MESH MAPPING EUROPEAN SEABED HABITATS

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Title:	**The Application of Optimal Allocation Analysis to the Stratification of Ground-Truth Sampling in Benthic Habitat Mapping**
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1. Introduction

1.1. Two stage approach to habitat mapping

It has been widely accepted by the scientific community that the most appropriate approach to seabed habitat mapping is a two-stage methodology, in which some form of remote sensing is undertaken during the first stage, to produce a good overview of the main seabed characteristics of the survey site, and allowing the preliminary delineation of ground-type boundaries. The second stage focuses on ground-truthing the ground-types and boundaries identified during the first stage (Foster-Smith and Sotheran, 2003; Brown *et al.,* 2002; Kostylev *et al*., 2001; Foster-Smith *et al.,* 2001;). Precisely how the first stage survey and data processing informs the second stage is a considerably complex area of habitat mapping methodology. Three main issues arise: firstly, how the remotely-sensed data are analysed to identify distinct ground-types; secondly, how the remotely-sensed ground-type data should direct the ground-truthing survey, which should be designed such that each ground-type is 'verified'; and thirdly, how the ground-type boundaries can be ground-truthed.

A number of general approaches to ground-truthing have been described in scientific literature, such as using 'rules of thumb' for determining the number of ground-truthing samples to take within each ground-type identified from remote-sensing. These concepts are based upon establishing a number of replicates such that some statistical robustness can be determined for the sampling. It is also generally agreed that both the area and potential heterogeneity of each ground-type should inform the ground-truthing sampling strategy. The former is easily calculated within GIS or image processing software packages, however the latter is a more elusive concept. As the ultimate aim of seabed habitat mapping is to determine the major habitats, their location and extent within an area, heterogeneity should relate directly to habitat. The concept of habitat is multi-parametric however, whereby a particular set of environmental (and possibly biotic) conditions are discerned, which describe the location of a community of organisms or single species. Habitat heterogeneity can therefore only be described using the same parameters as those that are used to define the habitat. This rests entirely upon the habitat classification system used and the region of study. For MESH, the EUNIS habitat classification scheme has been adopted, which relies upon the following main parameters to aid classification:

1. Salinity (e.g. fully marine or estuarine).
2. Zone (which relates to both sea level and subtidal light attenuation i.e. supralittoral to circalittoral / deep sea).
3. Substratum (sedimentology based descriptions e.g. muds through to rock).
4. Energy regime (i.e. degree of exposure through wave action and currents).
5. Biological community (i.e. key species).
6. Biogenic features (e.g. bioherms).
7. Geological structures (e.g. gas seeps or vents).

It is clearly evident that the first stage of habitat mapping, whereby remote sensing techniques are used to provide information on the distribution of seabed ground-types,

cannot provide the data needed to determine many of the above parameters. From background site research it may be possible to readily determine the salinity, zone and possibly broadscale energy regime, and some remote-sensing techniques may allow a geological interpretation which may allude to certain sedimentalogical descriptions. Whether such characteristics can be determined for each ground-type in any semi-quantifiable way, however, is highly questionable. As such habitat heterogeneity is a difficult concept to use based only upon remotely-sensed and background data. Nonetheless, it is logical that if a ground-type is likely to be highly heterogeneous it may require more ground-truthing than a homogeneous ground-type in order to assess whether the ground-type equates to only one habitat. The basic assumption that remote-sensing provides information relevant to habitat characterisation is critical to habitat mapping. This assumption is widely made and seems to be fairly well supported (Brown *et al.,* 2002; Kostylev *et al.,* 2001) despite some critique of its basis in describing primarily substratum and topography/bathymetry, which may show a rather one-sided view of habitat classification which may not always be biologically valid (Diaz *et al.,* 2004). While such an assumption is used, it seems appropriate that remotely-sensed data could also be used to inform on habitat heterogeneity, or more precisely, 'ground-type' heterogeneity. Such data is readily amenable to calculations of basic statistics such as means and standard deviations for each identified ground-type. It must be emphasised however, that the input data are understood in the appropriate context: remotely-sensed data are not a direct measurement of some physical seabed attribute, but rather an acoustic picture showing a combination of factors, which while primarily result form seafloor characteristics including porosity, compactness, hardness and roughness, are also influenced by water column density and discontinuities,. In addition, such factors do not operate at a set scale, but a range of scales depending on the remote-sensing equipment, water depth, speed of sound through the water column etc. The absolute data readings are additionally affected by sea conditions (e.g. swell, currents etc.) and as such cannot be directly compared. Despite these limitations, the summary statistics generated from such data may be used as a method of comparing the different ground-types identified from analysis/interpretation of the remotely-sensed data and may be used as a proxy for within-ground-type heterogeneity.

In the case of subtidal seabed habitat mapping projects, the first stage remote-sensing survey usually involves collection of acoustic data *via* echosounding equipment. The resulting data usually comprises of depth and either a measure of seabed roughness and hardness or acoustic backscatter (Foster-Smith and Sotheran, 2003; Kostylev *et al.,* 2001). In shallow subtidal and intertidal seabed habitat mapping projects, the first stage remote-sensing survey usually utilises aerial photography, satellite imagery or LIDAR. The resulting data can include depth/height and amplitude or colour (RGB, scaled 0-255) (Brown *et al.,* 2002). From depth/height data a number of variables can be calculated such as slope angle, aspect and rugosity (surface complexity). Both the derived topographic variables and the backscatter/amplitude/colour data could be used as indicators of ground-type ('habitat') heterogeneity. These, in addition to empirical knowledge of each ground-type area, may be used to determine the sampling level for each ground-type for the ground-truthing survey.

1.2. Aims and objectives of study

The main aim of this study is to examine an objective method of designing ground-truthing surveys based upon remotely-sensed data. This is to support testing of the working hypothesis posed by habitat mapping scientists, that ground-types relate to habitat. The objectives are as follows:

1. Summarise methods of deriving ground-types from remotely-sensed data.
2. Derive summary statistics from the remotely-sensed data representing ground-type ('habitat') heterogeneity.
3. Use both area and remote-sensing data summaries for each identified ground-type to objectively stratify ground-truthing to test if each ground-type relates to a habitat using the Optimal Allocation Analysis approach.
4. Examine the results of Optimal Allocation Analysis in relation to practical feasibility and expert knowledge.

1.3. Application of Optimal Allocation Analysis to stratified ground-truthing

Optimal Allocation Analysis (OAA) may be defined as "A procedure used in stratified sampling to allocate numbers of sample units to different strata to either maximize precision at a fixed cost or minimize cost for a selected level of precision". OAA has been used in a wide variety of fields, ranging from computing to fisheries science (e.g. Harbitz *et al.,* 1998; Allen *et al.,* 2001, and Adams *et al.,* 2006). The closest existing application to seabed habitat mapping is the use of OAA in stratifying fishing effort in mid-water trawl surveys after acoustic surveys of the water column (Adams *et al.,* 2006). OAA is considered potentially useful in seabed habitat mapping for the following reasons:

1. OAA objectively uses existing data for a series of pre-determined strata ('ground-types') to stratify sampling effort.
2. OAA aims to maximise the resulting precision of the survey with respect to its objectives while minimising cost.
3. OAA allows both sampling precision, as defined by the coefficient of variation (CV), and maximum possible sampling level to be set by the user as appropriate.

It is thought that this approach may improve upon existing methods for allocating ground-truthing sampling effort between ground-types owing to its objective approach utilising existing data and area of ground-types. As explained above, ground-type heterogeneity is taken into account through the use of remote-sensing data as a proxy for habitat heterogeneity. The ground-truth survey precision may be defined as "the degree of mutual agreement among a series of individual measurements, values, or results" (Wikipedia, 2007). The higher the level of precision, the lower the variance between samples. In the case of most ground-truthing campaigns the only existing data are that from the stage one remote-sensing survey, where from within each ground-type a number of datapoints can be retrieved that can be used to generate variance for that remotely-

sensed variable. This is used as a proxy for actual habitat variance, which shall be targeted by the ground-truthing survey.

Improving upon and defining the precision of the planned ground-truthing survey is a key step in ensuring that a measure of accuracy can be established for habitat maps. Accuracy is closely related to precision, also called reproducibility or repeatability: the degree to which further measurements or calculations will show the same or similar results (Wikipedia, 2007). The main difference between accuracy and precision if that accuracy is the degree of veracity (i.e. is the result representative of reality?) while precision is the degree of reproducibility (i.e. do the results all fall closely together?). [Note that accuracy and confidence in habitat maps is discussed in the section of the MESH Guide entitled 'How good is my map?']

The OAA uses the input remotely-sensed data, which is assumed to represent the actual population (in the case of habitat mapping this can be considered as properties of ground-types), to describe a fully known situation, in which the coefficient of variation would be zero. The ground-truthing sampling program is then determined by entering either (a) a desired CV, or (b) a maximum number of samples. To achieve maximum precision, CV would have to equal zero and to achieve this the number of samples required would be more than the original input number of remotely-sensed datapoints, which is clearly not practical. An appropriate threshold level must be decided upon, for example a CV of 5% (which equates to 95% precision) indicates very good precision and is more practical in terms of number of ground-truthing samples recommended.

As explained, the use of OAA in the context of seabed habitat mapping rests upon the use of remotely-sensed data as a proxy for ground-type heterogeneity and this being meaningful for habitat ground-truthing. As this is a debatable issue we have chosen to use a number of remotely-sensed variables to investigate differences in the OAA output and also looked at combining more than one variable (e.g. slope angle and backscatter) to recommend an averaged number of ground-truth samples for a particular desired level of precision.

1.4. Location & context of pilot sites

Two survey sites have been used in this study to test the applicability and usefulness of OAA in determining the number of ground-truthing samples for within ground-type habitat detection (Figure 1). The first site is the North Maidens Peak, which is located with its centre point at 54°59.89' N, 5 ^{o}43.32' W, approximately 13 km east of the Northern Irish coastline in the North Channel of the Irish Sea. The site extends approximately 4.4 x 4 km and encompasses a bedrock intrusion and surrounding sedimentary region. It has been surveyed as part of the MESH North Western Shelf Consortium mapping effort and by the Agri-Food & Biosciences Institute (AFBI) as part of their ongoing research into the sensitivity of Northern Irish benthic habitats. In this worked example this site shall be used to test OAA to stratify a new ground-truthing survey, assuming that no data exists other than the data from multibeam echosounder surveying.

The second site is the North Channel Peaks, which is located with its centre point at 54° 25.74' N, 5° 31.67' W, approximately 23 km east of the Northern Irish coastline in the North Channel of the Irish Sea almost midway between Northern Ireland, Scotland and the Isle of Man. The site extends approximately 14.8 x 7.6 km and encompasses a number of bedrock outcrops ('peaks') and surrounding sedimentary areas. It has been surveyed by AFBI for the JNCC as part of potential offshore SAC selection research and also as part of the MESH North Western Shelf Consortium mapping effort. Surveying has been ongoing and opportunistic over this site since 2003, with some ground-truthing already undertaken through such efforts. After the multibeam echosounder survey in 2006 (see section 2.2) however, it was decided that additional ground-truthing be planned in order for a biotope map to be produced for the site. The use of OAA is considered here in terms of how much additional ground-truthing should be required/recommended.

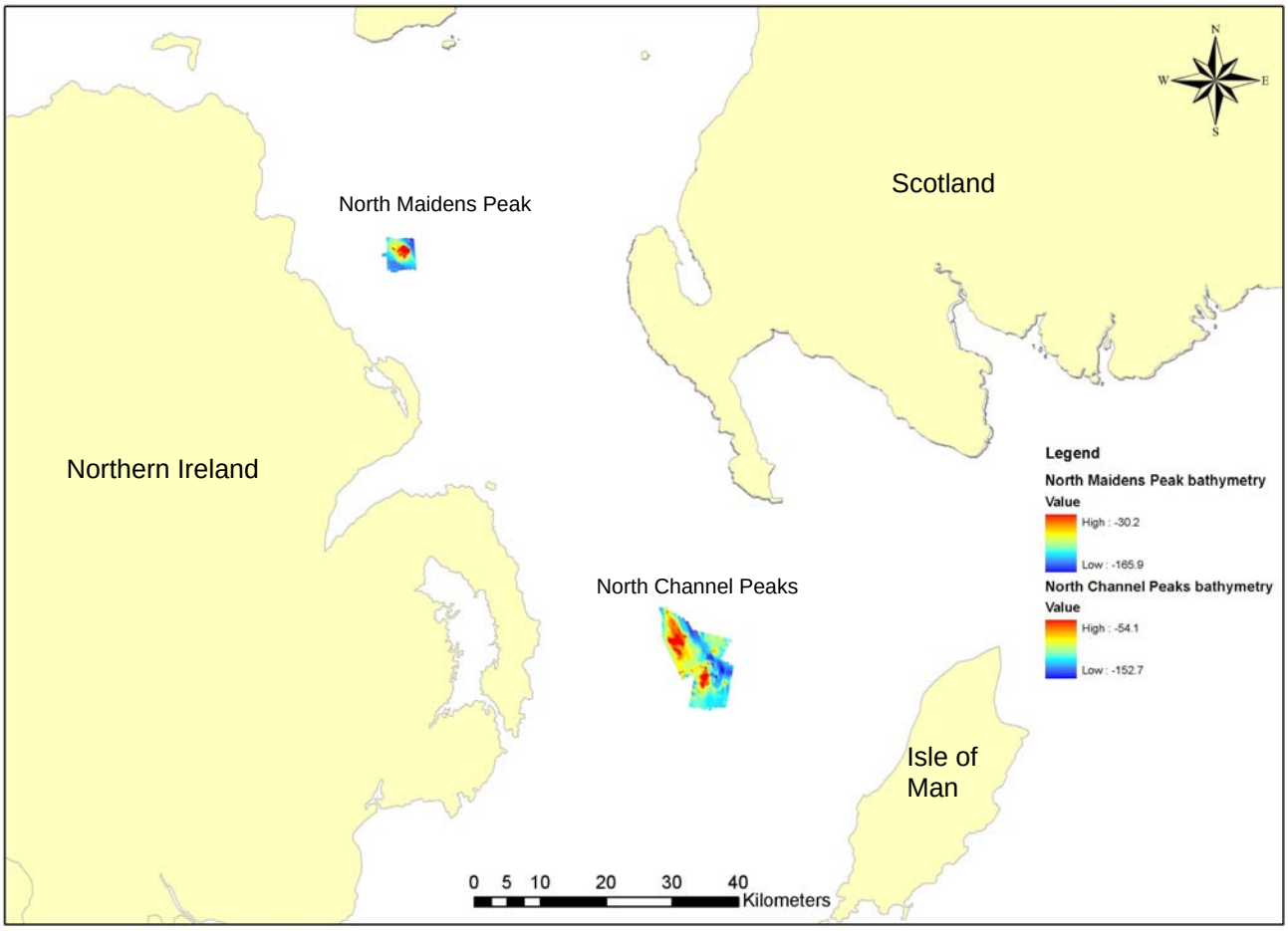

Figure 1. Location of pilot study sites in the Irish Sea.

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2. Optimal Allocation Analysis Methodology

2.1. OAA calculations

The first question in planning a sample survey is in relation to the size of the sample required for estimating the population parameter with a specified precision. Apart from the size of the sample, the only way of increasing the precision of an estimate is to devise sampling procedures which will effectively reduce the heterogeneity. One such procedure is stratified sampling. It consists of dividing the heterogeneous population of N units into subpopulations of $N_1, N_2 \ldots N_L$ units respectively, each of which is internally homogeneous. These subpopulations are non-overlapping and comprise of the whole population and are called strata.

$$N_1 + N_2 + \ldots + N_L = N$$

The values of N_h (see notation below) must be known. When the strata have been determined, a sample is drawn from each stratum, the drawings being made independently. The sample sizes within the strata are denoted by $n_1, n_2 \ldots n_L$ respectively. If a simple random sample is taken in each stratum, the whole procedure is described as stratified random sampling. This is a common procedure in sample surveys and is intended to give a better cross-section of the population than that of unstratified sampling.

The theory of stratified sampling deals with the properties of the estimates from a stratified sample and with the best choice of the sample sizes n_h (see notation below) so as to obtain maximum precision.

Notation:
The sub index "h" denotes the stratum and "i" the unit within the stratum. Furthermore:

N_h = Total number of units within stratum h.
n_h = Number of units from the sample in stratum h.
y_{hi} = Value obtained for the ith unit in stratum h.

$$W_h = \frac{N_h}{N}$$ = Relative size of stratum h

$$\overline{Y}_h = \frac{\sum_{i=1}^{N_h} y_{hi}}{N_h}$$ = Population Mean

$$\overline{y}_h = \frac{\sum_{i=1}^{n_h} y_{hi}}{n_h}$$ = Sample Mean

$$S_h^2 = \sum_{i=1}^{N_h} \frac{(y_{hi} - \overline{Y}_h)^2}{N_h - 1}$$ = Population Variance

$$\bar{y}_{st} = \sum_{h=1}^{L} W_h \overline{y_h}$$ = Estimator of the population mean

$$V(\bar{y}_{st}) = \sum_{h=1}^{L} \frac{W_h^2 S_h^2}{n_h} - \sum_{h=1}^{L} \frac{W_h S_h^2}{N}$$ = An unbiased estimate of variance of $\bar{y}_{st}$.

Let s_h be the estimate of S_h and $n_h = w_h n$, where the w_h have been chosen. In these terms the Expected $V(\bar{y}_{st})$ is:

$$V = \frac{1}{n} \sum_{h=1}^{L} \frac{W_h^2 s_h^2}{w_h} - \frac{1}{N} \sum_{h=1}^{L} W_h s_h^2$$

This can be rearranged to give the general formula for n

$$n = \frac{\sum_{h=1}^{L} \frac{W_h^2 s_h^2}{w_h}}{V + \frac{1}{N} \sum_{h=1}^{L} W_h s_h^2}$$

For the particular case of optimum allocation, where n is fixed the formula takes the form:

$$n = \frac{\sum_{h=1}^{L} (W_h s_h)^2}{V + \frac{1}{N} \sum_{h=1}^{L} W_h s_h^2}$$

Using the formula for the Co-efficient of Variation (CV) the Expected Variance (V) can be replaced to give

$$CV = \frac{S\tan dardDeviation}{Mean}$$

$$n = \frac{\left(\sum_{h=1}^{L} W_h s_h \right)^2}{\left(\sum_{h=1}^{L} W_h \bar{y}_h . CV \right)^2 + \frac{1}{N} \sum_{h=1}^{L} W_h s_h^2}$$

Therefore, for a specified Coefficient of Variation, the total number of samples can be calculated to obtain maximum precision.

The optimum value of the sample sizes n_i within each stratum are given by:

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$$n_h = n\frac{W_h s_h}{\sum_{h=1}^{L} W_h s_h}$$

In order to put the theory into practice in relation to seabed habitat mapping a 'population' is a population of remotely-sensed data for a survey site which is thought to relate to habitat heterogeneity and identification. Subpopulations or strata are the ground types that the remotely-sensed data are classified into prior to ground-truthing (see section 2.2 below).

For example, if you have 3 strata each with a sample mean and variance for each remotely-sensed variable denoted as $\bar{y}_1$, $\bar{y}_2$ and $\bar{y}_3$ and s_1^2, s_2^2 *and* s_3^2 respectively, then an estimate of the population mean can be calculated using the formula $\bar{y}_{st} = \sum_{h=1}^{L} W_h \bar{y}_h$.

That is

$$\bar{y}_{st} = W_1\bar{y}_1 + W_2\bar{y}_2 + W_3\bar{y}_3 \quad \text{Where} \quad W_h = \frac{N_h}{N} \qquad \text{A}$$

Using the relative size of each stratum and the sample variance, calculate

$$\sum_{h=1}^{3} W_h s_h = W_1 s_1 + W_2 s_2 + W_3 s_3 \qquad \text{B}$$

And

$$\sum_{h=1}^{3} W_h s_h = W_1 s_1^2 + W_1 s_2^2 + W_1 s_3^2 \qquad \text{C}$$

Now you have:
An estimate for the population mean – A
An estimate of the total weighted standard deviation for the strata – B
An estimate of the total weighted variance for the strata – C
The total number of units – *N*

The optimum number of ground-truthing samples (*n*) for a known Coefficient of Variation (CV) can be calculated:

$$n = \frac{B^2}{(A \times CV)^2 + \frac{1}{N} \times C}$$

which is equivalent to:

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$$n = \frac{\left(\sum_{h=1}^{L} W_h s_h\right)^2}{\left(\sum_{h=1}^{L} W_h \bar{y}_h . CV\right)^2 + \frac{1}{N}\sum_{h=1}^{L} W_h s_h^2}$$

By varying the Coefficient of Variation (CV) the number of samples (*n*) will change to give you the optimum number.

If you want to calculate the Coefficient of Variation (CV) for a known number of samples (*n*) then the following formula is used:

$$CV = \frac{\left(\sqrt{\frac{B^2}{n} - \frac{1}{N} \times C}\right)}{A}$$

which is equivalent to:

$$CV = \frac{\sqrt{\left(\frac{\left(\sum_{k=1}^{L} W_k s_k\right)^2}{n} - \frac{1}{N} . \sum_{k=1}^{L} W_k s_k^2\right)}}{\sum_{k=1}^{L} W_k \bar{y}_k}$$

Note: The number of samples (*n*) formula has been algebraically rearranged to give a formula to calculate the Coefficient of Variation (CV).

To calculate the optimum number of samples within each of the 3 strata, the following formulae and the optimum number of samples (*n*) are used:

$$n_1 = n \times \frac{B_1}{B}, \quad n_2 = n \times \frac{B_2}{B}, \quad n_3 = n \times \frac{B_3}{B}$$

which is equivalent to:

$$n_1 = n \times \frac{W_1 s_1}{\sum_{h=1}^{3} W_h s_h}, \quad n_2 = n \times \frac{W_2 s_2}{\sum_{h=1}^{3} W_h s_h}, \quad n_3 = n \times \frac{W_3 s_3}{\sum_{h=1}^{3} W_h s_h}$$

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2.2. Unsupervised classification of remotely-sensed data

There are a number of options available to classify remotely-sensed data gathered in the first stage of habitat mapping to identify ground-types that may relate to discrete habitats. It is beyond the scope of this study to examine these in detail but the reader is directed to the section of the MESH Guide entitled 'How do I make a Map?' for further information. To summarise the options available, remotely-sensed data may be subjected to the following analyses which all fall under the term 'unsupervised' classification owing to the fact that no ground-truthing data are available/incorporated at this stage and the remotely-sensed information is allowed to 'speak for itself' to identify patterns/trends within the dataset which may indicate different ground-types. The three main options are as follows:

1. Use 'expert judgement' to analyse the remotely-sensed data by eye through presentation of the various remotely-sensed datasets in a spatial context, for instance through the use of a Geographical Information System (GIS), and hand-draw (either on paper print-outs or digitally) boundaries of distinct ground-type after interpretation of the various 'layers' of remotely-sensed data. This is a method typically expounded and well developed by geologists. It should only be used where a very good understanding of the remotely-sensed data exists, such that data artefacts are discounted and subtleties detected.
2. Use a data clustering program to analyse the remotely-sensed data statistically. Many such programs exist within image processing software and GIS that can deal with large datasets efficiently. Nearly all of the available clustering routines, however, require the user to specify the desired output number of clusters. There are some recommendations in remote-sensing/image processing literature regarding how to determine the number of output clusters (Burroughs and McDonnell, 1998; Eastman, 1997) for instance through the use of histogram analysis, but in general it is a fairly subjective process and the best advice seems to be to run a number of analyses with different numbers of clusters and use expert judgement to determine which is appropriate to take forward. New statistical methodologies are being developed to determine the appropriate number of clusters after a few different numbers have been tried, for instance the Calinski and Harabasz (C–H) method (Orpin and Kostylev, 2006a and b; Hamilton, 2006). It is advised that users keep abreast of these developments.
3. Some remote-sensing techniques have specific software developed in association with them to classify the data (without ground-truthing). Such 'automated' classification softwares should be considered alongside the other options as they may be powerful in certain circumstances. For instance, GeoTexture™ software developed by GeoAcoustics Ltd. for use with their GeoSwath bathymetric sidescan sonar system has been fairly successful in producing ground-type boundaries that correspond to ground-truthing (Müller *et al.,* in press 2005). In addition QTC Inc. have developed a software package QTC-Multiview to analyse multibeam sonar backscatter data, which has also been successful (Preston *et al.,* 2004).
4. Use of topographic/bathymetric-derived variables to identify zones within the survey site through rule-based modelling. An example of a package developed for this is the Benthic Terrain Modeller (NOAA), which is available as an extension to ArcGIS, whereby bathymetric data collected by the remote-sensing technique are used to

derive a bathymetric position index which can be calculated over different spatial scales. This, combined with actual depth and slope, may be used to create a series of rules to identify zones within the site which may correspond to different habitats. The whole dataset is then classified according to these rules. This technique requires a thorough inspection of the dataset and is most suitable for use with high-resolution bathymetric data, for instance that generated from multibeam sonar or Lidar. It has been successfully applied in a number of environments (e.g. Iampietro *et al.,* 2005; Lundblad *et al.,* 2006).

Multibeam sonar was used to remotely-sense the seabed at both study sites. The Simrad EM1002S multibeam echosounder system was used to survey the North Maidens Peak site aboard the RV *Celtic Voyager* on 17-18/09/2005. Vessel heading and attitude corrections were input to the EM1002S *via* the Seapath 200; correcting bathymetric data in real time. Bathymetric data quality were monitored online with corrective actions taken in the case of data quality deterioration with SVP's casts where necessary to maintain accurate set up. Regular checks of processed lines displayed in the CARIS seabed mapping system were performed to check for mismatches between lines caused by sound velocity changes or other sources of error. A combined SVP graph was monitored regularly on the online EM1002S station to analyse changes in sound velocity. A hull mounted SV sensor was available to indicate variations between local sound velocity and that from the profile. This hull sensor was used for near field beam steering. The resulting data was cleaned and processed using CARIS SIPS and CARIS HIPS v5.3 SP2 software, and gridded at 4 m resolution to generate bathymetric XYZ data and gridded at 5 m for backscatter mosaic. To facilitate data processing, each survey line was tidally corrected using predicted tides derived from Polpred software from the Proudman Oceanographic Laboratory. The Polpred model used was the Continental shelf Model CS3-30HC. Each survey line was processed separately in Swath Editor and following this in the Subset Editor along with adjacent lines. When necessary a preliminary automatic filter cleaning in swath editor was used.

In addition, a Simrad EM2000 multibeam echosounder system was also used on 25 June 2003 aboard the RV *Lough Foyle* to survey the main peak. Post-processing of bathymetry data was carried out on Neptune (Simrad Survey Systems) Version 4.11 for Windows, and subsequent to editing poor data points the bathymetric and amplitude data were processed using the Poseidon suite of programmes for production of the sonar mosaics. Further quality assurance/quality control was performed on the data using Cfloor by Roxar and Fledermaus by IVS software, resulting in cleaned 5 m resolution bathymetric XYZ data. Upon inspection, with the two datasets overlaid upon one another other, it was decided that the Simrad EM1002S dataset would be used to trial unsupervised classification techniques and the OAA approach. This was largely because there was complete overlap between the datasets but additionally the EM1002 bathymetric data were at a slightly higher resolution and showed fewer artefacts which may have been amplified by data classification. Both datasets showed the same depths at the same locations so both had been collected and processed to a good hydrographic standard.

A Reson SeaBat 8101 150° 240 kHz ER (extended range) multibeam echosounder was used to survey the North Channel Peaks site aboard the RV *Corystes*. Data were

collected over the area of interest during two periods within June 2006: 1) 17/06/2006 – 18/06/2006, and 2) 21/06/2006 – 22/06/2006. The Reson 8101 was deployed with the following ancillary parts:

- TSS DMS2-05 motion reference unit and SG Brown Meridian Surveyor gyro-compass to measure vessel movement.
- Valeport SVP (sound velocity profiler) to measure speed of sound through water.
- Communication Systems International (CSI) Inc. GBX differential GPS (dGPS) system, with the differential corrections obtained from the IALA Beacon system, for horizontal position control.
- QPS QINSy Version 7.5 Integrated Navigation and Surveying software.

During the survey QPS QINSy Version 7.5 software was used for acquisition and quality assurance/quality control. This recorded all the acquisition data and also applied sound velocity at the sonar head and through the water column. Roll, pitch, timing, and heading calibrations were undertaken with this software.

Post-processing of the Reson bathymetric data was undertaken by Marcin Plichta. Tidal corrections were applied to the multibeam data from nearby cleaned tidal gauge for Portpatrick and Bangor (N.I.), courtesy of the British Oceanographic Data Centre, through the QINSy software. XYZ data was cleaned and gridded at both 5 m and 10 m resolution. Where small gaps occurred in the data coverage interpolation was undertaken within QINSy to produced both full-coverage grids and 'real' data grids (no interpolation). XYZ files consisted of eastings, northings and depth with reference to the lowest astronomical tide (LAT). Positions are in Universal Transverse Mercator (UTM) Zone 30N projection.

The Reson 8101 backscatter data were saved as xtf files, and this produced sidescan-like imagery of good resolution. Tim Le Bas of the National Oceanography Centre processed this data to create cleaned backscatter mosaics, using the in-house developed software PRISM. Owing to certain artefacts the final backscatter mosaic resolution was provided at 1 m^2. The mosaics were provided as georeferenced ERDAS Imagine files which are readily imported and merged within GIS.

Using Spatial Analyst routines within ArcInfo 9.1 (ESRI) the following datasets were derived from the bathymetric grids for each site:

- Slope angle (0-90°).
- Aspect (0-360°).
- Hillshaded bathymetry (from various angles to highlight features).

In addition, the Benthic Terrain Modeller (NOAA) extension for ArcGIS was used to generate bathymetric position index (BPI) at varying spatial scales for each dataset and also to calculate rugosity (surface complexity) from the bathymetric data.

Each data layer was stored and presented within the GIS such that they could be examined together, along with the original bathymetric data grid and the backscatter mosaics.

The datasets were then subjected to unsupervised classification through cluster analysis and maximum likelihood classification. A number of combinations of the variables were investigated, including all of and combinations of a subset of depth, slope angle, aspect, BPI and rugosity. As rugosity and slope angle are highly correlated only one of these layers were used in each test of the unsupervised classification.

The clustering program used was 'Iso Cluster' found within the Spatial Analyst tools of ArcInfo. This technique uses a modified iterative optimisation clustering procedure, also known as the migrating means procedure (please see ArcGIS 9.1 WebHelp, ESRI, 2006). Using this technique a range of cluster numbers were trialled and mapped by using maximum likelihood classification (also found within the Spatial Analyst tools).

The Benthic Terrain Modeller was used to undertake rule-based modelling. For both sites broad and fine BPI, depth and slope angle were carefully examined throughout the sites to identify trends which may correspond with seabed features and ground-types. Using the Modeller routine, a classification dictionary for each site was created populated by a set of rules expressed as ranges of values for each variable. This dictionary was then used to classify the datasets and produce a final map of the various seabed 'zones'.

2.3. Extracting relevant data from large datasets using GIS

The resulting classified acoustic data were stored as a raster file (ESRI grid), with a cell size of 4 m for North Maidens Peak and 5 m for North Channel Peaks. Using the 'zonal statistics as table' routine within Spatial Analyst tools (part of the Spatial Analyst extension for ArcGIS) the classified raster was used to extract statistics from the other raster datasets (bathymetry, aspect, slope angle etc.), such that these statistics were calculated for each class/zone. The resulting area of each class, provided in m^2, along with summary statistics for the particular dataset/variable in question (minimum, maximum, range, mean, standard deviation, sum) are output into a DBF table. The statistics for each raster dataset are output into separate DBF files, and the variance for each variable within each class/zone may be calculated simply by squaring the standard deviation. The number of strata (or ground-types/classes/zones) were entered into a summary spreadsheet and the variable of interest (e.g. backscatter, slope angle etc.) listed as column headings. Against each strata an area value was entered for the site, then the mean and variance for that particular strata for the variable of interest, as extracted from the DBF files. This data was then used for running the OAA through the use of a Microsoft Excel macro.

2.4. Operating the OAA macro in MS Excel

AFBI/QUB have developed two Excel macros which incorporate the calculations detailed in section 2.1 above. One macro prompts users to enter the required data while the other simply allows for data to be pasted in from other spreadsheets. A user guide is provided based upon the former macro. These macros are available upon request to the authors.

The macros allow the user to enter a desired coefficient of variation (CV), a measure of precision, and/or a maximum number of samples for the ground-truthing survey (see

section 1.3 above). The macro then calculates the recommended number of samples to achieve the desired CV for each strata (ground-type) based upon the input variable statistics and strata area or if maximum number of samples have been entered the CV will be calculated and the distribution of the samples between each strata allocated. It should be noted that the sample numbers are output in the same units as that used for area (for instance, m^2). Where a number of remotely-sensed variables (including those derived from bathymetry) would ideally be considered in such an analysis (for example slope, rugosity, backscatter, aspect), these can all be incorporated into the OAA and the results for each variable inspected and if applicable the results for each variable can be averaged (which the macro will do automatically).

It should be noted that although the OAA recommends the number of samples for each ground-type, it does not advise where these should be placed within each ground-type or what sampling equipment should be used. In sedimentary regions it is generally accepted that the biology of such areas is dominated by infauna, and therefore an appropriate infaunal sampling tool will be required, such as a grab or corer. Such samples cover a very small area, for instance the Day grab bite aperture is 0.1 m^2, and therefore each 1 m^2 sample recommended by the OAA will in reality require ten grab samples to cover such an area. Conversely however, where the ground-type is likely to be reef or cobbles/boulders epifauna will dominate the biological community and a suitable sampling platform for such communities would be a video/camera system (if visibility is adequate). Video systems can cover a larger area in less time than grab sampling, with the field of view at any one point usually approximating 1 m^2. It is therefore quite simple to cover the recommended sample area with video tows/drops on bedrock zones but much more time consuming to sample the recommended area in the sedimentary zones.

3. Optimal Allocations Analysis Results

For both study sites unsupervised classifications of the multibeam echosounder (MBES) datasets were undertaken successfully. In the case of the North Maidens Peak site, the MBES bathymetric data was exceptionally clean with very few artefacts that could be amplified in the unsupervised classification procedures. The MBES dataset for the North Channel Peaks, however, did have a number of artefacts owing largely to the fairly poor sea conditions during the survey. It was found that all methods of unsupervised classification 'highlighted' such artefacts, as would be expected, but that in particular the clustering techniques (both Iso Cluster and PCA) resulted in very small patches of ground-types throughout most of the survey area, which would have been impossible to use for mapping of broadscale habitats owing to the issues of accurately ground-truthing them (especially as the depth range for these sites is -30 m to -166 m). Nonetheless, such maps may be meaningful in identifying finer scale habitats and should not be discarded as may explain finer scale patterns later identified from ground-truthing. In both study sites it was found that a combination of bathymetry, slope and aspect in cluster analysis was effective, with the resulting map for the North Maidens Peak showing a clear pattern for a suite of environmental conditions that could be meaningful for habitat identification. For the North Channel Peaks site however, the bathymetric artefacts resulted in a very

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fractured classified map which would be difficult to interpret as it stands without significant editing. Cluster analysis was found not to deal effectively with MBES backscatter data where it is presented and used in the analysis as a greyscale mosaic, owing to the large number of artefacts found in the mosaics and in particular an along-track change in grey scale as a result of the acoustic angular response curve. Where backscatter mosaics are used it may be an option to undertake a manual expert interpretation first, by drawing around notable features and then using this new data layer in unsupervised classification alongside the bathymetry and bathymetry-derived datasets.

In both cases, upon inspection of the unsupervised classifications it was decided that the results of the Benthic Terrain Modeller classification (rule-based modelling) were most appropriate, in terms of representing broadscale habitats and practicalities of ground-truthing the resulting ground-types.

3.1. North Maidens Peak

The MBES data reveal a substantial peak (igneous intrusion) of bedrock surrounded by softer sediment. The peak has the appearance of a platform, with near-vertical sides and a fairly level top. The main peak extends approximately 1.4 km by 1.5 km, with an additional smaller intrusion to the west adjacent to the main peak, extending approximately 0.3 by 0.6 km. The peak rises up over 100 m from the surrounding seabed at the steepest points, with the platform shoaling at between -30 and -55 m (Chart Datum). The surrounding seabed appears to comprise of mega-rippled sediments, indicating strong tidal reworking and which are likely to be of a medium to coarse grain size. The backscatter data for this site were mosaiced at 4 m resolution and therefore fine detail is difficult to see over the artefacts, however the main features are highly visible, with a darker but heterogeneous reflectance over the peak areas and lighter reflectance for much of the sedimentary region. The megaripples are also evident from the backscatter data, indicating that there may be some sorting of sediment across the megaripples such that trough and crest are characterised by different grain sizes. In addition, a lighter reflectance area is shown towards the middle of the main peak, indicating that there is possibly a sediment veneer over part of the peak.

The resulting Benthic Terrain Modeller classified map highlighted the features identified from inspection of the MBES datasets (Figure 3.1.1), in particular classifying the steeply sloping edges of the peak and immediately surrounding area at the base of the peak. It has also highlighted the crests of the sediment megaripples, and the top of the peaks. It has not, however, been able to identify areas on top of the peak which may be covered by a sediment veneer, which is mainly as by using only bathymetry-derived data this is difficult to predict (it would require backscatter data input, or prevailing tidal current data). The resulting classified zones have been described as:

1. Sedimentary plain (close to flat / constant slope; depth limited -166 to -68 m).
2. Low relief features (small crests/hummocks; depths unrestricted).
3. Ridges/slopes 1 (features/regions that are higher than their surroundings, with a BPI greater than zone 2; depths unrestricted).

4. Valleys/slopes 2 (features/regions that are lower than their surroundings; depths unrestricted).
5. Steep/high relief ridges (steep/high relief regions that are significantly higher than their surroundings, with a BPI greater than zone 3; depths unrestricted).
6. Steep/high relief valleys – cliff walls (steep/high relief regions that are significantly lower than their surroundings, with a BPI lower than zone 4; depths unrestricted).
7. Rock plateau/flat (close to flat / constant slope; depth limited -68 to -31 m).

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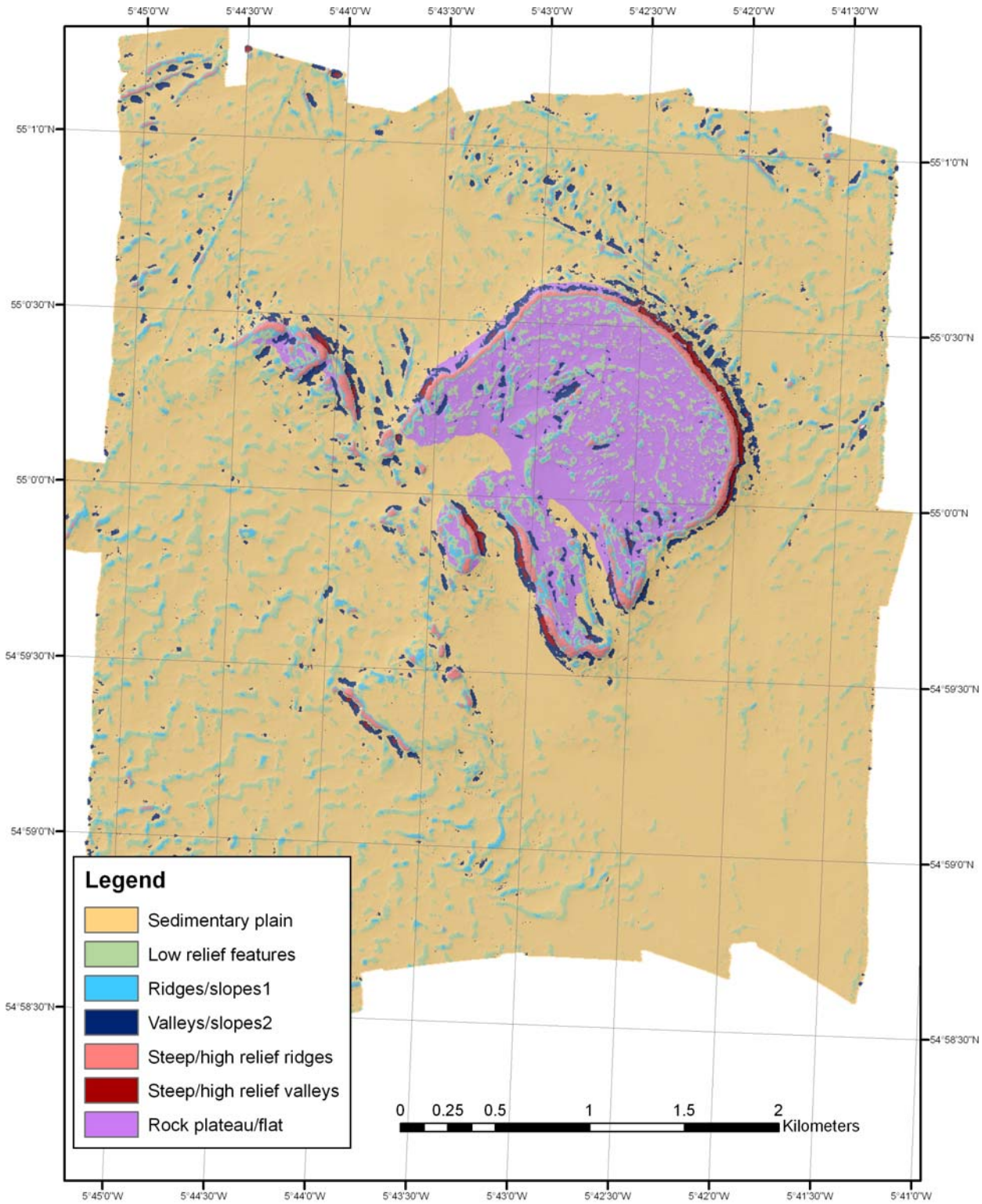

Figure 3.1.1. Map showing the rule-based classification of MBES datasets to derive ground-types ('zones') using Benthic Terrain Modeller at the North Maidens Peak site.

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After careful inspection of the MBES datasets and bathymetry-derived datasets it was deemed that the variables slope, backscatter and aspect were likely to be most representative of habitat heterogeneity. Owing to scale issues, BPI results (which in this case range from -1893 to 2714) could not be incorporated into the OAA, although this issue will be looked into in future work. The summary statistics for each of the variables were extracted for the Benthic Terrain Modeller zones (Figure 3.1.1), and entered into the Excel spreadsheet macro containing embedded calculations for OAA. The area of each zone was also added (in m^2). The coefficient of variation (CV) was set at 5% (i.e. 95% precision) for calculating the optimal sample numbers per ground-type. The results for each variable, and the average scores, are presented in Table 3.1.1.

Table 3.1.1. Sample numbers required for a CV of 5% for each ground-type ('zone'). Samples are in m^2.

		Slope angle	Backscatter	Aspect	Average
Total samples		**276**	**91**	**117**	**162**
Zone 1	**Sedimentary plain**	**181**	**68**	**88**	**112**
Zone 2	**Low relief features**	**35**	**12**	**15**	**21**
Zone 3	**Ridges/slopes 1**	**7**	**2**	**2**	**4**
Zone 4	**Valleys/slopes 2**	**14**	**2**	**3**	**7**
Zone 5	**Steep/high relief ridges**	**14**	**1**	**2**	**6**
Zone 6	**Steep/high relief valleys – cliff walls**	**3**	**0**	**0**	**1**
Zone 7	**Rock plateau/flat**	**22**	**6**	**7**	**12**

It is notable how much variation there is in the number of total recommended samples between the different input variables. In particular, slope angle recommends three times the number of samples than that of backscatter, with aspect agreeing quite closely to number recommended by backscatter. Further research is required to understand why the use of slope angle results in such a different output in terms of recommended sampling level for the same level of precision (95%).

In the case of zone 6 (steep/high relief valleys – cliff walls) when both backscatter and aspect datasets with analysed through OAA, no samples are recommended in order to achieve 95% precision. This is because the weighted standard deviation in zone 6 is very small relative to the total weighted standard deviation for all strata. Table 3.1.2. summarises the data for each of the input variables used in the OAA, which helps to unravel which factors have affected the final recommended sample numbers. This information is further presented graphically in Figure 3.1.2.

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Table 3.1.2. OAA input data summaries for the North Maidens Peak site.

Zone	Proportion of total site area	Slope angle mean	Slope angle standard deviation	Backscatter mean	Backscatter standard deviation	Aspect mean	Aspect standard deviation	Sum of standard deviation rank orders
Zone 1	0.751	4.06	3.52	117.87	53.86	178.94	97.07	5
Zone 2	0.127	5.51	4.04	110.04	56.31	183.81	100.55	9
Zone 3	0.020	7.37	5.38	103.24	56.69	184.19	102.09	13
Zone 4	0.022	12.24	9.46	88.77	64.32	170.95	108.40	18
Zone 5	0.013	17.37	14.69	104.81	57.22	173.04	104.82	18
Zone 6	0.003	30.47	14.47	65.97	61.07	122.06	90.04	14
Zone 7	0.063	5.89	5.10	97.28	55.91	186.35	86.96	6

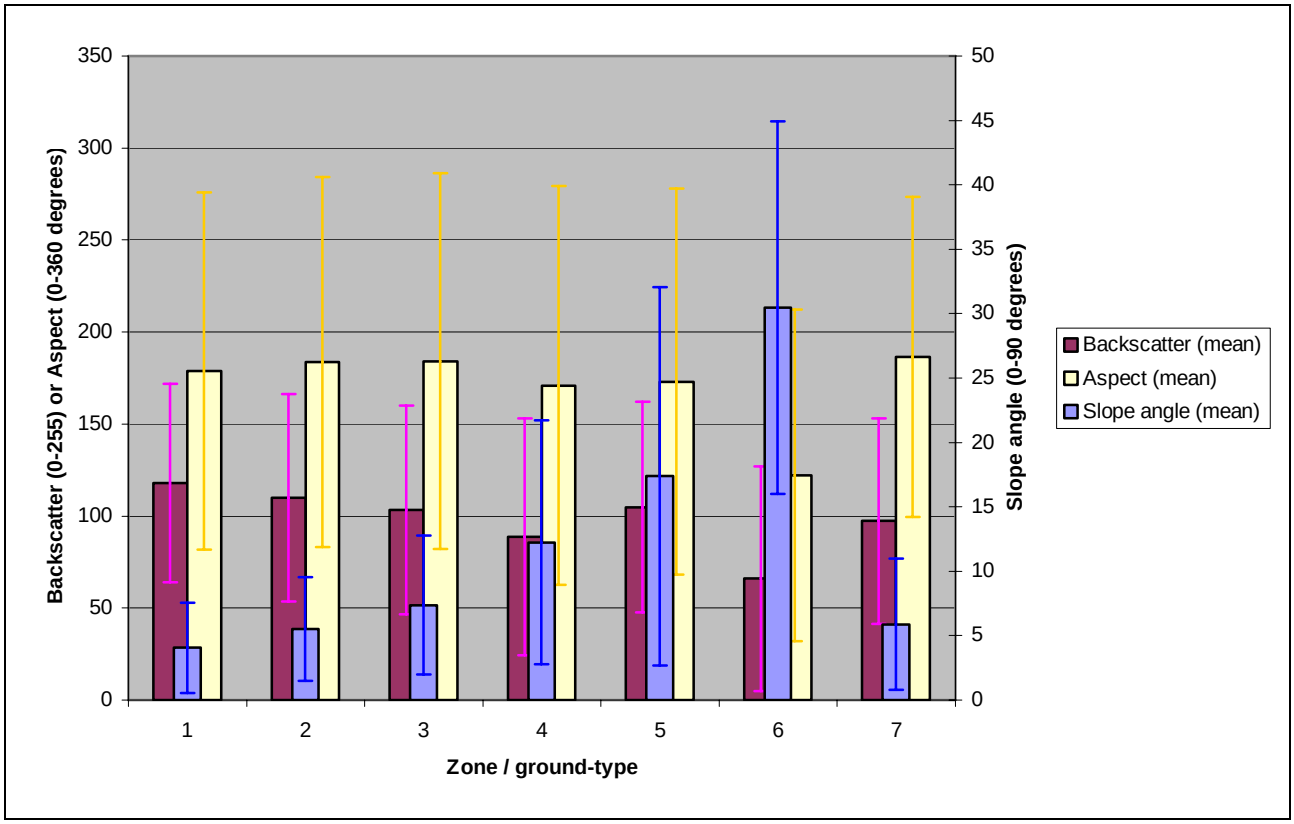

Figure 3.1.2. OAA input variables summary statistics for each zone (ground-type) North Maidens Peak site (standard deviation is represented by the error bars).

It appears that area of ground-type/zone has a great impact on the OAA and that in this case the recommended sample numbers for each ground-type follow the order of ground-type areas. It is also apparent however, how the variance for each ground-type impacts upon the OAA calculations, as for zones 3 and 5 based upon their area we would expect more samples for zone 3 than for zone 5. In the case of using slope angle as an input

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variable, this results in more recommended sampling for zone 5 than zone 3, contrary to what had been expected based upon zone area alone. Results for backscatter and aspect however indicated very similar levels of sampling for these two zones, owing to the fact that for these two variables the variance is similar in both zones, unlike the case for slope angle where zone 5 has nearly three times the variance of that in zone 3.

Based upon this trial of the use of OAA in guiding stratification of ground-truthing samples, it is apparent that the choice of input variables has a great impact upon the resulting recommended level of sampling. Further application of the technique to more datasets will provide an improved assessment of which remotely-sensed datasets are most applicable and most readily represent true habitat heterogeneity. It seems justifiable however, to use 3 variables known to have an effect on habitat type or perhaps represent ground-type heterogeneity as has been conducted in this study, and use the average findings to guide sampling effort.

3.2. North Channel Peaks

The MBES data revealed a complex topography of bathymetric rises ('peaks') and deep sedimentary basins. The peaks generally had a heterogeneous appearance, which is often an indicator of bedrock outcrops, however in addition deeper complex areas were also found near the major peaks and to the east of the survey area within the sedimentary basins. Two major peak areas can be identified, one to the northwest (approx. 3 km by 3 km in area) and the other in the south of the area (approx. 3 km by 1.5 km in area). Additional smaller peaks are also found between these, which are less distinct and appear to be deep, lower relief bedrock outcrops. The backscatter data revealed a large number of potential ground-types, ranging from the classic darker reflectance of reef sites to large expanses of low-reflectance homogeneous areas (sedimentary 'plains'). In addition to the east was an area of sand waves or megaripples, adjacent to an area giving a mixed appearance of mid-reflectance values. To the northwest of the major northerly peak were areas of alternating high and low reflectance, which may also be megaripples. In the middle of the survey site, in the main sedimentary basin, trawl scars could be seen on the backscatter mosaic, indicative of paired otter boards. This suggests that the sedimentary area is trawled for *Nephrops norvegicus*.

The unsupervised classification of the MBES data took a lot of iterative attempts due to the issues of data artefacts. Although the Benthic Terrain Modeller produced improved classifications over cluster analysis, it was found that while some features were very clearly identified by using BPI combined with depth and/or slope angle in the classification dictionary, other features seemed to be obscured even when using fine BPI data layers created over a short spatial scale. This may have largely been due to the high number of bathymetric artefacts in the MBES data for this site, which then resulted in the BPI calculation amplifying such errors. After many attempts at defining the classification dictionary using BPI values, it was finally decided that the high resolution of the MBES data was itself amplifying artefacts through the classification. An attempt at resolving this issue was to re-run the classification on dataset grids of a slightly coarser resolution, to smooth over the artefacts, at the risk of smoothing over real features. Slope angle, depth

and BPI were re-calculated on a 10 m grid, however once again when BPI was used in the classification too many artefacts obscured the main ground-type patterns. Therefore only depth and slope angle (both at 10 m resolution) were used to generate the final zone map. Upon inspection of the final Benthic Terrain Modeller classified image (Figure 3.2.1), it appeared to correspond well with the backscatter mosaic. The resulting zones were described as following:

1. Low relief bedrock.
2. Homogeneous sedimentary plain (*Nephrops* bioturbated mud?)
3. Deep (>100m) medium-high relief bedrock outcrops (slope > 4°).
4. Shallow (<100m) medium-high relief bedrock outcrops (slope > 4°).
5. Coarse and/or mixed sediment.
6. Mixed sediment with boulder or cobble fields (plus possible sediment veneer).

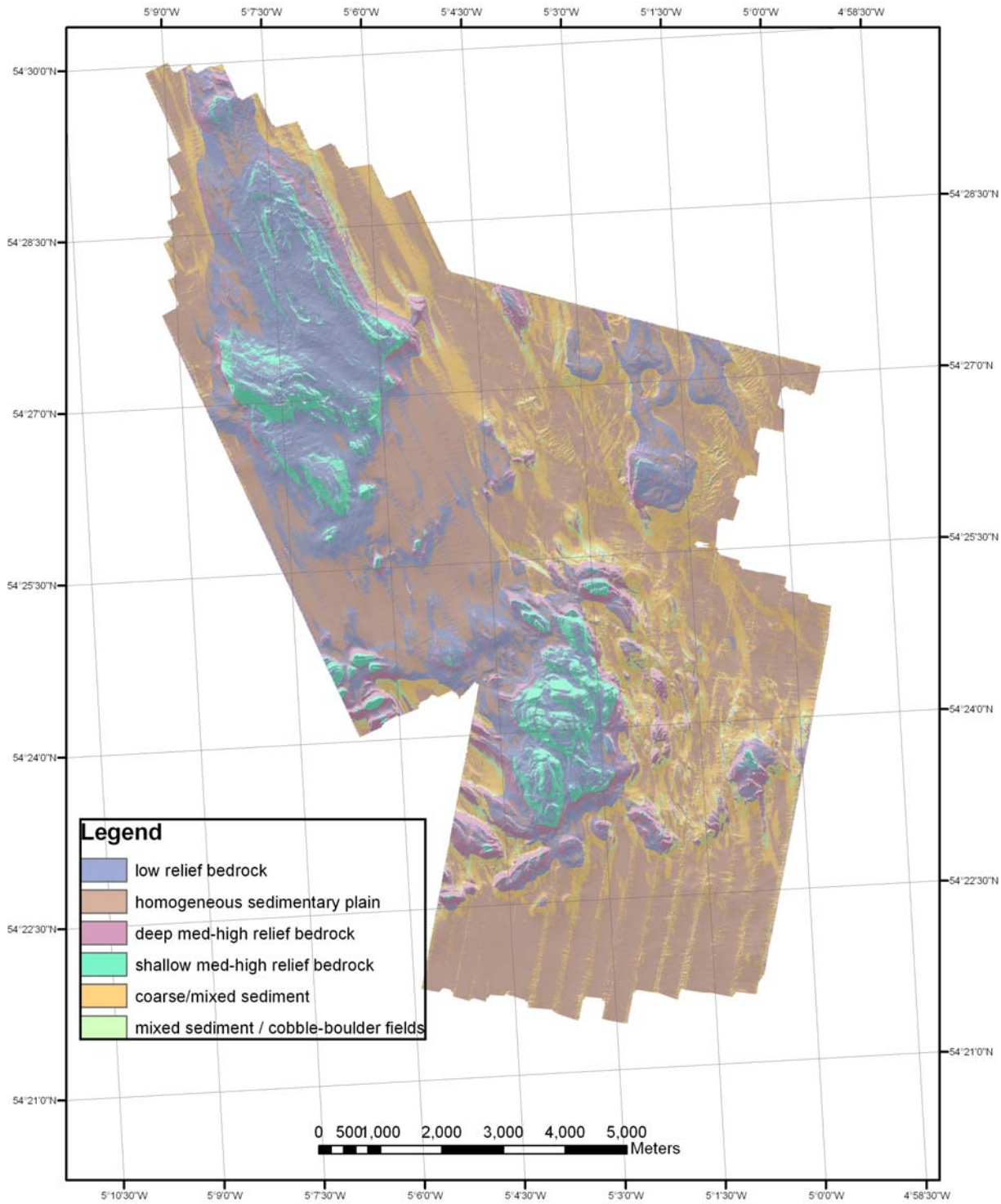

Figure 3.2.1. North Channel Peaks rule-based classification of MBES datasets to derive ground-types ('zones') using Benthic Terrain Modeller.

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3.2.1. Use of Optimal Allocation Analysis to guide ground-truthing effort

As for the North Maidens site, for the North Channel Peaks after careful inspection of the MBES datasets and bathymetry-derived datasets it was deemed that the variables slope, backscatter and aspect were likely to be most representative of habitat heterogeneity. The summary statistics for each of these variables were extracted for the Benthic Terrain Modeller zones (Figure 3.2.1), and entered into the Excel spreadsheet macro containing embedded calculations for OAA. The area of each zone was also added (in m^2). The coefficient of variation (CV) was set at 5% (i.e. 95% precision) for calculating the optimal sample numbers per ground-type. The results for each variable and the average scores, are presented in Table 3.2.1.

Table 3.2.1. Sample numbers required for a CV of 5% for each ground-type ('zone'). Samples are in m^2.

		Slope angle	Backscatter	Aspect	Average
Total samples		**108**	**84**	**141**	**111**
Zone 1	Low relief bedrock.	**20**	**18**	**33**	**24**
Zone 2	Homogeneous sedimentary plain (*Nephrops* bioturbated mud?)	**16**	**33**	**61**	**37**
Zone 3	Deep (>100m) medium-high relief bedrock outcrops	**40**	**9**	**12**	**20**
Zone 4	Shallow (<100m) medium-high relief bedrock outcrops	**16**	**4**	**7**	**9**
Zone 5	Coarse and/or mixed sediment	**14**	**16**	**26**	**18**
Zone 6	Mixed sediment with boulder or cobble fields.	**2**	**3**	**3**	**3**

It is notable that for this site, slope angle does not result in much increased recommended numbers of samples compared to backscatter and aspect, unlike the North Maidens Peak site. Slope angle however, again results in a slightly different distribution of sample numbers between the zones, in particularly requiring the highest number on zone 3, whereas for both backscatter and aspect input variable results, zone 3 requires the fourth highest number of samples to be placed in zone 3. This can be directly related to the differences in the variance between zones for each of the input variables. Aspect and backscatter show a fairly similar pattern in terms of the rank order of variance for these variables for each zone, whereas slope angle reveals a different pattern, with a markedly higher level of variance in zones 3 and 4 compared to the other zones. A summary of the input data used in the OAA analysis is provided in Table 3.2.2. and presented graphically in Figure 3.2.2.

As with the North Maidens Peak it is clear that the affect of zone area upon the OAA calculations is most notable, with the largest areas resulting in the highest recommended samples, although where an input variable's variance differs markedly between zones, as was most notable for slope angle, this appears to have a significant impact on the output. As noted in section 3.2.1 above, further research is required into which input variables should best represent true habitat heterogeneity for use in OAA.

Table 3.2.2. OAA input data summaries for the North Channel Peaks site.

Zone	Proportion of total site area	Slope angle mean	Slope angle standard deviation	Backscatter mean	Backscatter standard deviation	Aspect mean	Aspect standard deviation	Sum of standard deviation rank orders
Zone 1	0.23	2.23	0.97	700.37	287.28	175.09	101.54	10
Zone 2	0.43	0.77	0.44	562.97	272.15	170.40	102.40	8
Zone 3	0.09	7.79	5.32	735.41	375.18	158.45	97.83	14
Zone 4	0.05	7.03	3.88	761.33	297.22	166.65	100.19	10
Zone 5	0.18	2.25	0.85	692.94	317.77	170.94	99.50	11
Zone 6	0.03	4.54	1.03	761.40	363.27	162.51	96.64	10

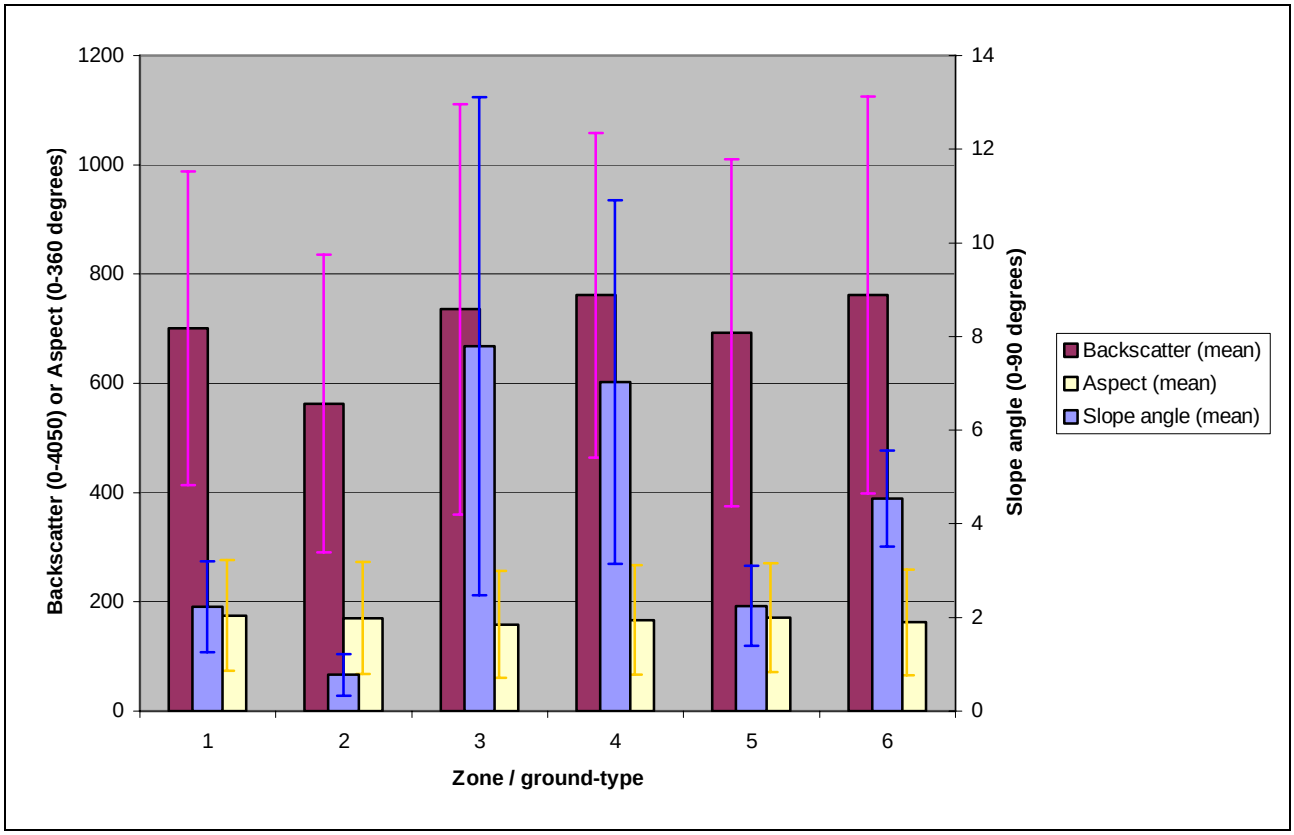

Figure 3.2.2. OAA input variables summary statistics for each zone (ground-type) North Channel Peaks site (standard deviation is represented by the error bars).

In order to assess how much sampling, (with consideration to choice of equipment) is required to achieve an estimated precision of 95% based upon the statistical variation in bathymetry-derived and backscatter data for the North Channel Peaks site, we must first

incorporate the coverage of existing ground-truthing. Each existing Day grab sample was considered as representing 0.1 m^2, and the video drops area coverage calculated by multiplying the tow length (in m, as measured on GIS) by 1 m^2. Note that a thorough examination of the February 2006 video footage has not been made, so if any of the footage is of poor quality (e.g. bad visibility or too far off the seafloor) this will reduce the area covered that can be used for further analysis, however as long tows were made any loss of usable footage is likely to have a minimal impact on the following analysis. The existing ground-truthing coverage (from 2003 to present) amongst each ground-type is provided in Table 3.2.3.

Table 3.2.3. Existing coverage of ground-truthing for each ground-type (in m^2).

Ground-type	Video2006	Video2003	Grabs2006	Grabs2003	Total
1. low relief bedrock (sediment veneer?)	1333	125	0.2	0.3	1458.5
2. homogeneous sedimentary plain (bioturbated mud?)	291		0.7		291.7
3. deep (>100m) med-high relief bedrock outcrops	80		0.1		80.1
4. shallow (<100m) med-high relief bedrock outcrops	115	168	0.5		283.5
5. coarse / mixed sediment	165		0.5		165.5
6. mixed sediment / cobble & boulder fields					0
TOTAL	1984	293	2	0.3	2279.3

It is evident that in all cases apart from ground-type 6 (mixed-sediment/cobble & boulder fields) that according to the results of the OAA, to achieve a CV of 5%, the required samples/ areas have already been covered. It is important that the sampling technique is recognised here, as for ground-types 2 and 5, both sedimentary from examination of the MBES backscatter mosaic, most of their coverage has been by video drops, which do not provide adequate information on the infaunal community for biotope classification. The video drops are however, very useful in giving a 'landscape' view of the seabed and also will indicate if bioturbation is common or features such a ripples, trawl scars etc. are present.

To address this issue, for sedimentary ground-types, the total recommended sampling area has been divided: one third to be sampled by video tows and two-thirds to be sampled by grabs or cores. Preferably at least some of the grab/core samples should fall on habitat patches covered by video drops/tows. The distribution of existing ground-truthing among ground-types does not follow that recommended by the OAA. When considering these points, additional sampling is suggested as provided in Table 3.2.4. Using the recommendations in Table 3.2.4. for additional ground-truthing, a series of locations have been selected for the forthcoming sampling program. These are presented in Figure 3.2.2.

Table 3.2.4. Additional ground-truthing requirements to build upon existing data for biotope mapping.

Ground-type	Extra video ground-truthing	Rationale	Extra infaunal sampling	Rationale
1. Low relief bedrock (sediment veneer?)	3x 50m video drops	To cover rock areas/patches that are yet to be sampled		
2. Homogeneous sedimentary plain (bioturbated mud?)	1x 200m video drop	To cover trawl scars identified from backscatter	24 Day grab samples	24.4m^2 recommended infaunal sample coverage (67% of OAA total for zone 2); due to practicality, 1 sample per m^2 is suggested as compromise
3. Deep (>100m) med-high relief bedrock outcrops *and* 6. mixed sediment / cobble & boulder fields	5x 200m video drops	To cover boundaries between deep bedrock and cobble/boulder areas that exist as small bordering patches		
4. Shallow (<100m) med-high relief bedrock outcrops	2x 100m video drops	To cover rock areas/patches that are yet to be sampled		
5. Coarse / mixed sediment	1x 100m video drop	To cover an area sampled by grabs	12 Day grab samples	11.8m^2 recommended infaunal sample coverage (67% of OAA total for zone 5); due to practicality, 1 sample per m^2 is suggested as compromise
TOTAL:	3x 50m drops 3x 100m drops 6x 200m drops		36 Day grab samples	

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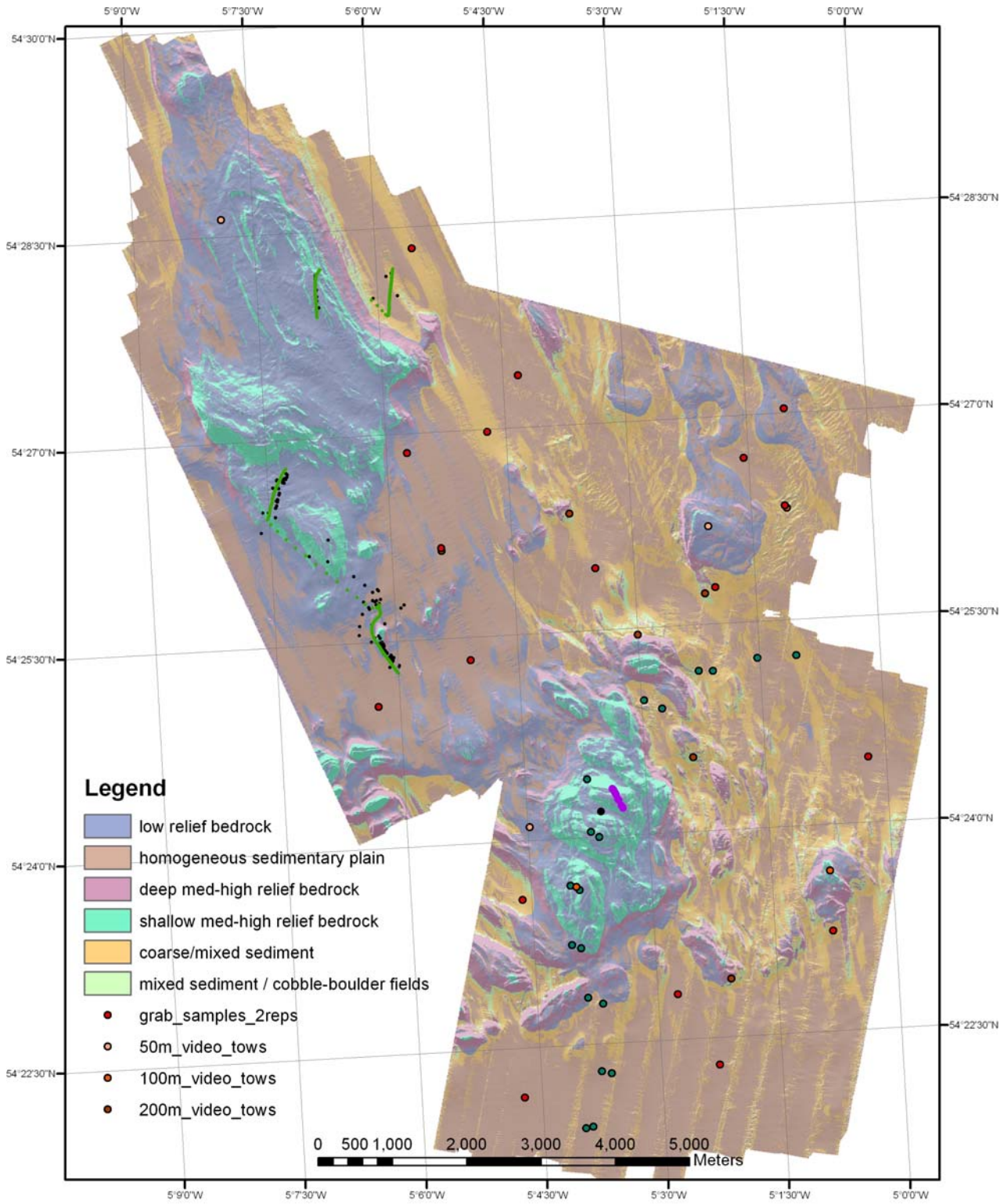

Figure 3.2.3. Proposed locations for additional ground-truthing at the North Channel Peaks site.

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4. Recommendations & Conclusions

This paper has demonstrated the ease of applicability of Optimal Allocation Analysis (OAA) to objectively stratify ground-truthing in order to identify and verify habitats, based upon remotely-sensed datasets. The OAA incorporates both area of each ground-type needing ground-truthing and the degree of heterogeneity of key variables within each ground-type to determine how best to stratify ground-truthing. The statistical method has been explained and assumptions clarified and justified.

The OAA method has been trialled on two sites, using multibeam echosounder-derived datasets. The output recommended sampling effort to achieve a statistical precision of 95% (a coefficient of variation (CV) of 5%) has been calculated for each site based upon three input datasets: slope angle, backscatter and aspect, all of which have been derived from multibeam echosounder data. The recommended sampling has been shown to be realistic in terms of effort and cost for ground-truthing surveys. It has also been shown able to objectively distribute such effort amongst pre-determined ground-types (as generated by unsupervised classification of remotely-sensed data). It can be concluded therefore, that this is a viable and easy to use method for stratification of ground-truthing where habitat mapping is undertaken in two steps (remotely-sensed data gathered first, followed by ground-truthing).

It is notable that there has been some difference between the recommended sampling for each input dataset in the OAA, which highlights the need for further research to consider which variables are most likely to be truly representative of habitat heterogeneity. As the OAA can also be applied retrospectively by incorporating maximum numbers of samples, such that the statistical precision of the ground-truthing campaign can be assessed, it is advised that this method is tested by habitat mapping scientists to ascertain how reliable and useful the analysis may be.

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