter 9 summarises the principal findings in answer to the three project objectives and presents the recommendations in terms of the original tender’s deliverables.
Chapter 2: Introduction

2 Introduction

2.1 Principals of remote-sensing in the marine environment

2.1.1 Acoustic properties of marine sediments

In marine surveying, as well as the depth of the water the ‘backscatter’ strength of the returning signal relative to the transmission geometry is also recorded which can be used to infer something of the physical characteristics of the sediments it interacts with (Figure 2.1). This is because the strength of the backscattered signal is dependent upon several factors, including: the acoustic source level, frequency, grazing angle and the composition of the seafloor including grain size, water content, bulk density, seafloor roughness and volume backscattering of at most a few metres water depth (Gardner et al., 1991, Blondel and Murton, 1997).

Figure 2.1. Schematic figure depicting simultaneous acquisition of (left) bathymetric data; (right) co-registered sonar imagery using MBES (after Lurton, 2002).

The nature of the interaction between marine sediments and high frequency acoustic energy is described in detail by Jackson and Richardson (2007). The physical structure and morphology of sediments has profound implications for the way acoustic energy will interact with them, depending on a range of parameters including grain size, textural and bulk density properties. Sediments are composed of primarily solid mineral particles, pore fluid, gas and organic material (Jackson and Richardson, 2007). In addition to the grain size, the mineralogical composition of the sediment will have significant impact on the interaction of acoustic energy. Biogenic processes can have significant effects on the sediments, for example by binding particles together, or through methane production from the degradation of organic
matter. Examples of processes such as these all have implications for the acoustic properties of substrate. Physical properties of the sediment such as heterogeneity also are extremely relevant, as the presence of larger scale inconsistencies such animal burrows; shells voids will further affect the nature of this relationship. Other significant physical effects occur in response to hydrodynamic regimes (past and present), where the establishment of semi-permanent and mobile bedforms serve to complicate the nature of this interaction further.

Figure 2.2. Schematic diagram showing how the manner in which acoustic energy returns to the instrument varies with the grazing angle across the swath.

The way acoustic energy interacts with the seafloor has significant implications for the strength, direction and quality of the signal that will be returned to the receiver. In all instances however, the seafloor functions as a rough interface which scatters the incident acoustic waves. As far as high frequency acoustics are concerned, the interaction comes from two properties; the returned energy from the seafloor interface (interface backscattering) and the energy which penetrates the sediment and is subsequently scattered by volume heterogeneities (volume backscattering) (Lurton, 2002). The relative significance of which are largely a function of frequency and grazing angle. For interface backscattering, the energy scattered either by direct reflectance (specular), which is typical at incidences close to vertical, or by
microscale roughness at more oblique grazing angles (Figure 2.2). Volume backscattering on the other hand is related to the degree of acoustic penetration at the interface, and is more dependent on transmission frequency and the relative position of the acoustic source above the seabed. This is also largely affected by large scale volume heterogeneities within the sediment, such as burrowing animals, voids, buried stones etc.

At the frequencies used for the MBES in this research (300 kHz), the penetration depth should be optimally on the order of a few centimeters for coarse sediments to 10 cm in finer sediments (Ferrini and Flood, 2006), although this may be somewhat diminished at greater water depths in the study area. The degree of subsurface of penetration for SSS is not always well known, but the imagery is affected in decreasing order of significance by local imaging angle, surface and volume characteristics of the seabed (Blondel, 2002). In the case of the towed 100 kHz SSS, it is anticipated that it would offer significantly more penetration around the nadir and near range than the hull mounted high frequency system (Blondel and Murton, 1997)

2.1.2 Data acquisition

In this project we use data from side scan sonar (SSS) and multibeam echosounder (MBES). Here we give an overview of their operation.

Figure 2.3. Schematic diagram showing the difference in the principal of the operations of a) Side scan sonar (SSS); and b) Multibeam echosounder (MBES). Modified from (Ocean Imaging Consultants Inc., 2010).
2.1.2.1 Side scan sonar

Side scan sonar (SSS) is based around the transmission and reception of an acoustic beam from each channel (port and starboard) that is characteristically wide across-track (±80-85°) and narrow along track (1° or less). The received signal is used to construct a sonar image (sonograph). The operational frequency is typically in range of hundreds of kHz, and more sophisticated systems can transmit and receive several along track sectors at the same time. The system used in both South and East Coast RECs was the Edgetech 4200, a dual frequency (100 and 400 kHz) system, comprising towfish, topside processing unit and umbilical (Figure 2.4).

Figure 2.4. Edgetech 4200 SSS system comprising towfish, topside processing unit and umbilical. (EdgeTech, 2010).

Figure 2.5. Side scan sonar deployment: (a) towfish; (b) instantaneously insonified area; (c) area covered by previous transmission (after Lurton, 2002). Descriptions of the provinces of the swath geometry are labeled: nadir; near range and far range.
These systems are usually towed close to the bottom to ensure maximum resolution (Figure 2.5), and the location of the towfish is estimated from cable out, layback or by tracking the relative position in the water column. This is most commonly achieved using an ultra short base line transponder (USBL), which acoustically monitors the relative position of the fish to a known reference point (usually the ships dGPS). The geometry of the insonification for a side scan sonar system is displayed in Figure 2.6. This approach can be used successfully to cover large areas of the seafloor. Problems arise with this method due to the occurrence of acoustic shadows caused by objects with a vertical relief in the water column, and this has significant effects on the quality and usefulness of the derived imagery. This problem tends to be of particular relevance in areas with localized slopes, or complex topography such as biogenic or rocky reefs, and bedforms in mobile substrate such as the South and East Coast REC areas. Problems commonly arise at the processing stage, when the difficulty of integrating the navigation data, and the process of mosaic generation can compromise the quality of the data available for interpretation.

Figure 2.6. Geometry of side scan sonar insonification (after Lurton, 2002).

Side-scan sonar does not (with the exception of interferometrics) have the capacity to incorporate information about the bottom topography, so in the absence of a flat bottom, it requires additional bathymetric data on which to base processing corrections. Without taking these factors into account, the intensity of the backscatter return is significantly affected by bathymetric variation, to the point that it is of limited usefulness for quantitative analysis. Traditional analysis of SSS is primarily image-based, using the constructed sonograph for visual interpretation.
2.1.2.2 Multibeam echosounders

Multibeam echosounders (MBES) consist of multiple individual beams arranged in an array perpendicular to vessel track. The basic geometry of a MBES system is described in Figure 2.7.

![Multibeam echosounder geometry](image)

**Figure 2.7.** Multibeam echosounder geometry (after Lurton, 2002). (Upper) Plan view with the swath width described by $L$ and the along-track (longitudinal) aperture $\theta_L$. Vertical view with across-track transversal beam aperture $\theta_T$, and the maximum beam tilt angle $\theta_M$.

MBES arrays are typically constructed of between 100 and 500 beams with individually small angular widths (typically $1-3^\circ$). The smaller focus of the beams in a MBES array means a smaller insonified footprint and resultantly there is less averaging of data. The angular sector of these systems can be up to $150^\circ$, covering up to 7.5 times water depth (Lurton, 2002). The transducer array can be configured in either an equidistant or equiangular manner, occasionally with the option of both. The operational frequencies of these systems vary in relation to their intended applications, and are usually a function of water depth; ranging from 12 kHz offshore to upwards of 500 kHz for high-resolution work near-shore or on targeted sites.

The systems used in the course of this study function in the 300 kHz band; a Kongsberg EM3000D in the East Coast (AS Kongsberg-Maritime, 2003) and an EM3002D used in the South Coast (AS Kongsberg-Maritime, 2006). The EM3000D is a dual head 300 kHz MBES designed primarily for high resolution mapping in shallow water (Figure 2.8). This system was the predecessor to the more recent EM3002D, which has the same nominal band of operational frequency. The minimum operating depth for the system is 1 m below the sonar head, and the
maximum depth range in good conditions is in excess of 150 m (AS Kongsberg-Maritime, 2006). Used in the dual head mode, the transducer array is composed of 254 individual beams of 1.5° equiangular spaced at a distance of 0.9°, leading to a combined angular sector of up to 200°. The maximum sample rate of the system is 40 Hz.

![Figure 2.8. Kongsberg Simard EM3000D transducer on a retractable hull-mounting (AS Kongsberg-Maritime, 2003)](image)

Owing to the typical beam widths MBES need to be compensated for the effects of heave and inertial movement at the outer ranges. This is achieved by the simultaneous acquisition of ancillary data for MBES (pitch, roll, heave and yaw) to compensate for the motion inherent from the acquisition platform; position and heading data information, and sound velocity profiles (SVP) allow for the correction of the sound speed in the water column, and the improvement of beamforming. In contrast to SSS, one of the principal advantages of using MBES is due to the fact that the backscatter imagery is bathymetrically co-registered, which means that it is theoretically possible to compensate for the effects of bathymetric variation.

**Backscatter image construction**

The acoustic energy transmitted and received can be used to construct an acoustic image where each pixel represents a geospatially discreet x, y and backscattered echo-intensity. The geospatial accuracy of the SSS system is often less accurate than MBES, as it is based on a time series from the point of first return for a single transmission. However, this is balanced by an increase in the resolution and by
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reduced distance from the transmission source to the target. Often the positional information is based on the point of transmission/reception or on the position of the vessel from which the instrument is deployed (Figure 2.9). Furthermore, the construction of a geometrically accurate mosaic is further complicated by the inertial movements of the towfish relative to the vessel navigation (Figure 2.10), as compared to the explicit geometry and provenance of each beam in a multibeam array.

Figure 2.9. Echo generation for a side scan sonar: (A) noise and reverberation in the water column; (B) first bottom echo; (C) sand area; (D) rock; (E) silt; (F) object echo; (G) shadow from object (after Lurton, 2002).

Many of these factors contribute to problems in SSS imagery, which ultimately lead to inaccuracies when it is used for subsequent analysis. One of the most significant problems associated with the method is the difficulty of achieving good registration with adjacent lines of data at the stage of mosaicing. Acoustic shadows are also prevalent in SSS data owing to the high aspect ratio of a deep-towed system in comparison to the hull-mounted MBES sensors. However, the mechanism for relaying the information which relates the towfish position to the vessel from which it is deployed is possibly the most difficult to reconcile. Examination of Figure 2.3 shows a schematic diagram which illustrates the problem of towfish layback in the SSS system. This is particularly a problem in areas of turning, and where there are strong currents or tidal streams perpendicular to the vessel track. The effects of co-registration are most often evident in those instances where data have been
acquired by SSS and MBES systems, where the higher geospatial accuracy of the MBES backscatter imagery can be used to identify problems in the image registration processing stage.

In terms of the processing of SSS data, several stages of correction are usually applied. Initially, the raw data are recorded in traditional waterfall display where the pixels of backscatter imagery are stacked equally by the order of the time in which they were acquired. Subsequently, they need to be rendered in true geographic space; in order to archive this they are georectified incorporating the navigation data (plus layback or other known offset). The next phase of modification is the application of slant range correction which involves removal of the water column which is present in the SSS trace between the first point of contact on the port and starboard channels of the sensor. This appears in the raw side scan record as an opaque section of the record in the centre of the navigation line. The data will also need to be compensated for the effects of signal loss across the swath; this is usually achieved by the application of time-varying gain. This is typically applied at the post-processing stage, where it attempts to amplify the signal at the far range and decrease the relative strength of the signal close to nadir where the return is typically the strongest. All of these effects have the ability to compromise the image quality of a final backscatter sonograph, and has implications for the interpretation of the final product, and any subsequent analysis.

Figure 2.10. Sonar image construction. (Left) The pixel lines are stacked without trajectory correction. (Right) Fish navigation and movements are compensated in order to create a mosaic (after Lurton, 2002).
There are many similarities in terms of the construction of a SSS image as compared to a MBES echosounder. When integrated with motion referencing and positional data, multiple track lines can be used to construct a composite mosaiced image in the case of SSS data, in much the same way as for MBES (Figure 2.10). In some ways, it is possible to consider that each of the beams of a MBES function in the same way as SSS, albeit in a much more focused manner in the across-track domain, and that they are typically much further away from the source which is being insonified. In the along-track domain, the beam width is much narrower for SSS systems, and they typically have a significantly improved horizontal resolution. One of the most significant differences between the imagery generated from either system is in terms of the aspect ratio, which has bias depending on the grazing angles which have been included. The bias is typical in wide swath MBES (grazing angles from 15° to 90°) and deep-towed SSS (5° to -90°).

The principles for the image construction of MBES backscatter imagery are described as three fold by Le Bas and Huvenne (2009); single beam intensity, individual beam time-series or integrated time series (pseudo-sidescan). This research focuses on the analysis of individual beam-time series backscatter data (Figure 2.11). In this instance, the signal is recorded as a function of time, and its instantaneous intensity represents irregularities (microscale roughness or seabed nature) of the ground swept by the signal (Lurton, 2002).

In the case of beam-time series MBES backscatter, the centre of each individual beam is positioned and the time-series of echo intensity is represented by image pixels that are distributed spherically (over time) around the bottom detection point until the boundary of each adjacent beam is reached (Figure 2.11; (Lurton, 2002). This represents the formation of beam-time-series or ‘snippet’ data as opposed to beam-average backscatter, where there is only one echo-intensity measurement per beam, per ping (Le Bas and Huvenne, 2009).
Figure 2.11. Process of MBES beam time-series image formation. The time signals from each beam are placed along each footprint, honoring exact geometry of the depth measurement (after Lurton, 2002).

By providing the signal strengths from within the beam footprint at the bottom detection point only, this minimises the effect of noise in the water column. This process is repeated for each subsequent sample (ping) for the duration of sampling. Resultantly, beam-time series data is substantially more resolute than the beam-average backscatter and is of significantly more value for the purposes of quantitative analysis of backscatter imagery (Le Bas and Huvenne, 2009).

In terms of the constructed sonar image, two-dimensional representations of these time-series data (ie: frequency against time), whilst useful, are inappropriate for area-based segmentation and neighbourhood operations because they do not contain spatial information. However, constructing a geospatially, geometrically and radiometrically accurate sonograph (x, y, echo-intensity) is made more complex taking into account localised variations in the echo intensity due to the angular response of the sonar, local bathymetric variations and motion referencing effects from the vessel platform. This is made markedly more difficult with SSS, as it lacks the geospatial information inherently contained within the MBES data. If the geometry of the data can be used to equalize the effects of the local bathymetry on the backscatter intensity, then a much more representative image will result, and so improve the validity of further analysis.
2.1.3 Interpretation of acoustic backscatter imagery

Acoustic backscatter imagery derived from either SSS or MBES have a great deal in common, but there are also many fundamental differences, which mean that choice of approach in seafloor characterisation is usually dictated by the survey objectives. In many instances, including both the South and East Coast RECs, the datasets are used together and the results are often complimentary.

One of the most significant problems for SSS imagery is that in the absence of co-registered bathymetry, it is not possible to compensate the backscatter for the effects of localised bathymetric variation, and the resultant assumption of a flat bottom (which is seldom the case); or at best a gradient of local slope is applied as a correction. This is a problem which is reconciled to an extent with MBES backscatter, owing to the high geospatial accuracy associated with this technique provided it is properly installed, maintained and calibrated. This highlights the validity of its use for quantitative analyses (Lurton, 2002). In addition, although the size of objects can be directly measured from the height of acoustic shadows in traditional SSS imagery and towfish altitude (non-interferometric), it is not possible to derive true volumetric measurements or areal extents, and the areas of acoustic shadow are acoustically opaque. This means that whatever material is cast in shadow is not represented by any meaningful value. In areas of high geomorphological complexity such as both South and East Coast RECs, acoustic shadows are prevalent, and this presents a significant obstacle to quantitative analysis of SSS imagery in the manner proposed. Acoustic imagery generated from MBES is still affected by shadowing, but to a much lesser extent, owing to the fact that the acoustic source is hull-mounted, and that there are many individual beams in the transducer array. One effect of this is that SSS imagery in areas of high geomorphological complexity can give the misleading appearance of high textural complexity owing to the large variance in tonal backscatter, when in fact this is due primarily to acoustic shadowing. A distinction can be made between these kinds of artifact and genuine differences in sediment properties by skilled interpretation based on their bathymetric context, but in reality, this is a subjective process and does not lend itself to quantitative analysis.

However, many of these issues are offset to an extent by the often superior resolution of SSS for acquiring acoustic imagery and this is particularly evident when conducting a targeted survey. In these instances, towed systems can get much
closer to the targets meaning that higher frequency systems can be used in deeper water, and therefore be less subject to the effects of signal loss through spherical spreading and attenuation. They are however, usually much more prone to problems related to positional accuracy, which theoretically increases proportional to the towing depth; resultantly the image may have good resolution but poor spatial accuracy. This tends to mean that SSS imagery is most often used for discriminating between anomalous material and the surrounding sediments, as the low grazing angles cause large acoustic shadows which would not be evident when insonified using a hull-mounted system (MBES). It is therefore particularly useful for small object detection and the identification of texturally complex structures.

Backscatter data from MBES are also difficult to adequately compensate for the effects of radiometric and geometric distortions due to variations in source levels, beam patterns, gains and localised bathymetric conditions. Problems can arise owing to the lack of common reference points, and the influence of localised turbulence at the strong atmosphere-ocean boundary layer upon which acquisition platforms are usually deployed.

2.2 Ground-truth data

The process of acquiring ground-truth data for remote-sensing is a vital part of validating assumptions about observations (Mitchell and Coggan, 2007). It is often the case that seabed mapping surveys are conducted in two distinct stages; the initial being that of the geophysical data acquisition and subsequent processing, and the second, the acquisition of the ground-truth data to qualify the inferences made about the former (Clements et al., 2010). This is the approach that was followed in the REC areas, although there are subtle differences. In the first instance, the data from the South Coast were acquired very soon after the geophysical data acquisition (1-4 months) and independently of any interpretation of the results. In the case of the East Coast REC however, the ground-truth survey was conducted after a significant delay, and the design was based around an interpretation of the results of the SSS survey. This difference affects our results and so is an important point of clarification which will feature in the discussion. In principal, the minimum amount of delay in the collection of sediments and acoustic imagery is desirable, especially in areas of highly mobile substrate (South and East Coast REC).
The acquisition of many marine datasets is often the result of a combined effort, originating from multi-partner initiatives such as the M-ALSF’s REC programme. Other prominent examples include the Gulf of Maine Mapping Initiative (GOMMI); Mapping European Seabed Habitats (MESH) and Joint Irish Bathymetric Survey (JIBS). As such, a wide range of techniques, equipment and procedures may have been involved during acquisition. The systems most typically employed in ground-truth data for seabed mapping are well summarised in the MESH Standards and Protocols (Coggan et al., 2007).

The subject of grab samples for seabed mapping programs is covered in considerable detail in several relevant texts and papers (Blomqvist, 1991, Somerfield and Clarke, 1997, Mackie et al., 2007). Grab sampling is usually undertaken in this capacity for the determination of the geotechnical properties of the seafloor sediments, such as grain size distribution of the surficial sediments, and/or epifaunal or infaunal assemblage structures at the location of the sampling point (Harvey et al., 1998, Kostylev et al., 2001, Brown et al., 2004, Roberts et al., 2005, Collier and Brown, 2005, Brown and Collier, 2008).

Various different systems exist for performing what is essentially the same task, physically extracting a small area (typically less than 1.0 m²) of the surficial sediments for physical, chemical and biological analysis. In the work that was carried out for the REC areas, the sediment samples have been acquired using two different approaches; the Hamon and Clamshell grab. These are usually employed in response to different research or monitoring questions; with the Hamon grab more commonly used for the collection of small volume samples for faunal analysis (typical seafloor footprint of 0.1 m²), whereas the Clamshell grab is a hydraulic grab typically used for the collection of high volume samples for characterisation of bulk density (typical seafloor footprint of 1.0 m²). In general, ground-truth survey design methodology is significantly less developed in principal than for comparable terrestrial systems; a point which is well discussed by Clements et al. (2010).

2.3 Previous studies relating backscatter to grain size to biology

The nature of the relationship between acoustic and seabed properties is dependent on many factors; including the variety and heterogeneity of the sediments which have been insonified, the transmission frequency of the sonar and the geometry of
the source. The stability of the relationships observed are dependent on minimizing or mitigating against many of the issues affecting geophysical data acquisition at sea; such as survey design, dynamic motion artefacts, variation in instrumentation/operational parameters, and the conditions particular to each individual survey. In the literature, many of the successful reports of established relationships are specific to a range of circumstances observed at a particular location.

For example, the study which formed the basis for MEPF 09/P80 proposal (Collier and Brown, 2005) was conducted in Oban using a 100 kHz SSS. This study reported an $r^2$ significance between mean grain size and mean backscatter of 0.531 (Figure 2.12). By contrast, the significance of the correlation between the standard deviation grain size and backscatter was 0.351, leading to the conclusion that more heterogeneous sediments gave rise to more variable backscatter intensity. This was taken as strong indicator of the potential for SSS to make valid predictions of grain size characteristics.

Figure 2.12. Summary of relationships between acoustic properties and sediment grain size from the Oban study (Collier & Brown 2005).

Further examples of comparative studies include Goff et al. (2000), which performed analysis of 95 kHz MBES data in an area with depths ranging from 70 to 200 m off the New Jersey Margin. They reported a significant positive correlation between mean grain size (from approximately 300 grab samples) and mean backscatter, provided a range of criteria for the grain size distribution of the sediment samples (unimodal, well sorted samples) were met. This work was developed in 2004 (Goff et al., 2004), where MBES data were examined in a combined analysis of velocity,
attenuation, porosity, backscatter and reflectivity. Owing to the grain size distribution of the samples (primarily multi-modal), the analysis was conducted on the % composition of material, by coarse, medium or fine material (>4 mm). One of the principal findings was that where coarse % is significant, the interpretation of the backscatter data is limited by this relationship (Goff et al., 2004). This study attempted to use backscatter as a proxy for velocity, attenuation and density but was inconclusive owing to the abundance of coarse material.

Using the same 95 kHz MBES system (EM1000) for a similar application in a different environment (Short Bank and Santa Monica Canyon), Dartnell and Gardener (2004) examined the relationship between these variables in water depths between 40 and 450 m. This study was based around the prediction of seafloor facies derived from the percentage composition gravel, sand and mud from a total of 60 grab samples, which were compared to the results derived from bottom photographs. The accuracy assessment from this exercise resulted in a 72 % accuracy in the prediction of acoustic facies.

In a more recent example De Falco et al. (2010) used a 100 kHz Reson Seabat 8111 to attempt to differentiate between different seabed types off the coast of Sardinia in the Mediterranean Sea. This study examined the relationship between backscatter intensity and grain size at 1 $\phi$ intervals, reporting an $r^2$ significance of 0.55 (coarse fraction; 1-16 mm) and $r^2 = 0.7$ (0.016-0.5 mm), although the 0.7 correlation was biased owing to the bi-modal distribution of the sediment samples. The results of this study concluded that backscatter intensity alone was not an effective parameter for distinguishing all benthic habitats, but favored a combined approach to seabed classification.

Ferrini and Flood (2006) describe a significant relationship between sediment properties and MBES backscatter, in a restricted range of circumstances. In terms of the physical environment in this study, there were a limited range of depths (7-16 m) and there was a relatively low diversity in terms of the median range of grain size samples (1.4 to 2.4 $\phi$). The most significant of the traditional grain size descriptors was median grain size and backscatter intensity $r^2$ significance of 0.37.

The interrelationship between sediment and biology is also described by Rhoads (1974) and Gray and Elliott (2009). The general consensus on substrate-biota
interactions is that the relationship between species abundances and environmental parameters is often complex and still, on the whole, very poorly understood. This has sometimes led to dubious assumptions about benthic community being equivalent to bottom sediment or substrate type. There are significant problems with this type of simplistic approach (Zajac, 2008). Diaz et al. (2004) reports that the relationship between substrate, the substrate’s acoustic response and the benthic community is significantly more complex than is often assumed.

2.4 Introduction to the study areas

The South and East Coast REC areas represent significant interests for the aggregate extraction effort on the continental shelf off the coast of England; and have many similarities, and many important differences in terms of their physical environment.

2.4.1 South Coast REC

The physical environment of the South Coast REC (Figure 2.13) has been described previously in detail (Collier et al., 2006, Tappin et al., 2007, Diesing et al., 2009, James et al., 2010). In this area, the aggregate extraction effort is focused around sediment filled channels incised into the bedrock floor. The variation in bedrock geology is diverse in this region, ranging from Jurassic to Tertiary age strata of mixed calcareous and terrigenous rocks (Collier et al., 2006). This likely has a strong effect on biotope composition (Philpott and Limpenny, 2006).

This research is primarily concerned with the distribution of the Holocene sediments, whose composition is governed primarily by the pre-Quaternary bedrock, and the contemporary and palaeo-environmental processes acting on the site (British Geological British Geological Survey, 1989). The English Channel was not glaciated during the Quaternary, and so there were no glacio-marine sediments deposited. For the majority of the South Coast REC study area, the seabed is covered by a thin layer of intermittent lag deposits (typically <0.5 m deep), which are comprised of gravels and sandy gravels derived from calcareous material such as flint, chalk, sandstone, limestone and ironstone. Much of this material is not moving as a result of contemporary processes, as is attested to by the heavy levels of biofouling from serpulid worms, bryozoans and barnacles reported (Barne et al., 1996). This mineralogenic composition will have important implications for the acoustic response
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of the sediments (Jackson and Richardson, 2007). The exception to the presence of lag material is in areas where the sediments have been scoured by strong tidal streams, exposing the pre-Quaternary geology. Where the lag occurs, it is locally covered by mobile unconsolidated sediments, which typically exhibit low carbonate content, particularly close to shore.

![Figure 2.13. Overview of the bathymetry in South Coast REC. Data from Seazone. Cell size 40 m (Crown copyright).](image)

The relatively strong tidal currents in the area have been described as having winnowed sand from the surface (James et al., 2010). These gravelly sediments continue eastwards, although there are substantial tracts closer to shore which have a higher component of sand. These have been tidally constrained into large sand banks, waves and megaripple fields. Tidal velocities in the area are typically in the range of 0.5 ms\(^{-1}\) to 3.0 ms\(^{-1}\) (depth averaged), with the highest values south of the Isle of Wight. Tidal forcing is the dominant mechanism for sediment transport in the Channel, with the impact of wind driven waves being mostly episodic linked to storm events (James et al., 2010). The mean significant annual wave height for the Eastern English Channel, is between 0.75 and 1.75 m, with extreme 50 year events returning modeled values in excess of 8 m (Department of ABP Marine Environment...
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Research Ltd., 2004). The relatively high levels of bed stress in the area south of the Isle of Wight have resulted in the dominance of hard substrates (rock and gravel lag deposits) as the area is scoured of fine sediments. In terms of sediment transport in the Channel, the net movement is from west to east, with a bedload parting zone as a dividing line running south of the Isle of Wight. Smaller banner banks exist closer to shore, associated with the individual headland bay systems, which are associated with smaller scale local sediment transport paths and gyres which contribute to maintenance of the sandbanks themselves (James et al., 2010). The sediment transport pathways nearshore are broken into a series of cells which adhere to the headland embayment systems around the South Coast. These typically exhibit complex circulatory patterns, which are described elsewhere in significant detail (Barne et al., 1996). These effects are magnified close to the Isle of Wight and the Solent, where the localized bathymetric variations and tidal forcing combine to greater effect.

2.4.2 East Coast REC

Unlike the English Channel area, the area offshore East Anglia was significantly affected by the Quaternary glaciations, with the area lying at the periphery of many of the ice-sheet advances. The seabed therefore remains littered with glacial-derived sediments composed of various gradients of sand and gravel to muddy gravel (Horrillo-Caraballo and Reeve, 2008), which are typically organized into major morphological forms (Figure 2.14). The majority of the area is dominated by coarse sediments, with most variability occurring immediately offshore Great Yarmouth, where there is a more significant proportion of mud in the shallow inshore gravels banks. The occurrence of these muddy gravel spreads represents thinning of the seabed sediments and the exposition of older substrates, and is typically restricted to areas dominated by strong tidal and sea wave driven bottom currents (Balson et al., 2002).

Reeve (et al., 2008) describes in detail the nearshore morphology of Great Yarmouth and the sandbanks which occur in the immediate vicinity. This dynamic environment is subject to a complex circulation and re-circulation of sediments between the shore, and the inner and outer sandbanks generally in an anticlockwise direction (Reeve et al., 2008). According to UKHO records, these features have been a constant feature of the Norfolk and Suffolk coasts over the last 150 years. Whilst the banks
themselves have been largely physically consistent over this time period, the location, height and width of the individual banks have demonstrated significant variation (Reeve et al., 2001, Reeve et al., 2008). Recent work by Reeve and McCue (1996) and Wallingford (2002) have demonstrated that the sediment circulation in the vicinity of Great Yarmouth is dominated by the southerly transport of coarse grained material (>2mm median diameter), whilst finer grained materials are generally transported offshore.

Figure 2.14. Overview of bathymetry in the East Coast REC. Data from Seazone - cell size 100 m (Crown copyright).

The tidal environment in the vicinity of the East Coast REC is micro to low-mesotidal area which is characterized by the north-south orientation of tidal currents. Peak flow
is dominated in the southbound flood orientation, with maximum velocities observed of 1.45 to 1.75 ms\(^{-1}\). In terms of wind driven waves, the East Coast REC is constrained by the fetch limited energetic environment of the Southern North Sea, where 76% of the waves are less than 2 m and 40% are less than 1 m, with the largest waves approaching from the North and Northeast (Reeve et al., 2008, Pye and Blott, 2006).

The general trend in terms of sandbank mobility in the Southern North Sea is described in the Strategic Environmental Assessment (Balson et al., 2002). There was no consistent recorded direction of overall bank migration, although some of the offshore sand banks in the East Coast REC had elongated towards the northwest, the direction of regional sand transport. The surfaces of many of the sandbanks are covered in active sandwaves, which are indicative of the patterns of modern sediment transport in these areas. These are typically have crests aligned perpendicular or sub-perpendicular to the crest of the bank crest (Balson et al., 2002).
3 Methodology

The description of the methodology employed is based around the analysis conducted on of the South Coast and East Coast REC areas through the course of MEPF 09/P80. The analysis used SSS and MBES backscatter imagery, PSA and benthic faunal data from the archive. These datasets have been made available through the Marine ALSF GIS web portal (URL: http://www.marinealsf.org.uk) which is managed by the GeoData Institute at the University of Southampton. The first analytical phase was related to the evaluation of these archive datasets, and the assessment of their suitability to meet the objectives of the proposed research. This was achieved by examination of the data formats of the archived acoustic and PSA data, and a determination of their appropriateness for quantitative analysis.

3.1 Data extraction

3.1.1 Geospatial data integration

The initial phase of data processing for both study areas was to load the ship tracks and PSA stations into an ArcGIS v.9.3 project file with common geodetic parameters in UTM Zone 30N (South Coast) and Zone 31N (East Coast). The coordinates for each sample station were then used to generate polygons at a series of predetermined scales. These polygons were square with dimensions of 20 and 100 m² (South Coast) and 20 and 50 m² (East Coast). This point vector to polygonal vector conversion was performed using ET Geotools (ET (Edit Tools), 2010). The rationale for processing at a range of scales was to determine the optimum scale of observation and to examine the potential effects related to the sample’s position in the swath.

In practice differences in the survey design of the acquisition stage determined differences in the way the analysis could proceed for MEPF 09/P80. The principal difference between this South and East Coast datasets were (i) variation in the position of the PSA samples relative to the geophysical survey coverage – in the South Coast the PSA stations are regularly spaced, located at the centre of two orthogonal line intersections, whereas in the East Coast they were based on stratified design informed by interpretation of the geophysical data located on single lines, (ii) in the South Coast Clamshell and Hamon grabs were co-located, whereas
Chapter 3: Methodology

in the East Coast they were not and (iii) the way the geophysical data had been processed. This matter is discussed more fully in each of the respective Review and Evaluation Chapters (4 and 6). In the case of the South Coast, the data from both orientations were recorded with the intention that this could be factored into the analysis.

3.1.2 Backscatter image generation

In the South Coast study only processed backscatter imagery from the archive (URL: http://www.marinealsf.org.uk) was used. However, in the East Coast study area raw multibeam data was obtained which allowed us to create new imagery from source, and hence have full-control over the processing parameters. The raw sensor outputs (raw.all) files were processed using IVS3D’s Geocoder. The data were initially loaded into a project file in DMagic to enable dynamic selection and identification of individual survey lines. This was used interchangeably with the shapefile of the grab samples in ArcGIS to identify individual segments of lines which intersected the PSA stations, and these were isolated to be mosaiced in IVS3D’s FM Geocoder. Within this software environment, the individual segments were pre-scanned to determine the bounds of the file and export the correct geodetic parameters, before being mosaiced to a resolution of 30 cm; the same nominal resolution as the SSS. The optimal resolution for the beam time-series MBES backscatter data was higher than this, particularly in shallower water; however the pixel dimension was kept constant in order to standardise the comparison between the two approaches.
Figure 3.1. Comparison of archival SSS imagery with reprocessed MBES backscatter example at the site of a PSA station. a) Single line of SSS data in the vicinity of Station T1_11. b) as before but for two mosaiced lines of MBES data. Blue circle indicates position of the sample station, red box indicates the physical footprint of the 50 m pixel extraction.

When the mosaicing process was completed, the data were exported as ArcMap compatible grid (32-bit floating point) .asc files, and brought into the ArcMap project. An example of the generated imagery is presented in Figure 3.1, which shows the same area of seafloor in the archival side scan imagery (a), and with the MBES backscatter imagery processed at Imperial College for MEPF 09/P80 (b). Statistics were generated for each line segment, along with the angular range analysis output file (.xyz). These 32-bit .asc grids were converted using standard tools from the ArcMap 9.3 Data Management toolbox, and exported in .tif format.

3.1.3 Pixel extraction

In order to extract the pixel values from the imagery (archival and user-generated), each of the images were clipped using the individual polygons derived from the PSA sample locations. The resulting images were retained and used for the Zonal statistic
Chapter 3: Methodology

extraction using the Spatial Analyst extension in ArcGIS 9.3. This process was repeated for each of the quadrats which had coincident backscatter imagery from both SSS (Edgetech 4200) and MBES (Kongsberg-Simrad EM3002D [South Coast] and EM3002D [East Coast]) systems. This amounted to 26 usable stations in the case of the South Coast for both Hamon and Clamshell grabs, and 106 (Hamon) and 16 (Clamshell) in the case of the East Coast REC.

As described at the beginning of this Chapter, the main difference between the way the imagery was processed for the South and East Coast datasets was that the relative orientation could be considered for the South Coast, as most of the PSA samples has been insonified from two perpendicularly opposing orientations. In this instance, the data from both orientations were extracted in order that the relative effects could be examined through the course of the analysis. As a result of this processing, each of the 26 PSA (both Hamon and Clamshell) stations in the South Coast REC had at between 2 and 6 raster images (at the two scales 20m and 100m for each system, and variable by orientation) and associated table containing the summary statistics (count, area, minimum, maximum, range, mean, standard deviation and sum). In contrast, each of the 106 PSA Hamon and 16 Clamshell stations in the East Coast had four raster images; one for each system (SSS and MBES) at two scales (20 and 50 m).

In the case of the East Coast, the principal deviation from the method followed in the South Coast was related to the way the archived SSS imagery had been processed. At the time the analysis was conducted, the SSS imagery in the M-ALSF archive (pre-July, 2010) had been exported from the processing environment as slant range corrected .tif imagery which corresponded to the segments of raw SSS (as .xtf). For this reason, the segments of data which were used for the image extraction were based on the vessel navigation shapefile, which showed the location of the most proximal corridor of data to the PSA station. These segments were dynamically loaded into the ArcGIS project, and then the SSS imagery was subject to the same methodology as described for the South Coast. The extraction of the SSS imagery in 50 m images around the PSA sample for the East Coast allowed the generation of summary statistics using the ArcGIS Spatial Analyst extension.
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An example of showing the results of the process of extraction for one of the tiled images is presented for Station 100 (Figure 3.2a-d). In this example, the histograms show the frequency and composition of the backscatter pixel intensities for the same 20 and 100 m sample of backscatter imagery, centred on a grab sample location (Station 100). In this example, the 20 m sample imagery (1600 pixels at 0.5 m resolution), has only 8 different integer values, and 31 different values for the MBES backscatter (400 pixels at 1 m bin size). As the sample size increases to 100 m, this variability increases to 14 values in the case of the side scan (40,000 pixels at 0.5 m bin size), and 43 integers in the case of the MBES (10,000 pixels at 1 m bin size).

Similarly to the South Coast, an example is included from the East Coast REC to demonstrate the difference in the dynamic range of the data (Figure 3.2e and f). In this example, a histogram extracted from a 50 m window around Station T1_11, where 238 of the potential 256 values were encountered (27,889 pixels at 0.3 m bin size). Similarly, the results of the MBES image generation are displayed where 57 discreet values from a potential pixel depth of 4,294,967,296 floating point values were observed (86,436 pixels at 0.17 m bin size). However, the high dynamic range of the SSS data would appear to suggest that the data have been processed to optimally reflect the range of values encountered in the data across the bandwidth of the image format. This would mean that the measured response from markedly different material would not register a different response. The most significant benefit of using the 32-bit imagery is that the data is recorded as a measured value (dB) which can therefore be compared to other processed imagery in a meaningful way.
Figure 3.2. Example of histograms of backscatter intensity from Station 100 South Coast REC.  
a) SSS backscatter at 20 m; b) SSS backscatter at 100 m; c) MBES at 20 m; d) MBES at 100 m; 
e) Example of histograms of backscatter intensity from Station T1_11 East Coast REC: SSS 
backscatter at 50 m; and f) MBES backscatter at 50 m
3.2 Statistical Analysis

3.2.1 Data Integration
Following the extraction of the summary statistics from the backscatter imagery, the results of the archival data were spliced together based on a common attribute (Station ID) in a Microsoft Access database through ArcGIS. This allowed for integration of all the backscatter imagery from both of the REC areas at the variety of scales tested; 20 and 100 m (and opposing orientations) in the case of the South Coast, and 50 and 100 m in the case of the East Coast. This in turn facilitated analysis in conjunction with the results of the Hamon and Clamshell PSA results and the faunal analysis of the Hamon grabs. The output data products chosen from the Gradistat sediment analysis software (Blott and Pye, 2001) for all stations were the Folk and Ward mean ($M_z$), sorting ($\sigma_1$), skewness ($Sk_1$) and kurtosis ($K_G$). The statistics explored for the faunal analysis were univariate measures of diversity including number of individuals, number of species and various diversity indices in the Primer v.6 software environment (eg. Shannon’s, Brillouin’s, Fisher’s and Pielou’s evenness) (Clarke, 1993, Clarke and Gorley, 2006).

3.2.2 Excel
Provisional analysis and data conditioning was performed in Microsoft Excel, where cell formats were finalised, data were transposed and special characters in headers were removed or replaced with surrogates. The data were exported in generic formats (.csv) or vendor specific formats (.xls) to ensure compatibility with the GIS software.

3.2.3 SPSS v. 18
The main statistical analysis package that was used for this analysis was PASW’s SPSS v.18. The principal functions of the software that were utilised were the legacy dialogues for the box and whisker plots, descriptive and frequency statistics for the initial data exploration. The box and whisker plot is a descriptive tool which summarise the diversity of the samples in an easy to interpret visual manner (see Appendix 1 for full definition). This stage of the analysis was vital in the identification of outlying points which could have had the potential to affect results. The linear regression functionality and cross-plot graph dialogue were instrumental in presenting the results of the correlations between the variables.
3.2.4 Primer

Univariate and multivariate analyses of the biological contents and PSA distribution data from the Hamon grab (and PSA from the Clamshell) samples for both the South and East Coast REC areas were conducted in *Primer v.6* (Clarke, 1993, Clarke and Gorley, 2006). The principal functions of this software that were utilised were the creation of Bray-Curtis similarity matrixes of biological similarity, and Euclidian distance similarity matrixes of physical grain size parameters and first order statistics of backscatter imagery for comparison with other results (Clarke, 1993, Clarke and Gorley, 2006). Simprof testing was conducted through cluster analysis and non-Metric Dimensional Scaling Models (nMDS) plots, which were constructed from the generated similarity matrixes. Water depth was explored as a factor in the benthic community data and PSA, along with the results of the Simprof analysis both for community and particle size distribution. A series of diversity indices (Shannon’s, Brillouin’s, Fisher’s and Pielou’s evenness) were calculated to incorporate in the statistical analysis in SPSS (Clarke, 1993, Clarke and Gorley, 2006). Several of these factors were exported into SPSS and displayed as symbologies in the most statistically valid correlations observed between the parameters explored.
Chapter 4: Review and Evaluation of the South Coast REC Archive

4 Review and Evaluation of the South Coast REC Archive

In this Chapter we summarise the key acquisition, processing and archiving features of the datasets from the South Coast (MEPF REC 07/02) which were used in this project (MEPF 09/P80). The information presented has been largely gained from the final project reports (James et al., 2010), ground-truth acquisition reports (Gardline Geosurvey Ltd, 2008) and metadata from the M-ALSF web portal. This Chapter summarises issues encountered, illustrated with examples, which presented themselves as obstacles to the analysis for this project.

As previously described in the Introduction, a decision was made to focus the research effort on the South Coast as a logical extension of the original MEPF 09/P80 proposal for the Eastern English Channel (EECH) (James et al., 2007). Later the scope of the project was broadened to include data from the East Coast REC. It should be noted that the ALSF archive was developing during the course of this project. The bulk of the data discussed here was accessed from the archive in December 2009. However, additional data of relevance was released through the portal in July 2010 to coincide with the publication of the final report for the South Coast REC (James et al., 2010).

4.1 Review of acquisition and processing

The South Coast REC survey work was conducted by a consortium of partners including the British Geological Survey (BGS), Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Marine Ecological Surveys Ltd. (MES), Wessex Archaeology and Sussex Sea Fisheries District Committee. The geophysical data were collected and processed by a sub-contractor, Gardline Geosurvey Limited, in two separate cruises during the summer of 2007 under contract MEPF REC 07/02 (Gardline Geosurvey Ltd, 2008). Faunal analysis of the sediment samples were conducted by MES Ltd., and the particle size sediment samples were processed by Ambios Environmental Consultants (AEC Ltd.).
4.1.1 Geophysical Data

The geophysical data from the South Coast REC was collected by Gardline Geosurvey Limited (Gardline Geosurvey Ltd, 2008). The two systems collected of relevance to the MEPF 09/P80 project were SSS and MBES data, which were acquired simultaneously between the 1st of June to 24th of July 2007 aboard MV Confidante. Vessel positioning was determined using Starfix dGPS in accordance with the specification of the system, leading to a stated absolute accuracy of ±3 m, with greater relative accuracy.

The geophysical survey design was intended to cover an area of approximately 5000 km² with SSS and MBES using a ‘corridor’ design. A total of 28 corridors were proposed, each composed of three lines of adjacent data (one mainline and 2 wing lines). During the survey there was exceptionally bad weather, which forced a revision of the original plan. The revised plan reduced the total line coverage to 13 corridors contained 42 lines of data covering a total of 1945 km (Figure 4.1). This
saving was achieved by removing the wing lines from the east-west corridors, and shortening the length of the remainder overall. This meant significant reduction in the anticipated coverage and this had implications for subsequent comparison of the data for the MEPF 09/P80 contract (Gardline Geosurvey Ltd, 2008). The ground-truth effort was much less affected by the survey conditions, and a much more representative coverage of data was obtained across the REC area.

In addition to the reduced level of coverage, there were limitations to the quality of the acquired data, which was described as being marginal to good at best. In principal, when the quality of the acquired data had deteriorated, acquisition was suspended until such time as the situation improved. However, in practice, owing to the continuing occurrence of the bad weather during the survey, data continued to be acquired when the results were of marginal quality (Gardline Geosurvey Ltd, 2008).

### 4.1.1.1 Side scan sonar (SSS)

#### 4.1.1.1.1 Acquisition

The side scan sonar system used was an *Edgetech 4200* dual frequency system, which can simultaneously record data at 100 and 400 kHz. The data were recorded digitally using a *Coda Octopus 760*. The *Edgetech 4200* sensor has a horizontal beamwidth of 1°, and a vertical beamwidth of 50° the range is variable depending on water depth relative to towfish altitude, but was nominally maintained at a range of 100 m per channel.

The relative position of the SSS towfish to the *MV Confidante* was determined using a *Simrad HPR400* ultra short baseline transponder (USBL) fitted 1 m below the hull of the vessel. The normal expected range of return accuracies was in the order of 1% of slant range, with an expected composite angular accuracy of 1.2°. The propagation of these errors resulted in a positional uncertainty of the towfish of approximately ±10 m.

The SSS data was affected by the occurrence of strong tidal streams in the English Channel (2.0 - 2.5 m s⁻¹) in east and westerly direction, with large variation through the course of a tidal cycle. The effects on the towfish were most pronounced on the north south transects, where there was on occasion in excess of 50 m positional
layback between the SSS towfish and the navigated survey line (Gardline Geosurvey Ltd, 2008).

4.1.1.1.2 Processing and Archiving
The raw data were recorded as computer memory limited segments of individual lines in a coda compatible .xtf format, which were subsequently deposited in the archive. These segments were exported for both 100 and 500 kHz frequencies in the .xtf format.

The side scan data were processed by application of slant range correction, and were subsequently mosaiced using in Coda Geosurvey software. Individual tracks of data were then combined into a single mosaic. The mosaiced images were exported in Geotiff format with a pixel dimension of 0.5 m, which was divided into a series of 5 km² tiles over the extent of the survey area. The processed Geotiff imagery was archived as 8-bit integers, thereby limiting the dynamic range to a maximum of 256 values. There are no details of the mosaicing procedure in the metadata for the South Coast SSS or in the acquisition report to providing details of application time or angle varying gains etc. Resultantly, no further details of the processing methodology are available at present. Only 100 kHz processed data is currently in the archive, the 400 kHz data is only present in the raw .xtf format at the time of writing.

4.1.1.2 Multibeam Echosounder (MBES)

4.1.1.2.1 Acquisition
The MBES system used onboard the MV Confidante was the Kongsberg Simrad EM3002D with Simrad SIS topside acquisition systems and the MRU-5 inertial referencing system (Gardline Geosurvey Ltd, 2008). The EM3002D is a 300 (293-307) kHz, hull-mounted dual head system, capable of operating in equidistant or equiangular beam spacing. The transducer array consists of 256 individual beams with an across-track beam spacing of 1.5°, along-track beam spacing was variable dependent on vessel speed and ping rate which are described as being 2.5 m s⁻¹ (on average) and up to 25 Hz respectively. The MBES was calibrated for the variations in water column sound speed using an AML SV+T sound velocity profiler recorded at regular intervals.
4.1.1.2.2 Processing and Archiving

The bathymetric data from the survey were tidally corrected and processed using CARIS HIPS and Precise Point Positioning (PPP) to provide tidally corrected data referenced to Chart Datum (Lowest Astronomical Tide). The final digital elevation model was additionally subjected to ‘smoothing’ by comparison with simultaneously acquired SBES (Gardline Geosurvey Ltd, 2008).

Multibeam data products made available for analysis included the processed CARIS cleaned tidally corrected outputs (.xyz and .sd), with the backscatter data represented by Geotiffs. The cleaned soundings were available as 2 x 2 m gridded survey routes in .xyz format, containing at most 3 adjacent lines of data. Part of the rationale for the work in MEPF 09/P80 was to demonstrate the validity of using beam time-series (snippets) MBES backscatter for the determination of bulk sediment characteristics, as a data product of equal usefulness compared to the use of SSS for the purposes of object detection.

The multibeam backscatter data were processed by Gardline using a beta version of Geocoder, and output as 8-bit unsigned integers (Geotiff) images with a cell size of 1 m. In this software, these data were mosaiced into 3 line wide sections of their respective 13 individual corridors. The archive therefore consists of individual corridor strips rather than the geographic tiles that were used for the SSS imagery. Resultantly, at the intersections of these corridors, each ground truth sample locations can be represented by either the east-west or north-south MBES backscatter imagery. This proved to be an advantage for our analysis, as it allowed an analysis of orientation, but this may be a disadvantage for other potential users of the archive in the future.

4.1.2 Ground truth data

The ground-truth data were acquired between the 24\textsuperscript{th} of August and the 12\textsuperscript{th} of September 2007 aboard the \textit{MV Ocean Seeker} (Gardline Geosurvey Ltd, 2008). The grab samples were located at the centre of each geophysical data mainline at each intersection of the tracklines (Figure 4.1). A single Clamshell and Hamon grab sample was collected at each station.
4.1.2.1 Clamshell grab
The Clamshell is a hydraulic grab primarily used for geotechnical sediment descriptions. It typically has a high success rate even in coarse material, owing to the hydraulic mechanism as opposed to mechanical action of smaller grabs. The Clamshell grab used had a seafloor footprint of 1.0 m². For the work in the South Coast REC, the sediment was homogenised by mixing with a shovel before two 5 l subsamples were removed for PSA analysis by CEFAS.

4.1.2.2 Hamon grab
The Hamon grab is a mechanical grab used mainly for the recovery of samples of benthic macro infauna from coarse substrate, although these are often sub-sampled for particle size analysis. The grab functions by the means that when the platform reaches the seafloor, the loss of tension in the deployment cable activates the grab mechanism. When the winch is retracted, the tension in the arm moves the grab bucket through 90° through the sediment, sealing it off and securing the sample.

The Hamon grab used had a seafloor footprint of 0.1 m². Sub-samples were removed for PSA processing prior to sieving for biomass analysis. Blotted wet weight of major Phyla were recorded per samples, and used to estimate the total biomass as ash-free dry weight (AFDW) in grams using standard conversions for each of the faunal groups. Faunal extraction was performed under a stereomicroscope, after which point the mixed sample was preserved in industrial methylated spirits. The samples were subsequently sorted into major faunal groups before being analysed against a reference collection by Marine Ecological Surveys Limited (MES Ltd.), who are participants in the National Marine Biological Analytical Quality Control (NMBAQC) scheme.

In common for both methods, grain size statistics were generated for the samples using Gradistat software (Blott and Pye, 2001). Guidelines for the interpretation of the grain size statistics are defined as indicated in the software (See Appendix 2, Blott and Pye, 2001) The output files were exported into Microsoft Excel compatible spreadsheets for integration with the results of the image based analysis. The statistics which were summarised included percentage gravel, sand and silt and clay and Folk and Ward grain size in addition to the particle size distribution curves for the individual samples based on the components binned in 0.5 ϕ increments.
4.2 Archived Data Quality

There are several limitations of the geophysical data in the archive, some of which are unavoidable consequences of surveying at sea in bad weather. Other limitations of the data archive however were arguably avoidable. Issues encountered during acquisition include unrecorded variation in gain settings, unrecorded variations in the amount of cable deployed affecting towfish altitude. The most significant issues for the archive data are related to a lack of adequate metadata for the acoustic data in the South Coast, as it is not clear what level of correction (if any) have been applied.

In terms of working with the processed imagery in the archive, there are several incidental limitations which are of significant importance. When working with datasets which cover such a large area in such detailed resolution (<0.5 m) pixel size, CPU memory becomes an issue. Related to this memory issue, instabilities in CPU system performance are affected by the size of individual files and the volume of data be analysed simultaneously. This was an important issue for all of the geophysical imagery from the REC archive which was analysed.

A summary of the data formats and typical file sizes and descriptions are included in Table 4.1. The most memory intensive formats to manipulate were the Geotiffs, however this was less to do with the size of the individual tiles and more to do with the need to work with multiple tiles at the same time. The preferred operating system for the majority of the software being used in this project at the time of writing was Windows XP Professional 32-bit which limits the amount of physical memory (RAM) which can be used (4 GB). Analysis was hampered because many applications crashed or become unresponsive through the course of standard analysis.

With the exception of the MBES imagery, all remaining data required some degree of reformatting in order to conduct the analysis.

Table 4.1. Summary of archival data from the South Coast REC used in MEPF 09/P80

<table>
<thead>
<tr>
<th>Data type</th>
<th>Format</th>
<th>Example file name</th>
<th>Typical Size</th>
<th>Date of access</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Geotiff</td>
<td>Route_10_Backscatter.tif</td>
<td>100-750 MB</td>
<td>10/2009</td>
<td>Mosaiced 1-3 line Routes common orientations</td>
</tr>
<tr>
<td>SSS (100 kHz)</td>
<td>Geotiff</td>
<td>tile_001X003.tif</td>
<td>95 MB</td>
<td>10/2009</td>
<td>Mosaiced 5 km² tiles mixed orientations</td>
</tr>
<tr>
<td>Clamshell (PSA)</td>
<td>.xls</td>
<td>7261 Clamshell Grab Samples</td>
<td>1.5 MB</td>
<td>10/2009</td>
<td></td>
</tr>
</tbody>
</table>
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<table>
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<th></th>
<th>PSA graphs.xls</th>
<th>PSA results summary.xls</th>
<th>1 MB</th>
<th>10/2009</th>
</tr>
</thead>
<tbody>
<tr>
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<td>.xls</td>
<td>PSA graphs.xls</td>
<td>1 MB</td>
<td>10/2009</td>
</tr>
<tr>
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<td>10/2009</td>
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<td>.xls</td>
<td>PSA results summary.xls</td>
<td>1 MB</td>
<td>10/2009</td>
</tr>
</tbody>
</table>

4.2.1 Evaluation of Side Scan Sonar imagery

There are many problems with processed imagery from the SSS that limit the quantitative analysis of backscatter. The most pertinent issues are dealt with here in succession. Of additional note, although there are only a few selected examples presented here; this does not imply that these are the only such instances of issue in the archival data. These are intended to be representative examples to illustrate the concept of the types of problems which are recurrent throughout the archive for the South Coast REC.

4.2.1.1 Amplitude balancing

One of the most significant issues affecting the processed data is due to the amplitude balancing between adjacent and opposing orientations which are themselves products of the way the data have been mosaiced. In the case of the SSS imagery, all of the data have been mosaiced into a single image and separated into 5 km² tiles with a 0.5 m pixel size to cover the entire area of the survey. In these data, there are multiple instances of variation in backscatter response between adjacent and lines of opposing orientation, where amplitude balancing has not been suitably accounted for. This is particularly evident at the intersections, although it is also prevalent at the mosaic junctures between main and wing lines. Examination of Figure 4.2 highlights one such example of the problem of amplitude balancing, as well as highlighting other additional problems. The variance in brightness between the left hand north-south and the east-west ‘Route’, when compared to the higher contrast, low brightness north-south line which has been mosaiced on top of the composite image. As such, the degree of amplitude balancing between the lines of opposing orientation has not been successfully reconciled. This will clearly exert influence on the quantitative analysis.
Figure 4.2. Illustrated examples of problems with the South Coast REC SSS data. a) Section of intersection between EW and NS lines (Route 13). Towfish positional error up to 50m offset in boundaries (red ellipses); b) Mosaiced area of two adjacent lines showing acoustic shadowing due to topographic variation (Route 11); c) Profile U-V through two lines of adjacent imagery; d) Profile Y-Z through topographic shadow; e) Profile W-X through nadir of image (a).
4.2.1.2 Dynamic range

The SSS data was particularly affected by problems owing to the limited dynamic range of the data. In terms of the specifics, each of the greyscale stretches (Figure 4.3) was represented by only 32 individual values per channel (port [42-74] and starboard [74-106]) ranging from black to white and back again depending on the reflectance strength of the substrate and the position in the swath. At this stage, the same grey level intensity had two different values depending upon whether it had originated in the port or starboard channel. This was resolved by copying the raster in ArcGIS, and specifying colormap to RGB in the export options dialogue box. When this was adjusted to equalise the port and starboard channels, the 256 levels of greyscale were represented by every 8th integer of the total, meaning that only 32 values were used to summarise the diversity across the entire swath. In the resulting imagery, the new .tif visually appeared the same as the original image (Figure 4.3) from the archive. Although the range of values of the archive imagery covered the full potential bandwidth of the 8-bit image, it had effectively reduced it to 32 values, thereby severely compromised the integrity of the original raw .xtf data.

4.2.1.3 Towfish layback error

There is also significant evidence of registration errors caused by inadequate layback correction in the mosaiced imagery. An example of this problem is presented in Figure 4.2 and Figure 4.3, at an intersection between two adjacent lines on north-south data, and a single east-west mainline derived from the revised survey plan. This error has most likely resulted from the fact that each line was recorded from the opposite orientation (i.e. north bound; south bound). However, in the same figure there is reasonable registration evident between features on the north south and east west route. The USBL positioning system that was used recorded was stated to have afforded ±10 m system accuracy for the SSS onboard MV Ocean Seeker (Gardline Geosurvey Ltd, 2008). It is not clear how well this accuracy was manifest in the final processed result as at several instances there was significant evidence of positional layback in the SSS imagery. The presentation of this issue highlights some of the problems encountered whilst surveying in areas with high tidal streams.
Figure 4.3. Example of the issue with the image Colourmap at an intersection of EW and NS SSS in the South Coast REC. a) Displayed as 32 values per range (port and starboard). b) The same data normalised across 256 values, which utilises 32 integers across the bandwidth. All the Colourmaps had to be removed from the SSS imagery before quantitative analysis could commence.
4.2.1.4 Gain changes

There is also evidence of uncompensated gain changes in the processed SSS imagery, an example of which is presented in Figure 4.4a, e and f. This shows that at the scale of observation in this analysis, the results are sensitive to analogue gain changes which have been unaccounted for at the processing stage. In this example, the gain change which has occurred in the SSS between these two tiles (e and f) has had a marked effect on the statistics, showing an increase in mean backscatter intensity (233.86 to 239.74 RGB), and a decrease in the value of standard deviation backscatter intensity (9.35 to 6.25 RGB). This may initially seem insignificant, but examination of the histograms describing the contents of the analysis window (Figure 4.4e and f) shows that as the dynamic range of the values is so low already, the washout caused by gain saturation has had further detrimental effects on the statistical validity of comparison.

4.2.1.5 Nadir striping

Whilst largely unavoidably, the characteristic nadir striping in the central portion of the acoustic imagery will have detrimental effects on image-based analysis if not suitably accounted for. Profile U-V (Figure 4.2a) shows the localised effect of bisecting the nadir of the image, between approximately 150 and 200 m across the profile, whilst the western edge of the profile shows the mosaicing error which gives a similarly high value. The variation in the backscatter response in this profile is entirely the product of data processing, as based on co-examination of spatially coincident area of MBES imagery (Figure 4.5), there is no comparable variation in backscatter. When the longitudinal extent of this erroneous value is taken into consideration (ie. >50 m) the implications for image-based analysis of the mosaiced SSS imagery are significant. Similarly, the case of Profile W-X shows how even heterogeneous bedforms can be effectively masked at incidence angles approaching zero, without registering any perceptible change in reflectance (Figure 4.2). This is a significant consideration as all the South Coast PSA stations were located at nadirs.
Figure 4.4. Example of mosaicing artefacts and analogue gain change of SSS in the South Coast REC. Location of histograms (below) are indicated in lower case letters. a) Overview at intersection in SSS imagery. b) 100 m sample at west wing-line, c) 100 m sample based at centre line, d) 100 m sample at east wing-line, e) 100 m sample from pre-gain change SSS; f) 100 m sample from post-gain change SSS.
4.2.1.6 Acoustic shadows

Figure 4.2b (Profile Y-Z) illustrates the problem of acoustic shadow in a topographically complex area. The South Coast REC area has many instances with highly complex bedforms, and as such acoustic shadows resulting from low grazing angles of SSS are perceived to be of particular relevance. This example area has been insonified in two passes, one south-north (right-hand side of the mosaiced imagery), the other north-south (left-hand side). The area of acoustic shadow has occurred in the lee of the topographic feature (indicated in magenta; Figure 4.2b). Areas such as this have profound implications for the quantitative analysis of the backscatter in these and similar areas, although they could be potentially improved if more control was exerted in the mosaicing process. The area which is cast in shadow has been successfully insonified in the adjacent line, and could therefore theoretically have been included using the constituent components of this imagery.

The problem of acoustic shadowing is a fundamental limitation to the approach of using SSS for these types of applications, as analysis based solely on the pixel response cannot distinguish between high reflectance and shadow. Instead, this requires user intervention and quality controlling. This is a particular problem when the data set has such a limited dynamic range (32 values). Irrespective of this, the raw data components are stored in the archive, and resultanty could be reprocessed at a later stage which at least affords a transparency and reproducibility to the process.

4.2.2 Evaluation of Multibeam Echosounder Backscatter Imagery

Compared to the side scan imagery, the MBES backscatter data from the South Coast REC archive had a much wider dynamic range of pixels within the same image format, with a much lower range and value of mean greyscale intensity. This in itself illustrates the difficulty of internal calibration between the SSS and MBES sources. The MBES backscatter imagery corresponding to the SSS example (Figure 4.2) is shown in Figure 4.5. Co-examination of this example highlights the factors which have caused signatures in the SSS are not present in the MBES. What is immediately apparent is that the MBES images appear to be much more homogeneous that the SSS, particularly at the location of boundaries and bedforms. The outlines of transitional areas are evident, but without the benefit of comparison with the SSS these could be missed. However, this raises the question that perhaps
the apparent homogeneity of these environments is more representative than the dramatic contrast evidenced in the SSS imagery. In addition, it highlights the benefit of having data acquired using both systems, as if a feature is persistent in both, it gives a greater degree of confidence that it is genuine feature, and not a processing artefact. However, the spatial scale of the ground-truth data does not afford the luxury of being able to satisfy this type of interrogation.

4.2.2.1 Amplitude balancing
There are many examples in the archive of amplitude balancing problems in the MBES backscatter, where there are clear jumps in values associated with the junctures between adjacent lines (Figure 4.5). Profile U-V shows the same profile that was indicated in the SSS (Figure 4.2), and what little variance there is appears to be range dependent as was the case for the SSS. In the case of the latitudinal Profile (W-X), there is little evidence of the transitional bedform which appeared in the SSS record. It is apparent, but the expression of the difference between the transitional area and the surrounding substrate is on the order of the variation caused by the poor amplitude balancing.

4.2.2.2 Acoustic shadows
This is similarly the case for Profile (Y-Z) which crossed an area of high topographic relief into an area of acoustic shadow in the case of the SSS (Figure 4.2). The lack of issue with the acoustic shadowing is a function of the geometry of the sensor. Owing to the fact that the MBES is hull-mounted, as opposed to deep-towed, as detailed in the Introduction, although it does occur, shadowing is not of such relevance to these results. Additionally, the functionality of the multiple beams in the array coupled with the narrow beam angles, means that although shadowing will take place, it will have much less of an effect than in the case of the SSS. In the case of the MBES, whilst there is still a difference between these values, it is incrementally smaller than it was in the case of the SSS. Therefore, it seems that there is less of a difference between these values in spite of the fact that the full bandwidth was available, as only every 8th integer was displayed for the SSS.
Figure 4.5. Comparative example of the MBES data at the location of the SSS data South Coast REC shown in Figure 4.2; a) Section of intersection between EW and NS lines; b) Section of 2 adjacent mosaiced lines showing acoustic shadowing due to topographic variation (Route 11); c) Profile U-V across 2 lines of adjacent imagery. (d) Profile Y-Z through [b]; e) Profile W-X through the nadir of image (a).
4.2.2.3 Relative orientation of imagery

One of the most striking differences in the archived imagery for the MBES is the fact that the mosaics are preserved as “Routes”. This is exemplified in Figure 4.6, which shows an intersection between 3x3 lines running in both east-west (a) and north south orientation (b). In this case, the location of the pixel extraction polygon is shown at 20, 40 and 100 m for comparison.

The insonification orientation is relevant in a relative sense, as the pixel values contained within each sample will be at best approximate, but in several instances there may be marked variation owing to some external factor such as weather, sea state or a change in acquisition parameters. In this example, although the imagery appears similar, there are subtle differences in the statistics that will be derived at each of the opposing orientations, which influences the results. The data from the smaller 20 m and 40 m the imagery is most likely represented by data from the central line only, whereas the larger sample size (100 m) will include pixels from adjacent mosaiced survey lines rather than the single central line. This possibility increases in shallow water owing to the reduction in the swath width.

Figure 4.6. Example of MBES data at the location of an intersection in the South Coast REC. Mosaiced imagery is composed of 3 adjacent lines of data, but the ground-truth location may be represented by pixels from either EW (a), or NS oriented survey lines (b).
4.2.2.4 Dynamic motion artefacts

Motion artefacts caused by rough sea states have dramatic implications for hull-mounted sensors, but are unfortunately a realistic and unavoidable consequence of off-shore surveying, particularly in smaller vessels. In this instance, the survey vessel *MV Confidante* was 28.4 m in length by 7.3 on the beam (Gardline Geosurvey Ltd, 2008). In a towed system such as SSS, most of this movement will be translated as heave; however, in a hull mounted system the effects of the vessel’s pitch, roll and yaw are much more readily apparent. The example presented (Figure 4.7) shows the impact of dynamic residuals on MBES data at the same location as the analogue gain change presented for the SSS in Figure 4.4. This artefact is present as the undulations at the bounds of the swath on the east-west lines and on the westernmost of the north-south lines. In contrast, the eastern wing line of the north-south line is free from this effect, which also highlights the relevance of temporal disparity, which is an issue of considerable importance for some of the imagery. The time elapsed between different phases of acquisition can have marked effects on the resultant image quality and therefore on the statistical analyses conducted thereafter. Of additional interest at this intersection is the apparent difference in swath width when compared with a similar level of coverage as Figure 4.6. Here in Figure 4.7, the combined swath width of 3 lines has amounted to approximately 200 m as opposed to nearly 300 m in the case of the previous (Figure 4.6). When this is further compared with the level of coverage for the SSS, the results of comparison are similarly distinctive. Comparison between the MBES (Figure 4.7) and SSS (Figure 4.4) shows that for the same area, the swath width of the MBES is reduced significantly when compared to the SSS, to the point that comparative analysis between the port and starboard samples was not possible. This highlights another important issue in terms of experimental design for the use of MBES in shallow water surveys, where as in this case, the line spacing has been kept constant irrespective of depth.
4.2.3 Evaluation of Particle Size Analysis (PSA) Data

Of the 90 proposed stations, 64 Clamshell and 51 Hamon grabs were recovered. Only 26 of these stations have co-incident geophysical imagery. For these 26 grabs, the spread of the mean values are shown in box and whisker plots (see Appendix 1 for definition) in Figure 4.8a and in Table 4.2. The mean grain size of the Clamshell
grabs range between $-3.77 \phi$ (medium gravel) and $2.45 \phi$ (fine sand), with standard deviations of $0.29 \phi$ (very well sorted) to $4.42 \phi$ (extremely poorly sorted). Full guidelines for the interpretation of the grain size statistics include in Appendix 2 (Blott and Pye, 2001). For the spatially coincident Hamon grab samples, the spread of mean values was $-2.58 \phi$ (fine gravel) to $5.02 \phi$ (coarse silt) with a range of standard deviations about the mean from $0.31 \phi$ (very well sorted) to $3.18 \phi$ (very poorly sorted). The overall mean grain size for the Clamshell was $-0.51 \phi$ (very coarse sand) which is also lower than the $0.17 \phi$ (coarse sand) for the Hamon grab. The difference in the collection properties of the two grab systems employed is also illustrated in particle size distribution curves of Figure 4.9. These results are significant for our analysis, as it relies on an accurate particle size measurement on which to calibrate the backscatter imagery.

For the majority of samples, the Clamshell grab is dominated by coarser material, whilst the Hamon is dominated by fines. This is potentially due the difference in the capacity for retention of a system that is mechanical (Hamon) as opposed to one that is hydraulic (Clamshell). In this case, the Hamon’s inability to retain the fines, coupled with the much smaller footprint (0.1 as compared to 1.0 m$^2$) and sample size (unspecified to 5 l) has led to a marked variation in the results observed.
A further characteristic of the data is that more than half of the samples have more than one mode in their distribution (i.e., are bi-, tri- or poly-modal); this is important as the same mean derived from a sample with a more Gaussian distribution might affect the correlations with the acoustics. When the comparison between the different methods is conducted using only those samples which are unimodal in nature, the number of samples is markedly reduced, and the range of values experienced is dramatically altered. In this instance, further examination of Table 4.2 shows the summary statistics for the unimodal samples, the distribution of which are presented in Figure 4.8b. As can be seen, the range of mean values has decreased markedly for both the Clamshell (-0.62 $\phi$ [very coarse sand] to 1.73 $\phi$ [medium sand]) and Hamon grabs (-0.5 $\phi$ [very coarse sand] to 2.05 $\phi$ [medium sand]). However, the range of the standard deviation values was not restricted by this reduction in number, although the position of the median value has moved showing that a higher proportion of the remaining samples had a higher degree of sorting.

As a relevant and interesting adjunct to the main analysis based on the first order statistics, the degree of relatedness between the 26 Clamshell and Hamon grabs are examined in Figure 4.10. As documented, the $r^2$ value of 0.545 for the mean and 0.427 for the standard deviation grain size are low by comparison with the backscatter imagery (Figure 4.10.; $r^2=0.846$; $r^2=0.787$).
Chapter 4: Review and Evaluation of the South Coast REC Archive

Table 4.2. Distribution of mean and standard deviation grain size $\phi$ (Clamshell and Hamon) for South Coast REC (all samples and unimodal only).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Min Statistic</th>
<th>Max Statistic</th>
<th>Mean Statistic</th>
<th>Std. Dv. Statistic</th>
<th>Skewness Statistic</th>
<th>Kurtosis Statistic</th>
<th>Std. Error Statistic</th>
<th>Std. Error Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Hamon</td>
<td>26</td>
<td>-.258</td>
<td>.502</td>
<td>.17</td>
<td>1.62</td>
<td>.93</td>
<td>.48</td>
<td>1.88</td>
<td>0.89</td>
</tr>
<tr>
<td>Std. Dv. Hamon</td>
<td>26</td>
<td>.31</td>
<td>3.18</td>
<td>2.00</td>
<td>.92</td>
<td>-.73</td>
<td>.46</td>
<td>-.88</td>
<td>0.89</td>
</tr>
<tr>
<td>Mean Hamon Unimodal</td>
<td>12</td>
<td>-.50</td>
<td>2.05</td>
<td>.77</td>
<td>.89</td>
<td>-.046</td>
<td>.637</td>
<td>-1.47</td>
<td>1.23</td>
</tr>
<tr>
<td>Std. Dv. Hamon Unimodal</td>
<td>12</td>
<td>.31</td>
<td>2.67</td>
<td>1.35</td>
<td>.93</td>
<td>.449</td>
<td>.637</td>
<td>-1.65</td>
<td>1.23</td>
</tr>
<tr>
<td>Mean Clamshell</td>
<td>26</td>
<td>-3.77</td>
<td>2.45</td>
<td>-.51</td>
<td>1.71</td>
<td>-.11</td>
<td>.46</td>
<td>-1.10</td>
<td>0.89</td>
</tr>
<tr>
<td>Std. Dv. Clamshell</td>
<td>26</td>
<td>.29</td>
<td>4.42</td>
<td>2.23</td>
<td>1.22</td>
<td>-.30</td>
<td>.46</td>
<td>-1.02</td>
<td>0.89</td>
</tr>
<tr>
<td>Mean Clamshell Unimodal</td>
<td>12</td>
<td>-.62</td>
<td>1.73</td>
<td>.75</td>
<td>.83</td>
<td>-.434</td>
<td>.637</td>
<td>-1.55</td>
<td>1.23</td>
</tr>
<tr>
<td>Std. Dv. Clamshell Unimodal</td>
<td>12</td>
<td>.29</td>
<td>4.42</td>
<td>1.70</td>
<td>1.47</td>
<td>.912</td>
<td>.637</td>
<td>-.59</td>
<td>1.23</td>
</tr>
</tbody>
</table>

The value of the grain size distribution is described in Figure 4.8 and Table 4.2, where the minimum mean grain size observed was -3.77 $\phi$ (medium gravel) for the Clamshell as opposed to -2.58 $\phi$ (fine gravel) for the Hamon. The maximum observed mean values were 2.45 $\phi$ (fine sand) or the Clamshell and 5.02 (coarse silt) for the Hamon; however, this single high value was a statistical outlier and as such the results should not be viewed as representative of the substrate at large. The Clamshell grab had much more significant range of values for degree of sorting (standard deviation), although the mean values were similar (Table 4.2; 2.23 $\phi$ [Clamshell; very poorly sorted] 2.00 $\phi$ [Hamon; very poorly sorted]. The average values could be described as poorly sorted although full range of values were encountered (Folk and Ward, 1957, Blott and Pye, 2001), however the Hamon grab did not capture the more poorly sorted material to the same degree as the Clamshell (Figure 4.8). This situation is more clearly evidenced upon examination of Figure 4.9, where two examples of the particle size distribution curves are displayed for both Clamshell and Hamon at the same locations. In the first of the examples presented (Station 83), the Hamon grab samples are dominated by a higher percentage of fine material than the Clamshell, which has a more substantial proportion of coarse grained material. In addition, this sample is also bi-modal. In the second example presented (Station 92), the shape of the distribution is more closely matched between methods and the curves are largely similar (Figure 4.9). As previously
described, the particle size curves for the percentage contribution of all samples in the South Coast are presented in Appendix 3. Bearing this in mind, when only the unimodal samples are considered in the comparison between the grab sampling techniques, the number of samples included decreases and the strength of the correlations adjust. As has been demonstrated, this shows a weaker correlation of agreement between the mean grain sizes of both methods, but an increase in the correlation between the standard deviation values (Figure 4.10.) although the samples have been adversely affected by the significant reduction in number.

![Figure 4.10. Comparison of PSA (Mean and Std. Dv.) in the South Coast REC (Hamon and Clamshell). If there were no experimental error the correlations would be unity. a) Mean total samples (n=26; $r^2=0.545$); b) Std. Dv. total samples (n=26; $r^2=0.427$); c) Unimodal Mean (n=12; $r^2=0.278$); d) Unimodal Std. Dv. (n=12; $r^2=0.636$).](image)

**4.2.4 Evaluation of Benthic Faunal Data**

Twenty five of the 26 Hamon grab samples (0.1 m$^2$) which had coincident geophysical imagery were analysed for benthic fauna. This analysis was conducted by MES Ltd., who are participants in the National Marine Biological Analytical Quality
Control (NMBAQC) Scheme. The ash-free dry weight was converted to blotted wet weight using the technique described by Eleftheriou and Basford (1989). Direct count abundances of the total major group biomass of macrofauna (>1 mm) derived from the 25 samples are presented in Figure 4.11 and Table 4.3.

Table 4.3. Summary statistics for blotted wet weight (g) benthic Phyla in the South Coast REC.

<table>
<thead>
<tr>
<th>Phylum</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Dv.</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annelida (g)</td>
<td>25</td>
<td>.01</td>
<td>2.84</td>
<td>0.72</td>
<td>0.81</td>
<td>1.50</td>
<td>1.39</td>
</tr>
<tr>
<td>Crustacea (g)</td>
<td>24</td>
<td>0</td>
<td>6.24</td>
<td>1.05</td>
<td>1.64</td>
<td>1.91</td>
<td>3.43</td>
</tr>
<tr>
<td>Mollusca (g)</td>
<td>19</td>
<td>0</td>
<td>729.39</td>
<td>45.14</td>
<td>166.27</td>
<td>4.31</td>
<td>18.69</td>
</tr>
<tr>
<td>Echinodermata (g)</td>
<td>22</td>
<td>0</td>
<td>37.17</td>
<td>2.47</td>
<td>7.85</td>
<td>4.50</td>
<td>20.69</td>
</tr>
<tr>
<td>Miscellania (g)</td>
<td>23</td>
<td>0</td>
<td>4.32</td>
<td>0.71</td>
<td>1.16</td>
<td>2.16</td>
<td>4.38</td>
</tr>
<tr>
<td>Total Biomass (g)</td>
<td>25</td>
<td>0</td>
<td>735.78</td>
<td>39.34</td>
<td>146.04</td>
<td>4.90</td>
<td>24.27</td>
</tr>
<tr>
<td>Number of Species (#)</td>
<td>25</td>
<td>5</td>
<td>99</td>
<td>46.36</td>
<td>29.71</td>
<td>0.08</td>
<td>-1.45</td>
</tr>
<tr>
<td>Number of Individuals (#)</td>
<td>25</td>
<td>7</td>
<td>556</td>
<td>146.34</td>
<td>128.41</td>
<td>1.67</td>
<td>3.62</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.11a shows the distribution of the weighed contents of all Phyla in the available samples. In this case, Station 62 is a significant statistical outlier in three instances; based on the proportional weight of *Mollusca*, and again based on this contribution to total biomass and number of individuals in Figure 4.11c). Resultantly, these data are presented again in Figure 4.11b, with the axis adjusted to show the distribution of samples more clearly with this outlier removed.

Other outliers include the contributions from Stations 75 (*Mollusca, Echinodermata*), 78 (*Annelida*), 79 (All except *Annelida*), 95 (*Echinodermata* and Total Biomass) and 100 (Miscellania). The number of species and individuals are similarly presented in Figure 4.11c, which shows that Station 62 and 79 are outliers based on the larger number of individuals. This was primarily due to the abundance of *Mollusca* in the case of 62, and the combined numbers of all major groups in the case of Station 79.

The actual ranges of values encountered are presented in Table 4.3, where the spikes caused by the weight of *Mollusca*, and the effect on the total biomass and number of individuals on Station 62 can be seen. Co-Examination of Figure 4.1 and
Figure 2.14 shows that Station 62 occurs in isolation from the remainder of samples, and in shallow water close to shore. The lack of available samples in the immediate proximity may afford some explanation as to why there is not a comparable abundance elsewhere in the samples examined.

Figure 4.11. Box and whisker plots of blotted wet weight (g) benthic Phyla in the South Coast REC. a) Including statistical outlier Station 62. (from left): Annelida; Crustacea; Mollusca; Echinodermata; Miscellanea; Total Biomass. b) As for a), excluding Station 62. c) Direct count benthic faunal data (from left) Number of Species; Number of Individuals.
5 South Coast Results

In this Chapter the summary results are presented for the analysis conducted in the South Coast REC. The results are based on the pixels extracted from the M-ALSF archival imagery, and co-examined with the first order statistics from the PSA data. The interrelationships between the various parameters (acquisition system, scale of analysis and orientation) are examined in turn, and the results are compared to univariate measures of biological diversity.

5.1 Backscatter imagery extractions

5.1.1 Side scan sonar

The extraction of the SSS backscatter pixel intensities at two scales resulted in data from 26 stations which are summarised in Figure 5.1 and Table 5.1. The mean backscatter value at 20 m was 239.90, with a standard deviation about the mean of 10.33. The standard deviation of backscatter intensity was 8.90 values at 20 m. As the scale increased to 100 m, the mean value was 238.05, which did not represent a marked difference to that of the smaller sample size. Similarly, the deviation around the mean backscatter and the standard deviation of pixel values varied in the region of 1% (Table 5.1). The analysis showed that the first order statistics were not sensitive to the extraction size area. As the SSS data were mosaiced in their entirety, the relative orientation within the mosaic was not a factor for consideration.

Figure 5.1. Box and whisker plot of SSS backscatter in the South Coast REC at two scales (20 and 100 m; n=26). Note that the maximum RGB values are 255.
Table 5.1. Summary statistics for SSS backscatter in the South Coast REC at 2 scales (20 and 100 m; n=26).

<table>
<thead>
<tr>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Dv.</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistic</td>
<td>Statistic</td>
<td>Statistic</td>
<td>Statistic</td>
<td>Statistic</td>
<td>Std. Error</td>
<td>Std. Error</td>
</tr>
<tr>
<td>Mean 20 m (8-bit) RGB</td>
<td>26</td>
<td>222.07</td>
<td>253.74</td>
<td>239.90</td>
<td>10.33</td>
<td>-0.32</td>
</tr>
<tr>
<td>Std. Dv. 20 m (8-bit) RGB</td>
<td>26</td>
<td>2.97</td>
<td>18.46</td>
<td>8.90</td>
<td>4.14</td>
<td>0.60</td>
</tr>
<tr>
<td>Mean 100 m (8-bit) RGB</td>
<td>26</td>
<td>219.25</td>
<td>253.33</td>
<td>238.05</td>
<td>10.81</td>
<td>-0.10</td>
</tr>
<tr>
<td>Std. Dv. 100 m (8-bit) RGB</td>
<td>26</td>
<td>3.76</td>
<td>17.10</td>
<td>10.25</td>
<td>4.71</td>
<td>0.07</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The initial stage of data integration involved cross-plotting the values derived from the backscatter imagery against one another. In the example presented, this was approached between different scales with the same systems. Figure 5.4 shows the results of the correlation between mean and standard deviation backscatter for SSS at 20 and 100 m sample scale. The \( r^2 \) value is high for the SSS; for both the mean and standard deviation plots. Re-examination of Figure 5.1 develops the context to interpret these values. The SSS data (Figure 5.4) shows that while the \( r^2 \) value of the mean backscatter between scales is high (0.846), it is occurring within an extremely limited window of values (220-255). This is further supported by the strong positive correlation between the standard deviation values (0.787). Examination of the residuals show that many of the outlying points by and large adhere to the general trend of the data, and do not display additional distributions. In this respect, the 85% of the variation in SSS mean backscatter intensity at 100 m is common to the 20 m sample, and 79% of the variance in the standard deviation backscatter.
Chapter 5: South Coast Results

5.1.2 Multibeam echosounder

As was the case for the SSS dataset, the MBES data was processed at two scales (20 and 100 m) in an attempt to define an optimum analytical window size and examine the effect of variation thereafter. The results for the scale analysis are presented in Figure 5.3 and Table 5.2. The range of values encountered for the MBES backscatter data in the South Coast REC had a mean backscatter intensity of 147.22 at 20 m and 148.83 at 100 m. This was contrasted by a standard deviation around the mean of 34.72 for the smaller sample (20 m) as opposed to 24.17 pixels around the 100 m samples. The mean standard deviation within individual samples was 11.17 for the 20 m samples as opposed to 18.73 for the 100 m samples.

The occurrence of outlying points is evident in Figure 5.3, which can clearly be seen to be more prevalent in the 100 m samples. Based on the 26 samples, the introduction of the outlying points at 100 m is resulting from the samples size being beyond the edge of the swath. This has a tendency to occur in shallower water where the swath width of an individual line is already reduced owing to the geometry of the system (Chapter 2). This point is also highlighted by the higher relative values of standard deviation for the 100 m statistics (Figure 5.3). The introduction of outliers at the larger scale would appear to suggest that this may be approaching the limits of what is appropriate for analytical comparison.

Figure 5.2. Comparison of SSS backscatter in the South Coast REC at 2 scales (20 and 100 m; n=26). a) Mean ($r^2=0.848$); b) Std. Dv. ($r^2=0.787$).
In contrast to the SSS, the mean and standard deviation of MBES backscatter data show markedly lower $r^2$ values when the results of the pixel extraction at both scales are compared. The value associated between the means (0.467) is still reasonably strong, but the $r^2$ value between the standard deviation at two scales is much weaker at 0.045. This weak relationship is due to the presence of outlying samples, which are evident in Figure 5.4. These outliers originate in the 100 m samples, where the placement of the sample has slipped off the edge of the swath, and resultantly has introduced areas of 255 values, causing the samples to have higher mean and standard deviation values. The removal of the three outlying values (Figure 5.4c and d; Station 62, 89 and 95) caused the $r^2$ significance for the mean to increase to 0.895, and the standard deviation to 0.778. This was comparable to the level observed for the SSS, and is an assurance that the comparison is valid and appropriate. This means that any subsequent breakdown of the comparison in the MBES data which appears to be scale dependent can be at least partially attributed to the presence of outliers. Additionally, where this is the case, it provides assurance that in optimal conditions, the 20 m samples will be approximately 90% representative of the variance expected to be observed in 100 m samples.

Figure 5.3. Box and whisker plot of MBES backscatter in the South Coast REC at 2 scales (20 and 100 m; n=26). The imagery selected was iteratively selected based on the best quality imagery (free from artefacts, processing errors etc.).
Table 5.2. Summary statistics for MBES backscatter in the South Coast REC at 2 scales (20 and 100 m; n=26).

<table>
<thead>
<tr>
<th>Statistic</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Dv.</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>Std. Error</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 20 m (8-bit) RGB</td>
<td>26</td>
<td>109.11</td>
<td>170.47</td>
<td>137.70</td>
<td>15.64</td>
<td>0.15</td>
<td>-0.54</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>Std. Dv. 20 m (8-bit) RGB</td>
<td>26</td>
<td>7.58</td>
<td>19.20</td>
<td>12.16</td>
<td>3.09</td>
<td>0.53</td>
<td>-0.29</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>Mean 100 m (8-bit) RGB</td>
<td>26</td>
<td>114.04</td>
<td>184.86</td>
<td>143.0</td>
<td>18.01</td>
<td>0.57</td>
<td>0.17</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>Std. Dv. 100 m (8-bit) RGB</td>
<td>26</td>
<td>7.79</td>
<td>60.94</td>
<td>15.99</td>
<td>13.11</td>
<td>2.59</td>
<td>6.06</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This fact is well demonstrated by the fact that when all MBES samples are considered, the variance at 20 m can account for 47% at 100 m; similarly, in relation to standard deviation, 4.5% of the variability can be accounted for between scales. The removal of the outliers increased the significance of comparison hugely to 90% for the mean, and 78% for standard deviation, which was comparable to that observed for the SSS. This has demonstrated that more stringent quality control of the MBES could see the significance of these relationships improved, and that the presence of even a small number of outliers can have profound implications for the significance of the relationships observed.

In addition to the matter of scale, the effects of acquisition orientation were examined. In principal, adequate compensation for backscatter imagery should minimise the effects of the angle of insonification, as this is an acquisition and processing artefact that has significant potential to invalidate the significance of comparison. Problems in range compensation should be equivalent independent of acquisition orientation provided the operational parameters have not changed (i.e. angular sector, transmission frequency, sample interval etc.). Theoretically it would be envisaged that this would be more of an issue for SSS than for MBES, as the relative orientation of acoustic shadowing caused by the presence of bedforms would have more of an effect for a deep-towed than a hull-mounted system.
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Figure 5.4. Comparison of MBES backscatter for the South Coast REC at 2 scales (20 and 100 m; n=26). a) Mean ($r^2=0.467$); b) Std. Dv. ($r^2=0.045$); c) Mean (100 m outliers removed; $r^2=0.895$); d) Std. Dv. (100 m outliers removed; $r^2=0.778$).

The difference in pixel values between imagery from opposing orientations is summarised in Figure 5.5 and Table 5.3). Only 24 stations were used for this analysis, as the remaining two (Station 62 and 67) had no associated imagery in one or the other orientation. In the material presented these distributions are also described as a function of scale (20 and 100 m).

At both orientations, the number of outliers increases in number with the relative increase in scale from 20 to 100 m (Figure 5.5). This can be attributed to the fact that in several instances, the larger samples were recording areas with the no-data value (255), which is present in much of the archival imagery for both systems. This was distinct from the nearest values in the ranges encountered, which could have theoretically been masked; although for the purposes of comparison with the SSS data it was retained. This was due to the fact that it was not possible to remove no-
data values from the SSS, as they shared a common value with areas of acoustic shadow, which was prevalent across the majority of the samples. In addition, this retention enabled the identification of outlying values which may have otherwise gone unnoticed and have the potential to unknowingly distort the results of the analysis. Resultantly, as the sample size increased, several of the samples introduced the value 255, causing the incremental inflation of the mean value for that sample. Therefore the greater higher the area of 255, the higher the mean value recorded for that sample. The best indicator of this phenomenon is the increase in the standard deviation values, where a standard deviation of between 56.20 (NS) and 73.24 (EW) pixels would indicate the presence of 255 values being significantly larger than the mean of the remainder of samples.

Figure 5.5. Box and whisker plot of MBES backscatter in the South Coast REC at opposing orientations (EW/NS) at 2 scales (20 and 100 m; n=24). Outliers are indicated by Station number (Figure 3.1).

This situation is demonstrated clearly by the results in Table 5.3 where there is less variance between sample sizes at common orientations that there is between opposing orientations at the same scale. Furthermore, the mean backscatter intensities at the NS orientations are consistently lower than their EW counterparts (Table 5.3). For example, the mean backscatter intensity at 20 m EW is 146.18 as opposed to 141.15 NS. The standard deviation of the mean is highest at 20 m with 36.99 for EW and 19.22 for NS oriented samples. At 100 m the mean backscatter
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intensities are less varied between 147.58 for the EW and 144.29 for the NS lines. The standard deviation of the mean at 100 m varies between 17.49 for the EW and 12.75 for the NS.

Table 5.3. Summary statistics for MBES backscatter in the South Coast REC at opposing orientations (EW/NS) at 2 scales (20 and 100 m; n=24).

<table>
<thead>
<tr>
<th>Statistic</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Dv.</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 20 m (8-bit RGB) EW</td>
<td>24</td>
<td>101.09</td>
<td>253.00</td>
<td>146.18</td>
<td>36.99</td>
<td>2.07</td>
<td>4.69</td>
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<tr>
<td>Std. Dv. 20 m (8-bit RGB) EW</td>
<td>24</td>
<td>0.00</td>
<td>19.20</td>
<td>11.38</td>
<td>4.65</td>
<td>-0.95</td>
<td>1.55</td>
</tr>
<tr>
<td>Mean 20 m (8-bit RGB) NS</td>
<td>24</td>
<td>114.31</td>
<td>198.32</td>
<td>141.15</td>
<td>19.22</td>
<td>1.31</td>
<td>2.29</td>
</tr>
<tr>
<td>Std. Dv. 20 m (8-bit RGB) NS</td>
<td>24</td>
<td>5.00</td>
<td>54.49</td>
<td>11.99</td>
<td>9.45</td>
<td>4.26</td>
<td>19.73</td>
</tr>
<tr>
<td>Mean 100 m (8-bit RGB) EW</td>
<td>24</td>
<td>114.04</td>
<td>217.21</td>
<td>147.58</td>
<td>23.83</td>
<td>1.23</td>
<td>2.14</td>
</tr>
<tr>
<td>Std. Dv. 100 m (8-bit RGB) EW</td>
<td>24</td>
<td>7.79</td>
<td>73.24</td>
<td>20.09</td>
<td>17.49</td>
<td>1.86</td>
<td>2.67</td>
</tr>
<tr>
<td>Mean 100 m (8-bit RGB) NS</td>
<td>24</td>
<td>112.78</td>
<td>198.36</td>
<td>144.29</td>
<td>19.308</td>
<td>0.78</td>
<td>0.91</td>
</tr>
<tr>
<td>Std. Dv. 100 m (8-bit RGB) NS</td>
<td>24</td>
<td>7.34</td>
<td>56.20</td>
<td>14.70</td>
<td>12.75</td>
<td>2.71</td>
<td>6.61</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The effects of orientation were examined in more detail through the co-examination of the samples at the two scales (20 and 100 m); the results are presented in Figure 5.6. Although the correlations were performed with a reduced number of samples in all cases (n=24), the correlation between the orientations were poor. With the exception of the standard deviation of the mean at 100 m (0.397), in all cases the $r^2$ values were less than 0.1. This was also attributed to the large number of outliers at 100 m, which exhibited an increase in standard deviation in both orientations. In addition, Stations 93 and 99 were anomalous in that they had pixels in the EW orientation at 100 m, but not at 20 m owing to the position of the samples in relation the geophysical data acquisition, and this is the reason why the data selected to represent these samples in the analysis of scale were selected from the NS orientated imagery.
In terms of the remainder of analysis, where orientation was not explicitly considered, the data were iteratively evaluated to select the best quality imagery from either of the two orientations. The criteria for this decision was based on the imagery being free from artefacts, mosaicking errors or other areas of no-data, as detailed in the previous Chapter.

Figure 5.6. Comparison of MBES backscatter for the South Coast REC at opposing orientations (EW/NS) at 2 scales (20 and 100 m; n=24). a) Mean 20 m (EW/NS) ($r^2=0.036$); b) Std. Dv. 20 m (EW/NS) ($r^2=0.021$); c) Mean 100 m (EW/NS) ($r^2<0.001$); d) Std. Dv. 100 m (EW/NS) 100 m ($r^2=0.397$)

5.1.3 Co-examination of acoustic systems

In addition to the previous comparisons, the mean and standard deviation of backscatter intensity was compared between the SSS and MBES systems. Although the systems are fundamentally different for the reasons presented in the Introduction, it would be plausible that there may be a degree of relatedness between the first order statistics of the imagery. In the case of the comparison between the systems at 20 m, the results of the mean against mean backscatter
intensity are presented in Figure 5.7. In this instance, the $r^2$ value is 0.017 where standard deviation was much higher at 0.383. When the larger sample size (100 m) was analysed, the strength of this agreement increased slightly to 0.04 for the mean, and decreased to 0.096 for the standard deviation. The significant decrease in the standard deviation value as the sample size increased is due to the introduction of outliers as previously mentioned in this Chapter.

![Figure 5.7](image1)

5.2 Co-examination of grab samples and acoustic imagery

The results of comparison between the grab and acoustic imagery from the South Coast REC are presented in Figure 5.8 to Figure 5.15. These figures show the variance encountered in the correlation of backscatter image statistics with the first order statistics of grain size, both when expressed by scale and by system of acquisition. The grain size statistics are compared in two instances; firstly based on

![Figure 5.7](image2)
the total of all available samples, and secondly based on the results of those samples with a unimodal distribution only.

### 5.2.1 Side scan sonar Hamon PSA

For the SSS imagery (Figure 5.8), the correlations were the most significant observed for the comparison of the between acoustic imagery and PSA results in the South Coast. These were most significant at 20 m ($r^2=0.27$) than at 100 m ($r^2=0.25$) although the standard deviation cross-plots were less significant (both $<0.1$).

![Figure 5.8](image.png)

Figure 5.8. Comparison of SSS backscatter and PSA samples (Hamon) for the South Coast REC at two scales (20 and 100 m; n=26). Station Numbers are indicated in Figure 4.1. a) Mean 20 m ($r^2=0.27$); b) Std. Dv. 20 m ($r^2=0.041$); c) Mean 100 m ($r^2=0.247$); d) Std. Dv. 100 m ($r^2=0.035$).

When the data were filtered based on solely those grabs with a unimodal distribution, the number of samples was significantly reduced (n=12). In this respect, the level of agreements changed, improving to $r^2$ of 0.34 in the case of the mean SSS backscatter against mean grain size at 20 m and 0.266 at 100 m (Figure 5.9), although closer inspection of the x axis reveals that the majority of the variance in
the range of the original data has now been lost. The low significance of the standard
deviation correlations has not improved and remains low at \( r^2=0.002 \) at 20 m and
0.12 at 100 m (Figure 5.9).

\[ \text{Figure 5.9. Comparison of SSS backscatter and unimodal PSA samples (Hamon) for the South}
\] 
\[ \text{Coast REC at two scales (20 and 100 m; n=12). Station Numbers are indicated in Figure 4.1. a)}
\[ \text{Mean 20 m (r²=0.34); b) Std. Dv. 20 m (r²=0.002); c) Mean 100 m (r²=0.266); d) Std. Dv. 100 m}
\[ \text{(r²=0.012).} \]

\[ \text{5.2.2 Multibeam Echosounder Hamon PSA} \]

Examination of the multibeam backscatter imagery in conjunction with the results of
the Hamon grab samples was less significant than the SSS. The strongest observed
correlation was between mean MBES backscatter against mean grain size, where \( r^2 \)
was equal to 0.11 (Figure 5.10).
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Figure 5.10. Comparison of MBES backscatter and PSA samples (Hamon) for the South Coast REC at two scales (20 and 100 m; n=26). Station Numbers are indicated in Figure 4.1. a) Mean 20 m ($r^2=0.112$); b) Std. Dv. 20 m ($r^2=0.011$); c) Mean 100 m ($r^2=0.005$); d) Std. Dv. 100 m ($r^2=0.017$).

With the polymodal samples from the grain size distributions removed from the analysis, the number of samples decreased to 12, however the strength of the correlation was seen to increase to $r^2=0.32$ (Figure 5.11). This increase was observed in the case of the 20 m samples of mean MBES backscatter imagery; it was less than 0.001 at 100 m when conducted using the same statistical indices. This was interpreted as having resulted from the introduction of spurious values resulting from the increased scale causing the polygonal samples to slip off the edge of the swath. The standard deviation values decreased from the low significance observed previously to $r^2=0.005$ at both scales (20 and 100 m) (Figure 5.11).
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5.2.3 Side scan sonar Clamshell PSA

The values presented in Figure 5.12 describe the SSS imagery cross-plotted against the statistics from the Clamshell grab at both 20 and 100 m scales. The results show uniformly weak correlations between subjects and conditions of scale; although the 20 m scale is marginally higher with an $r^2$ value of 0.17 as compared to 0.14 at 100 m. In both instances, the standard deviation of values was less than 0.1 (Figure 5.12).

Figure 5.11. Comparison of MBES backscatter and unimodal PSA samples (Hamon) for the South Coast REC at two scales (20 and 100 m; n=12). Station Numbers are indicated in Figure 4.1. a) Mean 20 m ($r^2=0.32$); b) Std. Dv. 20 m ($r^2=0.005$); c) Mean 100 m ($r^2<0.001$); d) Std. Dv. 100 m ($r^2=0.005$).
Similarly to the Hamon grabs, all of the polymodal samples were removed from the dataset, and the results were correlated again. This had the effect of reducing the number of samples, but was attempted in the event that it had any significant bearing on the results observed. Figure 5.13 shows the effect of the exclusion of these values on the level of correlation observed in each of the cross-plots. As can be seen, the mean against mean cross-plot at 20 m has an $r^2$ significance of 0.508, while at 50 m this is lower than the smaller scale at 0.313, but these are both significantly greater than the agreement observed when the polymodal samples had been included in the analysis. The correlation resulting from the standard deviation of the values was similarly low in either case (Figure 5.13).
Figure 5.13. Comparison of SSS backscatter and unimodal PSA samples (Clamshell) for the South Coast REC at two scales (20 and 100 m; n=12). Station Numbers are indicated in Figure 4.1. a) Mean 20 m ($r^2=0.508$); b) Std. Dv. 20 m ($r^2=0.046$); c) Mean 100 m ($r^2=0.313$); d) Std. Dv. 100 m ($r^2=0.165$).

5.2.4 Multibeam Echosounder Clamshell PSA
All of the investigated correlations for the MBES and Clamshell grab yielded $r^2$ significance values of less than 0.01 (Figure 5.14). The inclusion of the three values with high standard deviations at 100 m (Stations 62; 95 and 89) did not compromise a better agreement. In general, the uniformly low correlations support the assumption that there is no statistically significant relationship between any of the variables tested.
Figure 5.14. Comparison of MBES backscatter and PSA samples (Clamshell) for the South Coast REC at two scales (20 and 100 m; n=16). Station Numbers are indicated in Figure 4.1. a) Mean 20 m ($r^2=0.062$); b) Std. Dv. 20 m ($r^2=0.073$); c) Mean 100 m ($r^2<0.001$); d) Std. Dv. 100 m ($r^2=0.002$).

Following the pattern for the analysis in the previous sections, the polymodal samples were removed from the correlation to see if this would improve the level of agreement. In this case, the MBES backscatter against Clamshell grabs produced significant improvements to the mean against mean plots, showing $r^2$ values of 0.4 at 20 m, and 0.344 at 50 m (Figure 5.15). The significance of the standard deviations were low, but still represented an improvement on the values seen with the full modality of samples Figure 5.14. In this instance, the standard deviation backscatter against grain size yielded an $r^2$ value of 0.138 at 20 m and 0.045 at 50 m (Figure 5.15).
Figure 5.15. Comparison of MBES backscatter and unimodal PSA samples (Clamshell) for the South Coast REC at two scales (20 and 100 m; n=12). Station Numbers are indicated in Figure 4.1. a) Mean 20 m ($r^2=0.40$); b) Std. Dv. 20 m ($r^2=0.138$); c) Mean 100 m ($r^2=0.344$); d) Std. Dv. 100 m ($r^2=0.045$).

5.2.5 Measures of biological diversity

The relationship between the numbers of species in the 25 Hamon grabs (owing to the absence of a processed sample for Station 93) was poorly correlated with mean SSS backscatter intensity (Figure 5.16). The samples were not separated according to the modal distributions of the grain size at each station as grain size was not considered for this phase of analysis. All samples returned correlations of $r^2<0.12$ at both scales using imagery generated by both SSS and MBES systems.
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Figure 5.16. Comparison of SSS and MBES backscatter and number of species (S) for the South Coast REC at two scales (20 and 100 m; n=25). Station Numbers are indicated in Figure 4.1. a) Mean SSS at 20 m ($r^2=0.044$); b) Mean SSS at 100 m ($r^2=0.12$); c) Mean MBES at 20 m ($r^2=0.004$); d) Mean MBES at 100 m ($r^2=0.007$).

Both methods have similarly low correlations related to the number of individuals in each of the 25 samples ($r^2<0.1$) (Figure 5.17). When these measures of diversity are considered in relation to the number of individuals in each of the samples, the relationships are even less significant. At this point between either 20 or 100 m scale, the $r^2$ values described insignificant associations between the acoustic imagery from both systems (SSS and MBES) and the number of individuals recorded from each of the Hamon grabs (n=25). Other diversity indices were correlated against the backscatter statistics at both scales; Species richness (Margalef’s) [d], Pielou’s eveness [J’], Fisher’s and Brillouin’s diversity indices. However, without exception, all values returned $r^2$ significance of less than 0.1.
Figure 5.17. Comparison of SSS and MBES backscatter and number of individuals (N) for the South Coast REC at two scales (20 and 100 m; n=25). Station Numbers are indicated in Figure 4.1. a) Mean SSS at 20 m ($r^2<0.001$); b) Mean SSS at 100 m ($r^2=0.021$); c) Mean MBES at 20 m ($r^2=0.025$); d) Mean MBES at 100 m ($r^2=0.039$).

5.2.6 Multivariate community data

The results of the species abundance data from the 25 Hamon grab samples from the South Coast REC were processed and analysed in Primer v.6 (Clarke and Gorley, 2006). The multivariate community data is presented in Figure 5.18, which shows a non-metric scaling model (nMDS) of biological similarity between samples obtained in the South Coast REC using the Hamon grab. The results were based on an untransformed Bray-Curtis similarity index of direct count species data (abundance). These results show that there are 8 statistically distinct groups (defined by Simprof) based on the abundance data from the $\phi$ biology, two of which contain only one sample (Stations 62 and 99). These were identified through the application of the Simprof test (Groups a-h), the results of which are evidenced in Figure 5.18b.
by the clusters in the dendrogram which are linked by the red lines. These groups are also evidenced by the symbology in the nMDS plot in Figure 5.18a.

Figure 5.18. Multivariate analysis of biological similarity in the South Coast REC (n=25). a) nMDS of Bray-Curtis similarity derived from abundance data of the Hamon grabs samples. The symbology is defined by Simprof testing in Primer v. 6.0. b) Cluster analysis of a); red branches are Simprof groups reflected in the nMDS plot.
Figure 5.19. Multivariate analysis of biological similarity in the South Coast REC (n=25). a) nMDS of Bray-Curtis similarity derived from abundance data of the Hamon grabs samples. The symbology is defined by depth (binned in 10 m increments) b) Cluster analysis of a); red branches are Simprof groups reflected in the nMDS plot; symbology is defined by depth.

Water depth was additionally examined as a factor in the analysis of the results presented, where the depth bin (Figure 5.19) is indicative of the depth range in which the sample was acquired (ie: 1 = 10-19 m; 2 = 20-29 m etc.). As is clear from Figure 5.19, there is overall a low degree of similarity between the samples in general,
particularly when examined in the context of the Simpof results presented in the previous section; however there is some evidence of depth stratification.

5.2.7 Multivariate particle size analysis

The results of the multivariate analysis of particle size are shown in Figure 5.20, where a dendrogram of the Euclidian distance of relatedness between particle size analyses for samples of the Hamon grab samples is presented. The red lines are the result of Simprof testing, which are indicative of a degree of relatedness beyond which there is no statistical evidence to support their distinction. The data subjected to this analysis were the logarithmic (Folk and Ward) grain size distribution binned at increments of 0.5 $\phi$ from -6.5 (very coarse pebbles) to $>8$ $\phi$ (clay), rather than simply the mean grain size. As is clear from Figure 5.20, there are 5 distinct groups based on the Simprof difference between the grain size distribution, and one group (e) contains the majority of samples. It is additionally interesting to note that Simprof Group e (Figure 5.20) contains the majority of the polymodal samples which were omitted from the correlations of the mean in previous Section 5.2. These samples appear have predominantly originated in deeper water (Figure 5.20).
Figure 5.20. Multivariate analysis of PSA in the South Coast REC (n=25). a) nMDS of Euclidian distance similarity derived from % composition in 0.5 ϕ data in the Hamon grabs samples. The symbology is defined by Simprof testing in Primer v. 6.0. b) Cluster analysis of a); red branches are Simprof groups reflected in the nMDS plot.

Similarly to the case with the biological similarity matrix, these results were then examined from the perspective of depth stratification to see if there were any additional environmental parameters affecting the relationship between individual samples. The results for the Hamon grabs are presented in Figure 5.21. There is
some degree of overlap between the classes identified by Simprof and the depth zonation in which the samples occurred, but it is not clearly defined.

Figure 5.21. Multivariate analysis of PSA in the South Coast REC (n=25). a) nMDS of Euclidian distance similarity derived from % composition in 0.5 ϕ data in the Hamon grabs samples. The symbology is defined by depth (binned in 10 m increments) b) Cluster analysis of a); red branches are Simprof groups reflected in the nMDS plot; symbology is defined by depth.

Multivariate analysis of the Clamshell particle size data was also conducted, but this was determined to be of a lesser significance for the purpose of comparison with the community data, as although it originated from samples derived at the same
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approximate location, it was inappropriate to compare to the biological data which was sampled using the Hamon grabs. These data were examined together as a non-Metric Dimensional Scaling model inclusive of both Hamon and Clamshell grabs (Figure 5.22a). As for the Hamon alone, there were still 5 distinct groups resulting from the Simprof analysis.

Upon inspection of the similarity dendrogram (Figure 5.22b), it is apparent that there is a good degree of similarity between the two methods, although there is a high degree of overlap for the majority of samples. This corresponds to the main group identified by Simprof in the dendrogram. The percentage similarity slice is based on the Euclidian distance at a slice level of 30, which can be seen from detailed examination of Figure 5.22b. This is particularly evident when the samples are stratified by depth. However, on the whole the degree of relatedness appears to diminish when the samples are separated according to acquisition method where the relationship appears to be visually more clearly differentiated by the Hamon (Figure 5.21).

This integrated analysis using both grab types was undertaken in an attempt to examine the relationship in a more comprehensive manner that by using the first order statistics alone. Using this combined approach, it is apparent that when viewed in conjunction with the particle size distribution curves in Appendix 2 the largest statistically valid group of samples identified by Simprof testing from the Euclidian distance similarity matrix was composed of multimodal grain size distributions (Figure 5.22a and b). This has important implications for the success of the analysis in general, and specifically for this area. Conducting this analysis supports the assumptions that the difference between the Clamshell and Hamon particle size results is more significant than by comparing means alone. This analysis reflects the distribution of the grain size better across the samples, similarly to using the grain size distribution curves (Appendix 2).
Figure 5.22. Multivariate analysis of PSA in the South Coast REC (n=52). a) nMDS of Euclidian distance similarity derived from % composition in 0.5 $\phi$ data in the Clamshell and Hamon grabs samples. The symbology is defined by depth (binned in 10 m increments) b) Cluster analysis of a); red branches are Simprof groups reflected in the nMDS plot; symbology is defined by depth.
5.2.8 Relationships between biology, grain size and backscatter

Using the classifications derived from the depth zones and the results from the Simprof analysis for Biological similarity and PSA similarity, the results were reconsidered. The most successful correlations produced through the analysis of the South Coast work were those related to the mean SSS backscatter and mean grain size at 100 m scale. The symbology of the correlation was modified to reflect the depth zone for each of the samples in order to investigate whether there was a depth dependency in the correlation (Figure 5.23). As can be seen from Figure 5.23a, the finer mean grain sizes tend to occur in the shallow water, as was true for coarser samples in deeper water. The results of the biological analysis (Simprof) are presented in Figure 5.23b, which shows that Group a and b tend to occur in finer mean grain size similarly to the shallow water stations in depth zones 1 and 2. Similarly, Group f had a good level of agreement with the coarser mean grain sizes and lower backscatter values, and Group h had the broadest distribution. The Simprof from the PSA data had a much clearer agreement with the mean grain size statistics (Figure 5.23c), which showed that the Groups d and e were clearly separated into a low backscatter smaller mean grain size/ high backscatter coarser mean grain size.
Figure 5.23. Examination of the strongest positive agreement for SSS in the South Coast REC at 100 m: mean backscatter against mean grain size. The symbology has been altered to reflect the results of the multivariate abundance and PSA data. a) Symbology reflects the depth of the sample; b) Simprof of multivariate biological similarity, and c) Simprof of multivariate PSA.

5.3 Summary

- At the sizes investigated (20 and 100 m), the scale of sample had little effect on the strength of agreement between mean and standard deviation grain size and backscatter from either system. The 100 m samples were determined to be less effective owing to the differences in angular sector and bottom coverage between the SSS and the MBES.
• There was only a moderate correlation between the results of the spatially coincident Hamon and Clamshell grab samples. Mean grain size had the best agreement when all samples were considered \( (r^2=0.545) \), whereas standard deviation grain size \( (r^2=0.636) \) was more significant when using only unimodal samples \( (n=12) \).

• The orientation of insonification did not affect the level of agreement between the acoustic imagery and the grab samples (at both 20 and 100 m scales). The most significant correlation established between spatially coincident backscatter statistics acquired at perpendicularly opposing orientations returned an \( r^2 \) significance of 0.152.

• When all stations were considered \( (n=26) \), the strongest positive correlation observed between the acoustics and sediment properties was between mean SSS backscatter intensity and mean grain size as determined by Hamon grab \( (r^2=0.27) \). When only unimodal grab samples were considered \( (n=12) \), the mean SSS and mean grain size (Clamshell) had an \( r^2 \) significance of 0.508.

• Standardised methods for the assertion of biological diversity correlated poorly with the backscatter statistics in the South Coast, irrespective of system or scale \( (r^2<0.1) \).

• Problems with acquisition due to survey conditions, data processing (especially for the SSS due to amplitude imbalance, low dynamic range and towfish layback errors) and a low numbers of samples (without replication) were determined to be the principal reasons for the low levels of agreement observed in the South Coast REC.
6 Review and Evaluation of the East Coast REC Archive

This Chapter summarises the key acquisition, processing and archiving features of the datasets from the East Coast (MEPF REC 08/04) which were used in this project. The information presented has been largely gained from the geophysical survey report (CEFAS, 2009) and metadata from the M-ALSF web portal. In a similar format to the South Coast Chapter (4), this section begins with a review of the acquisition and processing parameters, and concludes with an evaluation of the suitability of the data for the proposed analysis. Several of the issues which were identified as obstacles to analysis are presented and illustrated with examples.

As was case for the South Coast dataset, the M-ALSF archive was developing during the course of this project. The geophysical survey report and data discussed here were accessed from the archive in December 2009 (CEFAS, 2009). The ground-truth data was made publically available through the portal in July 2010. Thanks to the efforts of Claire Mason, Bill Meadows and Dave Limpenny at CEFAS, these data were made available prior to QC approval in June 2010 for the purposes of this project.

6.1 Review of acquisition and processing

The East Coast Regional Environmental Characterisation (REC) was conducted by a consortium of partners led by the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) as part of MEPF REC 08/04. The consortium included Marine Ecological Surveys Limited (MES Ltd), Wessex Archaeology (WA), the British Geological Survey (BGS) and Envision Mapping Limited.

An additional part of the attraction to the East Coast REC was due to one of the principal limitations of the South Coast area; namely the small number of stations which had coincident geophysical data and grab samples, and the poor weather conditions at the time of survey. In contrast, the conditions at the time of survey in the East Coast were much improved (CEFAS, 2009). The survey design for the geophysical component of the East Coast survey contained more than 238 separate intersections.

In contrast to the regularly defined sampling protocol in the South Coast, the location of the samples for the East Coast was based around the interpretation of the SSS
Chapter 6: Review and Evaluation of the East Coast REC Archive

survey results from the Autumn/ Winter 2008. In terms of the relative comparison to the South Coast Archive, there are many fundamental differences in the way the data have been conditioned. This was most significantly evident in the level of attention given to processing the SSS data, with regard to the correction of the positioning by USBL and the width of dynamic ranges.

In contrast to the South Coast archival data, the processed MBES backscatter imagery is not currently contained in the archive. In the absence of the processed MBES backscatter imagery for the East Coast REC; we obtained direct access to the raw MBES data from CEFAS in July 2010.

6.1.1 Geophysical Data

The data from the East Coast REC were acquired by BGS and CEFAS aboard the CEFAS vessel RV Endeavour over the course of two cruises (CEFAS, 2009). The first cruise was subdivided into three phases, the first of which (A) was conducted between 28th of September and the 14th of October 2008 (16 days). The second phase (B) was conducted between the 14th and the 25th of October 2008 (11 days [-3 for repair of MBES], and the final phase (C) between 26th and 30th of October 2008 (4 days) (CEFAS, 2009).

During this three phase 2008 cruise, the principal track lines were collected, consisting of corridors with different numbers of adjacent survey lines, ranging from one to three. The level of across-track coverage was therefore variable, although most often it was down to the width of a single line. Where there were adjacent lines, often these had been collected during different phases of the survey, and had poor registration of seabed features. In total, 43 corridors of data were acquired in Phase A, 27 in Phase B and 14 in Phase C.
Figure 6.1. Location of East Coast REC in the Southern North Sea showing distribution of Clamshell (red) and Hamon (blue) grab samples. Geophysical data corridors are indicated by the dashed lines; numeric labels indicate Station number.
Chapter 6: Review and Evaluation of the East Coast REC Archive

6.1.1.1 Side scan sonar (SSS)

6.1.1.1.1 Acquisition

Similarly to the SSS data acquired in the South Coast, these data were collected using an *Edgetech 4200* dual frequency system, with operating frequencies of 100 and 400 kHz. The software used to record the data was the *Edgetech Discover* package. The data were monitored in real time and recorded to .xtf format. Positioning of the SSS towfish was achieved using a *Kongsberg HiPAP* ultra short base line (USBL) transponder integrated with the ships positional GPS (CEFAS, 2009). Towfish position was estimated from the logged cable out and USBL, which was reflected in the naming conventions of the raw data files. Geotiff imagery was rendered using *TritonMap*, where images created had a spatial resolution of 0.3 m. The use of layback as opposed to USBL determined position for the tow fish was restricted to shallow waster where the transducer head for the USBL had to be retracted. The towfish was optimally towed between 15 and 20 m altitude, however in shallow water this was reduced to between 10 and 15 m to reduce the effect of prop wash on the data (CEFAS, 2009).

6.1.1.1.2 Processing and Archiving

The format of the archived data in the East Coast was the position corrected .xtf and a geocoded (Geotiff) mosaiced imagery. The SSS was processed using *ISIS® MBSS-Logger* which was used to recompute the navigation from the raw .xtf file. The data were slant range and water column corrected, and a constant beam angle and time varying gain correction were applied to all data. Side scan imagery was archived as 8-bit unsigned integer similarly to the South Coast data, although the internal contrast within the images was much broader due to the corrections applied. The processing flow followed for the East Coast SSS is detailed in Figure 6.2.

At the time of writing, only the 100 kHz data has been processed and stored in the archive. The higher frequency data is not yet available, which prevented a comparison of frequency performance in this project.
Figure 6.2. Processing flow for the SSS acquisition, processing and archiving in the East Coast REC (CEFAS, 2009).

### 6.1.1.2 Multibeam Echosounder (MBES)

#### 6.1.1.2.1 Acquisition

The MBES data was acquired using Kongsberg Simrad EM3000D transducer and topside data acquisition system (SIS). The 3000D is the predecessor to the EM3002D used in the South Coast REC geophysical survey work, although the systems are effectively similar. In terms of the specifics, the EM3000D is a dual head system which operates at frequencies in the band of 293-307 kHz. The topside processing unit encountered problems during Phase B of the first survey which were unable to be resolved (CEFAS, 2009). The processing unit was substituted for the BGS EM3002D topside unit, which was the next generation model of the same operational frequency (300 kHz). This is a significant deviation internally within the processing flow, and has the potential to introduce variation in the results. Sound velocity profiles were recorded at least every 24 hrs using a Reson sound velocity
profiler. Raw multibeam data containing the beam-time series information is not currently available through M-ALSF web portal; although the Caris cleaned output soundings are available as .gsf which contain beam average backscatter.

### 6.1.1.2.2 Processing and Archiving

Bathymetric data were processed in Caris and made available through the M-ALSF Marine GIS; as .sd [Fledermaus objects], .xyz [field sheets] and as.gsf [cleaned bathymetric soundings] formats. The MBES backscatter data were not processed as a matter of course. Resultantly, the data that are presented in this report were processed and analysed at Imperial College as part of MEPF 09/P80.

### 6.1.2 Ground-truth data

The ground truth survey was conducted in two stages between the 18th of May and the 14th of June 2009, also aboard CEFAS RV Endeavour (CEFAS, 2009, Crummy et al., 2009). The geotechnical phase of the ground-truth survey (Clamshell) was conducted over 6 days, and the Hamon grab sampling over 21 days for the remainder of the cruise. In contrast to the South Coast REC data, the stations are not spatially coincident but at different locations.

On the 9th of June 2010, access was given to the pre-QC version of the East Coast PSA data for the Clamshell and Hamon grabs. The position of the grab samples were based on the vessel position at the time of sample plus the vessel offset at the time of grab deployment.

### 6.1.2.1 Clamshell grab

The Clamshell grab used in the acquisition was a 340 l hopper type grab, and functions by combination of high voltage electricity (415 Volts) and high pressure hydraulics (200 bar) (Crummy et al., 2009). The geographical distribution of the Clamshell grabs in the East Coast REC is shown in Figure 6.1, relative to the location of the geophysical survey corridors. The site selection for the Clamshell grabs were based on manual interpretation of the 2008 geophysical survey, including side scan sonar, multibeam echosounder, seismic reflection boomer and magnetometer (Crummy et al., 2009). The sites were chosen by BGS based on a series of geological factors including: geological/ geomorphological interest, potential penetration depth based on sediment type and geographical spread. Wessex Archaeology were also involved in the site selection, which was targeted around
features of interest including: Channels and associated fills, edges of channels, evidence of peat, ravinement surfaces and submerged channels (Crummy et al., 2009).

Of the 19 Clamshell grabs conducted, 16 of them occurred within the bounds of the geophysical data. The remainder occurred over 100 m off the centre of a navigation line, and as such were omitted from the analysis presented later due to the assumption that areas of no-data would compromise the results.

6.1.2.2 Hamon grab.

These sediment samples were collected using the Cefas 0.1 m$^2$ Hamon grab, the mechanism of which is described in Chaper 3. The location of these samples was based on a collaborative effort by Cefas and Envision Mapping Ltd. The sites chosen by Envision were based on single beam bathymetry separating the areas into morphological strata, whereas the analysis of Cefas interpretation was based on the acoustic properties of the side scan sonar (Crummy et al., 2009).

Of the 156 samples acquired, 119 of them were less than 100 m from a line of navigation from the 2008 geophysical survey coverage, and 100 were less than 50 m. In relation to the course made good, and after stringent quality control of the resultant images, 106 stations were carried forwards for analysis with the geophysical data. Faunal analysis was conducted by MES Ltd., and the PSA analysis was conducted by CEFAS; both have been released through the M-ALSF web portal as of July 2010.

6.2 Archived data quality

For the East Coast REC we evaluated the processed SSS imagery, PSA and benthic faunal analysis which were acquired and processed BGS, CEFAS and MES Ltd. A summary of the data formats and typical file sizes and descriptions are given in Table 6.1. As was the case for the South Coast, the Geotiffs were the most memory intensive formats to work with. Excepting the SSS imagery, all remaining data which were used required some degree of reformatting in order to conduct the analysis reported here.
Table 6.1. Summary table of archival data from the East Coast REC used in MEPF 09/P80

<table>
<thead>
<tr>
<th>Data type</th>
<th>Format</th>
<th>Example file name</th>
<th>Typical Size</th>
<th>Date of access</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0000_20080928_220930_EastCoast_REC.all</td>
<td>10-500 MB</td>
<td>06/2010</td>
<td>Raw sensor outputs – obtained from CEFAS</td>
</tr>
<tr>
<td>SSS (100 kHz)</td>
<td>Geotiff</td>
<td>HREC35CO1.TIF</td>
<td>10-1500 MB</td>
<td>12/2009</td>
<td>Navigation integrated and Slant range corrected</td>
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<td>Clamshell (PSA)</td>
<td>.xls</td>
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<td>06/2010</td>
<td></td>
</tr>
<tr>
<td>Hamon (PSA)</td>
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<td>C3340_REC_HGs_resultsv5_2912010.xls</td>
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<td>06/2010</td>
<td></td>
</tr>
<tr>
<td>Hamon (Abundance)</td>
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<td>MESL_Grab_Abundance.xls</td>
<td>159 KB</td>
<td>06/2010</td>
<td></td>
</tr>
<tr>
<td>Hamon (Biomass)</td>
<td>.xls</td>
<td>MESL_Grab_Biomass.xls</td>
<td>17 KB</td>
<td>06/2010</td>
<td></td>
</tr>
</tbody>
</table>

6.2.1 Evaluation of Side Scan Sonar imagery

The 100 kHz SSS backscatter imagery collected in the East Coast REC were subjected to the previously defined processing flow, consisting of slant range correction and the application of TVG. The imagery in the archive was produced to a consistently higher standard with a significant increase in terms of dynamic range than that encountered from the South Coast REC. Although the SSS imagery was recorded as 8-bit unsigned integer (as for the South Coast dataset), the way in which it was processed developed a much more significant range of values and the contrast between across the range was much more effectively balanced. This is evident from comparison of Figure 4.2 and Figure 6.4. The archival imagery similarly had a colourmap applied, although this was a continuous linear stretch from 0 to 255, as opposed to being independent stretches for each sector (port and starboard) of the image. In addition to this, the East Coast imagery used the full band width of the 256 integer values, as opposed to the 32 discreet values across the full range as in the case of the South Coast. Irrespective of this broader degree of contrast, there are still issues with amplitude balancing across the swath as is evidenced by Figure 6.4. This is most likely a function of the volume backscatter at the frequency being used relative to the substrate being examined, and is suggested to be approaching one of the limitations of these type of sensor. The backscatter intensity is lighter in the far range, reflecting the loss of signal through surface scattering and attenuation at the outer limits of the swath.
At present only the 100 kHz SSS backscatter imagery is in the archive and it is not clear whether the 400 kHz SSS or MBES backscatter data is planned to be included later. In contrast to the SSS imagery in the South Coast, the imagery from the East Coast is not mosaiced into a single file, so there were no areas of overlapping imagery to resolve. The SSS imagery was therefore just a direct translation of the .xtf files recorded at 0.3 m resolution with the slant range correction and TVG applied. This was thought to be an advantage for our analysis. In contrast to the South Coast archive, the co-registration of features proved to be much more successful. In Figure 6.3, there is an example of good co-registration between the MBES bathymetry and the SSS from two opposing orientations, with no tangible evidence of layback error. However, there may be less evidence of layback in the East Coast data due to the fact that PSA stations (where we looked in detail at the imagery) are not all at line intersections. There is however evidence of an offset between the adjacent north-south lines, which is possibly due to the temporal disparity between acquisition or incorrectly applied tidal corrections.

6.2.2 Evaluation of Particle Size Analysis (PSA) Data

The survey design of the grab sampling effort across the East Coast REC was significantly different to that in the South Coast. As previously described (Crummy et al., 2009), the PSA sample locations were not situated at the intersections of the geophysical survey corridors, but rather at locations determined by the manual interpretation of the single beam morphology (Envision) and SSS record (Cefas). This was a marked departure from the regular sample intervals favoured in the South Coast REC acquisition (Gardline Geosurvey Ltd, 2008). Additionally, as there were large differences in swath coverage between the two acoustic systems, there were many instances where a PSA sample lay on the SSS coverage, but was off the bounds of the MBES swath. Regrettably, PSA data from these stations could not be used here which further reduced the number of available samples. A second major difference in the East Coast sampling programme was the lack of replication between the grab sampling methods (there was only one grab type at each location).
Figure 6.3. Illustrated examples of towfish layback and co-registration for East Coast REC SSS data. a) Position of complex bedforms in the southwest of the study area at the intersection between line 81a (EW) and 21b and the adjacent 21boff (NS). The isobaths between -27 and -30 m are included to show continuity of features. b) SSS imagery showing the backscatter relative to MBES derived isobaths. c) As for b) but from the EW line 81a.
Figure 6.4. Example of archival imagery from East Coast Rec. a) MBES bathymetric data acquired using EM3000D; SSS backscatter acquired using Edgetech 4200 from the same area. Note the across-track amplitude imbalance (lighter in the far range). Red polygon indicates the 50 m sample window for the acoustic imagery.

Others issues include the difference in the volume of the sampler, with the Clamshell having a 340 l capacity as compared to the 12 l capacity of the Hamon grab. There was a further difference in the volume of the sample subjected to PSA, with the 340 l capacity Clamshell analysis being based on a 10 l sub-sample of the sediment after mixing, whereas the 12 l capacity Hamon analysis was based on a 0.5 l sub-sample (Crummy et al., 2009). This point has important implications for the comparison with the acoustics.

Overall, the East Coast samples have a higher component of fine grained material, although they too are predominantly poorly sorted, similarly to the South Coast REC. The distribution of the mean and standard deviation of sediment grain sizes are described in Figure 6.6 and Table 6.2, which can be viewed in relation to the grain size classes and descriptors in Appendix 2 .(Blott and Pye, 2001). In Figure 6.6, the numbered stations are those identified as statistical outliers. The shape of the symbol denotes the significance of the outlier, where the asterisk is ‘extreme’ being
more than 3 box lengths from the end of the actual box, whereas points between 1.5 and 3 box lengths are also determined to be outliers but are denoted by a solid black circle (see Appendix 1 for full definition of box and whisker plot).

For the Hamon grab samples, the value of the mean grain size (Folk and Ward, 1957, Blott and Pye, 2001) ranges from -1.51 $\phi$ to 4.66 $\phi$ (very fine gravel –to- very fine sand) with a mean of 1.22 $\phi$ (medium sand) (Table 6.2). The standard deviation of these values ranged from 0.34 $\phi$ to 4.05 $\phi$ (very well sorted –to- extremely poorly sorted) with an average of 1.55 $\phi$ (poorly sorted). By contrast, the mean grain size for the Clamshell values in the box and whisker plot have a mean of 0.89 $\phi$ (coarse sand) ranging from a value of -0.84 $\phi$ to 4.80 $\phi$ (very coarse sand –to- very fine sand), with standard deviation around the mean of 0.58 $\phi$ to 3.86 $\phi$ (moderately well sorted –to- very poorly sorted) averaging at 1.82 $\phi$ (poorly sorted).

Similarly to the South Coast REC, the PSA distributions were examined using Gradistat (Blott and Pye, 2001), and using the descriptors the unimodal samples were isolated. Many of the grab samples were bi-, tri or polymodal in terms of their sediment distribution curves (Appendix 4). In light of this fact, only 57 of the 106 usable Hamon grab samples had unimodal distributions (Figure 6.6b), and resultantly these samples were analysed both separately and together to determine the significance of this effect on the strength of the relationships observed.

For the Clamshell grabs, 10 of the 16 usable stations were unimodal; the summary statistics are included in Figure 6.6d and Table 6.2. This also had a significant effect on the diversity of values encountered, which was most significant for the number of samples (n=16) which had now been reduced to 10 samples. The Clamshell grabs were for the most part unimodal (eg. Figure 6.5b), although those with variable distributions were not removed owing to the already limited number of samples. The distribution of all Clamshell PSA samples is included in Appendix 4.
Figure 6.5. Example of PSA % composition curve for 2 Clamshell samples with differing cgrain size distributions. a) Polymodal Station 1; b) Unimodal Station 46. Full range of Clamshell samples are included in Appendix 4.

As can be clearly seen from examination of Figure 6.6b and Table 6.2, the range of mean values has decreased markedly to a range of $0.63 \phi$ (very coarse sand) to $2.70 \phi$ (fine sand) with a mean of $1.54 \phi$ (medium sand). The standard deviation of values in the samples had similarly decreased to $0.34 \phi$ (very well sorted) to $2.25 \phi$ (very poorly sorted) with an average standard deviation of $0.80 \phi$ (moderately sorted).

Thereby, removal of the samples by the criteria of unimodality has caused a significant loss of diversity and range of values in the Hamon grab samples. This also had an effect on the variability in the degree of sorting within the samples.
Table 6.2 Distribution of mean and standard deviation grain size $\phi$ (Clamshell and Hamon) for East Coast REC (all samples and unimodal only).

<table>
<thead>
<tr>
<th>Statistic</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Dv.</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Hamon</td>
<td>106</td>
<td>-1.51</td>
<td>4.66</td>
<td>1.22</td>
<td>0.28</td>
<td>0.24</td>
<td>1.02</td>
</tr>
<tr>
<td>Std. Dv. Hamon</td>
<td>106</td>
<td>0.34</td>
<td>4.05</td>
<td>1.55</td>
<td>0.34</td>
<td>0.24</td>
<td>-1.11</td>
</tr>
<tr>
<td>Mean Hamon (Unimodal)</td>
<td>57</td>
<td>0.63</td>
<td>2.70</td>
<td>1.54</td>
<td>0.17</td>
<td>0.32</td>
<td>0.14</td>
</tr>
<tr>
<td>Std. Dv. Hamon (Unimodal)</td>
<td>57</td>
<td>0.34</td>
<td>2.25</td>
<td>0.80</td>
<td>0.47</td>
<td>1.51</td>
<td>1.49</td>
</tr>
<tr>
<td>Mean Clamshell</td>
<td>16</td>
<td>-0.84</td>
<td>4.80</td>
<td>0.87</td>
<td>1.31</td>
<td>1.88</td>
<td>-4.87</td>
</tr>
<tr>
<td>Std. Dv. Clamshell</td>
<td>16</td>
<td>0.58</td>
<td>3.86</td>
<td>1.82</td>
<td>0.99</td>
<td>0.31</td>
<td>-0.78</td>
</tr>
<tr>
<td>Mean Clamshell (Unimodal)</td>
<td>10</td>
<td>0.29</td>
<td>4.80</td>
<td>1.47</td>
<td>2.06</td>
<td>0.69</td>
<td>-4.66</td>
</tr>
<tr>
<td>Std. Dv. Clamshell (Unimodal)</td>
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<td>0.58</td>
<td>2.74</td>
<td>1.38</td>
<td>0.77</td>
<td>0.69</td>
<td>-1.23</td>
</tr>
</tbody>
</table>

Figure 6.6. Box and whisker plots of grain size $\phi$ for the East Coast REC. a) Total Hamon samples (n=106; from left): Mean; Std. Dv. b) Total Clamshell samples (n=16; from left) Mean; Std. Dv; c) Unimodal Hamon samples (n=57; from left): Mean; Std. Dv. d) Unimodal Clamshell samples (n=10; from left) Mean; Std. Dv.
6.2.3 Evaluation of the Benthic Faunal Data

In the case of the East Coast REC, all 106 of the Hamon grab samples (0.1 m²) which had coincident geophysical imagery were analysed for benthic fauna by MES Ltd. The blotted wet weight and direct count abundances of the total major group biomass of macrofauna (>1 mm) based on the 106 samples are presented in Figure 6.7a to f and Table 6.3.

In this case as compared to the material presented for the South Coast, the larger number of samples necessitates examining each contributing Phylum individually. Although all of the samples were individually processed, several of the largest contributing samples were acquired with replicates. Specifically this affected Station 498, which was replicated in duplicate, and Stations 463, 468, 498, 499 and 513 which were sampled in triplicate. The vast majority of the outliers in all of the plots (Figure 6.7a-f) were from these Stations which were subject to replication. The same patterns are evident in all of the plots; the median weights are all low, and the distribution is positively skewed.

Table 6.3. Summary statistics for blotted wet weight (g) benthic Phyla in the South Coast REC.

<table>
<thead>
<tr>
<th>Phylum</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Dv.</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annelida (g)</td>
<td>106</td>
<td>0</td>
<td>19.93</td>
<td>1.30</td>
<td>2.89</td>
<td>4.03</td>
<td>19.38</td>
</tr>
<tr>
<td>Crustacea (g)</td>
<td>106</td>
<td>0</td>
<td>2.56</td>
<td>0.20</td>
<td>0.44</td>
<td>3.80</td>
<td>15.56</td>
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<tr>
<td>Mollusca (g)</td>
<td>106</td>
<td>0</td>
<td>22.98</td>
<td>0.54</td>
<td>2.43</td>
<td>7.94</td>
<td>71.02</td>
</tr>
<tr>
<td>Echinodermata (g)</td>
<td>106</td>
<td>0</td>
<td>51.55</td>
<td>0.86</td>
<td>5.14</td>
<td>9.40</td>
<td>92.66</td>
</tr>
<tr>
<td>Miscellania (g)</td>
<td>106</td>
<td>0</td>
<td>12.65</td>
<td>0.76</td>
<td>2.11</td>
<td>4.21</td>
<td>19.42</td>
</tr>
<tr>
<td>Total Biomass (g)</td>
<td>106</td>
<td>0.02</td>
<td>55.72</td>
<td>3.66</td>
<td>7.68</td>
<td>4.04</td>
<td>21.16</td>
</tr>
<tr>
<td>Number of Species (#)</td>
<td>106</td>
<td>1</td>
<td>96</td>
<td>21.05</td>
<td>19.68</td>
<td>1.82</td>
<td>3.11</td>
</tr>
<tr>
<td>Number of Individuals (#)</td>
<td>106</td>
<td>2</td>
<td>1482</td>
<td>116.46</td>
<td>250.03</td>
<td>3.71</td>
<td>14.65</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>106</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Examination of Figure 6.7a and Table 6.3 shows that the wet weight biomass of *Annelida*, has a mean value of 1.3 g across the 106 samples, however, there are several statistical outliers evident in examination of the box and whisker plot ranging as high as 19.93 g. The mean wet weight of *Crustacea* was shown to be 0.20 g with a maximum of 2.56 g which was the least significant in terms of overall contribution.
to weight (Figure 6.7b and Table 6.3). Organisms from the Phyla *Mollusca* and *Echinodermata* share a common distribution; with the positively skewed distribution and a single large extreme outlying value (Figure 6.7c, d and Table 6.3). In the case of *Mollusca* the mean weight was 0.54 g whereas the maximum value was 22.98 g, in contrast to *Echinodermata*, which had a mean of 0.86 with a maximum of 51.55 (Table 6.3). These distributions were mirrored in the case of the number of species and Individuals recorded in the 106 grab samples. The number of species had a minimum of 1, a maximum of 96, with a mean of 21.05. The number of individuals conversely had a minimum of 2, a maximum of 1482, and a mean of 146.34.

The East Coast faunal data had smaller mean and maximum values for *Crustacea*, *Mollusca*, *Biomass* and number of species. It did have a larger mean and maximum for *Annelida*, *Crustacea*, and maximum number of individuals, but the South Coast had a higher mean number of individuals. The phylum *Echinodermata* had a smaller maximum, but a larger mean weight (g) in the East Coast than in the South Coast. However, the number of outlying samples in the East Coast is proportional to the increase in the number of samples when compared to the South Coast.
Figure 6.7. Box and whisker plots of blotted wet weight (g) benthic Phyla in the East Coast REC. a) Annelida; b) Crustacea; c) Mollusca; d) Echinodermata; e) Total Biomass. f) Direct count benthic faunal data (from left) Number of Species; Number of Individuals.
Chapter 7: East Coast Results

7 East Coast Results

7.1 Backscatter imagery extraction

The backscatter imagery in the East Coast archive was extracted at the location of the grab samples. Of the original 154 (Hamon) and 19 (Clamshell) grabs acquired, 106 and 16 samples respectively were suitable for analysis. The samples which were unsuitable were not represented by data using one or other acoustic system (MBES or SSS), or had large areas of missing values (no-data).

The analysis was conducted at a scale of 20 and 50 m as a point of compromise between the results of the South Coast investigations (20 and 100 m). The reason for this was that the relationships demonstrated at 100 m were uniformly less than their 20 m counterparts. However, the use of a larger sample size was warranted owing to the fact that the sample locations were frequently positioned away from the nadir of the acquisition lines.

7.1.1 Side scan sonar

For the SSS imagery at the location of the 106 Hamon grabs, the summary statistics of the backscatter data are presented in Figure 7.1 and Table 7.1. As is immediately apparent from examination of the left axis in Figure 7.1, the dynamic range of values encompasses much more of the available range of values than did the South Coast counterpart dataset (Figure 5.1). Table 7.1 shows that at 20 m the mean backscatter for all 106 samples was 168.38 based across a range of 54.27 to 238.03 with a standard deviation of mean of 38.08 pixels. The standard deviation of values had an average of 39.26 with a corresponding range of 14.08 to 67.62 pixels.

When the sampling was conducted at a scale of 50 m, the SSS imagery had a mean of 168.82 across a range of 72.32 to 238.88 RGB values. The standard deviation of the values had an average of 40.96 with a range of 16.36 to 67.41 pixels. The standard deviation of SSS backscatter is also evident in Figure 7.1, where a large number of outlying values are evident outside of the range of 99 % of values. This is promising, as a range of responses is needed for the method of predicting seabed properties to work.
Chapter 7: East Coast Results

Figure 7.1. Box and whisker plot of SSS backscatter in the East Coast REC at the location of Hamon grab stations at 2 scales (20 and 50 m; n=106). Outliers are numbered according to Station (Figure 5.1).

Table 7.1. Summary statistics for SSS backscatter in the East Coast REC at the location of Hamon grab stations at 2 scales (20 and 50 m).

<table>
<thead>
<tr>
<th>Statistic</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Dv.</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
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<td></td>
<td></td>
<td>Statistic</td>
<td>Statistic</td>
<td>Statistic</td>
<td>Statistic</td>
<td>Statistic</td>
<td>Statistic</td>
</tr>
<tr>
<td>Mean 20 m (8-bit) RGB</td>
<td>106</td>
<td>54.27</td>
<td>238.03</td>
<td>168.38</td>
<td>38.08</td>
<td>-0.87</td>
<td>0.23</td>
</tr>
<tr>
<td>Std. Dv. 20 m (8-bit) RGB</td>
<td>106</td>
<td>14.06</td>
<td>67.62</td>
<td>39.26</td>
<td>11.33</td>
<td>0.00</td>
<td>0.23</td>
</tr>
<tr>
<td>Mean 50 m (8-bit) RGB</td>
<td>106</td>
<td>72.30</td>
<td>238.88</td>
<td>168.82</td>
<td>36.45</td>
<td>-0.59</td>
<td>0.23</td>
</tr>
<tr>
<td>Std. Dv. 50 m (8-bit) RGB</td>
<td>106</td>
<td>16.36</td>
<td>67.41</td>
<td>40.96</td>
<td>9.49</td>
<td>0.21</td>
<td>0.23</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>106</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Co-examination of the SSS samples at the two scales (20 and 50 m) is presented in Figure 7.2. Based over 106 samples, the levels of agreement were very good by comparison with the South Coast (Figure 5.4), although this was to be expected on account of the smaller difference in the physical scale of the samples. However, the significance of the agreement is more convincing on account of the larger number of samples. With the samples at 50 m there was an increased potential for the introduction of variation. The level of agreement observed between the SSS was high for both comparisons, with mean backscatter producing an $r^2$ value of 0.94 with standard deviation of 0.565. This shows that the mean backscatter intensity of the
samples is robust when sampled at both of these scales, and that the variance captured at 50 m is representative of the mean observed at 20 m. Therefore, 94% of the variance in mean backscatter is shared between the samples at the two scales. The correlation of the standard deviations is still highly significant, although the degree of variation at 20 m only accounts for 57% of the variance at 50 m.

Figure 7.2. Comparison of SSS backscatter imagery for the East Coast REC at Hamon grab locations at 2 scales: 20 and 50 m (n=106). a) Mean ($r^2$=0.94); b) Std. Dv. ($r^2$=0.565).

In contrast to the Hamon grabs, although there were fewer Clamshell locations which were coincident with both the acoustic imagery, the range of pixel intensities associated were reasonably representative of the patterns at large. When sampled at a scale of 20 m at the location of the Clamshell grabs (n=16), the SSS backscatter imagery had a mean value of 159.68 with a range of values encompassing 65.11 to 211.23 pixels. The standard deviation values had a mean of 37.22 with a range of 15.43 to 86.63 pixels. At a 50 m sample size, these values were altered slightly, with a mean for all samples of 160.11 and the range of mean values contracting at 68.80 to 194.82. The average standard deviation was 43.83 with a range of 31.15 to 85.00 (Table 7.2). To a large extent, these values reflect the diversity in the acoustic data at the location of the Hamon grab samples (Table 7.1).
Figure 7.3. Box and whisker plot of SSS backscatter in the East Coast REC at Clamshell grab locations at 2 scales (20 and 50 m; n=16).

Similarly to the case of the Hamon grab samples, co-examination of the results of the SSS at the location of the Clamshells was undertaken (Figure 7.4). When the assessment was made from the SSS imagery in the M-ALSF archive, the results were similarly high, with the mean against mean SSS (20 and 50 m) returning an $r^2$ value of 0.907 with comparable standard deviations of 0.724 (Figure 7.4). This demonstrates a similar relationship as was the case for the Hamon samples, where 91% of the variance in the samples can be explained between scales. The standard deviation of backscatter intensity is much higher than the Hamon samples, with the correlation coefficient accounting for 72% of the variability between scales.

Table 7.2. Summary statistics for SSS backscatter in the East Coast REC at Clamshell grab locations at two scales (20 and 50 m; n=16).
Figure 7.4. Comparison of SSS backscatter in the East Coast REC at Clamshell grab locations at 2 scales (20 and 50 m; n=16. a) Mean ($r^2=0.979$); b) Std. Dv. ($r^2=0.724$).

7.1.2 Multibeam echosounder

The results for the MBES backscatter imagery are presented summarily in this section. For Figure 7.5 and Table 7.3 the left axis of the box and whisker plot is negative as the dB intensities are described in their native units and not as RGB composite value of greyscale. Similarly, the standard deviation is variable in that although the values of the recorded measurements are negative, the amount of standard deviation is closely based around zero.

For the acoustic imagery (at a scale of 20 m) derived from the raw MBES data at the location of the Hamon grab samples (n=106), the mean value was -23.37 with a range from -32.99 to -15.60 dB (Table 7.3). The standard deviation within the samples averaged at 2.39 with a range from 1.32 to 4.80. When the sample size was increased to 50 m, the adjustment of values was very slight, changing from the mean of -23.32 representing a decrease of 0.05 dB. The range of values was also similar from -32.78 to -15.82 dB. The standard deviation at 50 m had an average of 2.52 with a range of 1.36 to 4.75 dB (Figure 7.5).
Figure 7.5. Box and whisker plot of MBES backscatter in the East Coast REC at Hamon grab locations at 2 scales (20 and 50 m; n=106).

Table 7.3. Summary statistics for MBES backscatter in the East Coast REC at Hamon grab locations at 2 scales (20 and 50 m; n=106).

<table>
<thead>
<tr>
<th>Statistic</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Dv.</th>
<th>Skewness</th>
<th>Kurtosis</th>
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<tbody>
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<td>Statistic</td>
<td>Statistic</td>
<td>Statistic</td>
<td>Statistic</td>
<td>Std. Error</td>
<td>Statistic</td>
<td>Statistic</td>
</tr>
<tr>
<td>Mean 20 m (32-bit) dB</td>
<td>106</td>
<td>-32.99</td>
<td>-15.60</td>
<td>-23.37</td>
<td>3.22</td>
<td>-0.24</td>
<td>0.23</td>
</tr>
<tr>
<td>Std. Dv. 20 m (32-bit) dB</td>
<td>106</td>
<td>1.32</td>
<td>4.80</td>
<td>2.39</td>
<td>0.69</td>
<td>0.98</td>
<td>0.23</td>
</tr>
<tr>
<td>Mean 50 m (32-bit) dB</td>
<td>106</td>
<td>-32.78</td>
<td>-15.82</td>
<td>-23.32</td>
<td>3.11</td>
<td>-0.27</td>
<td>0.23</td>
</tr>
<tr>
<td>Std. Dv. 50 m (32-bit) dB</td>
<td>106</td>
<td>1.36</td>
<td>4.75</td>
<td>2.52</td>
<td>0.62</td>
<td>0.88</td>
<td>0.23</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>106</td>
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</tbody>
</table>

Co-examination of the backscatter values at the two scales (20 and 50 m) returned a strength of agreement of $r^2$ value of 0.957, with standard deviation at both scales producing a lesser, but still very significant value of $r^2=0.756$ (Figure 7.6). The uniformly high values in both instances show that a sample size of 20 m effectively captures the trends and patterns in the data at 50 m, and this is particularly significant as it is over such a large number of samples (n=106). The variance in mean backscatter intensity at 20 m accounts for 96% of the variation at 50 m, compared to 76% in terms of the standard deviation.
In the case of the Clamshell grabs locations (n=16), the processing of the acoustic imagery was approached in a similar way. For the samples at 20 m, the imagery derived from the raw MBES backscatter had a mean value of -23.11 with a range of -30.16 to -18.03 dB (Table 7.4). The standard deviation of mean values was 2.27 ranging from 1.44 to 3.68 dB. When sampled at a scale of 50 m there was very little adjustment in the values. The mean -23.16 increased by 0.05 dB, and the range was comparable at -30.30 to -18.49 dB. The standard deviation of values similarly was 2.53 with a range from 1.86 to 3.27 dB (Table 7.4).
Table 7.4. Summary statistics for MBES backscatter in the East Coast REC at Clamshell grab locations at 2 scales (20 and 50 m; n=16).

<table>
<thead>
<tr>
<th>Statistic</th>
<th>N</th>
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<th>Max</th>
<th>Mean</th>
<th>Std. Dv.</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean 20 m (32-bit) dB</td>
<td>16</td>
<td>-30.16</td>
<td>-18.03</td>
<td>-23.11</td>
<td>3.99</td>
<td>-0.25</td>
<td>0.56</td>
</tr>
<tr>
<td>Std. Dv. 20 m (32-bit) dB</td>
<td>16</td>
<td>1.44</td>
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<td>2.27</td>
<td>0.66</td>
<td>0.94</td>
<td>0.56</td>
</tr>
<tr>
<td>Mean 50 m (32-bit) dB</td>
<td>16</td>
<td>-30.30</td>
<td>-18.49</td>
<td>-23.16</td>
<td>3.77</td>
<td>-0.45</td>
<td>0.56</td>
</tr>
<tr>
<td>Std. Dv. 50 m (32-bit) dB</td>
<td>16</td>
<td>1.86</td>
<td>3.27</td>
<td>2.53</td>
<td>0.47</td>
<td>0.00</td>
<td>0.56</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>16</td>
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<td></td>
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</tr>
</tbody>
</table>

Similarly to the previous examples, co-examination of the samples returned an $r^2$ of 0.979 and the relative comparison between standard deviation at the two scales was 0.668 (Figure 7.8). The significance of the relationship between the samples at the 2 scales means that 98% of the variance in the backscatter at 50 m can be accounted for in the 20 m samples, and similarly the case for the standard deviation is 67%.

This shows that although a relevant consideration, the variance between samples at scales of 20 and 50 m is of a low significance, and that the variance captured at 20 m is representative of the patterns evident at 50 m. This is more significant for mean (98%) than for the standard deviation (67%), although both exhibit a strong positive correlation.

Figure 7.8. Comparison of MBES backscatter in the East Coast REC at Clamshell grab locations at 2 scales (20 and 50 m; n=16). a) Mean ($r^2=0.979$); b) Std. Dv. ($r^2=0.668$).
7.1.3 Co-examination of acoustic systems

A comparison between the MBES and SSS was conducted at the same scales (20 and 50 m). In spite of the fact that the systems and the way that the data were processed were so markedly different, it could reasonably be expected that a linear relationship would be obtained. At 20 m, the correlation between systems returned an $r^2$ value of 0.381, with a correlation of 0.121 between the standard deviation of backscatter imagery (Figure 7.9). Without exception, the level of agreement improved as the sample size was increased to 50 m, showing an $r^2$ of 0.442 for the correlation of the means, and 0.245 for comparison of the standard deviations. This is much more significant than the 0.017 correlation between the means over 26 samples in the South Coast at 20 m, and 0.008 at 100 m, reinforcing the conclusion that the acoustic data have been more effectively processed in the East Coast REC.

Figure 7.9. Comparison of backscatter from different acoustic systems in the East Coast REC at Hamon grab locations (MBES against SSS at 20 and 50 m; n=106). a) Mean 20 m ($r^2=0.381$); b) Std. Dv. 20 m ($r^2=0.121$); c) Mean 50 m ($r^2=0.442$); d) Std. Dv. 50 m ($r^2=0.245$).
Similarly to the situation with the Hamon grab samples in the previous paragraph, the imagery from the Clamshell grabs was analysed with respect to the acquisition using different systems. The results of this phase of analysis are presented in Figure 7.10. Theoretically, the imagery from both types of grab sampling methodology could be considered together, but as the remainder of results deal with the samples separated by the method of their acquisition (Clamshell or Hamon). In the case of the 20 m samples, the mean MBES against SSS returned an $r^2$ value of 0.559, with the comparative standard deviation of the same samples showing a value of 0.002. When the sample size was increased to 50 m, the strength of the correlation between the mean decreased to 0.389 and the strength of agreement for the standard deviation increased slightly to 0.014.

![Figure 7.10. Comparison of backscatter from different acoustic systems in the East Coast REC at Clamshell grab locations (MBES against SSS at 20 and 50 m; n=16). a) Mean 20 m ($r^2=0.559$); b) Std. Dv. 20 m ($r^2=0.002$); c) Mean 50 m ($r^2=0.389$); d) Std. Dv. 50 m ($r^2=0.014$).]
7.2 Co-examination of grab samples and acoustic imagery

7.2.1 Side scan sonar Hamon PSA

The results for the SSS data are given in Figure 7.11, which shows the significance of the correlations between the acoustic imagery and the PSA results. The general trend followed the same pattern at both scales for the Hamon grab, with an $r^2$ value of 0.067 and with a correlation of the standard deviations returning 0.212 at 20 m scale. At 50 m, the significance of both increased, with the correlation between means of 0.074 and between standard deviations of 0.269 (Figure 7.11). Although this correlation is more significant than those achieved in the South Coast area, the significance is interpreted as being low, as the standard deviation values for the PSA data were not normally distributed (Figure 7.11d and Figure 7.12), and as such do not fully satisfy the requirements for this statistical analysis.

Figure 7.11. Comparison of SSS backscatter and PSA samples (Hamon) for the East Coast REC at 2 scales (20 and 50 m; n=106). Station Numbers are indicated in Figure 6.1. a) Mean 20 m ($r^2=0.067$); b) Std. Dv. 20 m ($r^2=0.212$); c) Mean 50 m ($r^2=0.074$); d) Std. Dv. 50 m ($r^2=0.269$).
Figure 7.12. Histogram showing the total distribution of all Std. Dv. grain sizes in the East Coast REC (n=106). Note the non-gaussian, non–normal distribution of the samples.

When the PSA stations which have polymodal grain size distributions are removed from the correlation, the number of samples reduces from 106 to 57. The relationships were then re-evaluated using only the unimodal samples. For the SSS data, this had a negligible effect on the validity of the correlations, resulting in an $r^2$ significance of 0.005 at 20 m and 0.01 at 50 m. The standard deviation decreased in significance, from the previous levels around 0.2 which had been observed using all samples to $r^2=0.005$ at 20 m and 0.041 at 50 m. The removal of the polymodal samples, also caused the distribution of the standard deviation samples to conform to a normal Gaussian distribution (Figure 7.13b and d). This supports the previous assumption that the singular instance of high agreement for the SSS ($r^2=0.269$), was an artefact of the distribution of the standard deviation grain size values.
7.2.2 Multibeam Echosounder Hamon PSA

In contrast to the SSS, the MBES samples acquired at the location of the 106 Hamon grabs returned a correlation with $r^2$ values which were larger for the mean backscatter against mean grain size than previously obtained, and additionally were larger at 20 m than at 50 m sample size. At 20 m the mean backscatter against mean grain size produced a correlation of 0.278, which reduced as the sample size increased to 0.266 at 50 m (Figure 7.14). For the standard deviation of values, the results at 20 m (0.064) were lower than at 50 m (0.088), but these were both affected by the bi-modal distribution of the grain size values when the samples were considered in their entirety.
Figure 7.14. Comparison of MBES backscatter and PSA samples (Hamon) for the East Coast REC at 2 scales (20 and 50 m; n=106). Station Numbers are indicated in Figure 6.1. a) Mean 20 m ($r^2=0.278$); b) Std. Dv. 20 m ($r^2=0.064$); c) Mean 50 m ($r^2=0.266$); d) Std. Dv. 50 m ($r^2=0.088$).

The MBES backscatter analysis was similarly conducted with the unimodal grain size samples only from the Hamon grab. Closer inspection of the x axis on Figure 7.14 and Figure 7.15 and re-examination of Figure shows that the range of Figure 5.6 shows that the range of grain size has decreased substantially. With this loss of diversity in the mean values, the $r^2$ significance has also been reduced; to 0.145 in the case of the 20 m samples and 0.182 in the case of the 50 m samples. The standard deviation values did not alter significantly returning $r^2$ significance values of 0.048 at 20 m and 0.102 at 50 m (Figure 7.15).
Figure 7.15. Comparison of MBES backscatter and unimodal PSA samples (Hamon) for the East Coast REC at 2 scales (20 and 50 m; n=57). Station Numbers are indicated in Figure 6.1. a) Mean 20 m ($r^2=0.182$); b) Std. Dv. 20 m ($r^2=0.145$); c) Mean 50 m ($r^2=0.048$); d) Std. Dv. 50 m ($r^2=0.048$).

7.2.3 Side scan sonar Clamshell PSA

For the Clamshell grab samples (n=16), the correlation between the values of the mean SSS backscatter and mean grain size was lower at 20 m ($r^2=0.179$) than at 50 m ($r^2=0.211$). The strength of the correlations for the values of standard deviation were uniformly low, but increased with the sample scale from 0.014 at 20 m to 0.028 at 50 m (Figure 7.16).
Figure 7.16. Comparison of SSS backscatter and PSA samples (Clamshell) for the East Coast REC at 2 scales (20 and 50 m; n=16). Station Numbers are indicated in Figure 6.1. a) Mean 20 m ($r^2=0.179$); b) Std. Dv. 20 m ($r^2=0.014$); c) Mean 50 m ($r^2=0.211$); d) Std. Dv. 50 m ($r^2=0.028$).

As had been the case with the previous samples, the removal of those samples which were characterised by a polymodal grain size distribution curve reduced the number of available samples significantly (Figure 7.17). Ten of the sixteen Clamshell samples were univariate in composition. The correlations resulting from the use of these samples returned lower values than when all of the samples were considered together. The mean against mean samples had decreased in significance, with $r^2$ values of 0.069 at 20 m and 0.088 at 50 m. In contrast, the standard deviation of the samples had remained much the same (Figure 7.17).
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Figure 7.17. Comparison of SSS backscatter and unimodal PSA samples (Clamshell) for the East Coast REC at 2 scales (20 and 50 m; n=10). Station Numbers are indicated in Figure 6.1. a) Mean 20 m ($r^2=0.069$); b) Std. Dv. 20 m ($r^2=0.049$); c) Mean 50 m ($r^2=0.088$); d) Std. Dv. 50 m ($r^2=0.022$).

7.2.4 Multibeam Echosounder Clamshell PSA

The correlation values for the Clamshell grab and MBES backscatter returned the highest levels of agreement from all of the analysis conducted, at both scales in either South or East Coast REC (Figure 7.18). The strength of agreement between mean MBES and mean grain size at 20 m had an $r^2$ significance of 0.523 and the standard deviation of these values was 0.04. When the scale of analysis was increased to 50 m, the agreement between the mean values increased to 0.623 although the agreement of the standard deviation had decreased to 0.009. Of additional significance, the removal of the single outlying value (Station 3) did not decrease the strength of the relationship - in contrast, the relationship increased to 0.653. The other potentially spurious value was Station 45, which included a substantial area of no-data. However, these data were included for the remainder of
the analysis owing to the low number of samples overall using this method, as a comparable method had been followed for the South Coast REC. Additionally, in contrast to the South Coast dataset, it was possible to define a specific value for the no-data condition, and in doing so omit this value from the processing results. The removal of Station 45 caused a decrease in the significance of the correlation to 0.638, however the number of Stations at this point had reduced to 14 which was determined to be sub-optimal (Figure 7.18).

Figure 7.18. Comparison of MBES backscatter and PSA samples (Clamshell) for the East Coast REC at 2 scales (20 and 50 m; n=16). Station Numbers are indicated in Figure 6.1. a) Mean 20 m (r²=0.523); b) Std. Dv. 20 m (r²=0.04); c) Mean 50 m (r²=0.623); d) Std. Dv. 50 m (r²=0.009).

When the polymodal samples were removed from this phase of analysis for the Clamshell and MBES data, the strength of agreement decreased for all of the cross-plots (Figure 7.19). The mean grain size against backscatter had reduced to 0.351 at 20 m, and 0.461 at 50 m, while the standard deviation correlations had similarly decreased to 0.014 in the 20 m samples, and <0.001 in the 50 m imagery.
Figure 7.19. Comparison of SSS backscatter and unimodal PSA samples (Clamshell) for the East Coast REC at 2 scales (20 and 50 m; n=16). Station Numbers are indicated in Figure 6.1. a) Mean 20 m ($r^2=0.351$); b) Std. Dv. 20 m ($r^2=0.014$); c) Mean 50 m ($r^2=0.461$); d) Std. Dv. 50 m ($r^2<0.001$).

### 7.2.5 Measures of biological diversity

As was the case for the South Coast dataset in Chapter 5, various measures of biological diversity were explored in relation to the first order statistics derived from the acoustic imagery from both MBES and SSS systems. In addition to direct measurements including total biomass (wet weight) and number of species and individuals, various diversity indices were explored, including Species richness and Margalef’s index. Equitability was measured as expressed using Pielou’s evenness index and the Simpson index. Other count based measures were explored including Fisher and Brillouin’s. The examples which are presented below are those of which produced a correlation coefficient where $r^2$ is greater than 0.1. Only the SSS (not the MBES) produced a comparative agreement in excess of this threshold. For the SSS these results were analysed relative to the previous scales of observation (20 and 50...
m). Figure 7.20 shows the relationship between the number of species and mean SSS backscatter at 20 m, whilst accompanied by the box and whisker plot showing the overall distribution of the 106 samples obtained using the Hamon grab.

The remainder of acoustic statistics produced at 20 m scale which produced $r^2$ values in excess of 0.1 were Brillouin’s, Species Richness (Margalef’s) and $H'$ (Shannon’s) diversity index. The strength of correlations produced were highest for Brillouin ($r^2=0.263$), followed by Species Richness (Margalef’s) ($r^2=0.258$) and Shannon’s ($H'$) ($r^2=0.21$) (Figure 7.21). Of additional interest, the distribution of the range of values for the indices are displayed for each of these Stations in box plots to the right of the Figures. Brillouin’s index produced the strongest agreement, and this was interpreted as being particularly significant in that it a low number of contributing outliers ($n=2$). In contrast, the Species Richness index (Margalef’s) produced a larger number of outliers ($n=7$) with a correspondingly lower level of agreement. All remaining correlations with the diversity indicies at 20 m produced correlations of less than 0.1. These results appear to suggest that there are weak positive correlations between Brillouin’s, Margalef’s and Shannon’s diversity indices and mean SSS backscatter intensity.
Figure 7.21. Comparison of backscatter and diversity indices (Hamon) for the East Coast REC at 20 m (n=106). All values for both systems (SSS and MBES) are presented where $r^2<0.1$. a) SSS against Brillouin’s ($r^2=0.263$); b) Box and whisker plot of Brillouin’s; c) SSS against Margalef’s ($r^2=0.258$); d) Box and whisker plot of Margalef’s; e) SSS against Shannon’s ($r^2=0.21$) and f) Box and whisker plot of Shannon’s.
When the same correlations were attempted at the 50 m scale, several of these relationships improve; the correlation coefficient between the number of species increased from 0.219 to 0.264, while Brillouin’s index increased from 0.263 to an $r^2$ value of 0.318 (Figure 7.22). Similarly the strength of agreement between Margalef’s index increased from 0.258 to 0.307, while Shannon’s index increased from 0.21 to 0.25. All remaining parameters investigated revealed $r^2$ values of less than 0.1 and therefore were determined to be less significant. This appears to suggest that the positive correlation observed with the SSS is scale sensitive, and appears to increase at the scales observed (from 20 to 50 m).

Figure 7.22. Comparison of backscatter and diversity indices (Hamon) for the East Coast REC at 50 m ($n=106$). All values for both systems (SSS and MBES) are presented where $r^2<0.1$. a) SSS against Brillouin’s ($r^2=0.318$); b) SSS against Margalef’s ($r^2=0.307$); c) SSS against number of species ($r^2=0.264$); and d) SSS against Shannon’s ($r^2=0.25$).
7.2.6 Multivariate community data

The multivariate analysis of community diversity is presented in Figure 7.23. In the first instance, direct count abundance data were processed as a Bray–Curtis similarity matrix which identified 24 discreet classes based on Simprof testing of the species composition. These classes were identified during the dendrogram clustering stage (Figure 7.23), and exported as factor which was subsequently applied to the MDS plot in Figure 7.23b. This shows that the similarities between groups are not particularly well defined, and secondly that there is a lot of overlap between adjacent clusters.

The lack of group similarity is further described when the biological similarity is analysed from the perspective of the depth zonation in which the samples were acquired (Figure 7.24). These samples were subdivided into 10 m interval depth bins, where 1=10-19 m; 2=20-29 m etc. This was conducted to provide assurances that the patterns of biological differentiation were not solely based on abiotic parameters. The samples from the depth zone 5 (50-59 m) were the only ones which occurred in a single aggregation that appeared to agree with the biological ordination, whereas the others tended to be ubiquitous and occurred across the entire range of biological groups. It was concluded that water depth did not exert a straightforward influence on the biological community according to the results of the 106 Hamon grab samples. However, several of the Simprof groups occurred exclusively in the same depth zones.
Figure 7.23. Multivariate analysis of biological similarity in the East Coast REC (n=106). a) nMDS of Bray-Curtis similarity derived from abundance data of the Hamon grabs samples. The symbology is defined by Simprof testing in Primer v. 6.0. b) Cluster analysis of a); red branches are Simprof groups reflected in the nMDS plot.
Figure 7.24. Multivariate analysis of biological similarity in the East Coast REC (n=106). a) nMDS of Bray-Curtis similarity derived from abundance data of the Hamon grabs samples. The symbology is defined by depth (binned in 10 m increments) b) Cluster analysis of a); red branches are Simprof groups reflected in the nMDS plot; symbology is defined by depth.
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7.2.7 Multivariate particle size data

A similar approach was followed for the particle size analysis data, where the cumulative percentage of the samples occurring in incremental bins (0.5 $\phi$) were processed in a Euclidian distance similarity matrix and the results are presented in Figure 7.25. In this instance, 17 separate classes were identified from the composition of the 106 Hamon grab samples. The nMDS plot shows the organisation the samples according to the composition of the grabs, rather than based solely on the mean or standard deviation. This shows that while several of the samples which may share a similar mean grain size, they may have an overall composition which means that they are different in a more specific way. This is not clearly reflected in the Simprof groupings of the samples when they are considered relative to the grain size distribution of the samples which were derived from their Gradistat output (Blott and Pye, 2001), as is attested to by Table 7.5. This shows that there is not a clear agreement between the Simprof groupings from the dendrogram and the unimodal versus polymodal distributions. Groups j and q are composed of predominantly polymodal and poorly sorted to very poorly sorted unimodal samples. This is in contrast to Groups b, c, f and g which are composed of unimodal, well to moderately well sorted samples (Figure 7.25).
Figure 7.25. Multivariate analysis of PSA in the East Coast REC (n=106). a) nMDS of Euclidian distance similarity derived from % composition in 0.5 $\phi$ data in the Hamon grabs samples. The symbology is defined by Simprof testing in Primer v. 6.0. b) Cluster analysis of a); red branches are Simprof groups reflected in the nMDS plot.
Table 7.5. Contingency table of the Simprof PSA results compared to the graphical descriptors of grain size distribution from the Hamon grab samples from Gradistat (Blott and Pye, 2001). Simprof groups correspond to those in Figure 7.25 and Figure 7.26. Guide to abbreviations: MS= Moderately Sorted, PS=Poorly Sorted; VPS=Very Poorly Sorted; EPS=Extremely Poorly Sorted; MWS=Moderately Well Sorted; VWS=Very Well Sorted; WS=Well Sorted.

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As was the case for the biological similarity modelling, when these groupings are analysed using depth as a factor, the patterns observed from the previous example are provided with more of a context (Figure 7.26). The patterns presented appear to suggest that the grab sample composition is not clearly related depth zonation in which the samples originate, or at least that any pattern in existence is more complex that a one to one relationship.
Figure 7.26. Multivariate analysis of PSA in the East Coast REC (n=106). a) nMDS of Euclidian distance similarity derived from % composition in 0.5 $\phi$ data in the Hamon grabs samples. The symbology is defined by depth (binned in 10 m increments) b) Cluster analysis of a); red branches are Simprof groups reflected in the nMDS plot; symbology is defined by depth.
7.2.8 Relationships between biology, grain size and backscatter

The results of the most successful correlations for both systems were taken forwards to be analysed in conjunction with the results of the multivariate analysis, using the factors of depth (binned), Simprof (biological similarity) and Simprof (PSA similarity).

As can be seen from Figure 7.27, the strongest positive correlation observed at 50 m was that between Brillouin’s diversity index and mean SSS backscatter \( (r^2=0.318) \).

When the individual stations are viewed in relation to the depth zones at which they occur, it is immediately apparent that there is not a clear pattern. Therefore, there is no evidence of linearity as the depth zones are well mixed through the cross-plot (Figure 7.27a). However, for Brillouin’s index it is reasonable to expect that the patterns would reflect the Simprof groupings, as they are both derived from the same abundance data. This is evident in Figure 7.27b, as the values which have a low score on the Brillouin’s index tend to aggregate with the low mean SSS values (eg. Group a; Group m), whilst the reverse is also true (eg. Group w; Group x). For the final cross-plot (Figure 7.27c), the results of the Simprof analysis from the PSA data were used to define the symbology of the Figure, similarly to the nMDS ordination and dendrogram (Figure 7.23 to Figure 7.26). In this case, the groups which are similar based on the PSA composition did not appear to adhere to the same degree as in the previous cross-plot. Of additional interest related to this was the fact that the correlation between the first order statistics of the grab samples correlated poorly against Brillouin’s index, with mean, skewness and kurtosis returning \( r^2 \) values of less than 0.1. When cross-plot against standard deviation grain size, Brillouin’s index returned an \( r^2 \) value of 0.243.
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Figure 7.27. Examination of the strongest positive agreement for SSS in the East Coast REC: mean backscatter against Brillouin’s diversity index. The symbology has been altered to reflect the results of the multivariate abundance and PSA data. a) Symbology reflects the depth of the sample; b) Simprof of multivariate biological similarity, and c) Simprof of multivariate PSA.

In contrast to the side scan sonar imagery, the MBES backscatter did not agree to the same extent with the biological indices. The strongest agreement observed in the case of the MBES and the Hamon grabs was between mean backscatter at 20 m and mean grain size ($\phi$). This was lower than the best agreement between the SSS, but was also determined to be significant owing to the abiotic parameters being tested and the large number of samples (n=106). Similarly to the case presented above, the samples were individually labelled according to the depth zone of their provenance (Figure 7.28). The previous investigation into these significances was
based on a biological index – whereas the correlation between mean backscatter against mean grain size would intuitively be expected to agree better with an abiotic parameter such as depth, or multivariate analysis of sediment properties. This appears to be the case, with more clear evidence of the groups adhering to the linear trend in the case of Depth and Simprof (PSA) (Figure 7.28a and c) than for Simprof (biological similarity) (Figure 7.28b).

Figure 7.28. Examination of the strongest positive agreement for MBES in the East Coast REC: mean backscatter against mean grain size. The symbology has been altered to reflect the results of the multivariate abundance and PSA data. a) Symbology reflects the depth of the sample; b) Simprof of multivariate biological similarity, and c) Simprof of multivariate PSA.
7.3 Summary

- At the sizes investigated (20 and 50 m), sample scale has a small but insignificant effect on the strength of agreement between samples. The larger sample size gave the highest correlations. The results suggest that SSS is slightly more sensitive to scale than MBES, and that standard deviation is more variable than mean backscatter.

- The MBES backscatter consistently outperformed the SSS in the comparisons with the mean of acoustic imagery, both with the total samples (n=106), and the unimodal only (n=57). The most successful instance is related to the Clamshell grab, which produced an $r^2$ significance of 0.623 at 50 m. However, the standard deviation MBES backscatter does not appear to be as good an indicator of grain size sorting.

- The Clamshell grab consistently produced more significant correlations with the acoustic backscatter, although this effectiveness was partially compromised by the low number of samples (n=16) when compared to the Hamon grab (n=106). This is potentially due to the experimental design by which they were acquired, the larger initial sample size, better retention of coarser grained material and the larger volume of material subjected to PSA.

- The comparison between acoustic imagery and biological diversity showed a dependence on the system. There was a uniformly low significance for the MBES ($r^2<0.01$ at both scales), however, SSS showed a positive correlation with several of the interrelated diversity indices (Brillouin’s, Shannon’s, and Margalef’s). The most significant of these was Brillouin’s which had an $r^2$ significance of 0.263 which increased to 0.318 as sample size increased from 20 to 50 m.

- The higher degree of success of the analysis in the East Coast area compared to the South Coast was largely attributed to the better quality of processing the imagery received. This was coupled with a significantly larger number of samples, better sea conditions at the time of survey and the fact that the analysis was performed on single passes of data rather than processed mosaics. The archived SSS performed significantly better than in the South Coast, but our own processed MBES imagery performed the best of all.
8 Discussion

The work conducted for MEPF 09/P80 has explored in detail the relationship between acoustic backscatter imagery and seabed sediments using data from the MALSF archive for the South and East Coast REC. These data have been critically evaluated by relating first order statistics of the acoustic imagery to PSA data from sediment samples. The Review and Evaluation Chapters (4 and 6) have demonstrated the significant differences that exist between several of the datasets which fulfil effectively the same function in both areas. These have arisen as a result of differences in: survey design, acquisition, processing and how data were subsequently archived. The results presented in Chapters 5 and 7 (South and East Coast respectively) examine several important factors that influence the significance of relationships between the variables examined, including scale, system of acquisition; insonification orientation, and more generally; survey design. In this Chapter, these results are examined together in the context of each other’s findings.

8.1 Geophysical data quality (SSS and MBES)

In spite of the fact that both the remotely sensed data were collected using the same systems (300 kHz MBES; 100 and 400 kHz SSS), fundamental differences in the way the surveys were carried out have given rise to significant variation in our analysis.

8.1.1 Survey design

Both surveys used a corridor system of intersecting lines (Figure 4.1 and 6.1), however for the East Coast there was usually only a single line in each corridor, whereas for the South Coast, there were generally 3 adjacent lines (one main and two wing lines). In the East Coast, particularly for the MBES in shallow water, given also that positions of the ground-truth samples was variable with regard to their relative location in the swath, this results in several cases where the sample lay off the geophysical imagery. This is clearly unfortunate, however in principal positioning the samples outside of the nadir is advantageous for quantitative work.

8.1.2 Sea state

As described in Chapter 4, the survey conditions during the South Coast phase of acquisition were dominated by bad weather and strong tidal streams. There were
also periods of acquisition in the East Coast (Chapter 6) where conditions deteriorated, but this was far less common. Nevertheless, there are examples of the effects of weather and seastate in both archive data sets. The survey conditions can have profound effects on backscatter data, ranging from mosaicing boundary artefacts, to layback error introduced by strong tidal streams, to dynamic motion artefacts. Irrespective of the geometric accuracy of the soundings, when surveys have been conducted in poor conditions, the accuracy of the returning signal will be affected, and this goes part of the way to explaining the poor results from the South Coast. What is clear is that hull-mounted systems are particularly prone to the effects of rough seastates. This is particularly evident for systems where the transducers are mounted athwartships, where the effects of roll will have the most profound impact on the interpretability of the resulting data. Existing research into the effects of sea state and data quality on backscatter data analysis are discussed by McGonigle et al. (2010).

In terms of best practice guidance, these cannot be adequately described in terms of absolute conditions, rather it is the cumulative effects of local conditions (bathymetry, tidal streams, wind against tide), coupled with the relative severity of conditions compared to the stability of the survey vessel. Larger, more stable platforms are generally less prone to these effects. In the case of the REC surveys, the MV Confidante (South Coast) is a much smaller vessel (28.4 m in length and 7.3 m on the beam) designed primarily for near shore and coastal surveying than the CEFAS RV Endeavour (East Coast) which is 73.9 m and 15.8 m by comparison (CEFAS, 2009). As such, some of the problems may have arisen as a result of the vessel being a less stable platform bearing in mind the survey objectives and the exposed nature of the location.

8.1.3 Layback
An additional problem related to acquisition was uncertainty in the towfish position relative to the position of the survey vessel; this was particularly relevant in the South Coast SSS dataset. Owing to technical problems with the USBL positioning system, the specified positional accuracy of 10 m was seldom evident, and there were several instances at which it is possible to see layback errors of up to 50 m between adjacent lines. In the acquisition report it is noted in the daily logs that there was a problem with the USBL (Gardline Geosurvey Ltd, 2008), which persisted to a point
where additional calibrations were carried out. After this fact, issues were acknowledged with the system but were not recorded with any degree of regularity. As a response to the problems, it appears that the layback was estimated; however these records are undifferentiated in the archive, and furthermore the data have all been mosaiced together. Resultantly, we believe the accuracy of the system was far below the specifications, and introduced undesirable positional inaccuracy between the acoustic and sediment data.

8.1.4 Dynamic range
A serious problem for the South Coast REC analysis was the very low dynamic range of the processed SSS imagery, with just 32 integers out of a possible 255 values (8-bit) actually utilised. In contrast, the East Coast data were saturated to the point that in several 50 m samples the full bandwidth of the 8-bit image was occupied. This does not however, reflect any such comparable variance in the properties of the seabed sediments. The range of values encountered for the MBES in the East Coast was more than in either case for the South Coast, but recorded less variation than the SSS (as described in Chapter 6). This would be largely expected as the low grazing angle of the SSS system would tend to dramatise any variance in terms of surface texture -particularly as the sample window moves away from nadir. This is also emphasised in terms of the TVG corrections, which are evident in Figure 6.4. As can be seen here, the lack of effective compensation across the range has resulted in dramatic contrasts in amplitude moving away from the nadir to the far range of the swath. This and similar results have affected the image–based statistics. The more potential bandwidth that is used, the less is available for the expression of response to different sediments, as any differences would have to be based on the shape rather than deviation in the actual RGB values.

The presence of shadows and areas of strong reflectance has also had the effect of extending the range of values, although if the lines of data are stretched based on the values contained in those lines alone, this will mean that the data cannot be effectively calibrated. Whilst there were many other problems with the South Coast SSS, on a positive note, the mosaiced lines had been internally calibrated as they had all rendered from the same final mosaic before being differentiated into 5 km² tiles.
8.1.5 Data formats

The raw MBES data were not available in the M-ALSF archive for either of the REC areas. The focus of the deliverables was on processed bathymetric data (gridded as .xyz and .sd; ungridded as .gsf), and 8-bit MBES backscatter imagery. In contrast, raw SSS data was made available through the M-ALSF portal via GeoData for both areas. We see no physical or technical reason why one dataset should be available and not the other, as if anything the data volume of the MBES is significantly less than the raw SSS when stored as .xtf, particularly as it was recorded and logged at two frequencies. The scientific success of our project is due to our arrangement to access the raw MBES data from the East Coast through agreement with CEFAS. It is unclear to us whether these data will be made available through the archive either in raw or processed form.

8.1.6 Comparison of SSS and MBES statistics

As a means of internally QC’ing the geophysical data a comparison between the SSS and MBES imagery was carried at both areas. This was intended to give a comparison in a relative sense, as they are fundamentally different types of sensor, looking sediment properties in different ways (Chapter 2). However, it was anticipated that a general positive trend would be evident in the data, irrespective of the lack of calibration between the RGB imagery and dB values. The first order statistics extracted around each grab station from the two acoustic sources were therefore compared. For the 26 stations in the South Coast, the mean against mean had an $r^2$ significance of just 0.017 at 20 m and 0.04 at 100 m, which was disappointingly low, while the standard deviation values were slightly more encouraging at 20 m (0.383) than 100 m (0.096). The low contribution at 100 m was only partially explained by the presence of outliers, as the removal of three Stations (62, 89 and 95; Figure 5.3) saw the number of samples decrease to (n=23) and significance for the mean decrease to 0.037; however, the significance of the standard deviation increased markedly to 0.575 (Figure 8.1). This appears to suggest that the standard deviation is more adversely affected by the error introduced by the large scale samples, and that it is a good indicator for quality control of the acoustic imagery.
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Figure 8.1. Revision of Figure 4.7c and d with the removal of outliers. Comparison of backscatter from different acoustic systems in the South Coast REC with 100 m Std. Dv. outliers removed (MBES against SSS at 100 m; n=23). a) Mean ($r^2=0.037$); b) Std. Dv. ($r^2=0.575$).

In the case of the East Coast, the relationship between the mean against mean backscatter (MBES against SSS) returned a stronger correlation, with an $r^2$ significance of 0.381 at 20 m, and 0.442 at 50 m based on the results of 106 samples. In addition, the standard deviation of values was 0.121 at 20 m and 0.245 at 50 m based on the comparison between systems at the same scales. This situation was supported by the results of the analysis at the location of the Clamshell grabs (Figure 7.8), where an even more significant correlation was established. With a much lower number of samples (n=16), the mean against mean backscatter was 0.559 at 20 m and 0.389 at 50 m. The standard deviation, in contrast, was weak with $r^2$ significance of 0.002 at 20 m and 0.014 at 50 m. This supports the premise that it was possible to establish a more significant correlation than had been observed at the South Coast, particularly where more stringent quality control had been applied to the samples. This agreement between the SSS and MBES, coupled with the large number of samples increases confidence in the value of comparison with the ground-truth data. One potential reason why the standard deviation values did not agree as well was because of the fact that the range of values for the SSS were significantly larger than the MBES, due to the existence of shadows caused by bedforms and low grazing angles of the system, coupled with less effective compensation across the swath.
8.2 Particle size distribution data quality (Hamon and Clamshell).

8.2.1 Experimental error (replicates)

In the South Coast there appears to have been no within-method replication, but in the East Coast REC, we found 5 stations with replication from which we can gain some insight into the experimental error involved in collecting and analysing sediment from a given location. Example particle size distribution curves and summary statistics resulting are presented in Figure 8.2 and Table 8.1. As can be seen, there is significant variation when using the same method, and this helps to account for some of the variability in the results which would have reduced the levels of agreement with the acoustics.

![Figure 8.2. Examples of the least (a, Station 463) and most consistent (b, Station 519) particle size distribution curves from the East Coast at Stations with replicates. The first order statistics derived from these samples are presented in Table 8.1.](image)

Table 8.1. Summary first order statistics from the East Coast Hamon grab samples which included replication (within method).

<table>
<thead>
<tr>
<th>Station</th>
<th>Mean Grain Size (Phi)</th>
<th>Std. Dv. Grain Size (Phi)</th>
<th>Skewness (Phi)</th>
<th>Kurtosis (Phi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>463a</td>
<td>-0.40</td>
<td>2.65</td>
<td>0.01</td>
<td>0.70</td>
</tr>
<tr>
<td>463b</td>
<td>1.33</td>
<td>1.73</td>
<td>-0.36</td>
<td>0.97</td>
</tr>
<tr>
<td>463c</td>
<td>-1.06</td>
<td>2.92</td>
<td>-0.01</td>
<td>0.62</td>
</tr>
<tr>
<td>468a</td>
<td>1.13</td>
<td>2.03</td>
<td>-0.47</td>
<td>1.65</td>
</tr>
<tr>
<td>468b</td>
<td>0.01</td>
<td>2.45</td>
<td>-0.39</td>
<td>0.77</td>
</tr>
<tr>
<td>468c</td>
<td>0.66</td>
<td>2.45</td>
<td>-0.43</td>
<td>1.37</td>
</tr>
<tr>
<td>498a</td>
<td>4.06</td>
<td>2.66</td>
<td>0.33</td>
<td>0.82</td>
</tr>
<tr>
<td>498b</td>
<td>4.11</td>
<td>2.72</td>
<td>0.27</td>
<td>0.82</td>
</tr>
<tr>
<td>499a</td>
<td>0.55</td>
<td>4.05</td>
<td>-0.17</td>
<td>0.82</td>
</tr>
<tr>
<td>499b</td>
<td>3.64</td>
<td>2.77</td>
<td>0.33</td>
<td>0.87</td>
</tr>
<tr>
<td>499c</td>
<td>1.15</td>
<td>3.12</td>
<td>-0.18</td>
<td>1.63</td>
</tr>
<tr>
<td>519a</td>
<td>2.03</td>
<td>0.93</td>
<td>-0.10</td>
<td>1.87</td>
</tr>
<tr>
<td>519b</td>
<td>1.80</td>
<td>1.19</td>
<td>-0.31</td>
<td>1.79</td>
</tr>
<tr>
<td>519c</td>
<td>1.75</td>
<td>0.99</td>
<td>-0.27</td>
<td>1.38</td>
</tr>
</tbody>
</table>
8.2.2 Grab type

Of more significant concern for our analysis was the grab type. We were fortunate to have duplicate Clamshell and Hamon grabs at each of the South Coast stations. The amount of variation encountered at the same location between the different methods was clearly demonstrated (Figure 4.9 and Appendix 3), which shows $r^2$ significance between the mean grain sizes of the Hamon and Clamshell grabs of just 0.545 (total samples) and 0.278 (unimodal samples only). The standard deviation of values yielded correlations with an $r^2$ of 0.427 (total samples) and 0.638 (unimodal only). These two grabs are undoubtedly sampling different things, and therefore it is unsurprising that there is variance in terms of any resultant comparison with the acoustic data.

8.2.3 Temporal disparity

Due to the way most marine surveys are carried out, geophysical data is usually acquired first, then processed and used to inform the ground-truthing phase of the acquisition, as was the case for both the South and East Coast surveys. The operating procedures for SSS and MBES acquisition are not compatible with drift acquisition of video ground truth data, and it is not usual for them to be conducted from separate vessels. Typically, therefore there is a time lag between geophysical and sediment sample acquisition. Whilst this may be largely unavoidable, it is generally agreed that in order to form the basis for useful comparison, the duration of this lag should be kept to an absolute minimum. This is particularly relevant in shallow water with complex hydrodynamic and sediment transport regimes. Even during the geophysical survey data acquisition, variations in conditions will arise over the course of a day which may be visible in the final mosaic (Figure 4.7). These issues have the potential to interface with registration errors like layback and confusion can result from an inability to distinguish between one another particularly in the absence of permanent fixtures. This is particularly true in the case of migratory bedforms, which are prevalent in both of the REC areas used in this research.

The main difference in terms of the approach to the survey design between the two REC areas used in this research is that for the South Coast was more rigidly defined from the outset, and as such the ground truth component was conducted immediately following the geophysical data acquisition. In contrast, the East Coast geophysical data were collected in the Winter of 2008, and were used to direct the
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ground truth effort based on a manual interpretation of the SSS record. Subsequently, the ground-truth data acquisition took place in the Spring and Summer of 2009. Therefore, it is difficult to be confident that an area of geophysical imagery can be assumed to representative of sediments acquired at the same precise location several months later, particularly in hydrodynamically complex areas, such as the South and East Coast RECs.

8.3 Relationships between acoustic and sediment data

8.3.1 Scale of acoustic extraction

The scale at which the backscatter imagery was sampled was explored in both the South and East Coast REC areas. In the South Coast, the backscatter imagery was sampled at 20 and 100 m. Examination of the results from the correlations throughout Chapter 5 highlight the fact that while the scale of analysis has an impact on the strength of agreement observed; it was not singly responsible for a large improvement. When the sample size is increased, the significance of the agreement with the PSA data appears to reduce, or change negligibly in most cases. The resulting variation is largely attributed to the introduction of areas of the geophysical data coverage was incomplete, or areas of 255 value caused the mean and standard deviation of the values to be increased. This was reflected in the comparison of the 20 and 100 m samples from the same system, which yielded an $r^2$ significance of 0.846 for the mean against mean SSS and 0.467 for the MBES based in the results of 26 samples. The correlation of the standard deviation values at the two scales showed that the MBES samples at 100 m were less representative of the 20 m samples than the SSS (Figure 5.4 [SSS=0.787; MBES=0.045]). This was, however, redressed by the removal of the outlying stations from the comparison which saw the strength of the correlation increase to a level comparable to the SSS (Figure 8.1).

This effect was not as pronounced in the case of the East Coast REC (Chapter 7); where similar analysis revealed that the correlation between mean and standard deviation backscatter (same system at different scales) did not lead to as significant a reduction in the strength of the correlation between the variables. In this case, the sampling window at the larger scale was reduced to 50 m while the smaller window was maintained at 20 m. The larger number of samples affords a greater confidence
to the patterns observed. This also meant that a higher threshold for quality control could be established, as there were more a wider variety of samples to choose from.

Based on the 106 samples, comparison of the mean against mean backscatter values at 20 and 50 m resulted in an $r^2$ significance of 0.94 for the SSS, and 0.957 for the MBES, while the standard deviation was comparably high at 0.756 for the MBES and 0.565 for the SSS. For the 16 Clamshells, both of the means were highly significant ($r^2 < 0.9$) and the standard deviation values at 20 m reflected the variance observed at 50 m (MBES $r^2 = 0.666$; SSS $r^2 = 0.724$).

These results appear to suggest that 100 m is too large a sample window when working with high frequency shallow water MBES, although this is largely because there is more space for errors and omissions to be introduced. At scales of this size and larger, which will typically exceed the coverage of the angular sector, the possibility of mosaicing artefacts increases, along with the likelihood of introducing areas of no-data. This is exacerbated in shallow water, when surveying using a hull-mounted sensor (eg. EM3000D), as the water gets shallower (assuming a constant angular sector) the swath width of the coverage is reduced. The lane spacing in the South Coast was approximately 100 m irrespective of water depth and resultanty, in shallow water gaps began to appear in the mosaiced imagery at the bounds of adjacent lines, several of which introduced values to MBES samples. The imagery produced from the SSS did not suffer a comparable reduction in the angular sector, as the system is towed at depth and not hull-mounted (Chapter 2). Theoretically, the 255 value could have been excluded from the analysis, but from the perspective of comparative treatment of the data, it was not possible to omit the 255 value from the SSS data as a significant proportion of the data containing this value was representative of areas of acoustic shadowing.

In the East Coast, this was less of a problem for two reasons; as the effects of acoustic shadowing were less pronounced in the SSS, and as the MBES was processed specifically for the purposes of this analysis, the no-data regions were assigned a nominal value which was excluded from the calculations. In this respect, the results from the East Coast may be taken as indicative of the results which could have been achieved in the South Coast with optimal processing. The second reason that processing was more straightforward was that the MBES data were not mosaics...
of multiple adjacent lines, but rather the individual portion of one individual line that intersected the PSA sample location. Therefore, the effects of mosaicing artefacts from adjacent lines as seen in the South Coast examples was not a consideration for any of the East Coast analysis, either for MBES or SSS. If the sample size had increased to 100 m it would have been necessary to mosaic segments from adjacent lines otherwise many samples would have had significant areas of no-data introduced.

The strong level of agreement observed between the acoustic imagery in the East Coast is reassuring of the fact that the difference between the method of acquisition and the number of the samples has not significantly affected the relationship between the variables tested at the two scales. Bearing this in mind, the results are inconclusive for the sample size, as several of the correlations were stronger at 20 than at 50 m, while for several of the others, the reverse was true. What is evident is that between a scale of 20 and 50 m (or 100 m with a reduced number of samples) that there is little variance in terms of the significance derived from first order statistical relationships. However, this is largely dependent on the compensation that has been applied to the acoustic data, and the position in the swath that the sample has been taken from.

The inherent inaccuracy involved in identifying the position at which the grab sample was taken based on the ships position means that it is not strictly relevant to try and compare a smaller scale of sample. The difference in the physical footprint of the samples is markedly different depending on the technique used both Hamon (0.1 m$^2$) and Clamshell (1.0 m$^2$). Bearing this in mind, whilst a sample of backscatter imagery of 100.0 m$^2$ or larger may be appropriate for analysis of bedform patterns or textural variation, it is logically too large to compare to the composition of a 0.1 m$^2$ grab sample, especially when the exact position at which it was acquired is uncertain (at the resolution of the sample). The larger the sample of backscatter imagery, the higher the chances that the correlation will break down, as was seen in the South Coast analysis. However, the application of a more stringent quality control did not improve the significance of the general results to such a point that they were statistically meaningful.
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Of further related significance, the pixel dimensions of the archival image data for the South Coast the acoustic imagery in the archive was different for both systems. The cell size of the imagery was 0.5 m² for the SSS and 1.0 m² for the MBES backscatter. For the East Coast, control over the process of mosaic generation for the acoustic imagery meant that the resolution of both SSS and MBES could be standardised the native resolution of the archival SSS (0.3 m²).

In order to obtain a representative sample of grain size for a spatially relevant comparison with the acoustic data, the largest sample size with the most effective retention is the most appropriate. In this case this was the Clamshell grab, which had a seafloor footprint of 1.0 m² and the hydraulic mechanism for operation which ensured representative capture and retention of the coarse fraction. It stands to reason that the spatial disparity between 1.0 m² and 20 m² (Clamshell at both RECs) is less significantly different than 0.1 m² and 100 m² (Hamon South Coast REC). In practice, the most significant comparison appears to result from the data which are most spatially appropriate with the highest positional accuracy in all respects.

8.3.2 Insonification direction

When using simple attributes such as mean and standard deviation over reasonably large sample boxes (20-100m), the difference in results from orthogonal insonification directions should be negligible. In the South Coast however, the $r^2$ significance of the relationship was shown to be less than 0.1 for all but the standard deviation of the samples at 100 m (0.397), which was the result of six outlying values which should have arguably been removed from the analysis (Figure 5.5). The removal of these values was explored, and did go some way to standardising the response of the variables, but it did not improve the significance of the relationships to the point that they were statistically significant. The distribution of the remaining samples is presented in Figure 8.3 and Table 8.2, and the correlation of the backscatter variation (within system) is displayed in Figure 8.4. Therefore, the mean and standard deviation MBES backscatter intensity within both 20 and 100 m samples at a given orientation could only account for between 12 and 15% of the variation at the opposing orientation.
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Figure 8.3. Revision of Figure 4.5 with outliers removed. Box and whisker plot of MBES backscatter in the South Coast REC at two orientations (EW/NS) at two scales (20 and 100 m).

Figure 8.4. Revision of Figure 5.6 with outliers removed. Comparison of MBES backscatter for the South Coast REC at opposing orientations (EW/NS) at 2 scales (20 and 100 m; n=18). a) Mean 20 m (EW/NS) ($r^2=0.126$); b) Std. Dv. 20 m (EW/NS) ($r^2=0.124$); c) Mean 100 m (EW/NS) ($r^2=0.145$); d) Std. Dv. 100 m (EW/NS) 100 m ($r^2=0.152$).

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Table 8.2. Revision of Table 5.3 with outliers removed. Summary statistics for MBES backscatter in the South Coast REC at opposing orientations (EW/NS) at 2 scales (20 and 100 m; n=18).

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Statistic</th>
<th>Statistic</th>
<th>Statistic</th>
<th>Statistic</th>
<th>Statistic</th>
<th>Statistic</th>
<th>Statistic</th>
<th>Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Min</td>
<td>Max</td>
<td>Mean</td>
<td>Std. Dv.</td>
<td>Skewness</td>
<td>Kurtosis</td>
<td>Std. Error</td>
<td>Std. Error</td>
</tr>
<tr>
<td>Mean (8-bit RGB) 20m EW</td>
<td>18</td>
<td>114.64</td>
<td>170.47</td>
<td>139.53</td>
<td>15.45</td>
<td>0.13</td>
<td>0.54</td>
<td>-0.35</td>
</tr>
<tr>
<td>Std. Dv. (8-bit RGB) 20m EW</td>
<td>18</td>
<td>7.58</td>
<td>19.20</td>
<td>12.17</td>
<td>3.43</td>
<td>0.59</td>
<td>0.54</td>
<td>-0.42</td>
</tr>
<tr>
<td>Mean (8-bit RGB) 100m EW</td>
<td>18</td>
<td>114.04</td>
<td>175.91</td>
<td>141.62</td>
<td>17.69</td>
<td>0.38</td>
<td>0.54</td>
<td>-0.05</td>
</tr>
<tr>
<td>Std. Dv. (8-bit RGB) 100m EW</td>
<td>18</td>
<td>7.79</td>
<td>17.47</td>
<td>11.83</td>
<td>2.85</td>
<td>0.47</td>
<td>0.54</td>
<td>-0.69</td>
</tr>
<tr>
<td>Mean (8-bit RGB) 20m NS</td>
<td>18</td>
<td>114.31</td>
<td>152.35</td>
<td>136.38</td>
<td>12.27</td>
<td>-0.22</td>
<td>0.54</td>
<td>-1.28</td>
</tr>
<tr>
<td>Std. Dv. (8-bit RGB) 20m NS</td>
<td>18</td>
<td>6.14</td>
<td>15.16</td>
<td>10.40</td>
<td>2.58</td>
<td>0.08</td>
<td>0.54</td>
<td>-0.69</td>
</tr>
<tr>
<td>Mean (8-bit RGB) 100m NS</td>
<td>18</td>
<td>112.78</td>
<td>156.88</td>
<td>138.84</td>
<td>13.61</td>
<td>-0.37</td>
<td>0.54</td>
<td>-1.05</td>
</tr>
<tr>
<td>Std. Dv. (8-bit RGB) 100m NS</td>
<td>18</td>
<td>7.34</td>
<td>16.14</td>
<td>10.10</td>
<td>2.36</td>
<td>1.36</td>
<td>0.54</td>
<td>1.80</td>
</tr>
<tr>
<td>Valid N (listwise)</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As has been demonstrated through the course of this analysis, depending on the provenance of the data from the perspective of orientation, the results of any subsequent analysis are not significantly related. Figure 5.3 and Table 5.3 show the difference in values resulting from a perpendicular variation in the orientation of MBES backscatter imagery, and this is developed by the revision of this material in relation to the omission of outlying values arising from a more stringent quality control. This reduced number of samples is undoubtedly more robust than using a larger number of more dubious values, but the overall result is largely unchanged. What this does demonstrate clearly is that the inclusion of even a small number of outlying values can have a significant effect on the strength of the subsequent correlation. Undoubtedly, this would be more significant if the analysis was conducted on SSS owing to the lack of ability to reconcile the changes in amplitude as a result of the bathymetric variations experienced. This would be exacerbated in the presence of complex bedforms as was demonstrated in the South Coast REC (Figure 4.2).

8.3.3 Ground truth location

The explicit location of the sample on the swath at the point of acquisition is of vital importance, as if it is too close to the nadir, it will run the risk of inadequate
compensation and the introduction of spurious values. This was the case in the South Coast, where owing to the original survey design, the PSA samples taken at the centre of the intersections between NS and EW corridors of geophysical data. Resultantly, for the purposes of comparison with the acoustic data, each sample was represented by a significant proportion of imagery that had originated at the nadir of the survey line. Therefore, the inadequacies introduced at the data processing stage in the range compensation would have profound impacts for the pixel values contained in these samples. As was demonstrated in Figure 4.2 (Profiles W-X and U-V), the intersection of the nadir in poorly compensated SSS data had the effect of masking known boundaries and bedforms, effectively saturating the data with high integer values. Alternatively, if too close to the bounds of the swath, the imagery runs the risk of being too heavily influenced by artefacts at the edges of the mosaic between adjacent lines. This is one of the principal benefits that was achieved by using the East Coast data, where the provenance of each acoustic image could be traced to a single line of data, and resultantly avoid the problems of mosaicing artefacts between adjacent lines. For the purposes of comparison, the position of the ground-truth samples relative to the acoustic swath for the South and East Coast are summarised in Table 8.3.

<table>
<thead>
<tr>
<th></th>
<th>Clamshell</th>
<th>Hamon (&gt;100 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>16</td>
<td>119</td>
</tr>
<tr>
<td>Minimum:</td>
<td>2.39</td>
<td>0.08</td>
</tr>
<tr>
<td>Maximum:</td>
<td>134.02</td>
<td>94.98</td>
</tr>
<tr>
<td>Mean:</td>
<td>32.97</td>
<td>27.65</td>
</tr>
<tr>
<td>Standard Deviation:</td>
<td>34.13</td>
<td>20.59</td>
</tr>
</tbody>
</table>

The optimum position in the range would be in the central two sixths of the sample either side of nadir, corresponding to the portion occupying 33-66% of the swath which should ideally be free from artefacts from the mosaicing process and introduced system error. Ideally there would be flexibility in terms of the availability of raw data to allow for the mosaic to be constructed independently of adjacent lines of data, as was the case for the East Coast REC.

The precision with which the location of the grab sample is resolved is also significant for comparisons at the scale we are performing analyses. In the case of
the RECs, the grab sample locations were based on the ships position at the time of deployment, which is a common if quite coarse method for determining the position of samples. The USBL which was used in the geophysical survey could have been employed in the determination of these position an added a higher level of precision. This would have helped to provide assurances that the comparison with the geophysical imagery would be accurate and relevant.

8.3.4 Relationships obtained

There is undoubtedly a relationship between backscatter imagery and grain size, however the relationships between the variables is complex. This appears to be largely governed by the way the samples have been acquired and processed. The difficulty arises in attempting to discern which of these factors has exerted the most significant influence on the results.

The rationale for the survey design can have a profound effect on the results of the comparison. In the East Coast REC, the location of the geotechnical samples (Clamshell) was based on a user-defined interpretation of the SSS imagery, and this may have contributed to the strength of the correlation obtained (SSS $r^2=0.211$ at 50 m). However, this coefficient was significantly lower than the correlation observed for the MBES backscatter ($r^2=0.623$ at 50 m) which resulted from the use of exactly the same PSA samples ($n=16$). This improvement is undoubtedly due to better data processing of MBES backscatter. As was the case in the South Coast, the less effective retention of coarse material in the Hamon samples appears to have adversely affected the strength of the relationships observed with the acoustic data.

The distribution of the Hamon grabs in the East Coast appears to have been more focussed on providing general coverage than on maximising the variability in the acoustic response. However, despite the reduced number there is still a comparable degree of diversity in terms of the backscatter statistics (Figures 7.6 and 7.7). In terms of their grain size composition for both methods, however, Figure 6.6 highlights the fact that when only the univariate samples are considered the vast majority of diversity has been removed from the sediment samples (Figure 6.6b and d). Therefore, irrespective of whether the removal of polymodal samples improves agreement, it means that the majority of these samples are unsuitable for this type of analysis.
In the case of the South Coast results (Chapter 5), the largest significance based on the 26 samples was between the Hamon grab and the SSS at 20 m ($r^2 =0.27$). The strength of this significance was lower at 100 m. When based on the smaller number of unimodal samples in this area, the $r^2$ significance increased to 0.34 at 20 m. This was more significant than the relationships obtained from the Clamshell grabs at the same location, which when unseparated by the modality of the samples produced an $r^2$ significance of 0.17 at 20 m and 0.144 at 100 m. The significance of these relationships increased when unimodal samples only were used. At 20 m using the 12 unimodal samples, the SSS and mean Clamshell grain size had an $r^2$ significance of 0.508, compared to 0.313 at 100 m.

This pattern was similarly followed in relation to the MBES imagery, although the significance was less for all samples. For instance, when compared to the mean backscatter imagery, the mean grain size of the Hamon grab returned an $r^2$ significance of 0.112 at 20 m, compared to 0.005 at 100 m. However, this relationship could be improved at 100 m by the removal of additional outlying values, which only affected the MBES imagery owing to the reduced swath coverage. The removal of the three outliers from the standard deviation MBES backscatter at 100 m improved the significance of all the samples whilst reducing the number of samples, but this additionally did not improve the significance to a point where the relationship could be described as meaningful (Figure 8.5, Table 8.4 and Figure 8.6).

![Figure 8.5. Revision of Figure 5.3 with outliers removed. Box and whisker plot of MBES backscatter in the South Coast REC at 2 scales (20 and 100 m; n=23). The imagery selected was iteratively selected based on image quality (free from artefacts, processing errors etc.).](image-url)
Table 8.4. Revision of Table 5.2 with outliers removed. Summary statistics for MBES backscatter in the South Coast REC at 2 scales (20 and 100 m; n=23).

<table>
<thead>
<tr>
<th>Statistic</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Dv.</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean MBES (8-bit) RGB 20</td>
<td>23</td>
<td>144.64</td>
<td>170.47</td>
<td>139.96</td>
<td>14.93</td>
<td>0.10</td>
<td>-0.52</td>
</tr>
<tr>
<td>Std. Dv. MBES (8-bit) RGB 20</td>
<td>23</td>
<td>7.58</td>
<td>19.20</td>
<td>12.04</td>
<td>3.14</td>
<td>0.67</td>
<td>0.48</td>
</tr>
<tr>
<td>Mean MBES (8-bit) RGB 100</td>
<td>23</td>
<td>114.04</td>
<td>175.91</td>
<td>141.40</td>
<td>16.64</td>
<td>0.37</td>
<td>0.48</td>
</tr>
<tr>
<td>Std. Dv. MBES (8-bit) RGB 100</td>
<td>23</td>
<td>7.79</td>
<td>17.47</td>
<td>11.54</td>
<td>2.73</td>
<td>0.59</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Valid N (listwise) 23

Figure 8.6. Comparison of MBES backscatter and PSA samples for the South Coast REC at 100 m (n=23). Station Numbers are indicated in Figure 4.1. a) Mean Hamon (r²=0.024); b) Std. Dv. Hamon (r²=0.063); c) Mean Clamshell (r²=0.014); d) Std. Dv. Clamshell (r²=0.068).

The removal of polymodal samples from the analysis reduced the effective number of samples to 12, but increased the significance of the comparison to 0.32 at 20 m,
although this was irrelevant at 100 m. The removed samples also included those which were determined to be outliers, at the point where the results were revised in the previous section. When compared to the results of the 26 stations for the Clamshell grab, the MBES returned an $r^2$ significance of 0.062 at 20 m and >0.001 at 100 m. This was altered to show values of 0.4 at 20 m and 0.344 at 100 m when only the unimodal samples were used, which is a positive result, although it is based on a small number of samples (n=12). This appears to suggest that the best agreement observed in the case of all samples (n=26) is between the Hamon grab and the SSS at 20 m; however, when only unimodal samples are considered and potential outliers were removed, the Clamshell grab and the SSS imagery produced the most significant correlation ($r^2=0.508$). Bearing in mind the low number of samples (n=12) coupled with the restrictions imposed on the SSS data as a result of the processing and data format issues, this means that these values need to be approached with a degree of caution.

As previously demonstrated, the scale of comparison is relevant, however between 20 and 100 m there was a negligible difference in the results of the SSS, but as can be seen from the results, there are significant reductions in the relevance of comparisons with the MBES. This has occurred as a result of the reduction in the swath width and resultantly coverage in comparison between the two systems, and as was demonstrated, this could be improved by more stringent quality control of the samples which were included. However, owing to the small number of samples in total (n=26), many of the problematic samples were retained in the analysis as these were present in the archive, and so relevant from the perspective of evaluation.

By way of a provisional context, Collier and Brown (2005) also reported a good correlation between the mean SSS backscatter against mean grain size ($r^2=0.531$), but for the purposes of comparison, this was with a range of mean grain sizes from 1.2 (medium sand) to 5.6 $\phi$ (coarse silt). In contrast all of the comparative analysis conducted for MEPF 09/P80 was in much coarser material, particularly the South Coast (Table 4.2). The East Coast data had a more significant proportion of finer grained samples from the Hamon grab, but when the unimodal samples were isolated, the diversity of the samples collapsed (Table 6.2).
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In the case of the East Coast dataset (Chapter 7), the comparisons are more reliable for a number of reasons. Firstly, there is a significant increase in the number of samples available for the Hamon grab (n=106). However, based on the results of the South Coast it appears to suggest that the Hamon PSA samples are producing a less significant relationship than the Clamshell when unimodal samples are considered with the acoustics in isolation. Although it is not possible to replicate the comparison between the analysis of Clamshell and Hamon composition from the same location, there are replicates using the Hamon grab at 5 locations, which was not possible in the South Coast REC. Secondly, the relative orientation is not a consideration, as the vast majority of samples were only insonified in one instance using each method (SSS and MBES). Finally, the scale of comparison is more relevant to the dimensions of swath for the MBES (20 and 50 m), and the issue of mosaicing artefacts has been removed as each sample is represented by data from a single line.

What is clear from the East Coast analysis of PSA against acoustic imagery is that the variance in terms of mean grain size is largely controlled by the distribution curves of the samples, and that those samples which deviate from a single mode have the ability to govern the strength of the correlations observed. The Clamshell grab appears to be providing evidence of greater success in terms of the significance of the relationships observed between variables tested, however, this needs to be qualified by the use of more samples in general, and within method replication.

Therefore, the reasons for the increased relevance of agreement in the East Coast are interpreted as being due less to do with the ground type, and more to do with the increased dynamic range (pixel depth) of the backscatter data and the amplitude compensations applied to the backscatter imagery. Both of these are a direct function of the processing environment. As suggested for the South Coast, the fact that the SSS data had a stronger positive correlation when compared to mean grain size (whilst still weak), was suspected to be a false positive for reasons already discussed.

8.4 Relationship between acoustic and biology data
The comparison of the abundance and biomass data from the Hamon grabs with the acoustic data in the South Coast REC project produced uniformly insignificant
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results. All of the parameters tested returned $r^2$ significance of equal to or less than 0.1. This was reflected in the structure of the nMDS plots which were examined in Chapter 5, which showed a low level of distinction based on the biological similarity of the samples. The biological distinction between the eight groups identified through clustering in the nMDS plots did not show clear evidence of depth stratification. The nMDS plots of particle size distribution show that the groups could be differentiated in terms of the modality of the samples, which have separated out into uni-, bi-, tri- and polymodal groups. When viewed in the context of the best agreement observed for the South Coast REC (SSS and Hamon grab; $r^2 = 0.27$ [20 m] and 0.247 [100 m]), this appears to suggest that the significance of this correlation does not appear to be relevant when viewed in terms of either Simprof groups of biological similarity or depth stratification for any of the samples tested. In addition, the comparison of the biotope data demonstrates that the image based statistics can be used to separate the acoustic imagery into groups based on their multivariate properties, however, these groups appear to have a large degree of overlap when based on even simple properties of the image. In addition, at the level of the distinctions in terms of biotope, the differences between groups are made primarily on the basis of abiotic factors. In this respect, based on the analysis of the biotopes in the South Coast REC, it does not appear to be possible to predict the biotope based on even multivariate components of the MBES backscatter imagery.

In the case of the East Coast REC data, the faunal analysis was conducted on the basis of the Hamon grabs, which had much less significant relationships evident with the acoustic data from either system than the Clamshell grabs. However, several of the diversity indices returned positive correlations with the SSS imagery and these were demonstrated to be sensitive to scale. At 20 m, Brillouin’s diversity index had an $r^2$ significance of 0.263 which increased to 0.318 as the sample size increased to 50 m. This was the most successful correlation at both scales of analysis, and means that for a significant proportion of the SSS backscatter intensity increases, there is a corresponding increase in the diversity of the samples. Similarly, there were increases in several related diversity indices which were all derived from the same abundance data. Margalef’s index of species richness also had a similarly strong positive correlation, with $r^2$ significance of 0.258 at 20 m and 0.307 at 50 m. However, this value fails to take the species evenness into account. The Shannon
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index (H’ loge) also returned significant values, yielding an $r^2$ significance of 0.21 at 20 m and 0.25 at 50 m. Based on a perfect relationship, the interpretation of these values means that as the mean side scan backscatter intensity increases, the species diversity, richness and evenness of distribution increases. Based on the results at the East Coast, up to 32% of the variability in diversity can be explained by mean SSS backscatter intensity.

The analysis of the abundance data in the multivariate environment is more complex to interpret as there were so many discreet groups identified using Simprof analysis in Primer. There was some evidence of depth stratification in terms of the samples, however, the vast majority originated in either Zones 2 (20-29 m), 3 (30-39 m) or 4 (40-49 m). In contrast, 6 samples originated in Zone 5 (50-59 m) and 2 samples from Zone 1 (10-19 m). The remaining groups were well mixed in terms of their biological distinction, and further so in terms of the PSA analysis. In terms of the strongest correlations, the presentation of Brillouin’s index correlated against mean SSS at 50 m shows little evidence of any pattern in terms of the depth stratification of by PSA composition based on the particle size distribution data. There is more significance in the Simprof (bio) data (Figure 7.25b), although this is to be expected as both of these measurements are derived from the same data. Conversely, the second most significant relationship involving the Hamon grabs which was observed in the case of the East Coast data was that of the mean gain size against mean MBES backscatter (20 m). When this was analysed in conjunction with the depth stratification and the Simprof results, the mean grain size had the strongest visual agreement with the results of the particle size distribution Simprof (Figure 7.26). The biological groupings appeared to have a degree of agreement with these results of the correlation, but to a much lesser degree than the PSA data.

These results appear to suggest that the more reliable (populous) results in the East Coast demonstrate a clearer relationship between the SSS data and the diversity indices than was the case in the South Coast REC. It is possible that more detailed analysis could draw deeper patterns out of these data. What is evident from examination of the data is that the majority of the data points occupy a central position in the distribution, and therefore, removal of extreme values could adversely affect the strength of agreement observed. It is worth considering why it should be the case that the mean SSS backscatter should give a more significant level of
agreement with diversity indices than MBES data, particularly when the latter has already presented a stronger evidence of agreement with the grain size.
Conclusions and Recommendations

In this chapter we summarize the project findings in terms of the original tender’s aims and deliverables.

9.1 Conclusions

Objective 1. Is multibeam backscatter suitable for direct translation into seabed parameters?

Side scan has for many years been the instrument of choice for seabed characterization. In contrast, MBES data are used primarily for determination of bathymetry, with information about the characteristics of the bottom generally being viewed as an incidental bonus. However, this is changing as the reliability and precision of the sensors increases along with the processing power and sophistication of the means of compensation.

The most promising results from our study were made using the 16 Clamshell grabs and MBES imagery in the East Coast. Here we achieved an $r^2$ significance of 0.628 between mean MBES backscatter against mean grain size (Table 9.1). This was more significant than the 0.461 observed between SSS for the same samples. It is unfortunate that we are unable to definitively say which method was the more accurate, as the SSS data was not processed by ourselves and visual inspection of it revealed across-track amplitude imbalance which would have undoubtedly degraded its performance. However, we note that the correlation achieved between the MBES and mean sediment grain size is higher than that obtained by Collier and Brown (2005) using SSS data collected in Oban ($r^2=0.531$). As to predicting biological diversity, in both our REC study areas, the SSS outperformed MBES (Table 9.2). The reason for this would need further investigation that was beyond the scope of the current project. Hence our work has proven the ability of MBES to predict sediment properties to the same degree as SSS, although its ability to predict biological diversity is less certain.

Objective 2. Are first-order statistics sufficient for predicting mean sediment grain size and sediment sorting?

A factor that clearly emerged from our work was the dependence of the first-order statistical correlations on the sediment grab system used. Our approach assumes
we know the grain size distribution at each station precisely, or at least within reasonable experimental error. From the co-incident grab sampling in the South Coast REC, it was clear that the Hamon and Clamshell grabs gave very PSA different results, presumably as a consequence of their different sizes (0.1 m² Hamon as opposed to 1.0 m² Clamshell), and the mechanics of operation. The Hamon grab consistently under-sampled the coarse sediments, and so misrepresented the bottom type. It was satisfying therefore, when we moved to the east Coast analyses that our best predictive correlation between sediment grain size and acoustics were achieved for the Clamshell grabs (MBES, $r^2=0.628$). This correlation fell significantly when the Hamon grabs were substituted (MBES, $r^2=0.278$), despite the far higher number of stations (106, compared to just 16 Clamshell) which should have worked to improve the correlation. Note that a Hamon grab was also used to collect the samples in The Oban study (against which we benchmark the results from this project), but the sediments here are much finer than in the aggregate-extraction areas of the RECs (mean grain size across all recovered
samples being 3.78 φ in Oban compared to 0.18 (Hamon) or -0.51 (Clamshell) in the South Coast REC and 1.40 (Hamon) or 1.04 (Clamshell) in the East Coast REC.)

Looking forward to a time when we are confident enough to directly map acoustic data into seabed properties, having poor calibration from ground truth data will clearly invalidate the entire exercise. **Our work has therefore highlighted the need for accurate seabed sampling for quantitative analysis.**

The results achieved in the South Coast REC were consistently poor. However we believe this was due to the poor quality of the processed acoustic imagery available rather than any flaw in the analytical method used. We therefore conclude that when maximum care was taken in the processing of the acoustic imagery and a representative grab sample was available there was a good predictive relationship between the first order statistics of the backscatter to predict the mean sediment grain size (best performance $r^2=0.628$). However, the ability to predict the sediment sorting however was considerably lower (best performance $r^2=0.269$).

**Objective 3. Is there a direct relationship between acoustic data and assigned infaunal biotope class?**

[NB Owing to the lack of variability in the biotope data for the South Coast and a lack of any biotope for the East Coast REC our analysis used diversity indices which could be derived directly from the abundance data in both areas.]

**Table 9.2. Best-performing acoustic-biological index correlations.**

<table>
<thead>
<tr>
<th>Study area</th>
<th>Backscatter Imagery</th>
<th>Biological index</th>
<th>Correlation ($r^2$)</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Coast</td>
<td>SSS – 100 kHz, sampled at 100m</td>
<td>Number of species</td>
<td>0.12</td>
<td>5.16b</td>
</tr>
<tr>
<td>East Coast</td>
<td>SSS – 100 kHz, sampled at 50m</td>
<td>Diversity (Brillouin’s)</td>
<td>0.318</td>
<td>7.22a</td>
</tr>
</tbody>
</table>

In the South Coast REC results from the 25 grab sample locations which had faunal analysis and coincident acoustic imagery, comparison of a series of values (number of species, number of individuals, biomass, Shannon’s, Brillouin’s Margalef’s and Pielou’s indices) for both MBES and SSS systems returned correlations with an $r^2$ significance of $<0.12$. Part of the reason for this low correlation is undoubtedly due to the poor quality of the acoustic data in this area. However the biological diversity in the samples themselves were also in terms of the PSA distributions and water depth, but no clear relationship was established between these parameters. Part of
the reason for the low correlation between the acoustics and biological diversity is probably also due to the lack of a strong relations with the intermediary factor sediment grain size.

In the East Coast REC, similar analysis over a much larger number of samples (106) revealed much the same patterns for the MBES data with all the variables tested returning correlations with an $r^2$ significance of $< 0.1$. For the SSS data on the other hand, several of the diversity indices returned values of a higher significance. When correlated against the mean SSS backscatter intensity (20 m), Brillouin’s index of diversity returned a significance of 0.263, which increased to 0.318 at 50 m. The same pattern followed for Margalef’s index of species richness ($r^2 = 0.258-0.307$) and Shannon’s diversity index ($r^2 = 0.21-0.25$). This indicates a weak but significant positive correlation between measured biological diversity and mean SSS backscatter. However the relationships are clearly subtle and more research is needed in this area to better understand them.

9.2 Recommendations

We make the following recommendations based on our research.

9.2.1 The appropriateness of current MEPF archive backscatter datasets for use for quantitative seabed analysis.

1a) Are the best archive formats being used?

The best archive formats are not being used at present, and this severely limits the potential for future analysis. The SSS sonar data is available in the raw form for both frequencies (100 and 400 kHz); however, there is no raw MBES backscatter data in the archive. Our project would have been far-less successful without direct access to raw unprocessed MBES data from the East Coast REC.

The backscatter imagery is currently stored as Geotiffs with a pixel depth of 8-bits (256 colours of grayscale). While this is good in terms of compatibility with a wide a range of end users, it is limited in its usefulness for more advanced quantitative, as it does not have the capacity to express the diverse range of materials encountered. The use of 16- and 32-bit imagery allows for the true depth of the signal to be preserved. Further if the imagery were expressed in measured units (dB) as opposed to greyscale pixel values, this would allow for a greater degree of internal
consistency across the data. The acoustic imagery should be preserved and archived at its native resolution for re-rendering by future users, and the archived format should be preserved at a bit depth appropriate for the sensor. Low resolution 8-bit imagery has its place in the archive as it is useable by a wide variety of users, but there should be other options.

1b) Do current acquisition and processing methods limit future quantitative extraction?

The difference in the quality of the SSS imagery between the South and East Coast REC's has been clearly demonstrated through this research. The more considered acquisition and processing for the SSS in the East Coast has returned more significant correlations at all levels, and this should be used as a point of reference for future data processing. The method by which the backscatter is compensated for radiometric and geometric distortions is of unparalleled significance for quantitative data extraction. It is important to stress that in this project we deliberately did not attempt any particularly complicated quantitative analysis. Despite this, our analysis was severely compromised in the South Coast REC by the acquisition affects such as analogue gain changes and the archiving of mosaiced corridors of poorly processed imagery with a low dynamic range. Without any doubt, the strength of agreement obtained from the East Coast MBES is due to the level of processing of the raw data.

Our reliance on accurate seabed samples also raised two issues about the suitability of the current acquisition methods for future quantitative extraction. First, it is clearly preferential to collect the acoustic and grab samples in the shortest overall time possible to minimize the effects of environmental change. We recognize of course, this is not always practically possible because of vessel availability, but recommend that the mobility of the seabed should be carefully considered in the future as significant time lags between the various phases of the surveys add another layer of uncertainty for quantitative work. This is likely to be most significant in shallow waters close to shore, where tidal forcing and sediment transport pathways have the capacity to cause large scale seabed movements at the timescales in question. Of the three surveys compared in Table 9.1, the East Coast had the longest delay
between the collection of the acoustics and the grabs, if this had been shorter then our best correlation may well have been even higher.

The second issue relates to the accuracy of the Hamon grab sampler for particle size analysis. It was fortunate that co-incident Hamon and Clamshell grabs were available in the South Coast REC so we could compare performance. The Hamon grab clearly under samples the coarse component in this area and therefore makes these particle size data unreliable in these aggregate extraction areas.

**1c) Should the raw (“ping”) data values be archived for future reprocessing from source?**

In future, all raw data should be recorded and archived as a matter of course to allow flexibility in processing. Different end users will want different things from the data, and future processing methods will allow for old data to be reinterpreted in new ways. At the moment whilst SSS ping data is available MBES is not. We see no physical or technical reason why one dataset should be available and not the other, as if anything the data volume of the MBES is significantly less than the raw SSS when stored as .xtf, particularly as it was recorded and logged at two frequencies. We note that in the Humber REC, at the time we accessed the archive in January 2010, there was raw MBES data available – but this was the beam-averaged data and not the beam-time series data that we used in our processing. The REC datasets represent a valuable resource for understanding the UK shelf and given that this is a rapidly developing field it is important to preserve as much information as possible for future use.

**9.2.2 How MEPF survey strategies, processing methods and sampling techniques could be optimised to best meet future seabed monitoring objectives.**

**2a) Is it necessary to collect side scan as well as multibeam backscatter?**

In principal SSS is less robust for quantitative analysis owing to the potential for acquisition and processing artifacts such as shadows, instrument roll/pitch and layback errors. However, due to the large differences in the quality of the data processing evident in the archive it was not possible for us to directly compare the performance of SSS versus MBES in either of the RECs studied. We note however that we achieved comparable performance in terms of correctly predicting sediment
grain size values from the East Coast REC MBES dataset to that of our previous study in Oban that used a SSS dataset. The success of both these studies however came from careful in-house processing at Imperial College London. At this stage of the development of the subject we conclude that the accuracy of the geophysical processing far outweighs differences between sensor types in their ability to predict seabed properties.

In general terms our work has confirmed the benefit of collecting both SSS and MBES backscatter. The MBES is more accurately positioned but the SSS is more effectiveness for topographic feature recognition. In many respects the two data sets are complimentary, as they are looking at different things, in fundamentally different ways owing to the sensor geometry. Additionally, having an independent method with which to cross-reference interpretations is an indispensable aid to analysis. In terms of recommendation, if it is possible to acquire both datasets without compromise to either, this should be undertaken where possible.

2b) Are certain sonar frequencies better suited to determine seabed type in the study area? Would using multiple frequencies increase our ability to classify seaboards (given that both surface and volume backscatter vary with frequency)?

In both RECs it was clearly demonstrated that it is possible to collect temporally coincident SSS (at two frequencies) and single frequency MBES without cross talk between systems. However, unfortunately we have not been able to address frequency-related science issues as no processed 400 kHz SSS mosaics were available in the archive. Note that it is not really appropriate to attempt to directly compare the performance of 100 kHz SSS backscatter with 300 kHz MBES data as they fundamentally different types of sensor. In the future it would therefore be highly desirable to process the 400 kHz records (the raw xtf is available in the archive) as it would provide the opportunity to empirically test the relevance of frequency as a factor in the determination of grain size characteristics using acoustic data in these areas. In terms of the physics of backscattering, the depth of sediment that returns signal due to volume backscattering is directly proportional to frequency (low frequencies penetrate deeper), so making frequency-response comparisons should give important constraints on the internal sediment structure. For future quantitative analysis, we would also recommend the re-processing the raw 100 kHz South Coast SSS from the .xtf files for the problems of layback error to be corrected.
However, it is not clear to us how easy this would be in practice as the status of the raw USBL data is not known to us.

2c) Do limits on the insonification angles need to be set?
Placing all of the ground truth stations at the nadirs of the geophysical data in the South Coast REC was a potentially serious issue for our work. Within the nadir, the signals are largely returned to the instrument by reflection rather than scattering and the data from these areas are notoriously difficult to effectively compensate. We are unable to separate the effect of this sampling strategy from the inadequate data processing issues, but both undoubtedly led to the poor performance of the prediction method. In the East Coast REC the sample stations were randomly positioned across swath and the data processing quality was much higher – both of which contributed to the far superior analysis. In general, the most useful data for quantitative for bottom characterisation are those with low grazing angles from the middle third of the angular sector in both port and starboard sectors. The nadir should be avoided as should the far ranges which commonly suffer signal loss.

2d) Should repeat (multi-pass, multi-azimuth even) surveys over sample sites be collected to improve the accuracy of automated seabed parameter extraction?
Covering the same area of seabed from a variety of orientations and using a range of settings would afford a higher degree of flexibility for quantitative analysis. However it is understandable that in the REC surveys, with their emphasis on regional characterization, this was not a high priority objective. We found large differences in our analysis of the South Coast REC data from perpendicular orientations, but the correlations were so poor throughout that it is not possible to draw firm conclusions from this. The requirement for more sophisticated experimental design awaits the next phase of study.

2e) Are current processing protocols appropriate for future data use?
We strongly recommend that in the future better documentation of the geophysical processing sequence is recorded and archived. In the South Coast REC, we can only speculate as to the source of the poor final images due to a paucity of information. Further we noticed from our assessment of the entire MEPF archive a great variety in the quality of the accompanying metadata. We strongly recommend in the compliance to a more regular set of archived products.
2f) Should MEPF be calibrating sonar at well-described reference sites to ensure internal consistency and reach the level of accuracy required?

Establishing a network of calibration patches of known seabed types that are stable over time would be highly desirable for future MEPF work. This would not only allow some standardization between surveys, but also act as a baseline for time-lapse studies designed to investigate, for example, the direct affects of marine aggregate extraction on the surrounding seabed.

9.3 Final remarks

We have demonstrated that through careful data processing robust relationships between acoustic backscatter and sediment grain size distributions can be established. This gives the potential to produce a sediment map directly from an acoustic mosaic. The link between acoustics and benthic biology however remains more tenuous and so requires further research, possibly in areas with stronger contrasts of fauna. The MALSF REC surveys mark a significant advance in our understanding of the seabed on the UK continental approach. The underlying ethos of data achieving and free access to all is highly commendable. Whilst our project has highlighted several limitations of the archive, it should be remembered that the field data were not specifically collected with our research objectives in mind, and so the success we have achieved is testament to “collect once use many times” principal of the MALSF programme.
References


References


References


References


Appendix 1: Anatomy of a box plot

The box and whisker plots used in this report visually represent five statistics for each sample: the minimum, the lower quartile, the median, the upper quartile and the maximum. The rectangle encompasses the middle half of the sample, with a quartile at each end. (Figure A.1). Therefore, the length of the rectangle is the interquartile range of the sample. The line drawn across the rectangle represents the sample median. The whiskers indicate the sample maximum and minimum. The following diagram shows a dotplot of a sample of 20 observations (actual sample values used in the display) together with a boxplot of the same data.

![Diagram of a box and whisker plot](image)

**Figure A.1. Anatomy of a box and whisker plot in SPSS.**

Values which are more than three box lengths from either end of the rectangle are displayed by asterisks; values which are between one and a half and three box lengths from either end of the box are represented by solid dots. These are determined as outliers based on the expected distribution of a normal Gaussian population.
Appendix 2

Size scale adopted in the GRADISTAT program (Blott and Pye, 2001).

<table>
<thead>
<tr>
<th>Grain size</th>
<th>Descriptive terminology</th>
<th>Udden (1914) and Wentworth (1922)</th>
<th>Friedman and Sanders (1978)</th>
<th>GRADISTAT program</th>
</tr>
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MEPF 09/P80: Acoustic backscatter and physical properties of the seabed
Appendix 3: Particle Size Distributions for the South Coast REC

In the following pages we present a comparison of the particle size data from all the co-incident Hamon/Camshell grabs used in this study. Each grab is referenced by station number, the positions of which can be seen on the map below.

Location of South Coast REC in the English Channel showing distribution of spatially coincident Clamshell and Hamon grab samples. Samples with coincident geophysical data are displayed in red; the remainder in grey, labels indicate Station number. Geophysical data corridors are indicated by the dashed lines.
Appendix 3: Particle Size Distributions for the South Coast REC

MEPF 09/P80: Acoustic backscatter and physical properties of the seabed
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MEPF 09/P80: Acoustic backscatter and physical properties of the seabed
In the following pages we present a comparison of the particle size data from the Camshell grabs used in this study. Each grab is referenced by station number, the positions of which can be seen on the map below.
Appendix 4: Particle Size Distributions for the East Coast REC
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MEPF 09/P80: Acoustic backscatter and physical properties of the seabed
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MEPF 09/P80: Acoustic backscatter and physical properties of the seabed