MESH MAPPING EUROPEAN SEABED HABITATS

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Title:	**Acoustic Ground Type Maps of north-west Anglesey**
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Summary:	Acoustic ground type maps have been created from a supplied multibeam dataset combined with particle size analyses. The original data was collected in August 2005 to the north-west of Anglesey by JNCC for the MESH project. This report documents how maps of slope, aspect, rugosity and geofacies were created as an initial step in habitat mapping. Video data and benthic samples will be analysed by other partners to reinterpret the geofacies into benthic environments.
Keywords:	MESH, multibeam echosounder, acoustic geofacies, slope, aspect, rugosity
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1. Executive summary

In August 2005, multibeam sonar data was collected by JNCC to the north-west of Anglesey. The acoustic data was groundtruthed with sediment samples and video tracks. University College Cork was subcontracted by JNCC to prepare the initial steps towards a habitat map using this data: the interpretation of the acoustic seabed mapping data in conjunction with the sediment analyses that groundtruth the different acoustic signatures.

Final results are provided to JNCC in ArcGIS format. The attribute tables with summary metadata are designed as specified in the MESH data exchange format. The MESH Standards and Protocols document was consulted to review the recommended procedures for acoustic data study and sediment analysis.

From depth information, rasters of slope, aspect and rugosity (seabed “bumpiness”) were created using spatial analyses tools in a GIS software package. The 4 survey areas are characterised by steep slopes of up to 45 degrees. Slope proves to be a valuable factor to habitat mapping in this region. Combined with dominant tidal current directions, interpreted from current-related lineations in backscatter values and the orientation of asymmetric sediment waves, the aspect of the slope is classified according to its orientation: facing the dominant current direction, in the shadow of the currents or running parallel to the current direction. Rugosity, a measure of terrain complexity, mainly reflected slope variability and even when analysed to a higher standard failed to achieve a resolution at an appropriate scale to reflect biodiversity.

A detailed study of georeferenced images of backscatter values (the intensity of the acoustic return signal) and bathymetry was conducted. Using expert judgement, the combination of backscatter intensity, backscatter texture and seafloor morphology was examined, 111 different geofacies were recognised and subsequently delineated manually in GIS software.

The particle size analyses of 8 samples was made available by JNCC and was analysed in detail with the aid of a statistics package called GRADISTAT. With a very complex seafloor, there was little correlation between the 8 sediment samples and their corresponding acoustic signature, allowing only a very tentative extrapolation from acoustic ground type to sedimentary environment. Video data and benthic samples will be analysed by other partners to reinterpret the geofacies into benthic environments with more confidence and detail.

This document reports on the rational and methodology of the procedure outlined above. It provides backgrounds information on the different techniques and their merit in habitat mapping. The report presents the different product results in georeferenced charts for the 4 survey areas. The results are critically analysed with comments and recommendations added for future habitat research.

2. Introduction

Multibeam sonar systems provide a full coverage of depth data (potentially to hydrographic standards) and acoustic backscatter intensity of the sea floor. Groundtruthing via optical validation data and particle size analyses of sediment samples allow for a range of interpretations relevant to habitat mapping.

In August 2005, multibeam data was acquired about 14 miles to the north and north-west of Anglesey (Figure 1) using the Kongsberg-Simrad EM1002 hull-mounted on the R/V Celtic Voyager. A total of 17 Van Veen grab samples have been collected of which 8 have been analysed for particle size. An additional 20 video camera drops and 9 video tows were recorded (Figure 2). Video data and benthic samples will be analysed by other partners to reinterpret the geofacies into habitats. This report documents the initial steps towards a habitat map: the interpretation of the acoustic signature with sediment analyses as groundtruthing information.

Figure 1: Multibeam echosounder data in the Irish Sea collected by JNCC in August 2005.

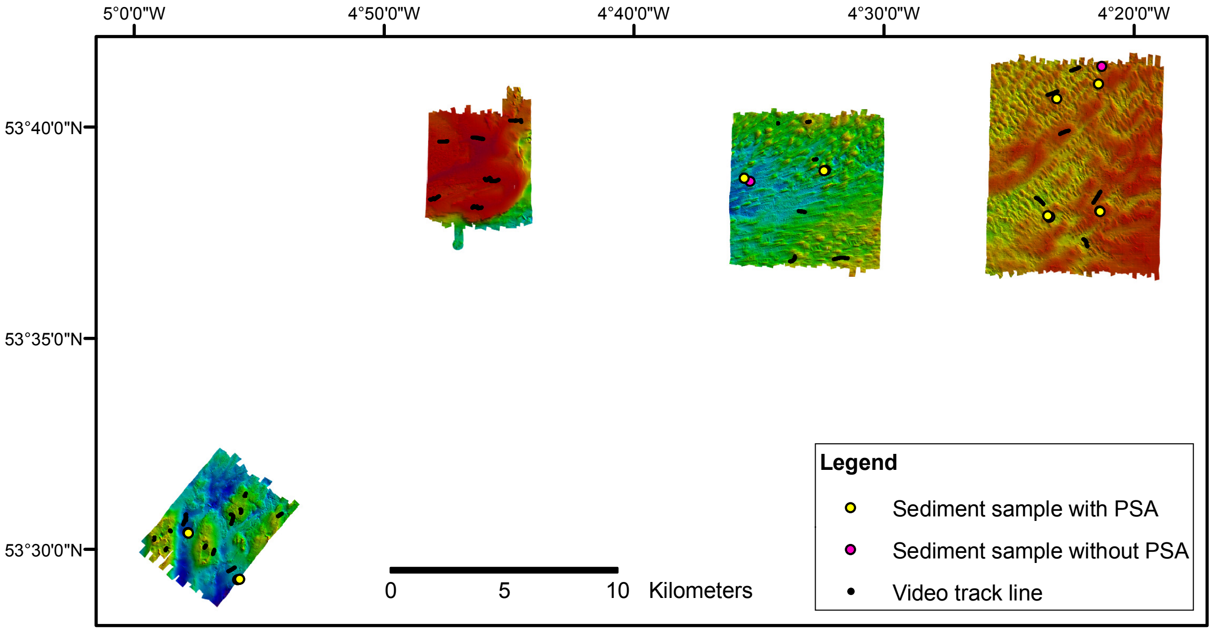

Figure 2: Multibeam echosounder data with sediment samples and video lines.

2.1. Multibeam bathymetry: slope, aspect and rugosity

Multibeam bathymetric data provides valuable information to assist in the production of habitat maps. It creates an extremely accurate digital representation of seafloor topography in a digital terrain model (DTM). The spatial analysis functions of a geographic information system (GIS) allows the extraction of several derived products from bathymetric data, such as slope, aspect, and rugosity. Through a set of standard algorithms, these derived products, and the relationships between them, can be examined to classify the benthic landscape.

Slope information gives an impression of the steepness of the terrain and can be used for further analysis. The output measurement units for slope can be in degrees or percentages. In this project the slope unit is presented in degrees.

A map with *aspect* values displays the steepest down slope direction from each cell to its neighbours for an entire region. It is most commonly used with an elevation raster to identify the direction of slope. The values of the output raster are the compass bearing of the maximum slope.

Rugosity can best be defined as the ratio of surface area to planar area. Basically, rugosity is a measure of terrain complexity or the "bumpiness" of the terrain. In the benthic environment, rugosity can be used to aid in the identification of areas with high biodiversity, depending on the scale of the input bathymetry.

2.2. Multibeam backscatter and bathymetry: acoustically distinct regions

Backscatter intensity can be linked to physical properties of the surficial sediments (texture, dewatering, compaction, density, porosity, velocity), and to bottom roughness produced by features such as ripples, benthic reworking, pebbles, rock surfaces, bioherms etc. It can reveal significant information aiding remote sea-floor characterization (e.g. Goff et al., 2000).

Generally, high backscatter intensity for a large angular range is associated with rock or coarse-grained sediment and low-backscatter intensity characterizes finer-grained sediments (Brekhovskikh & Lysanov, 1982). However, direct observations, using video and sampling techniques are needed to verify such interpretations. Preliminary distinction of regions with similar backscatter values can be made and is of great relevance in the initial stages of habitat mapping. Patterns of seafloor topography represent regions of geomorphological feature types and the physiography governing the spatial distributions of benthic habitats.

Because of the complexity of the backscatter pattern in the surveyed areas, backscatter texture and morphological information derived from the bathymetry data is combined with the backscatter intensities in order to define acoustic similarities and differences. This technique is often used while mapping the seabed (e.g. Dartnell and Gardner, 2004).

2.3. Sediment samples: describing the ground type

Sediment samples are used for groundtruthing and to correlate between sediment type and acoustic ground type. In the 4 survey areas, JNCC analysed the particle size distribution of 8 grab samples to be used as groundtruthing dataset to describe the acoustic ground types (Figure 2). Of the 8 analysed samples, 4 were collected in area 1, 2 in area 2, none in area 3 and 2 in area 4. Sample coverage is limited with a small percentage of all acoustic signatures “truthed” and the accuracy of the correlation is therefore expected to be limited.

3. Methods

3.1. Calculating slope, aspect and rugosity

Before slope, aspect and rugosity could be calculated, new bathymetry rasters needed to be created from the raw depth data. This involved multiple processing steps in CARIS HIPS and SIPS software version 5.4 as well as in ESRI ArcGIS software version 9.1. In CARIS HIPS, a Bathymetry Associated with Statistical Error (BASE) surface was created. A BASE surface is a multi-attributed, geo-referenced image which can be enhanced with sun-illumination and a customized colour map. A range-weighting scheme, based on a sounding’s distance from a node, is always applied when creating a BASE surface. As second weighting scheme, the swath angle was chosen which is based on a beam's intersection angle with the seafloor. Therefore, the weight a sounding contributes to the BASE surface varies by the sounding's grazing angle with the seafloor. In an area with overlapping survey lines, the grazing angle weight ensures that a higher weight priority is given to beams from the inner part of a swath than to the outer beams from adjacent survey lines.

Soundings with an angle between 90 and 75 degrees are given a weight of 1.0. The weight decreases linearly to 0.01 as the grazing angles with the seafloor decreases to 15 degrees. After several tests, a gridding resolution of 10 m was chosen while creating the BASE surface. Higher resolution BASE surfaces, e.g. 5 m and 2 m, contain unnecessary detail that significantly increased computation time. The BASE surface was exported into a text file (xyz) using the tool Export Wizard – BASE surface to ASCII. This output text file contains information of meters easting, meters northing and positive values of depth for every node. With positive depth values altered into negative values using Golden Software Grapher version 4.0, the file was exported as a .csv file. In ArcView, the .csv file was imported and the xyz information plotted. In CARIS, the data was originally projected in UTM zone 30N, and a reprojection of the spatial reference was needed so that all points plotted in geographic coordinate system WGS 1984. This projection was performed using a tool in ArcToolbox: Data Management Tools – Projections and Transformations. The individual points were consequently interpolated to a GIS raster. Using the Spatial Analyses tool in ArcView, kriging was selected as the statistical terrain generation method. Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z values. Unlike the other interpolation methods supported by Spatial Analyst, kriging involves an interactive investigation of the spatial behaviour of the phenomenon represented by the z values before the user selects the best estimation method for generating the output surface. For every sounding of the swath, the kriging estimate of the depth is obtained from the soundings of its neighbourhood (Chauvet 1994). The cell size of all rasters was fixed at 10 m ($8.9892*10^{-5}$ decimal degrees), so technically the interpolation mechanism didn't change the output raster (as input resolution was also set at 10 m), however, kriging does produce a more reliable surface.

Via the ArcGIS Spatial Analyst toolbar, slope values were calculated. The Slope function calculates the maximum rate of change between each cell and its neighbours. Every cell in the output raster has a slope value. The lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain. When the slope angle equals 45 degrees, the rise is equal to the run and is expressed as a percentage, the slope of this angle is 100 percent. As the slope approaches vertical (90°), the percentage slope approaches infinity.

Aspect values were calculated via the same ArcGIS Spatial Analyst toolbar. Aspect is measured clockwise in degrees from 0 (due north) to 359. The value of each cell in an aspect dataset indicates the direction the cell's slope faces. Flat areas having no down slope direction are given a value of -1. Physically similar habitats are likely to support similar biological communities. Aspect is a measure of slope orientation and joined with current orientation can be a very useful parameter. The linear patter in the backscatter data and the orientation of the asymmetry of the sediment waves reveal the predominant tidal direction in each survey area. The aspect rasters were then reclassified using the Spatial Analyst tool in ArcView and the slope orientation values were categorized into 3 classes: slopes facing the dominant tidal currents (up-slope), slopes facing away from those currents (down-slope) and slopes where currents run along-slope. Profiles over sand waves in the survey areas were made in CARIS HIPS and exported in Microsoft Office Excel 2003. Their asymmetry confirmed a dominant flood current to the ENE-NNE. The exact azimuth of the dominant current direction in the different survey areas were defined in ArcGIS. The angles to which the slopes are orientated were changed accordingly in the 4 aspect rasters.
With "x" being the azimuth in each area, the aspect values were classified as follows, also see Figure 3:

- Class 1: Yellow - Currents along-slope: slope orientations between x – 90º and x - 45º and between x + 45º and x + 135º
- Class 2: Green - Currents down-slope: slope orientations between x - 45º and x + 45º.
- Class 3: Red - Currents up-slope: slope orientations between x + 135º and x + 225º.

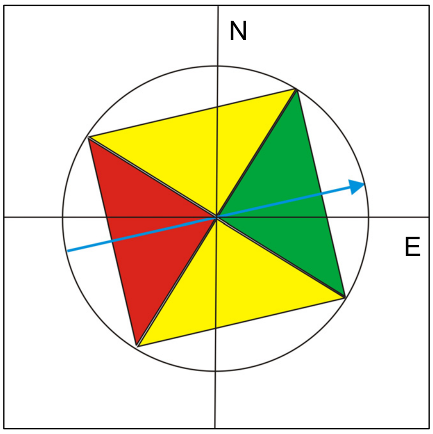

Figure 3: Classification of aspect values. Blue arrow: azimuth of the dominant tidal current direction.

The Benthic Terrain Modeller (BTM) is a collection of ArcGIS-based terrain visualization tools that can be used by coastal and marine resource managers to examine the deepwater benthic environment using input bathymetric datasets. It uses a process developed by Jeff Jenness to derive rugosity from an input bathymetric dataset (Jenness, 2003). This methodology creates an output that is similar to a Triangulated Irregular Network (TIN).

With this software extension, the Bathymetric Position Index (BPI) was calculated. Bathymetric Position Index (BPI) is a measure of where a referenced location is relative to the locations surrounding it and has proved to be useful for seafloor classification as mentioned in the MESH Standard and Protocols document. The BPI of the DTMs collected for this project was calculated on a large and fine scale, but the high complexity of the seafloor morphology with a high density of seabed features in areas 1 and 2 did not result in easily distinguishable regions. The BPI method was therefore not used as a parameter for the seafloor morphology analysis presented here.

Similar to BPI dataset creation, rugosity derivation relies, in part, on a neighbourhood analysis using a 3 grid cell by 3 grid cell neighbourhood. An algorithm was passed through the Raster Map Algebra Operation object within Spatial Analyst that calculates the planar distance between the centre point of the centre cell and of each of the eight surrounding cells in the neighbourhood. Next, using the Pythagorean Theorem, the surface distance was calculated for each planar distance using the difference in elevation between the cells. The result of this function was sixteen separate grid datasets with each cell value equal to this surface distance. The area formed by three adjacent sides was calculated, resulting in eight triangular surface area grids (Figure 4). These grid datasets are combined to obtain a surface area dataset for the input bathymetric dataset. Finally, a dataset that represents the ratio of surface area to planar area was created representing rugosity for the study area. Rugosity values close to 1 indicate flat, smooth locations; higher values indicate areas of high-relief. Rugosity calculated at the scale of this survey is expected to highly correlate with slope.

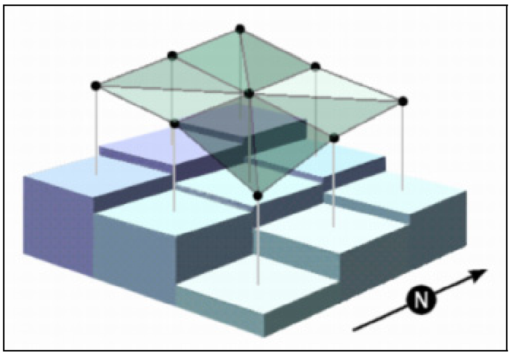

Figure 4: Representation of the surface area dataset created from the rugosity builder (Jenness, 2003)

The BTM was developed as part of a cooperative agreement between the Oregon State University (OSU) Department of Geosciences and the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center. The algorithms and methods that were utilized within the tool were developed and refined by the OSU project team, under the direction of Dawn Wright.

3.2. Delineating acoustically distinct regions

Cleaned multibeam bathymetric and backscatter data was provided by the JNCC as georeferenced mosaics, presented in Figure 5 to Figure 8. The resolution of the bathymetry images is 3 m, the resolution of the backscatter images is 5 m.

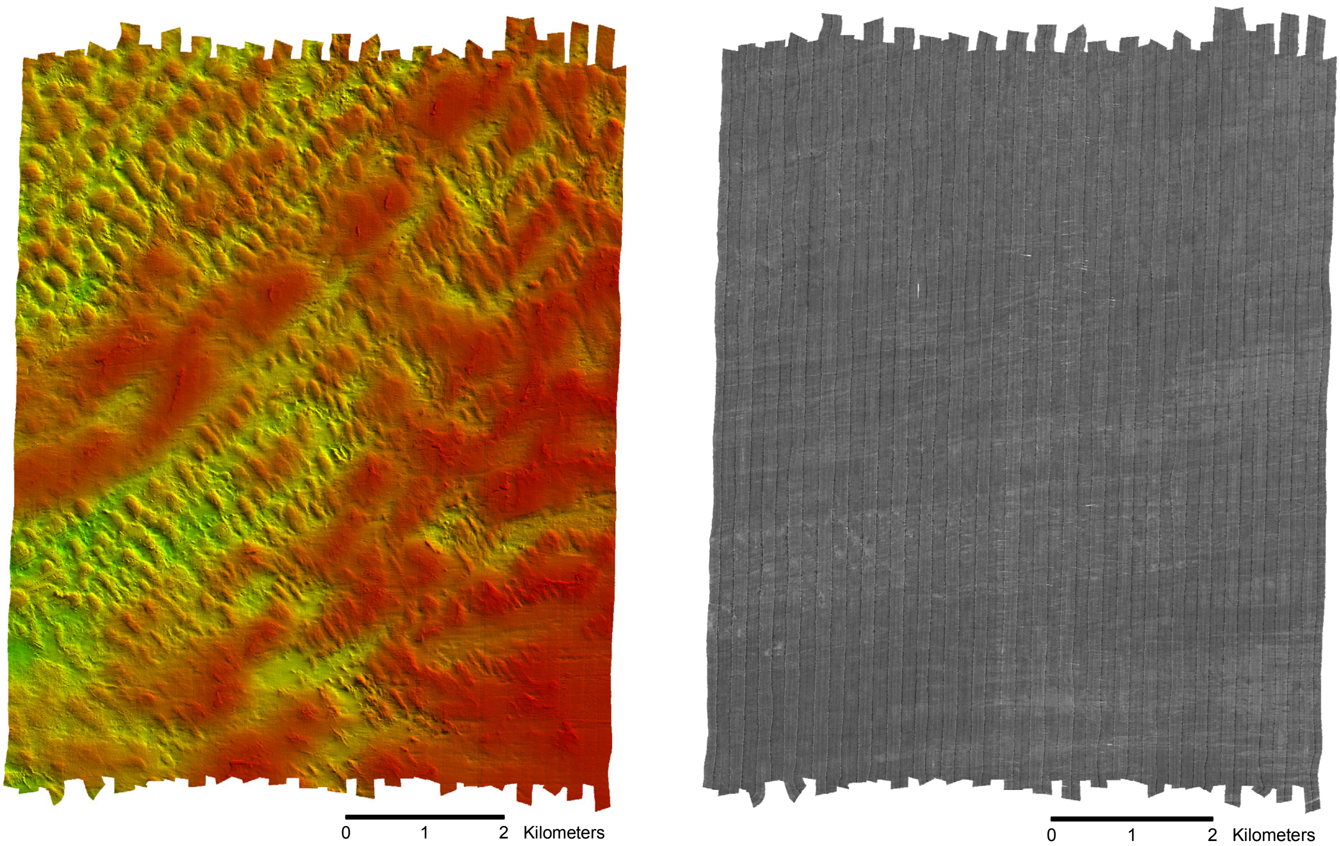

Figure 5: Bathymetry and backscatter images of survey area 1.

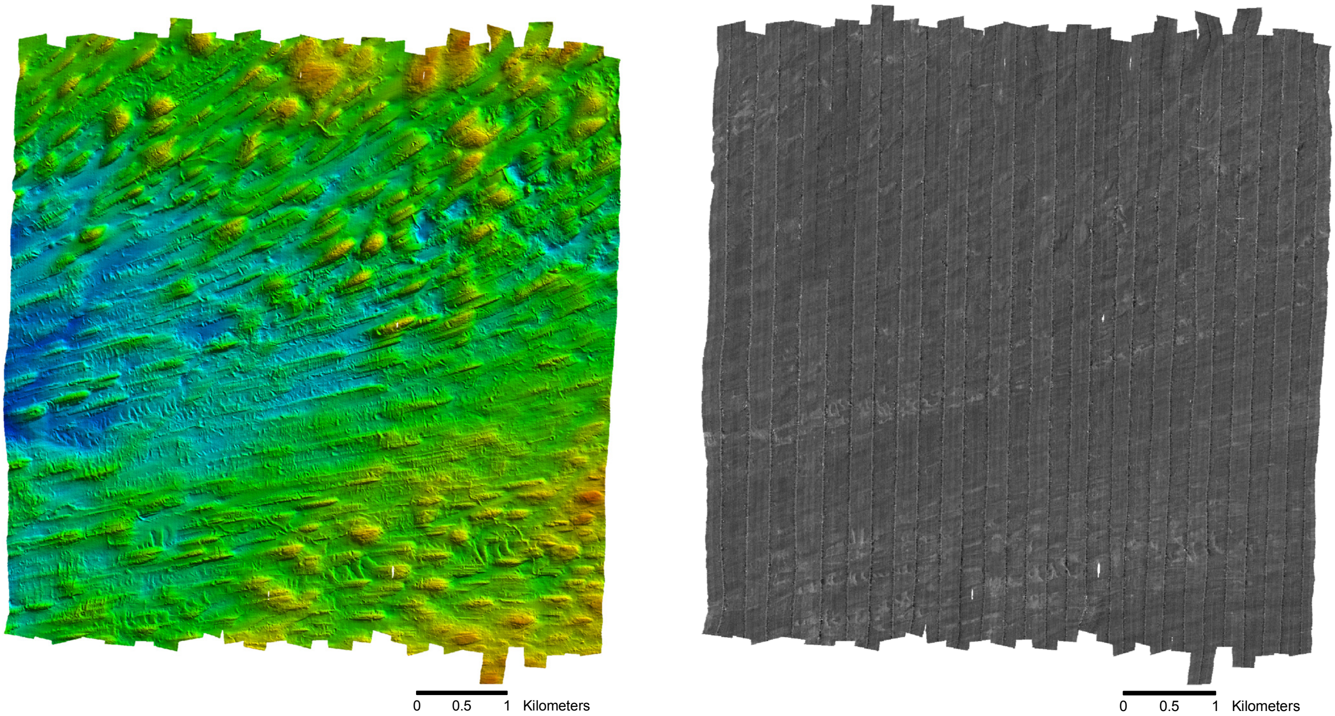

Figure 6: Bathymetry and backscatter images of survey area 2.

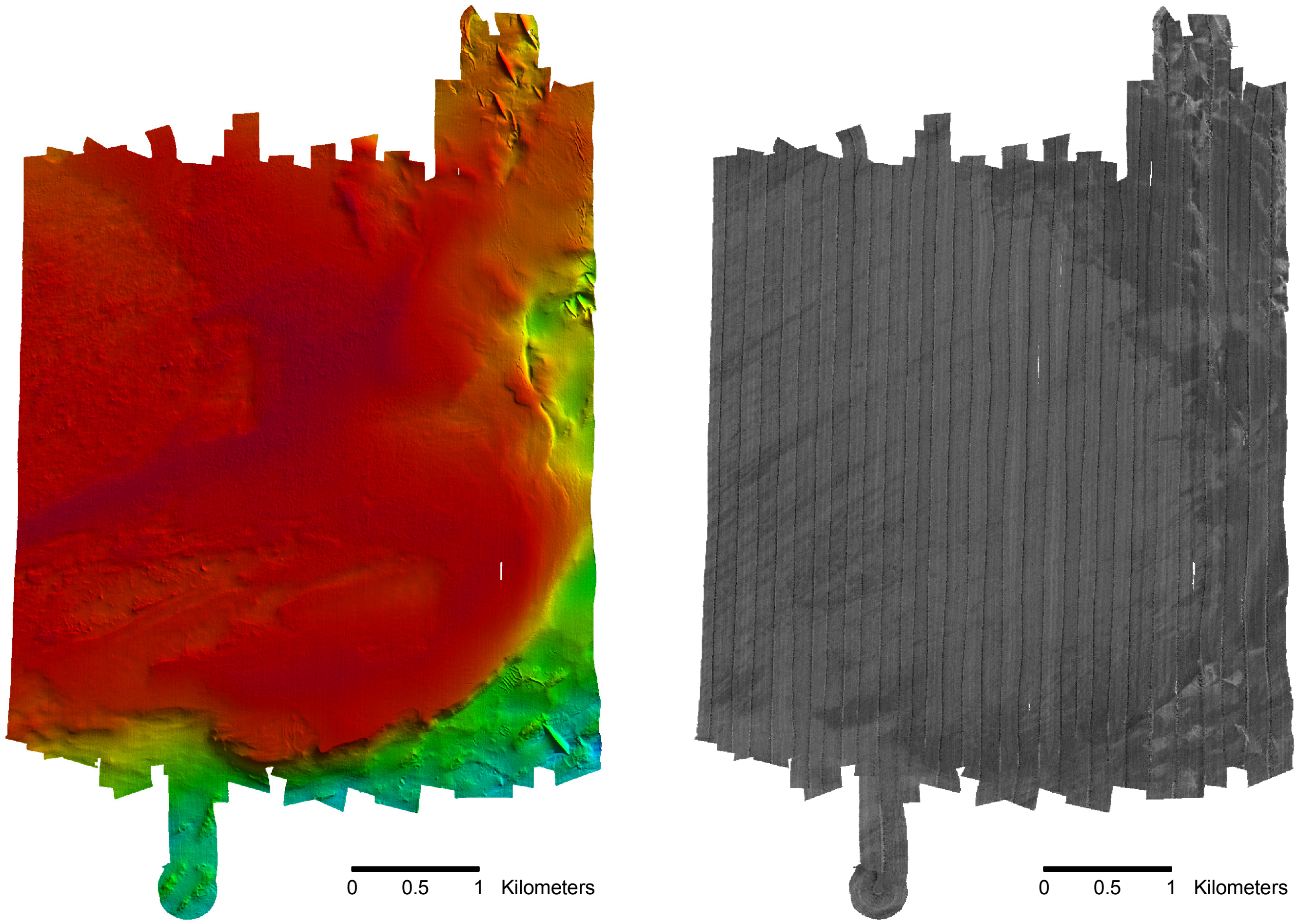

Figure 7: Bathymetry and backscatter images of survey area 3.

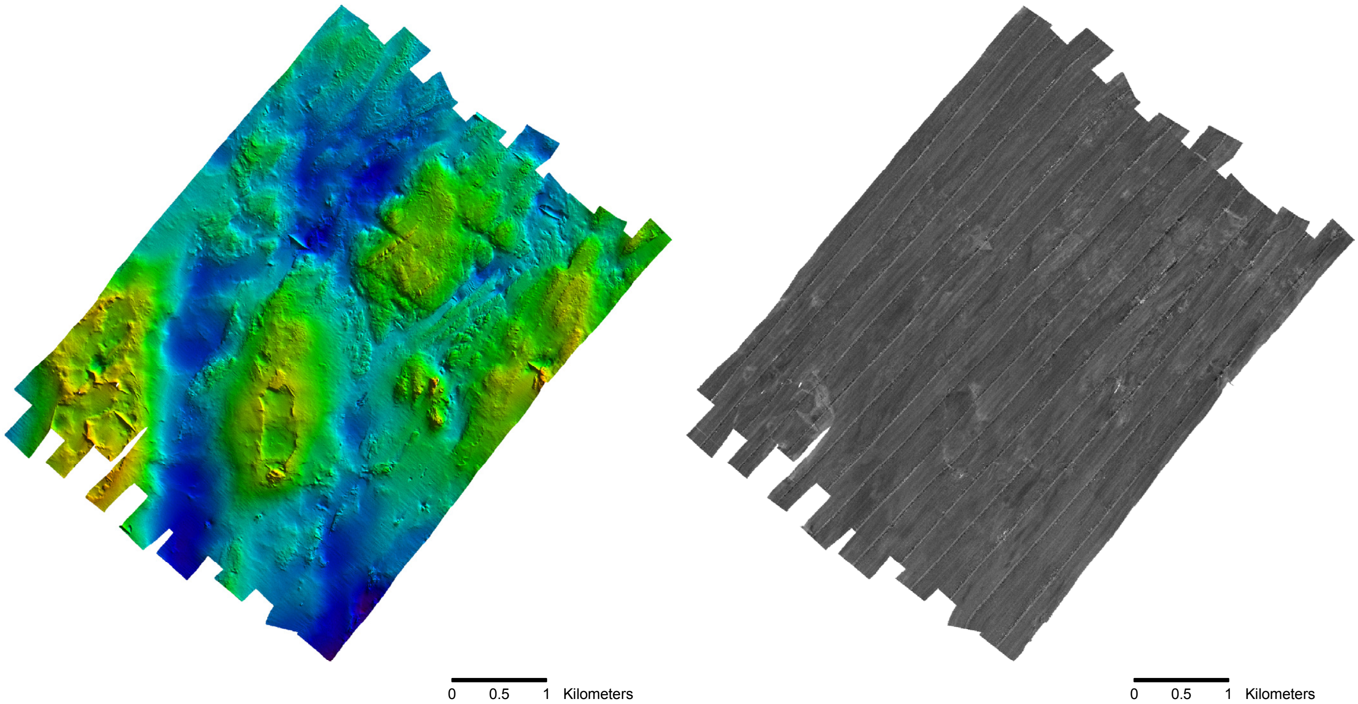

Figure 8: Bathymetry and backscatter images of survey area 4.

Textural classes derived from this data were developed by visual delineation of similar backscatter signatures. These classes were combined with morphological features identified from the bathymetry data to give a complete set of acoustic ground types.

Per polygon, four main acoustic parameters were described in text format (maximum length of 50 characters) in 4 attribute fields:

- Backscatter intensity: low, medium and/or high
  Attribute field: BACKSC_INT
  → Backscatter intensities were classified relative to each other per survey area. It would be incorrect to interpolate backscatter intensities over different survey areas as apart from local bottom slope and near nadir reflection, backscatter strength also varies with depth. The intensity allocated to a polygon ideally reflects the ground type signature and not acoustic shadows and survey artefacts, however it was not always possible to perfectly make that distinction.
- Backscatter texture: homogenous, mottled and/or banded
  Attribute field: BACKSC_TEX
  → The variations in backscatter occur on a very small scale in most regions of the survey areas and high detail delineation would lead to an indistinguishable clew of polygons. The texture of these regions was described with the predominant backscatter intensity described first in the previous field.
- Seafloor morphology: featureless or irregular
  Attribute field: MORPHOLOGY
  → On a larger scale, featureless and irregular parts of the seabed were separated regardless of the backscatter values.

- Prominent small and large scale seabed features: boulders, rock outcrop, mussel bed, steep slopes (>10º) etc.
  Attribute field: FEATURES
  - → Seabed features of a certain dimension can be recognised in the bathymetry data. Identification of some features was based on previous research and experience. The acoustic signature of a *Modiolus* mussel bed for example is well documented in the HabMap dataset in Caernarfon Bay and the resemblance in this GB000472 dataset justifies a similar interpretation. The definition of steep slopes is based on the sea floor slope index by Valentine *et al*. (2005).

These four attributes were summarised in a sentence in an attribute field called ORIG_HAB.

To tie the polygons together in a full coverage, the snapping function in ArcGIS was used to prevent the creation of overlapping or sliver polygons. To make sure vertices coincided where they should be identical, the Integrate tool in ArcToolbox – Data Management Tools – Feature class was applied.

To decrease the amount of polygons and to make the shapefiles more manageable, polygons with identical acoustic signature were merged using the Editor Tool – Merge. Non-adjacent polygons with the same ground type were hence combined in a multipart polygon.

3.3. Sediment characterisation

The entire grain-size distribution of sediment covering the seafloor influences acoustic backscatter signals. Previous research has confirmed that for interpretation of acoustic signature it is valuable to use standard statistical variables derived from the grain size distribution: e.g. mean, sorting, skewness and percentage coarse and fine fraction (e.g. Goff et al., 2000).

As advised in the MESH Standard and Protocols document, a grain size distribution and statistics package developed by Simon Blott is used for the analysis of unconsolidated sediments by sieving or laser granulometer. The development of this program, referred to as “GRADISTAT”, was inspired by Dave Thornley and John Jack at the Postgraduate Research Institute for Sedimentology at the University of Reading, UK, and the Department of Geology at Royal Holloway University of London, UK. It is provided in Microsoft Excel format to allow both spreadsheet and graphical output.

For the 8 samples, the percentage of sediment retained by 12 different sieves apertures was calculated by JNCC. Using these percentages as inputs into GRADISTAT, the following statistics were calculated using the Method of Moments in Microsoft Visual Basic programming language for each sample: mean, mode(s), sorting (standard deviation), skewness, kurtosis, D10, D50, D90, D90/D10, D90-D10, D75/D25 and D75-D25. Grain size parameters are calculated arithmetically and geometrically (in microns) and logarithmically (using the phi scale) (Krumbein and Pettijohn, 1938). Linear interpolation is also used to calculate statistical parameters by the Folk and Ward (1957) graphical method and derive physical descriptions (such as “very coarse sand” and “moderately sorted”).

The program also provides a physical description of the textural group to which the sample belongs and a sediment name (such as “fine gravelly coarse sand”) after Folk (1954) (Figure 9). Also included is a table giving the percentage of grains falling into each size fraction, modified from Udden (1914) and Wentworth (1922) (Figure 10). The program is ideal for the rapid analysis of sieve data and is freely available from the author (Blott & Pye, 2001).

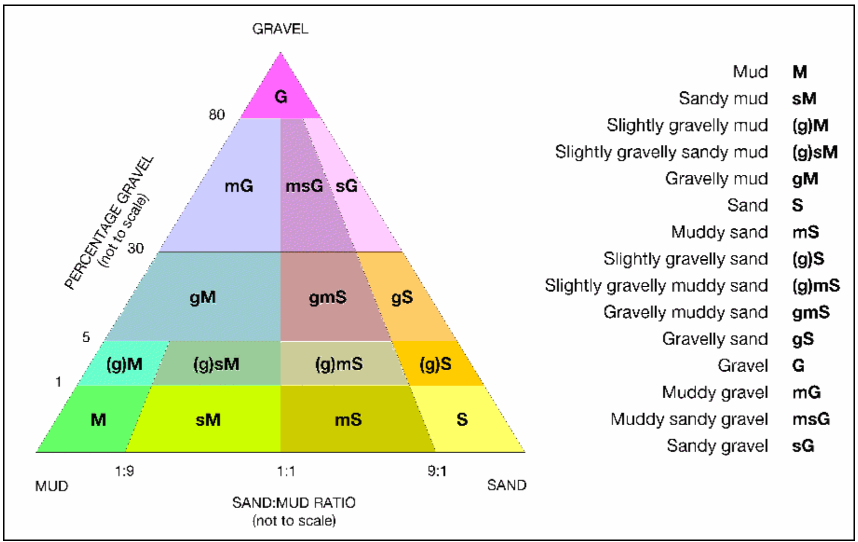

Figure 9: Grain-size classification based on Folk (1954).

Grain Size phi	mm	Descriptive term	
		Very Large	
-10	1024		
		Large	
-9	512		Boulder
		Medium	
-8	256		
		Small	
-7	128		
		Very small	
-6	64		
		Very coarse	
-5	32		
		Coarse	
-4	16		
		Medium	Gravel
-3	8		
		Fine	
-2	4		
		Very fine	
-1	2		
		Very coarse	
0	1		
	microns	Coarse	
1	500		
		Medium	Sand
2	250		
		Fine	
3	125		
		Very fine	
4	63		
		Very coarse	
5	31		
		Coarse	
6	16		
		Medium	Silt
7	8		
		Fine	
8	4		
		Very fine	
9	2		
		Clay	

Figure 10: Size scale adopted in the GRADISTAT program, modified from Udden (1914) and Wentworth (1922).

3.4. MESH Data Exchange Format

The 4 GIS vector files containing the acoustic ground types for each survey area are accompanied by shapefile attribute tables that are compatible with the MESH Data Exchange Format (DEF). Additional fields were created where needed or where it provided valuable information, but a core of 5 attribute fields was always included: FID, Shape, POLYGON or POINT, GUI and a data field (ORIG_HAB or DATA):

MESH DEF		
Field	**Format**	**Comment**
FID	Number	Feature ID. Internally generated identification number for each polygon (not visible when dbf is opened in Excel)
Shape	Text (8)	Internally generated text, indicating whether the feature is a polygon, point or line (not visible when dbf is opened in Excel).
POLYGON or POINT	Long integer Precision 8	Identification number for each polygon or point which must be manually created as ascending integers 1,2,3… etc. This label for each polygon/point is necessary to identify the original polygon/point because the *FID* field will change when datasets are merged.
GUI	Text (8)	Globally unique identifier (GUI) of the dataset. Consists of 2 letter country code (which corresponds to ISO3166-1) plus 6 digits. For this dataset the GUI is defined as GB000472.
ORIG_HAB or *DATA*	Text (255) Text (255)	The information identifying the habitat type present in a polygon, either code or text (the description of the habitat). The physical data value or description recorded in each polygon.

4. Results

4.1. Slope, aspect and rugosity

The spatial reference system for the electronic version of the rasters is the Geographical Coordinate System (GCS) WGS_1984. All maps in this report are projected in UTM zone 30N within the same GCS WGS_1984. A spatial reference grid is added in degrees, minutes and seconds. The view of the data thus presented is the same as during acquisition of the data.

The maps below were initially created in ArcView and exported as Enhanced Windows Metafiles (EMF) with a resolution of 300 dpi and a resample ratio of 1 to preserve the best quality.

4.1.1. Slope

Slope values maps are displayed in Figure 11 to Figure 14 with the legends showing the minimum and maximum values of slope in degrees.

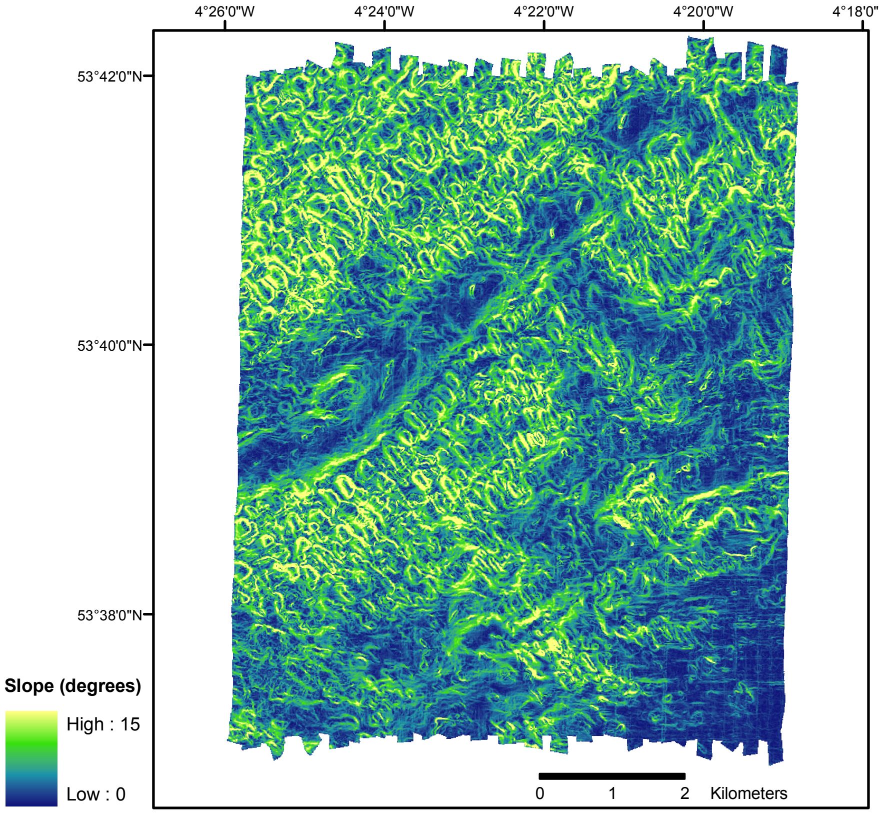

Figure 11: Raster with slope values in survey area 1

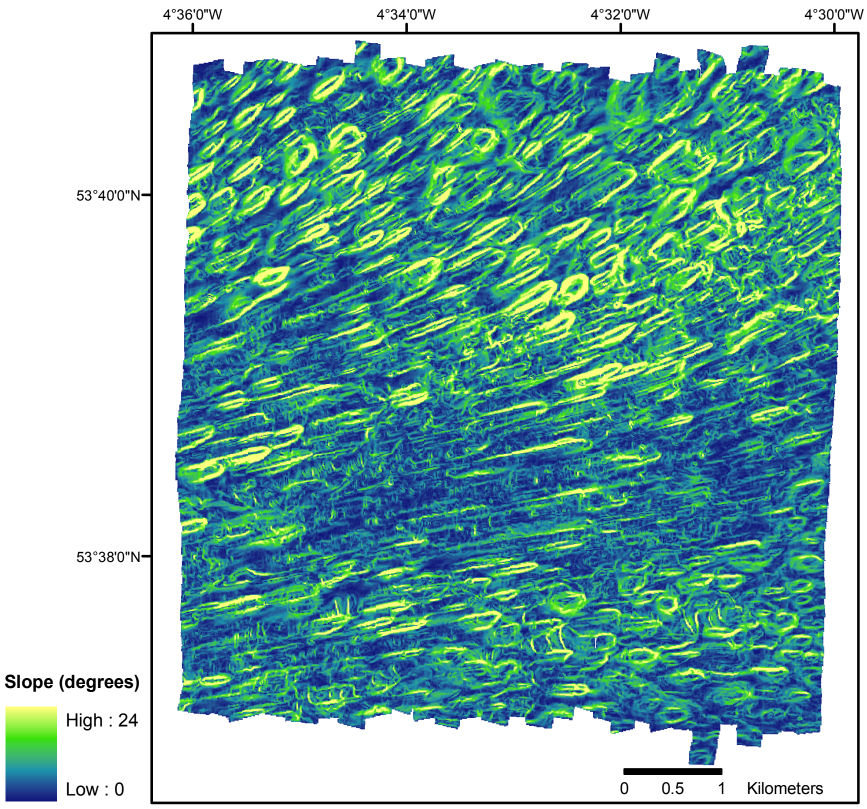

Figure 12: Raster with slope values in survey area 2

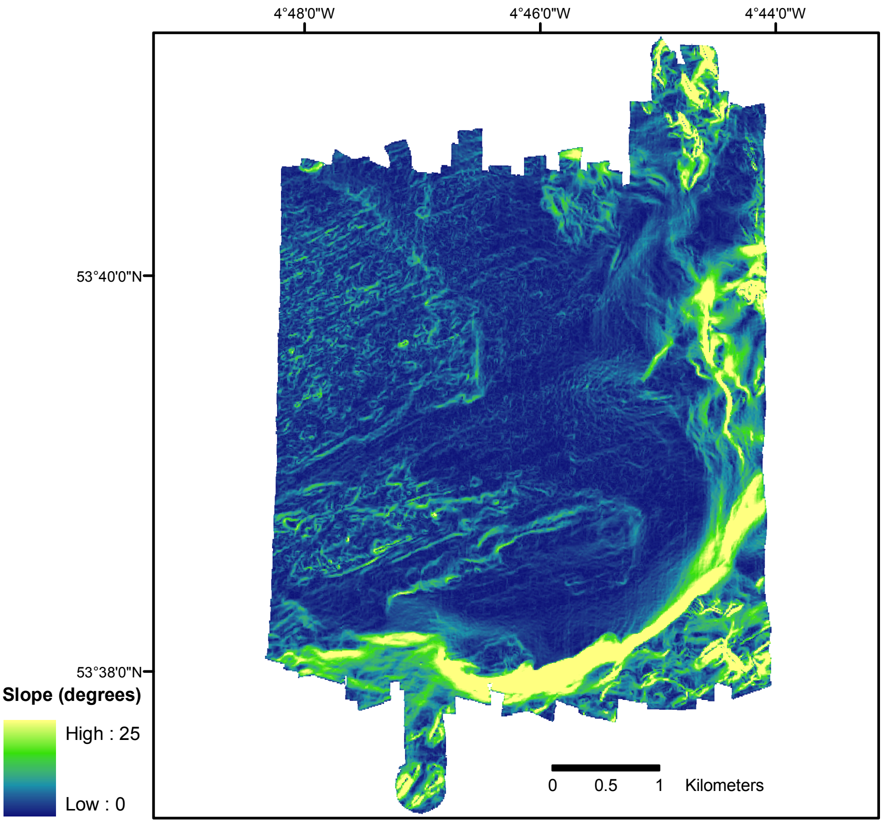

Figure 13: Raster with slope values in survey area 3

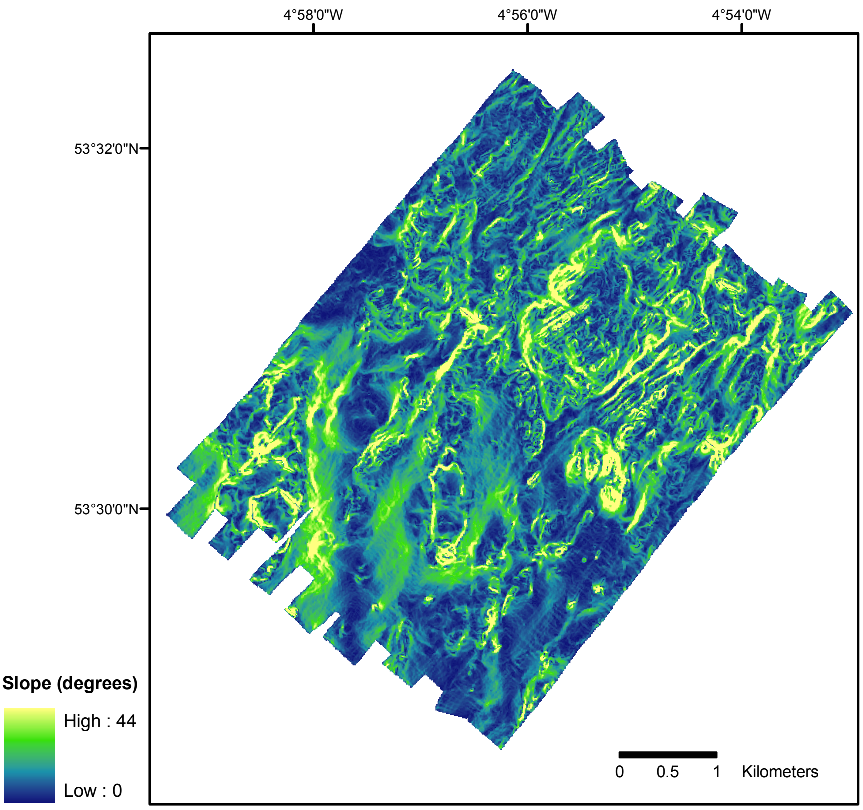

Figure 14: Raster with slope values in survey area 4

4.1.2. Aspect

Aspect values maps are presented in Figure 15 to Figure 18 using three categories associated with the dominant tidal current direction. The azimuth of the dominant current direction in the different survey areas were defined in ArcGIS. In Area 1, this azimuth is 83º, in Area 2 it is 81º, in Area 3 currents are orientated at 68º and in Area 4 at 53º.

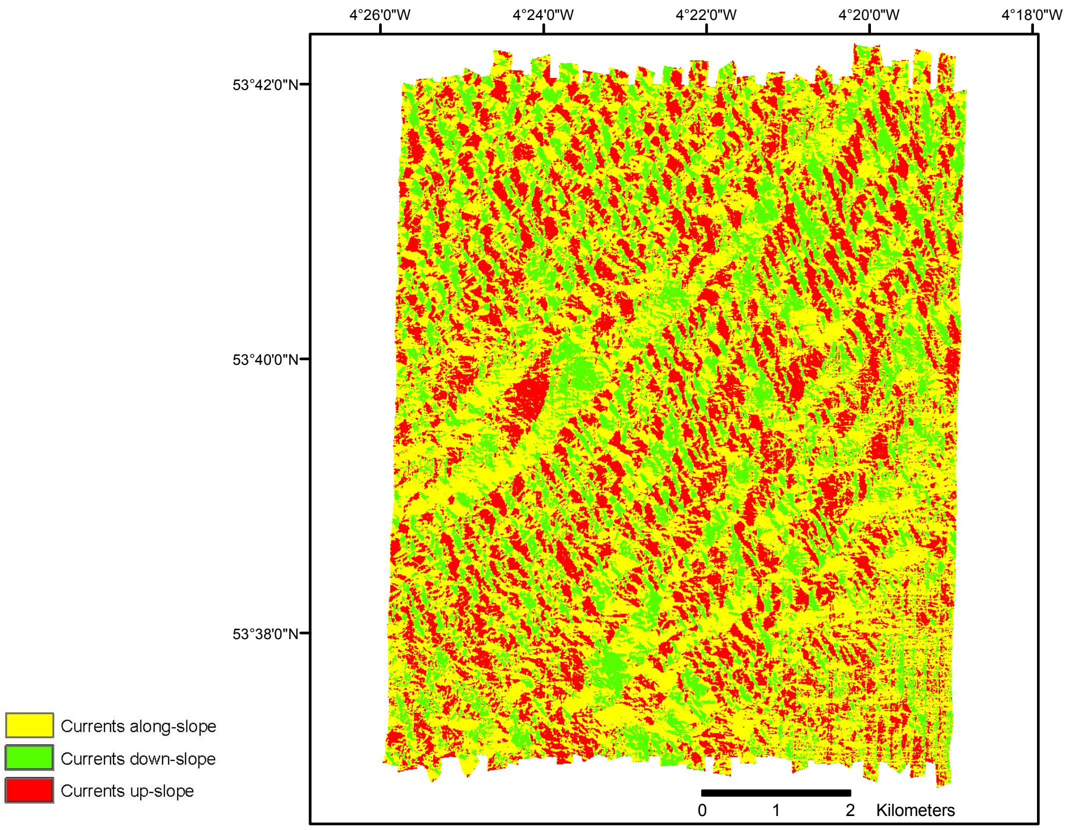

Figure 15: Raster with aspect classification in survey area 1

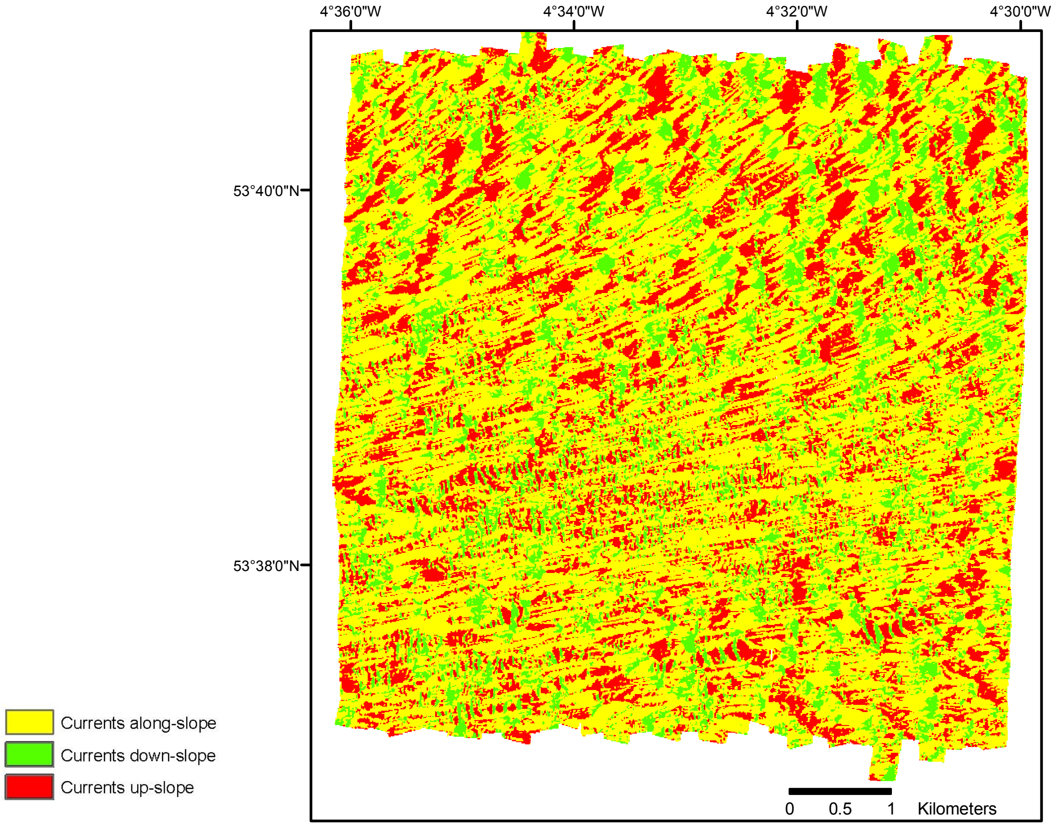

Figure 16: Raster with aspect classification in survey area 2

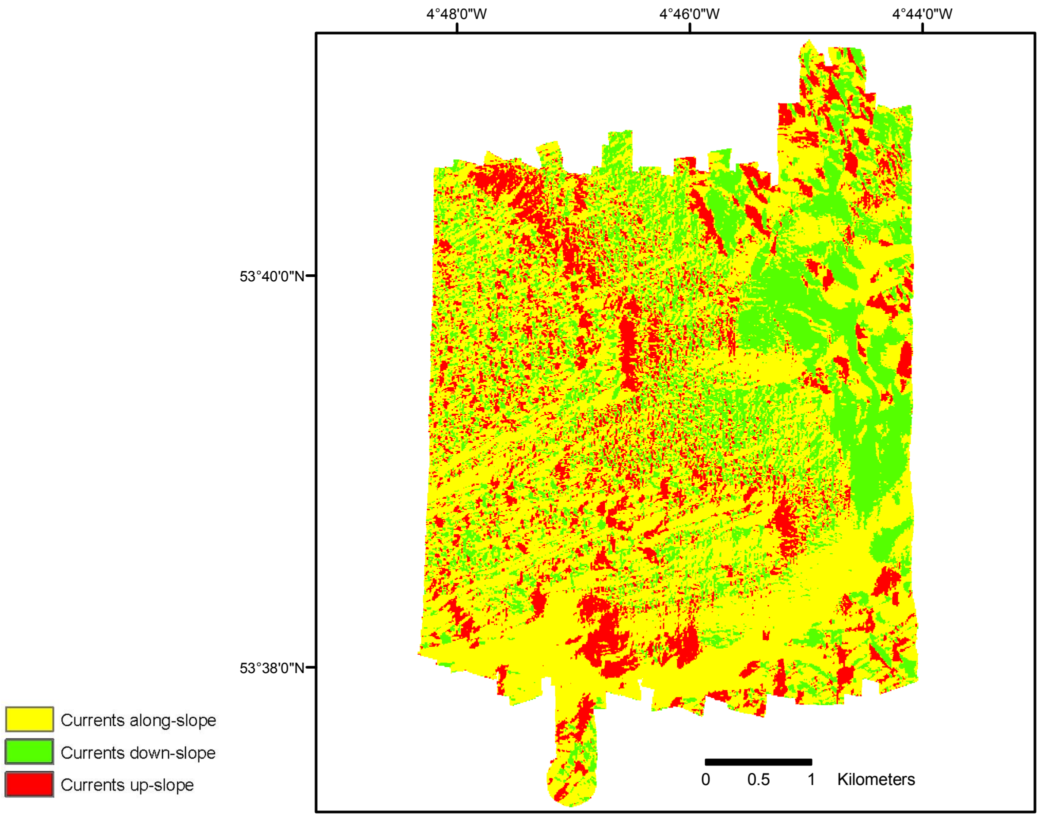

Figure 17: Raster with aspect classification in survey area 3

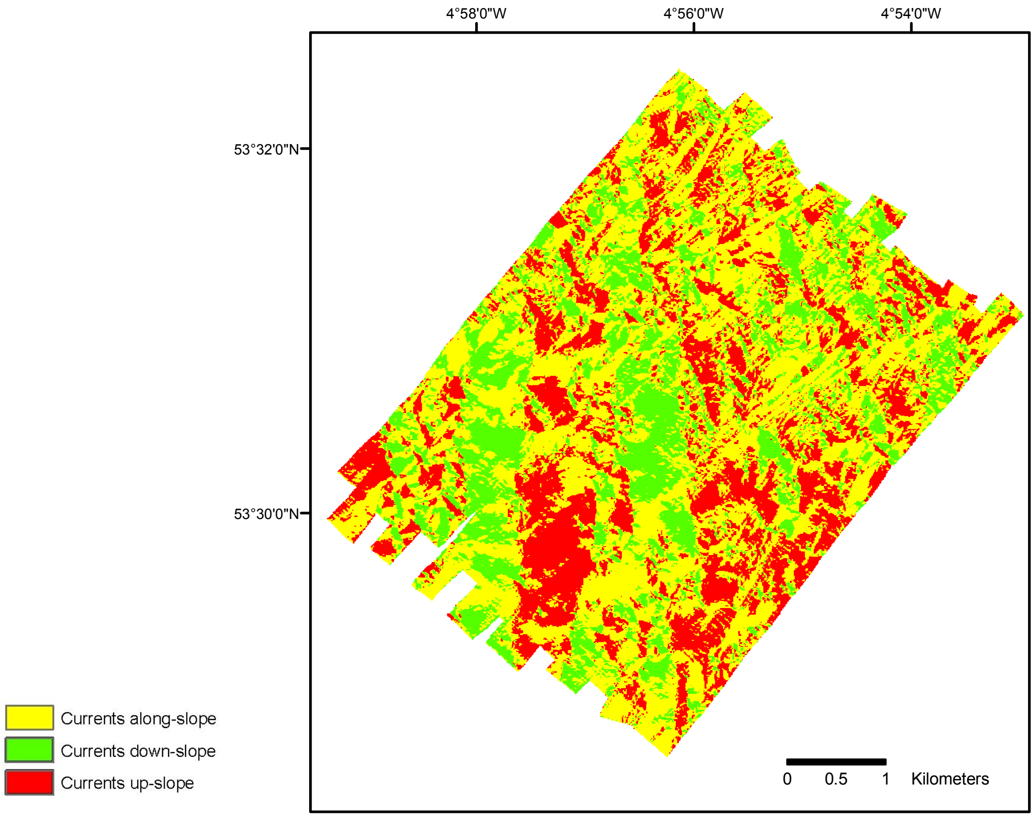

Figure 18: Raster with aspect classification in survey area 4

4.1.3. Rugosity

Rugosity values maps are created for each survey area and presented in Figure 19 to Figure 22.

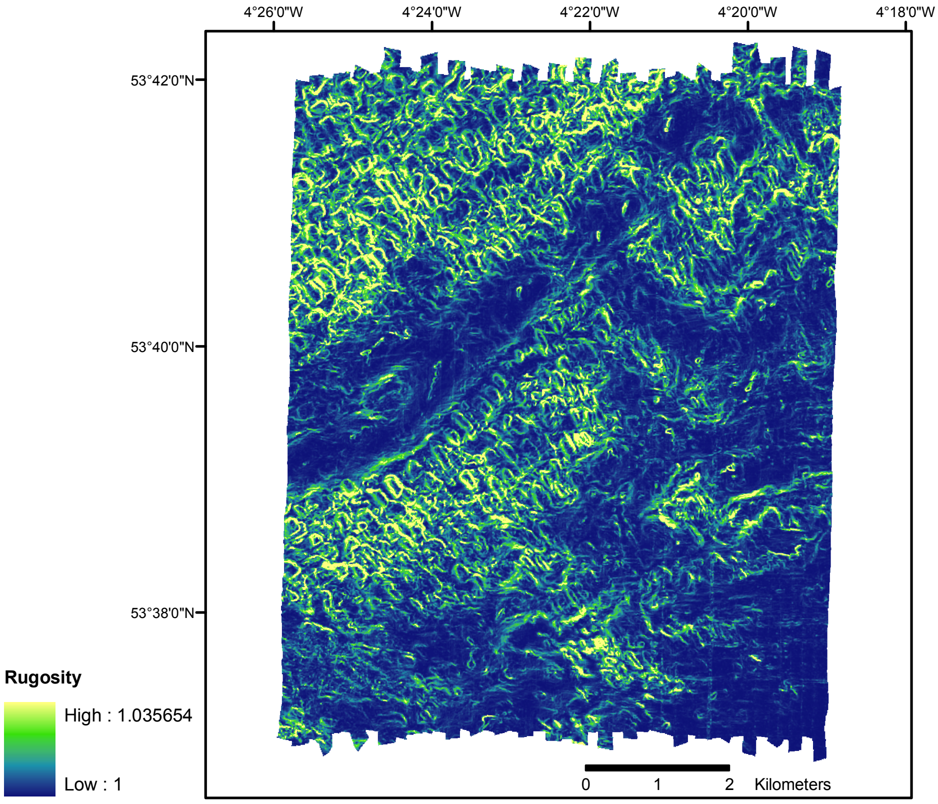

Figure 19: Raster with rugosity values in survey area 1

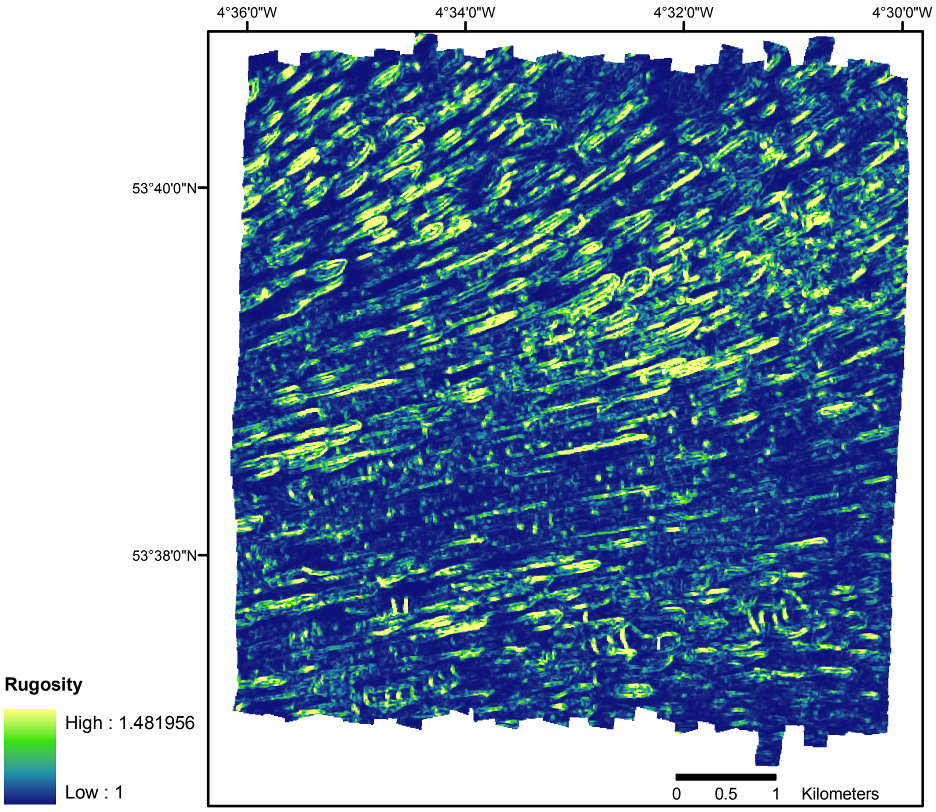

Figure 20: Raster with rugosity values in survey area 2

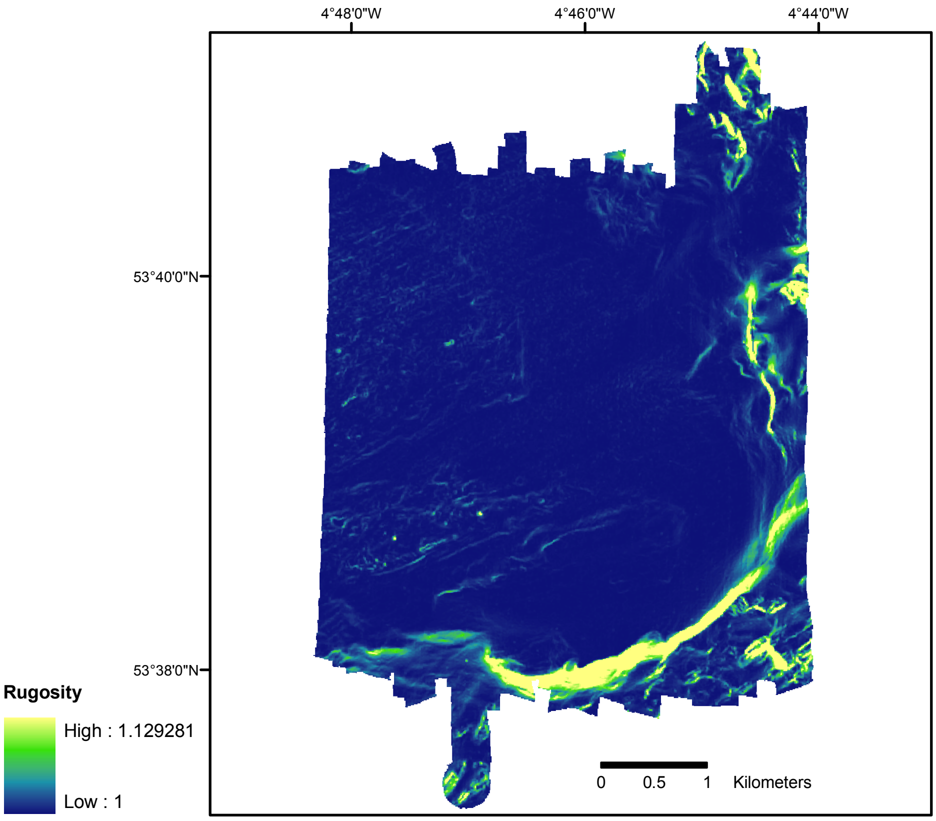

Figure 21: Raster with rugosity values in survey area 3

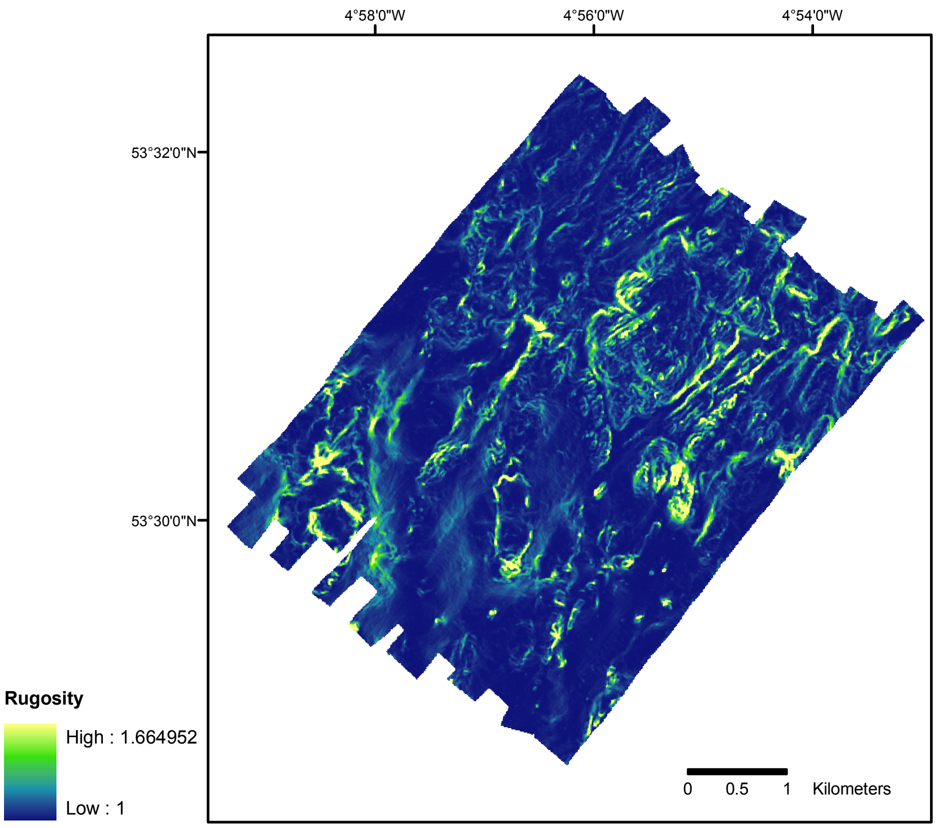

Figure 22: Raster with rugosity values in survey area 4

4.2. Acoustic ground types

Exactly 314 polygons were created manually over the 4 survey areas. The 111 different acoustic ground types defined are displayed in Figure 23 to Figure 26. To enhance the differences between acoustic signatures, larger maps could be created if required.

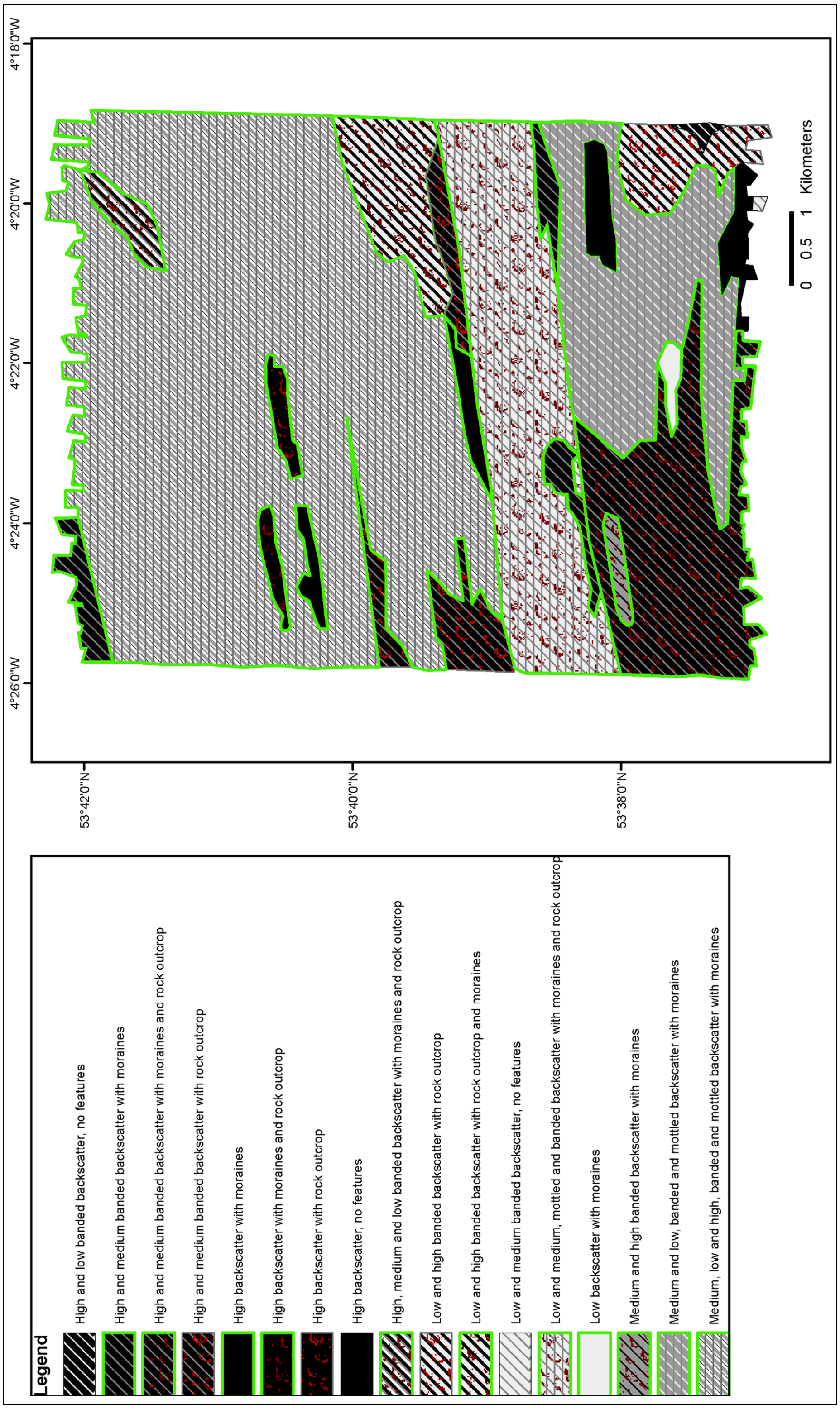

Figure 23: Acoustic ground types in survey area 1

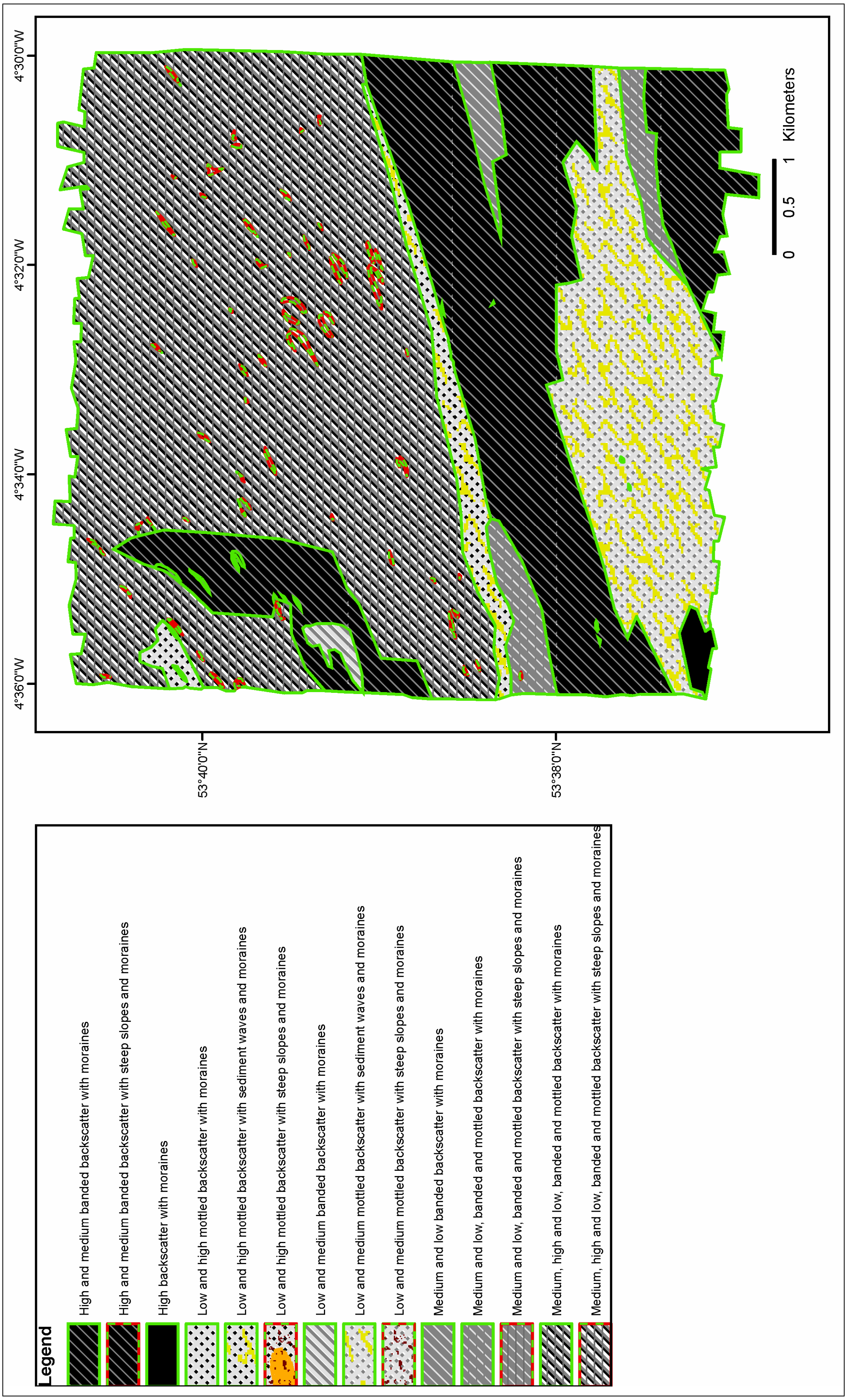

Figure 24: Acoustic ground types in survey area 2

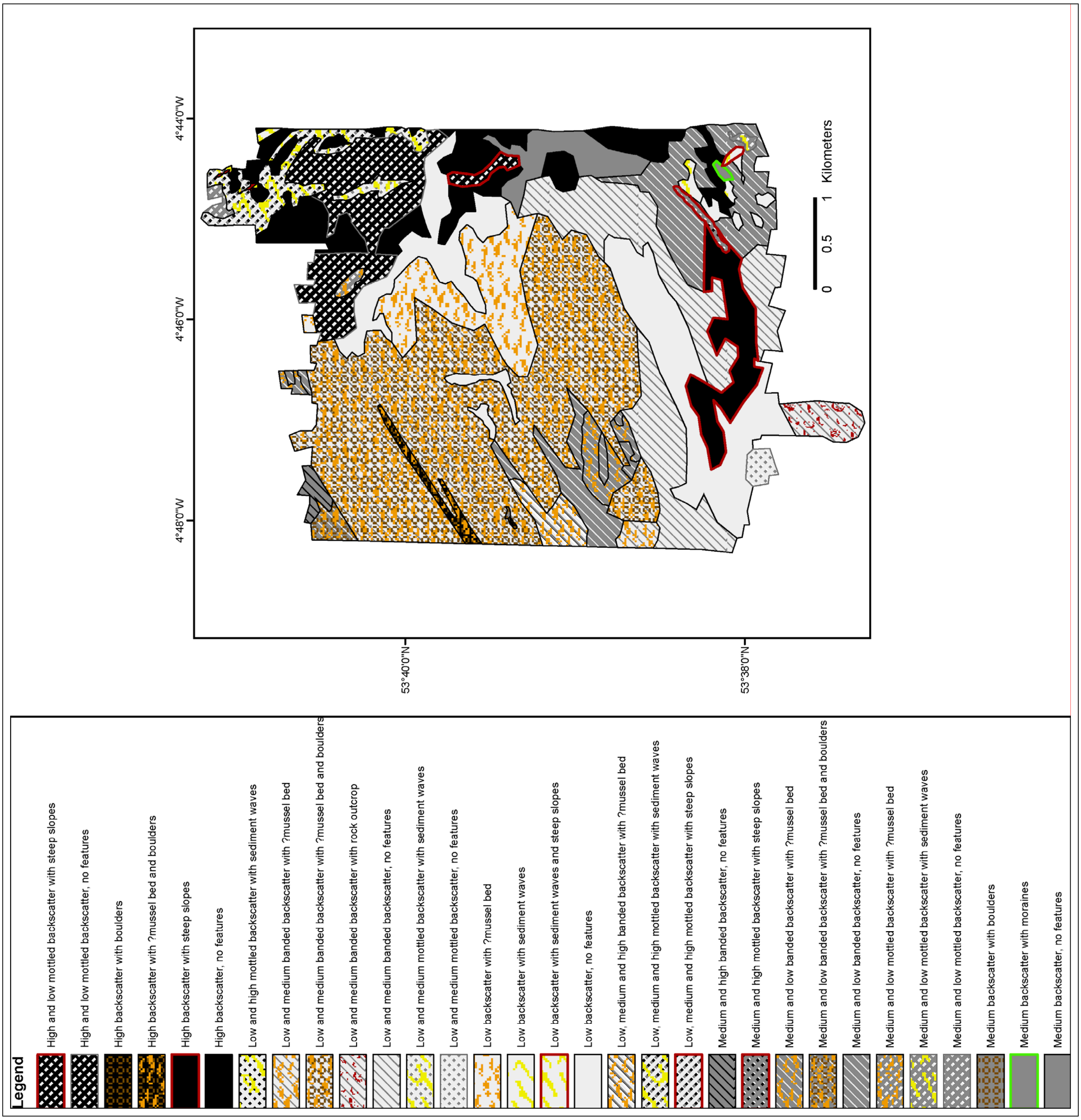

Figure 25: Acoustic ground types in survey area 3

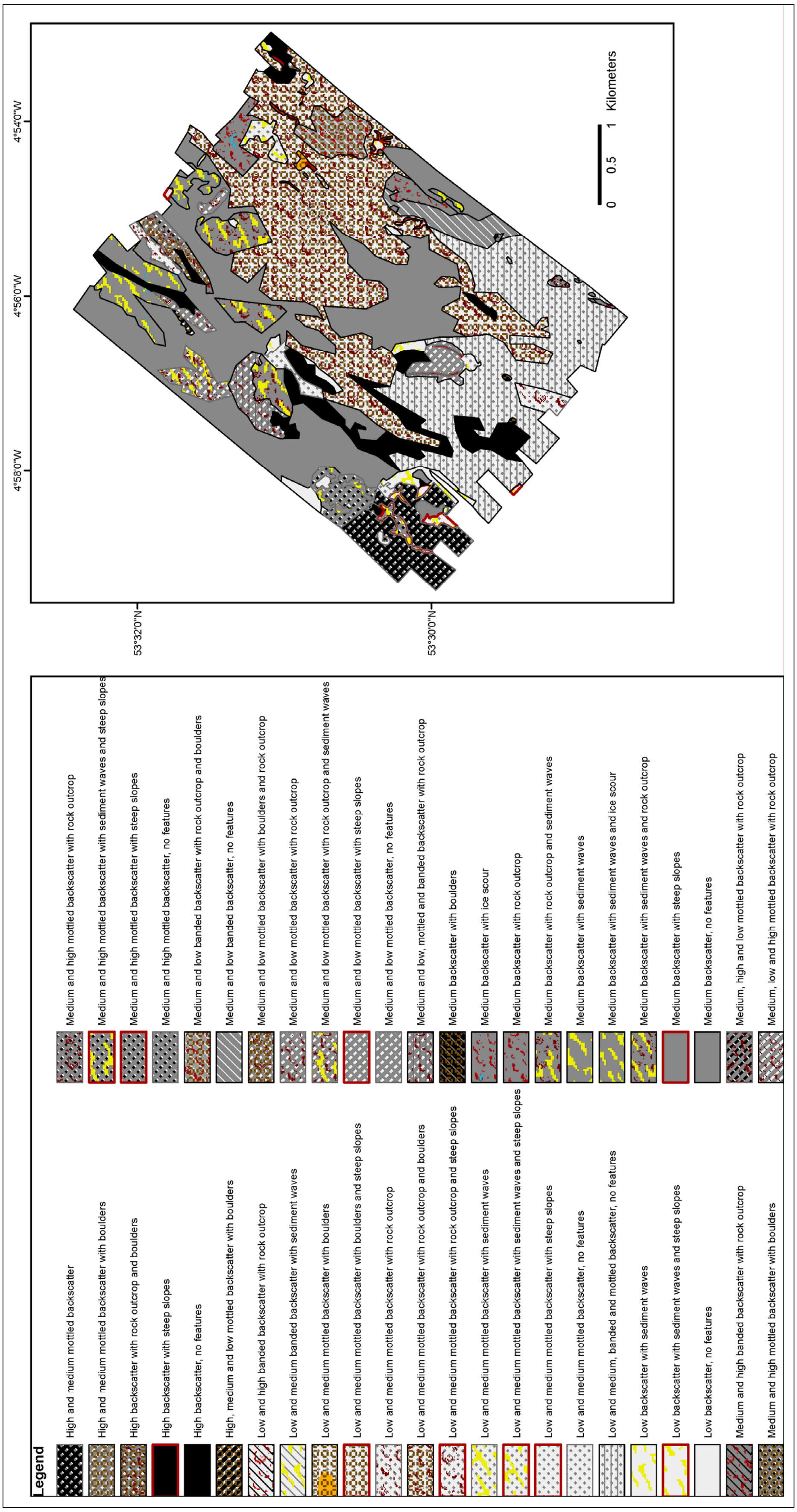

Figure 26: Acoustic ground types in survey area 4

4.3. Sediment sample analyses

The set of statistical methods used in this program is attached in Appendix 8.1. Tables with the full set of sample statistics are attached in Appendix 8.2. Where the distribution of the sample is polymodal, it should be noted that values of sorting, skewness and kurtosis are less representative.

Figure 27 to Figure 34 show grain size distributions using the phi scale and are referenced with sorting, textural group and the mode(s). When the distribution is polymodal, the primary mode was mentioned first followed by the second and third mode. In the particle size analyses provided by the JNCC, the fraction specified as being <63 micron (mud), was treated in GRADISTAT and in the graphics below as equally distributed between 0.06 micron (14ϕ) and 63 micron (4ϕ).

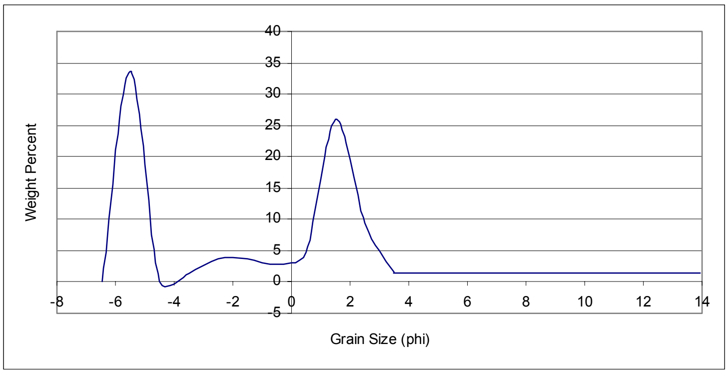

Figure 27: Sample 17.2, Area 4: Extremely poorly sorted Muddy Sandy Gravel, bimodal distribution (-5.5Φ, 1.5Φ).

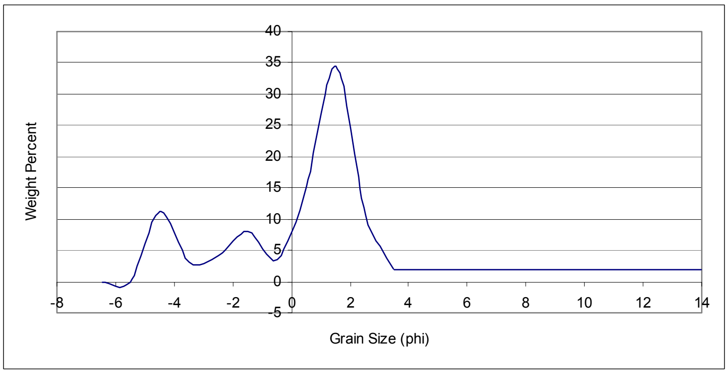

Figure 28: Sample 18.1, Area 2: Very poorly sorted Gravelly Sand, trimodal distribution (1.5Φ, -4.5Φ, -1.5Φ).

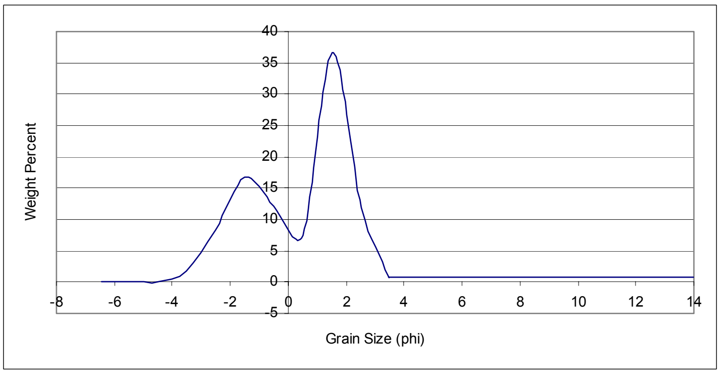

Figure 29: Sample 30.1, Area 2: Poorly sorted Gravelly Sand, bimodal distribution (1.5Φ, -1.5Φ).

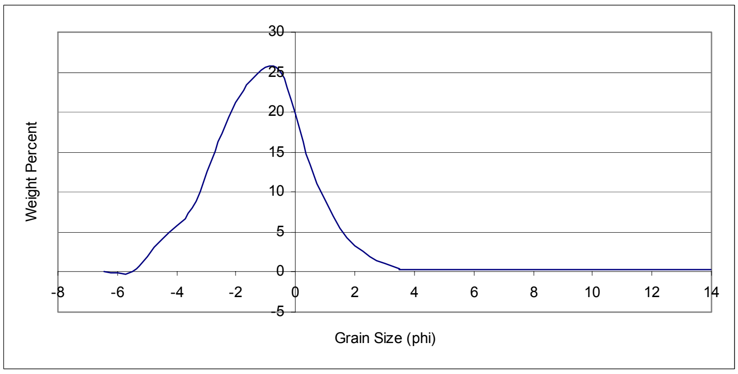

Figure 30: Sample 31.1, Area 2: Poorly sorted Sandy Gravel, unimodal distribution (-0.5Φ).

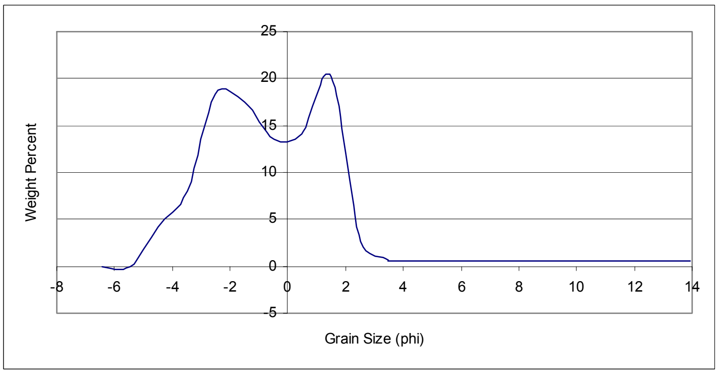

Figure 31: Sample 35.1, Area 1: Poorly sorted Sandy Gravel, bimodal distribution (1.5Φ, -2.5Φ).

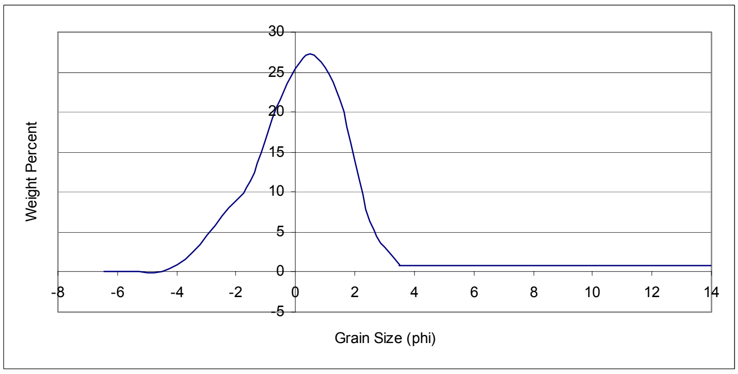

Figure 32: Sample 36.2, Area 1: Poorly sorted Gravelly Sand, unimodal distribution (0.5Φ).

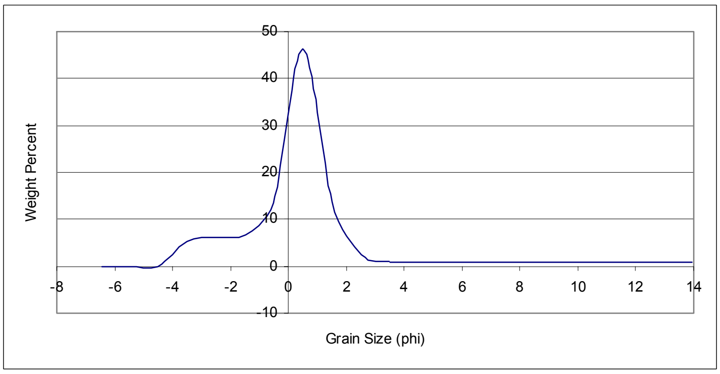

Figure 33: Sample 40.1, Area 1: Poorly sorted Gravelly Sand, unimodal distribution (0.5Φ).

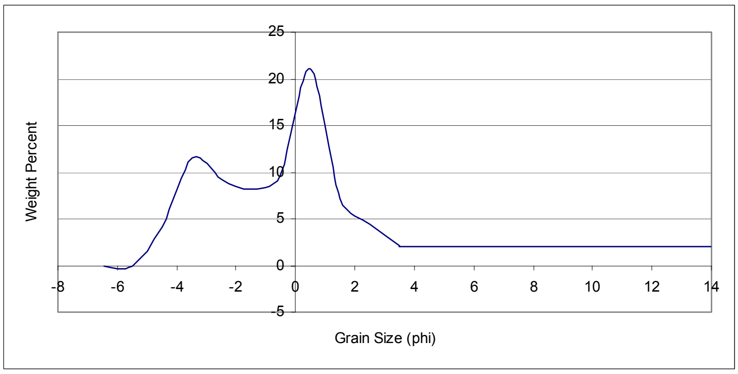

Figure 34: Sample 41.1, Area 1: Extremely poorly sorted Muddy Sandy Gravel, bimodal distribution (0.5Φ, -3.5Φ).

These samples are plotted on the Gravel Sand Mud diagram (Figure 35).

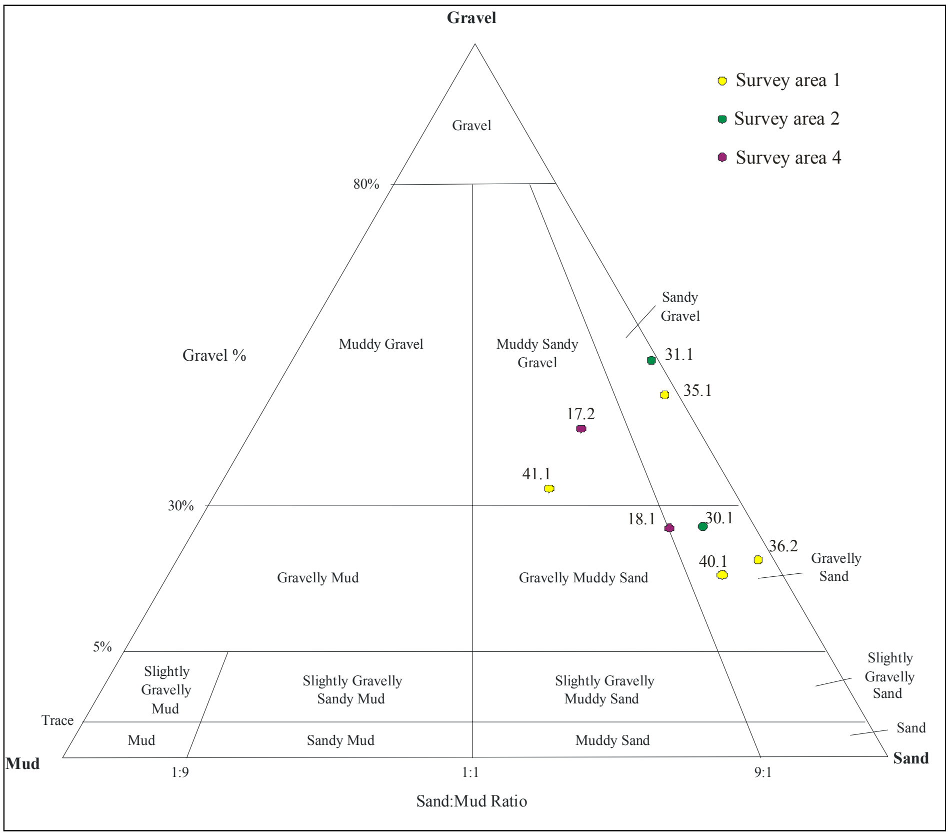

Figure 35: Sediment samples plotted on the Gravel Sand Mud diagram by Folk (1954).

4.4. Sediment ground types

Although sediment distributions have been rigorously analysed, with only 6.3% of the acoustic ground types being represented by a sample, it is very difficult to give the acoustic ground types an estimated sediment description.

From the particle size analyses of the collected sediment, it can be assumed that the dominant seabed material in all 4 survey areas is diamict. The percentage of mud, sand and gravel is variable and the sorting is typically very poor.

Using the definitions of Folk (1954) for sediment types, the 8 analysed samples were compared to the backscatter intensity at the site of recovery:
- Four samples with Gravelly Sand were found where backscatter values are relatively low and relatively medium. The mean of all four samples is Coarse Sand and all are poorly sorted.
- One sample with Muddy Sandy Gravel is recovered where backscatter values are relatively high. Its mean textural group is Medium Sand with modes of Coarse Sand and Medium Gravel. A second sample with this sediment type was taken just outside the surveyed area and cannot be used in this correlation exercise.
- Two samples with Sandy Gravel are located in areas of relatively medium backscatter values. Although these have similar backscatter signals, the distribution of these samples are slightly different. The first sample has one mode of Very Coarse Sand while the other sample is bimodal with Medium Sand and Fine Gravel.

Polymodal versus unimodal distributions do not correlate with distinct backscatter values. There is also no direct link between the mode(s) of the sediment and its backscatter signal. The backscatter may therefore be driven by fine scale (cm) rugosity and geotechnical properties (pore pressure and shear strength).

The relation between sediment and backscatter is too poorly correlated with too little samples to make a detailed estimate for all acoustic signatures. The following interpolations made are therefore rather broad and need to be confirmed with the video analysis:

- Very low and low backscatter values are correlated with Sandy Diamict. The ground type is estimated as Sandy around sediment waves with a morphology typical for sand waves in the present current regime.
- Medium backscatter values are correlated with Diamict which could be either Sandy or Gravelly.
- High backscatter values are correlated with Gravelly Diamict.

Any combination of backscatter values within a polygon is similarly reflected in the sediment descriptions. These descriptions are attached to the acoustic ground type shapefiles in an attribute field called SEDIMENT.

Where bathymetry data suggests the presence of rock outcrop, the backscatter intensity mostly doesn't confirm this with the expected higher values. Very often there is no variation at all over these outcrops, suggesting that either a sediment veneer covers most of these features or the hardness and surface roughness of the rocks and gravel are similar. Video analysis will verify this.

5. Conclusions

From bathymetry data, derivative raster were created showing values of slope, aspect and rugosity. Slope values of up to 45 degrees make the gradient of the seafloor a relevant factor to habitat mapping. Combined with dominant tidal current directions, interpreted from current-related lineations in backscatter values and sand wave asymmetry, aspect as a derivative parameter of slope proves useful: classified as facing the dominant current direction, in the shadow of the currents or running parallel to the current direction. Rugosity values show a short range with a maximium extent from 1 to 1.66. Changes in rugosity mainly reflect slope variability.

From georeferenced images showing backscatter values and bathymetry, a variety of backscatter intensity was depicted and combined with its textural arrangement. Joined with descriptions of morphologic features on the seafloor, 314 polygons were created manually to delineate acoustic ground types. Sediment information from 8 samples was added to the ground types with a tentative extrapolation to other areas with similar acoustic signature. Over 4 survey areas, 111 zones of different acoustic ground types were recognised, forming the building blocks for a final habitat map of this region.

6. Comments and recommendations

6.1. Data quality

The acoustic data collected in August 2005 by the JNCC is of very high quality. It allowed for high resolution spatial analyses relevant to habitat mapping. It could be argued that backscatter data acquired with a multibeam sonar system is of a lower quality then backscatter data acquired with a side scan sonar system, although the bathymetry data, as a primary output of the former technique, is of very high value to habitat mapping and to a general understanding of the geodynamics at the seabed.

The south-eastern part of survey area 1 is more affected by artefacts in comparison with the other survey areas. There was no particular change in weather conditions and the survey log book does not indicate any irregularities. Even after post-processing it affects the spatial analyses of the seafloor topography. A more detailed re-examination of the soundings in this region is needed to clean the dataset to a higher standard if greater confidence in acoustic ground types is required.

6.2. Groundtruthing data.

To allow for valuable acoustic ground interpretation, groundtruthing data is of great importance. There is a sufficient amount of video data collected for this project, but more sediment samples would have been useful to provide a better correlation between the acoustic signal and the particle size distribution of the sediment.

6.3. Resolution of rugosity

To try and maximise the value of rugosity as a parameter for biodiversity, it was considered whether there was merit in creating higher resolution bathymetry grids. The survey areas would need to be split into smaller sub-areas as the grid files for the whole area would be unmanageable in ArcGIS software. Using CARIS HIPS and SIPS hydrographic software, the highest resolution with which a BASE surface can be produced is 1 m with further interpolation. Higher resolutions would lead to bigger data gaps. To test the validity of this suggestion, a rugosity map has been produced for part of survey area 3 where the bathymetry image suggests high variations in rugosity. A 1 m BASE surface was created in CARIS HIPS and using the same procedure as described in chapter 2.1, a rugosity map was created with a 1 m resolution. The results of the rugosity maps can be compared in Figure 36 and Figure 37 and in fact show limited promise. The map using a 1 m resolution bathymetry grid contains too many survey artefacts to see a clear pattern and it does not improve on the rugosity map created with a 10 m bathymetry grid. In conclusion, as a parameter in habitat mapping, rugosity from the multibeam sonar data collected during this survey is less valuable than initially expected.

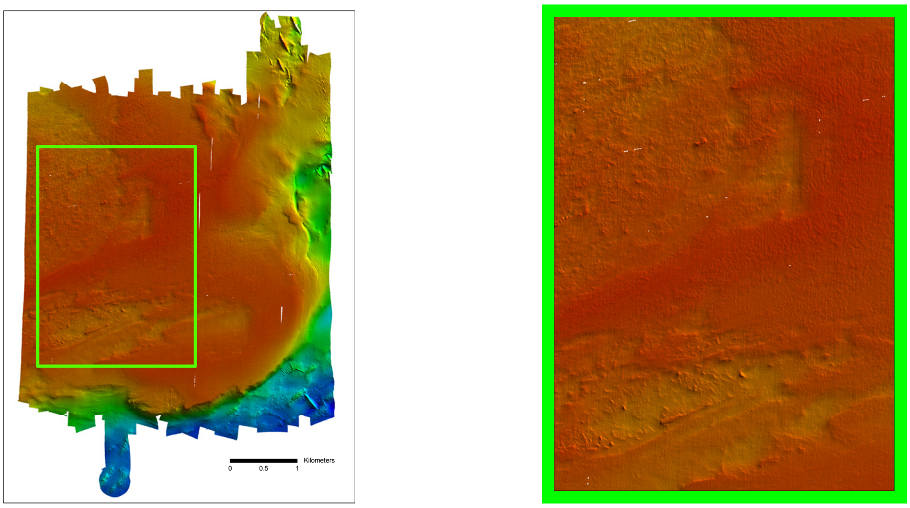

Figure 36: Location of zoomed in part of survey area 3 showing bathymetry.

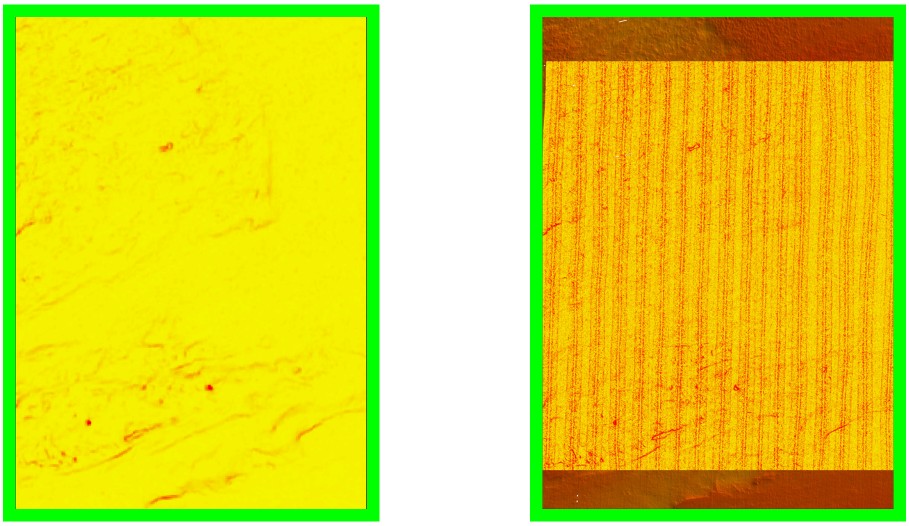
Figure 37: Rugosity maps of zoomed in region
Using a a) 10 m grid b) 1 m grid

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8. Appendices

8.1. Particle Size Analyses – Statistical methods

(a) Arithmetic Method of Moments

Mean	Standard Deviation	Skewness	Kurtosis
$\bar{x}_a = \dfrac{\Sigma f m_m}{100}$	$\sigma_a = \sqrt{\dfrac{\Sigma f (m_m - \bar{x}_a)^2}{100}}$	$Sk_a = \dfrac{\Sigma f (m_m - \bar{x}_a)^3}{100 \sigma_a{}^3}$	$K_a = \dfrac{\Sigma f (m_m - \bar{x}_a)^4}{100 \sigma_a{}^4}$

(b) Geometric Method of Moments

Mean	Standard Deviation	Skewness	Kurtosis
$\bar{x}_g = \exp \dfrac{\Sigma f \ln m_m}{100}$	$\sigma_g = \exp \sqrt{\dfrac{\Sigma f (\ln m_m - \ln \bar{x}_g)^2}{100}}$	$Sk_g = \dfrac{\Sigma f (\ln m_m - \ln \bar{x}_g)^3}{100 \ln \sigma_g{}^3}$	$K_g = \dfrac{\Sigma f (\ln m_m - \ln \bar{x}_g)^4}{100 \ln \sigma_g{}^4}$

Sorting (σ_g)		Skewness (Sk_g)		Kurtosis (K_g)	
Very well sorted	< 1.27	Very fine skewed	$< {}^{-}1.30$	Very platykurtic	< 1.70
Well sorted	1.27 – 1.41	Fine skewed	${}^{-}1.30 – {}^{-}0.43$	Platykurtic	1.70 – 2.55
Moderately well sorted	1.41 – 1.62	Symmetrical	${}^{-}0.43 – {}^{+}0.43$	Mesokurtic	2.55 – 3.70
Moderately sorted	1.62 – 2.00	Coarse skewed	${}^{+}0.43 – {}^{+}1.30$	Leptokurtic	3.70 – 7.40
Poorly sorted	2.00 – 4.00	Very coarse skewed	$> {}^{+}1.30$	Very leptokurtic	> 7.40
Very poorly sorted	4.00 – 16.00				
Extremely poorly sorted	> 16.00				

(c) Logarithmic Method of Moments

Mean	Standard Deviation	Skewness	Kurtosis
$\bar{x}_\phi = \dfrac{\Sigma f m_\phi}{100}$	$\sigma_\phi = \sqrt{\dfrac{\Sigma f (m_\phi - \bar{x}_\phi)^2}{100}}$	$Sk_\phi = \dfrac{\Sigma f (m_\phi - \bar{x}_\phi)^3}{100 \sigma_\phi{}^3}$	$K_\phi = \dfrac{\Sigma f (m_\phi - \bar{x}_\phi)^4}{100 \sigma_\phi{}^4}$

Sorting (σ_ϕ)		Skewness (Sk_ϕ)		Kurtosis (K_ϕ)	
Very well sorted	< 0.35	Very fine skewed	$> {}^{+}1.30$	Very platykurtic	< 1.70
Well sorted	0.35 – 0.50	Fine skewed	${}^{+}0.43 – {}^{+}1.30$	Platykurtic	1.70 – 2.55
Moderately well sorted	0.50 – 0.70	Symmetrical	${}^{-}0.43 – {}^{+}0.43$	Mesokurtic	2.55 – 3.70
Moderately sorted	0.70 – 1.00	Coarse skewed	${}^{-}0.43 – {}^{-}1.30$	Leptokurtic	3.70 – 7.40
Poorly sorted	1.00 – 2.00	Very coarse skewed	$< {}^{-}1.30$	Very leptokurtic	> 7.40
Very poorly sorted	2.00 – 4.00				
Extremely poorly sorted	> 4.00				

(d) Logarithmic (Original) Folk and Ward (1957) Graphical Measures

Mean	Standard Deviation	Skewness	Kurtosis
$M_Z = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$	$\sigma_I = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$	$Sk_I = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$	$K_G = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})}$

Sorting (σ_I)		Skewness (Sk_I)		Kurtosis (K_G)	
Very well sorted	< 0.35	Very fine skewed	$^+0.3$ to $^+1.0$	Very platykurtic	< 0.67
Well sorted	0.35 – 0.50	Fine skewed	$^+0.1$ to $^+0.3$	Platykurtic	0.67 – 0.90
Moderately well sorted	0.50 – 0.70	Symmetrical	$^+0.1$ to $^-0.1$	Mesokurtic	0.90 – 1.11
Moderately sorted	0.70 – 1.00	Coarse skewed	$^-0.1$ to $^-0.3$	Leptokurtic	1.11 – 1.50
Poorly sorted	1.00 – 2.00	Very coarse skewed	$^-0.3$ to $^-1.0$	Very leptokurtic	1.50 – 3.00
Very poorly sorted	2.00 – 4.00			Extremely leptokurtic	> 3.00
Extremely poorly sorted	> 4.00				

(e) Geometric Folk and Ward (1957) Graphical Measures

Mean	Standard Deviation
$M_G = \exp\frac{\ln P_{16} + \ln P_{50} + \ln P_{84}}{3}$	$\sigma_G = \exp\left(\frac{\ln P_{16} - \ln P_{84}}{4} + \frac{\ln P_5 - \ln P_{95}}{6.6}\right)$
Skewness	**Kurtosis**
$Sk_G = \frac{\ln P_{16} + \ln P_{84} - 2(\ln P_{50})}{2(\ln P_{84} - \ln P_{16})} + \frac{\ln P_5 + \ln P_{95} - 2(\ln P_{50})}{2(\ln P_{25} - \ln P_5)}$	$K_G = \frac{\ln P_5 - \ln P_{95}}{2.44(\ln P_{25} - \ln P_{75})}$

Sorting (σ_G)		Skewness (Sk_G)		Kurtosis (K_G)	
Very well sorted	< 1.27	Very fine skewed	$^-0.3$ to $^-1.0$	Very platykurtic	< 0.67
Well sorted	1.27 – 1.41	Fine skewed	$^-0.1$ to $^-0.3$	Platykurtic	0.67 – 0.90
Moderately well sorted	1.41 – 1.62	Symmetrical	$^-0.1$ to $^+0.1$	Mesokurtic	0.90 – 1.11
Moderately sorted	1.62 – 2.00	Coarse skewed	$^+0.1$ to $^+0.3$	Leptokurtic	1.11 – 1.50
Poorly sorted	2.00 – 4.00	Very coarse skewed	$^+0.3$ to $^+1.0$	Very leptokurtic	1.50 – 3.00
Very poorly sorted	4.00 – 16.00			Extremely leptokurtic	> 3.00
Extremely poorly sorted	> 16.00				

Figure 38: Statistical formulae used in the calculation of grain size parameters. *f* is the frequency in percent; *m* is the mid-point of each class interval in metric (m_m) or phi (m_Φ) units; P_x and Φ_x are grain diameters, in metric or phi units respectively, at the cumulative percentile value of x.

8.2. Particle Size Analyses – Results

PSA - Description	Sample							
	17.2, Area 4	18.1, Area 4	30.1,Area 2	31.1, Area 2	35.1, Area 1	36.2, Area 1	40.1, Area 1	41.1, Area 1
ANALYST AND DATE:	JNCC, 8/11/2005	JNCC, 8/11/2005	JNCC, 8/12/2005	JNCC, 8/12/2005	JNCC, 8/13/2005	JNCC, 8/13/2005	JNCC, 8/13/2005	JNCC, 8/13/2005
SAMPLE TYPE:	Bimodal, Extremely Poorly Sorted	Trimodal, Very Poorly Sorted	Bimodal, Poorly Sorted	Unimodal, Poorly Sorted	Bimodal, Poorly Sorted	Unimodal, Poorly Sorted	Unimodal, Poorly Sorted	Bimodal, Extremely Poorly Sorted
TEXTURAL GROUP:	Muddy Sandy Gravel	Gravelly Sand	Gravelly Sand	Sandy Gravel	Sandy Gravel	Gravelly Sand	Gravelly Sand	Muddy Sandy Gravel
SEDIMENT NAME:	Muddy Sandy Very Coarse Gravel	Coarse Gravelly Medium Sand	Very Fine Gravelly Medium Sand	Sandy Very Fine Gravel	Sandy Fine Gravel	Very Fine Gravelly Coarse Sand	Very Fine Gravelly Coarse Sand	Muddy Sandy Medium Gravel

PSA – grain size parameters		Sample							
		17.2, Area 4	18.1, Area 4	30.1,Area 2	31.1, Area 2	35.1, Area 1	36.2, Area 1	40.1, Area 1	41.1, Area 1
METHOD OF MOMENTS Arithmetic (μm)	MEAN	16632.6	3861.7	1617.0	4188.0	3973.2	1680.5	1819.4	3524.0
	SORTING	21912.6	7452.2	2196.6	5108.0	5296.8	2209.8	2797.7	5679.9
	SKEWNESS	0.671	2.107	2.448	2.478	2.356	2.903	2.739	2.180
	KURTOSIS	1.469	5.785	10.23	9.331	8.695	12.51	9.786	7.388
METHOD OF MOMENTS Geometric (μm)	MEAN	1134.8	598.3	609.8	2195.2	1640.8	861.2	714.8	371.2
	SORTING	26.81	9.205	5.316	3.205	4.252	3.325	5.348	22.16
	SKEWNESS	-0.503	-0.662	-1.391	-0.783	-0.778	-1.168	-1.889	-0.750
	KURTOSIS	2.379	4.243	6.655	6.943	5.635	9.052	8.531	2.230
METHOD OF MOMENTS Logarithmic (ϕ)	MEAN	-0.182	0.741	0.714	-1.134	-0.714	0.216	0.484	1.430
	SORTING	4.745	3.202	2.410	1.680	2.088	1.734	2.419	4.470
	SKEWNESS	0.503	0.662	1.391	0.783	0.778	1.168	1.889	0.750
	KURTOSIS	2.379	4.243	6.655	6.943	5.635	9.052	8.531	2.230
FOLK AND WARD METHOD (μm)	MEAN	1468.5	811.2	704.1	2239.6	1675.9	893.0	886.5	374.2
	SORTING	22.83	8.176	3.458	3.090	3.834	2.938	3.496	28.74
	SKEWNESS	0.203	0.234	0.393	0.014	-0.019	0.113	0.094	-0.391
	KURTOSIS	0.911	1.574	0.804	1.057	0.738	1.036	2.103	1.315
FOLK AND WARD METHOD (ϕ)	MEAN	-0.554	0.302	0.506	-1.163	-0.745	0.163	0.174	1.418
	SORTING	4.513	3.031	1.790	1.628	1.939	1.555	1.806	4.845
	SKEWNESS	-0.203	-0.234	-0.393	-0.014	0.019	-0.113	-0.094	0.391
	KURTOSIS	0.911	1.574	0.804	1.057	0.738	1.036	2.103	1.315
FOLK AND WARD METHOD (Description)	MEAN:	Very Coarse Sand	Coarse Sand	Coarse Sand	Very Fine Gravel	Very Coarse Sand	Coarse Sand	Coarse Sand	Medium Sand
	SORTING:	Extremely Poorly Sorted	Very Poorly Sorted	Poorly Sorted	Poorly Sorted	Poorly Sorted	Poorly Sorted	Poorly Sorted	Extremely Poorly Sorted
	SKEWNESS:	Coarse Skewed	Coarse Skewed	Very Coarse Skewed	Symmetrical	Symmetrical	Coarse Skewed	Symmetrical	Very Fine Skewed
	KURTOSIS:	Mesokurtic	Very Leptokurtic	Platykurtic	Mesokurtic	Platykurtic	Mesokurtic	Very Leptokurtic	Leptokurtic

PSA - Percentiles	Sample							
	17.2, Area 4	18.1, Area 4	30.1,Area 2	31.1, Area 2	35.1, Area 1	36.2, Area 1	40.1, Area 1	41.1, Area 1
MODE 1 (μm):	47250.0	375.0	375.0	1500.0	375.0	750.0	750.0	750.0
MODE 2 (μm):	375.0	23750.0	3000.0		6000.0			12000.0
MODE 3 (μm):		3000.0						
MODE 1 (ϕ):	-5.477	1.500	1.500	-0.500	1.500	0.500	0.500	0.500
MODE 2 (ϕ)	1.500	-4.489	-1.500		-2.500			-3.500
MODE 3 (ϕ):		-1.500						
D10 (μm):	12.55	130.1	167.2	547.9	305.8	262.9	270.1	1.326
D50 (μm):	504.5	454.2	467.6	2201.5	1809.4	828.6	758.7	787.1
D90 (μm):	51297.8	17247.4	4057.9	9570.9	9678.9	3874.7	4732.5	11290.2
(D90 / D10) (μm):	4086.6	132.6	24.27	17.47	31.65	14.74	17.52	8517.5
(D90 - D10) (μm):	51285.3	17117.2	3890.7	9023.0	9373.2	3611.9	4462.4	11288.9
(D75 / D25) (μm):	146.9	8.318	7.418	4.352	9.539	4.132	2.694	29.85
(D75 - D25) (μm):	37434.3	2012.8	1871.0	3675.7	4409.3	1331.7	883.7	3834.1
D10 (ϕ):	-5.681	-4.108	-2.021	-3.259	-3.275	-1.954	-2.243	-3.497
D50 (ϕ):	0.987	1.139	1.097	-1.139	-0.855	0.271	0.398	0.345
D90 (ϕ):	6.316	2.942	2.581	0.868	1.709	1.928	1.889	9.559
(D90 / D10) (ϕ):	-1.112	-0.716	-1.277	-0.266	-0.522	-0.986	-0.842	-2.734
(D90 - D10) (ϕ):	12.00	7.051	4.601	4.127	4.984	3.882	4.131	13.06
(D75 / D25) (ϕ):	-0.375	-1.560	-1.598	0.059	-0.415	-1.518	-1.911	-1.464
(D75 - D25) (ϕ):	7.198	3.056	2.891	2.122	3.254	2.047	1.430	4.899

PSA - Methods	Sample							
	17.2, Area 4	18.1, Area 4	30.1,Area 2	31.1, Area 2	35.1, Area 1	36.2, Area 1	40.1, Area 1	41.1, Area 1
% GRAVEL:	42.5%	26.5%	26.9%	53.3%	48.0%	21.0%	18.2%	33.1%
% SAND:	44.5%	66.1%	68.8%	46.3%	51.0%	77.9%	76.7%	44.5%
% MUD:	13.0%	7.3%	4.3%	0.4%	0.9%	1.2%	5.1%	22.4%
% V COARSE GRAVEL:	33.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% COARSE GRAVEL:	0.8%	11.2%	0.0%	4.1%	4.2%	0.0%	0.0%	4.2%
% MEDIUM GRAVEL:	1.3%	3.2%	1.8%	8.0%	8.0%	2.4%	5.4%	11.5%
% FINE GRAVEL:	3.8%	4.2%	8.4%	17.4%	18.3%	7.1%	6.1%	9.2%
% V FINE GRAVEL:	3.7%	7.9%	16.7%	23.9%	17.5%	11.5%	6.7%	8.2%
% V COARSE SAND:	2.8%	3.5%	12.1%	25.0%	13.6%	21.6%	13.4%	9.6%
% COARSE SAND:	4.7%	15.2%	7.4%	13.4%	14.1%	27.4%	46.3%	21.1%
% MEDIUM SAND:	25.9%	34.5%	36.7%	5.5%	20.2%	21.6%	13.7%	7.2%
% FINE SAND:	9.4%	10.9%	11.8%	1.9%	2.6%	6.3%	2.4%	4.4%
% V FINE SAND:	1.6%	2.0%	0.7%	0.5%	0.6%	1.0%	1.0%	2.2%
% V COARSE SILT:	1.3%	0.7%	0.4%	0.0%	0.1%	0.1%	0.5%	2.2%
% COARSE SILT:	1.3%	0.7%	0.4%	0.0%	0.1%	0.1%	0.5%	2.2%
% MEDIUM SILT:	1.3%	0.7%	0.4%	0.0%	0.1%	0.1%	0.5%	2.2%
% FINE SILT:	1.3%	0.7%	0.4%	0.0%	0.1%	0.1%	0.5%	2.2%
% V FINE SILT:	1.3%	0.7%	0.4%	0.0%	0.1%	0.1%	0.5%	2.2%
% CLAY:	6.5%	3.7%	2.2%	0.2%	0.5%	0.6%	2.6%	11.3%