The Process of Developing A Seabed Habitat Map For The Firth of Clyde

Scottish Sustainable Marine Environment Initiative

SSMEI Clyde Pilot

The Process of Developing a Seabed Habitat Map for the Firth of Clyde

S Tresadern

A Study Carried out for the SSMEI Clyde Pilot by ERT Scotland (Ltd)

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1 Introduction

1.1 Scottish Sustainable Marine Environment Initiative

The Scottish Executive instigated the Scottish Sustainable Marine Environment Initiative (SSMEI) in November 2002. The principle aim of the SSMEI is to develop new framework options for the sustainable development management of Scotland's marine environment. These options should embrace the concept of the ecosystem based approach and will be tested through the implementation of a number of pilot management schemes.

The SSMEI is intended to inform future Scottish Government policy with respect to management of the marine environment. The Clyde Pilot is one of these schemes, with the others being located in the Shetland Isles, Berwickshire Cost and the Sound of Mull.

1.2 SSMEI Clyde Pilot

The SSMEI Clyde Pilot is tasked with the development and delivery of more integrated and sustainable management of the marine and coastal areas of the Firth of Clyde through an effective and integrated stakeholder-regulator partnership. It aims to achieve this through the creation of a Marine Spatial Plan, together with improved decision support mechanisms and integrated decision making. These will be underpinned by the application of an ecosystem based approach to sustainable development.

In support of these aims, SSMEI Clyde Pilot issued a tender detailing a request for the modelling and production of a seabed habitat map using existing data sources.

1.3 Seabed Mapping Project Objectives

Key to implementing an ecosystem based approach to spatial planning and management is identifying “what is where”.

Traditional habitat mapping techniques, such as direct field observations, are often difficult to perform in the marine environment due to cost and logistical factors.

An alternative approach for producing a habitat map is to create a model of the environment based on observed correlations between habitats and various data that have been collected, for example depth or current speed.

The technique has been used in similar, existing initiatives, for example the UKSeaMap and Mapping European Seabed Habitat (MESH) projects (see Figures 1.1 and 1.2 respectively). Being broad scale national and international exercises the results from these models are, in the area of interest, at too low a resolution for the needs of the SSMEI and concentrate less on the issues pertaining to the Firth of Clyde itself.

The main objectives of the project were:

1) Model a seabed habitat map using readily available data.
2) Identify areas of selected species habitat preferences for use in prediction of location management for the following species:
    a. Edible crab (*Cancer pagarus*)
    b. Common lobster (*Homarus gammarus)*
    c. Norway lobster (*Nephrops norvegicus*)
    d. Great scallop (*Pecten maximus*)
    e. Queen scallop (*Aequipecten opercularis)*
3) Identification of potential marine locations.
4) Identification of potential mariculture locations.
5) Report identifying data gaps and/or methodological shortcomings, establishing a baseline and review of available data sources.

As a tool, a seabed habitat map can aid the stated objectives above by identifying where particular habitats exist. This aids forward planning by providing information on the physical and biological parameters that may exist in difficult to observe areas, e.g. the subtidal environment. The map can be used to assist identifying the locations of fisheries/species and inform future designations.

A secondary outcome of the project was to use the process of developing the map to identify data gaps and inform and future decisions on resources to be more effectively targeted.

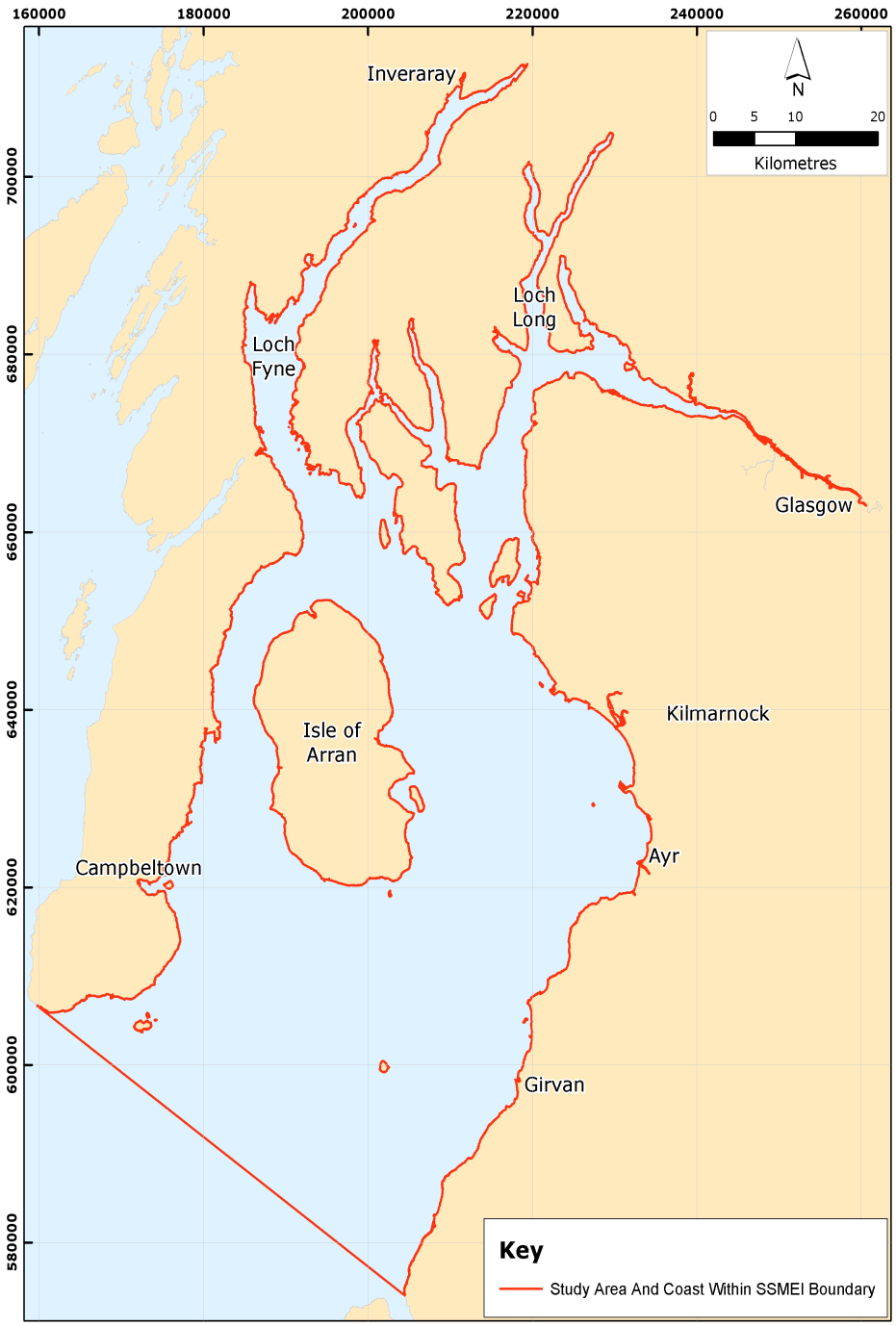
The modelling and delivery mechanism for the map was through a Geographic Information System (GIS). This comprises a database (containing the "what") and the ability to display and map that data visually in the form of a map (the "where").

In addition to traditional database tasks a GIS has the ability to perform spatial analysis on data, and this extends the "where" component beyond only display data to being able manipulate and query it for patterns and answers thus deriving the modelled output.

1.4 Geographic Location

The study area encompassed all the marine or tidal extents within the Firth of Clyde from the tidal weir at Glasgow Green to the heads of Lochs Long and Fyne and across from the tip of the Mull of Kintyre to Finnarts Point. The study area comprised around 1200km of coastline and encompassed a surface water area (at MHWST) of around 3000km^2.

Figure 1.3 Showing the location and selected geographic features of the study area.



2 Methods

2.1 Habitat Classification

A standardised method of classification greatly assists in the communication of ideas and data across boundaries whether they are commercial, sociological, political or geographical.

Marine habitats can be classified in a manner of ways, notably physically, such as intertidal/subtidal/mud/rock, or biologically, as in the examples of seaweed dominated or epifaunal communities.

The UK and European habitat classification standard is to use "biotopes", as determined by the European Nature Information System (EUNIS). Based on the JNCC biotope schema a biotope is defined within EUNIS as a unique combination of measurable and observable criteria, such as depth/height on shore, energy regime, substrate and inhabiting biology.

Table 2.1 details the example of the EUNIS high energy littoral (intertidal) rock biotopes. EUNIS levels are hierarchical in structure, defining biotopes sharing common characteristics at that level; the higher the EUNIS level number then the more specific the biotope being defined.

The table demonstrates how the hierarchical structure develops as further data is included in the assessment with combinations of physical variables defining the lower classifications and the integration of characterising biological species enabling the definition of more specific, higher classifications.

Table 2.1 EUNIS Classification and associated JNCC Biotope Example (note, not a complete record)

EUNIS level	EUNIS code	EUNIS name	JNCC 04.05 code	JNCC 04.05 name
1	A	Marine habitats	-	Marine habitats
2	A1	Littoral rock and other hard substrata	LR	Littoral rock (and other hard substrata)
3	A1.1	High energy littoral rock	LR.HLR	High energy littoral rock
4	A1.11	[*Mytilus edulis*] and/or barnacle communities	LR.HLR.MusB	Mussel and/or barnacle communities
5	A1.111	[*Mytilus edulis*] and barnacles on very exposed eulittoral rock	LR.HLR.MusB.MytB	*Mytilus edulis* and barnacles on very exposed eulittoral rock
5	A1.112	[*Chthamalus*] spp. on exposed upper eulittoral rock	LR.HLR.MusB.Cht	*Chthamalus* spp. on exposed eulittoral rock
6	A1.1121	[*Chthamalus montagui*] and [*Chthamalus stellatus*] on exposed upper eulittoral rock	LR.HLR.MusB.Cht.Cht	*Chthamalus* spp. on exposed upper eulittoral rock

2.2 Cartographic Modelling

Cartographic Modelling is the often applied method for the model development of a habitat map. It relies on geo-referenced/mapped datasets being combined and interrogated to identify areas that match defined selection criteria.

Providing the input datasets are of sufficient quality and resolution, the simplicity of the EUNIS structure lends itself well to cartographic modelling since each biotope is defined by its unique combination of those datasets together with its associated biological community.

Taking into account the resolution of the data to be used and the scale of the area to be mapped, the methodology used by ERT was raster overlay analysis, using the ESRI software package, ArcGIS and its Spatial Analyst add-on.

Raster overlay is relatively simple in concept, and can be envisaged by imagining the environment as being broken down into a layered map with each of its environmental parameters (e.g. depth, sediment, exposure etc) being represented per map layer.

The method lends itself very well to finding locations that meet particular criteria. Taking advantage of the simple grid structure of raster data enables a technique inherent in the data approach called map algebra to be used in constructing a model. Multiple data layers, each representing a different attribute about the grid location, can be combined at once to produce an output raster dataset.

The raster method is computationally simple, easy to set up and the results easy to interpret. A further advantage is that both continuous (e.g. depth) and discrete (e.g. substrate type) data can be input to the model with ease.

Figure 2.1 shows a simple, visual demonstration of the technique.

Firstly the area under review is split into a grid of cells for ease of modelling. Each of the environmental datasets is then formatted into the same grid formation as shown.

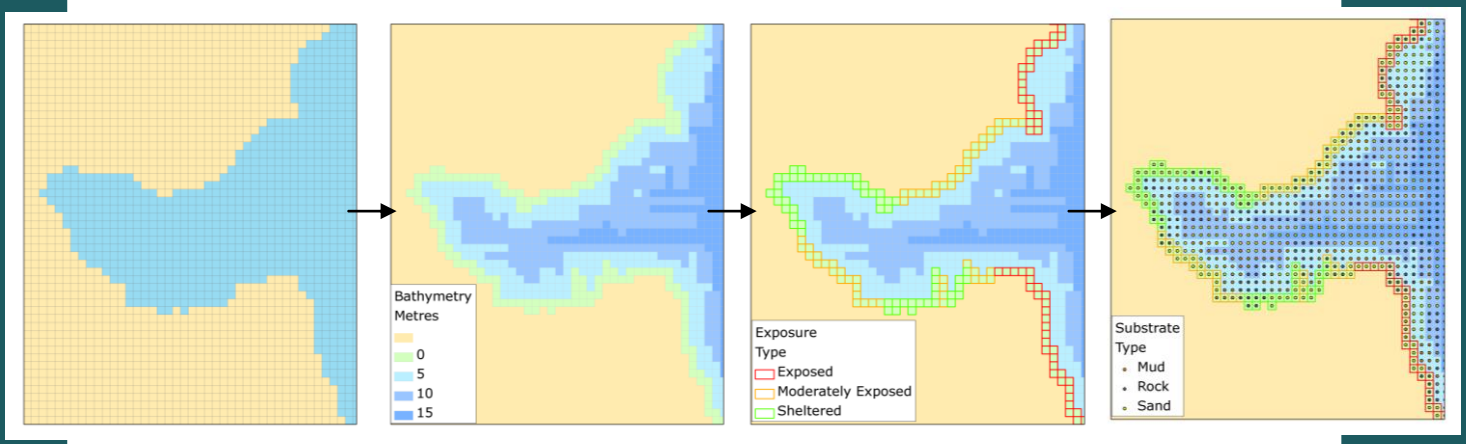


Figure 2.1 Conceptual demonstration of raster overlay analysis

Querying the resulting combination of two or more layers allows the model to return its results. In the first example in Figure 2.2, highlighted in light blue are areas that are intertidal AND with a substrate of sand AND a sheltered energy regime. In the second example, the model is returning the results of a query to select areas that are at 10m depth and mud substrate.

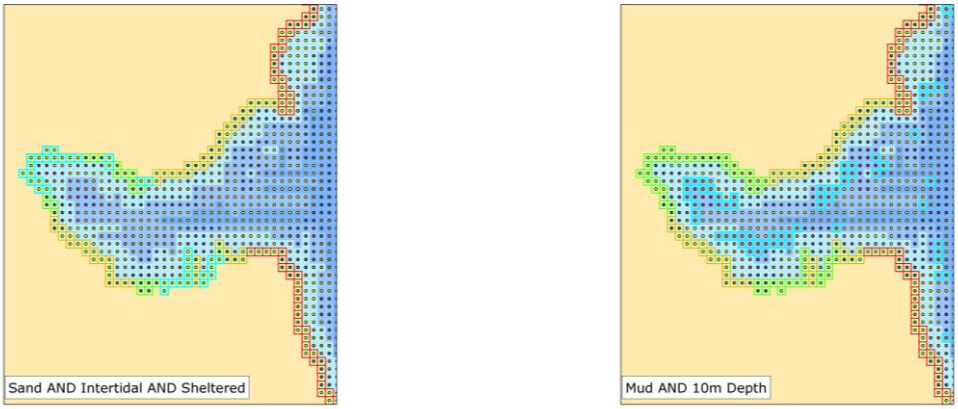


Figure 2.2 Example queries

It is the construction of these queries on the data and the amalgamation of their returned results that model the prediction of biotopes.

3 Data Inputs and Integration

Having determined the form of analysis on which to develop the habitat model the next step in the process was to ascertain the data required, their availability to the project and the suitability of the various data sources found.

At the level of detail the project was tasked with modelling the EUNIS classification scheme makes use of five broad data requirements to classify its range of biotopes:

- Height and Bathymetry
- Seabed Type
- Biology
- Energy Regime
- Salinity

A number of these data sets are readily available, either commercially or within government organisations. However, there is a wide variety in their intended use and consequently their suitability for inclusion in this modelling process. A data review consisting of an examination of all realistically attainable potential data sources was carried out.

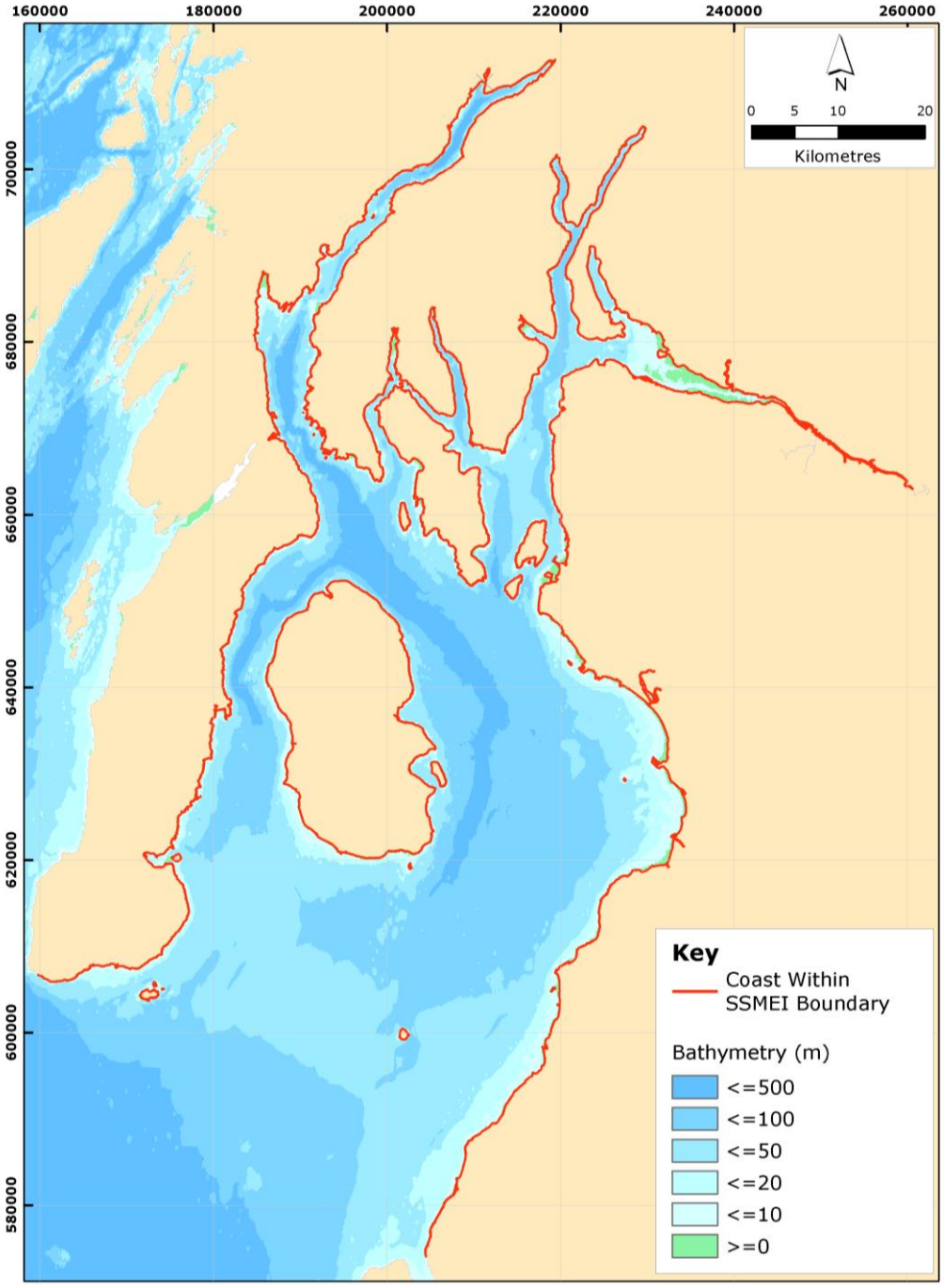
3.1 Height and Bathymetry

This data is required within the EUNIS classification to characterise the different depth zones that equate to infralittoral, circalittoral, offshore etc. The Seazone Hydrospatial dataset was used to provide this data.

This comprehensive data set includes a bathymetric raster dataset of cell size ~31m^2 extending from Mean High Water Spring down to some 200m beneath Chart Datum in the area of interest, as shown in Figure 2.3.

The 31m^2 cell size does not state that there is a sampled data point within the cell; all values are derived from an interpolation of a parent dataset of a lower spatial resolution. Nevertheless, this dataset has a high degree of confidence associated with it and was deemed sufficiently relevant, accurate and precise to enable further data review unnecessary on this variable.

Figure 2.3 Bathymetry data for the study area (Seazone Hydrospatial Data, 2007)



3.1.1 Height and Bathymetry Data Integration

Little manipulation of the bathymetric data was required, leaving it as 31m^2 cell size raster data structure.

The data were reclassified into depth bands (for the EUNIS classification: littoral, infralittoral, circalittoral and offshore zones) by stipulating these zones in the SQL queries performed on the combined dataset.

The depth ranges that were used to determine the EUNIS depth band are shown in Table 3.1. These were determined from the EUNIS Physical Comparative

Tables. They represent the average values at which biotopes of each depth band have been observed and recorded within the EUNIS classification scheme.

Table 3.1 Assigning depth range to EUNIS depth banding values

Depth (m)	EUNIS Biotope Depth Band
>0	Littoral
0 – 15	Infralittoral
15 – 100	Circalittoral
<100	Offshore

The only significant alteration required on the bathymetry data was to multiply up the values by a factor of 1000 to enable their incorporation into the combined dataset without loss of data (This was a functional requirement dictated by the software used as combining raster datasets can only be performed on integer based classifications in ArcGIS).

3.2 Substrate Type

Substrate composition data is an essential element required within the EUNIS classification to characterise the different types (rock, mud, sand etc) that the scheme uses to differentiate between biotopes.

Currently there is not any single dataset that spans the sub and intertidal zones for substrate data, these data are split into the offshore and intertidal areas. The reason for this is assumed to be historical with there being little need for a contiguous dataset.

3.2.1 Offshore Substrate Datasets

Two sources for the subtidal seabed substrate type in the offshore environment were identified, the DigSBS250 dataset from the British Geological Society (BGS) and the Admiralty Chart geology point data from the Seazone Hydrospatial dataset. Figures 3.2 and 3.3 show these two datasets in their raw format and native classifications.

Visually there is an immediate difference between the two datasets as expected. Although the Admiralty Chart data is a point dataset, polygon areas were derived from it before being used in the model. It should be remembered that the DigSBS250 data has also been derived from point source locations and interpolated by the BGS in-house.

For completeness of the project the model was run on each data source to produce different output maps, highlighting the differences that can be evident in using different datasets relating to the same variable.

Confidence levels in both datasets are difficult to ascribe however, due to the spatially sparse nature of the data gathering they are qualitatively assessed to be of low confidence. The justification for this is that the BGS data is more usually used at a broader scale than in this project. As an example of lack of confidence in its suitability for use in modelling, it has previously been noted as under-estimating the rock coverage in an area (UKSeaMap and HSMO).

The Admiralty Chart data are known observation points however their accuracy are open to question due to the various methods of the data collection. Reformatting and reclassifying the data for use in the model also makes inferences on the influence of the observations spatially that may not exist although this arguably applies to the BGS data too.

Figure 3.2 BGS DigSBS250 Dataset classified on the Rock_D variable (BGS DigSBS250 Dataset, 2007)

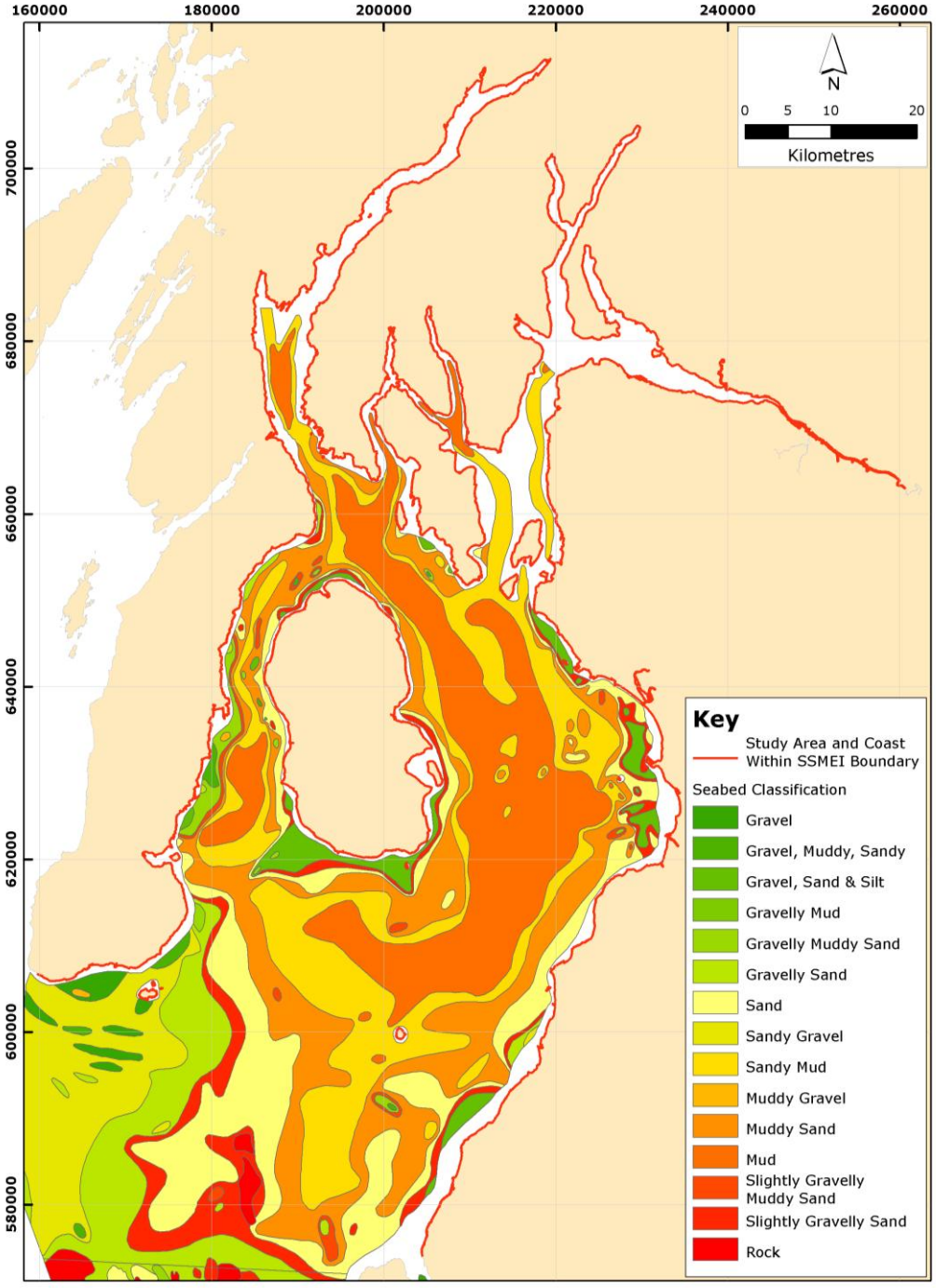
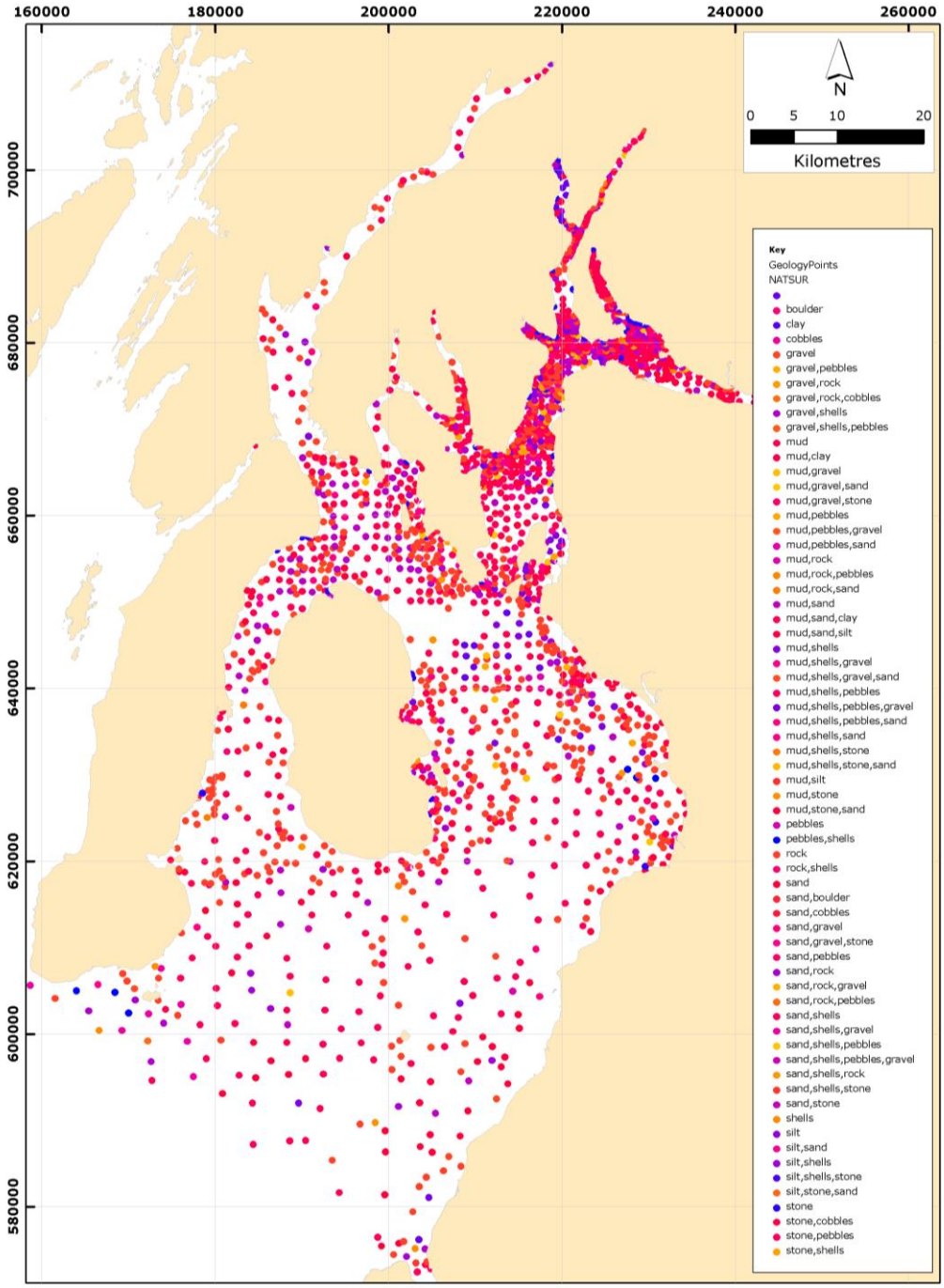


Figure 3.3 Admiralty Chart Geology Point dataset (Seazone Hydrospatial Dataset, 2007)



3.2.1.1 BGS Data Integration

The DigSBS250 data from the BGS is a commercially available dataset and is based on seabed grab samples of the top 0.1m, combined with cores and dredge samples where available. It is a well known and widely used dataset however its coverage is less complete in the inshore and near shore environment than it is further offshore. Additionally, it is a dataset using source data from a number of years ago with little updating of the product since its development.

Integration of the BGS data itself was not problematic as it had already been supplied in a format compatible with the ArcGIS software.

Issues surrounding the use of the data in the model were mainly concerned with the lack of complete geographic coverage of the area and the re-classification of the data into a simpler Folk classification. This re-classification is guided, as far as possible, by the modified Folk Classification used in the UKSeaMap and MESH projects (Long, D. 2006 BGS detailed explanation of seabed sediment modified folk classification) as demonstrated in Figure 3.4 and mapped in Figure 3.5

However, in modelling to as high a EUNIS level as possible, an assumption had to be made in separating the mud and sand classifications in the infra and circa littoral environments into “fine mud/sandy mud” and “fine sand/muddy sand” respectively. These sediment classifications are EUNIS specific subdivisions and while no data directly relating to “fine mud” or “fine sand” are present in the BGS data there are ”sandy mud” and “muddy sand” descriptions. The decision was taken to class the EUNIS “fine mud” and “fine sand” as equating to the BGS “mud” and “sand” classes.

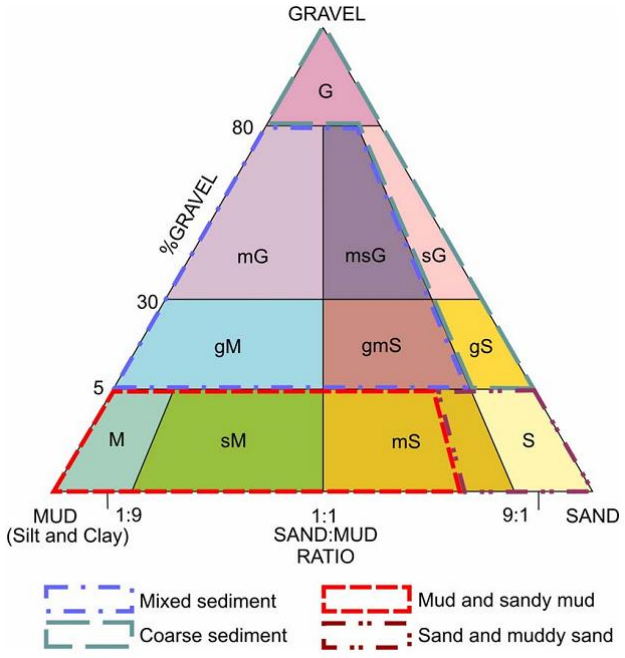


Figure 3.4 Modified Folk Distribution

Figure 3.5 Reclassified BGS Data (BGS, 2007)

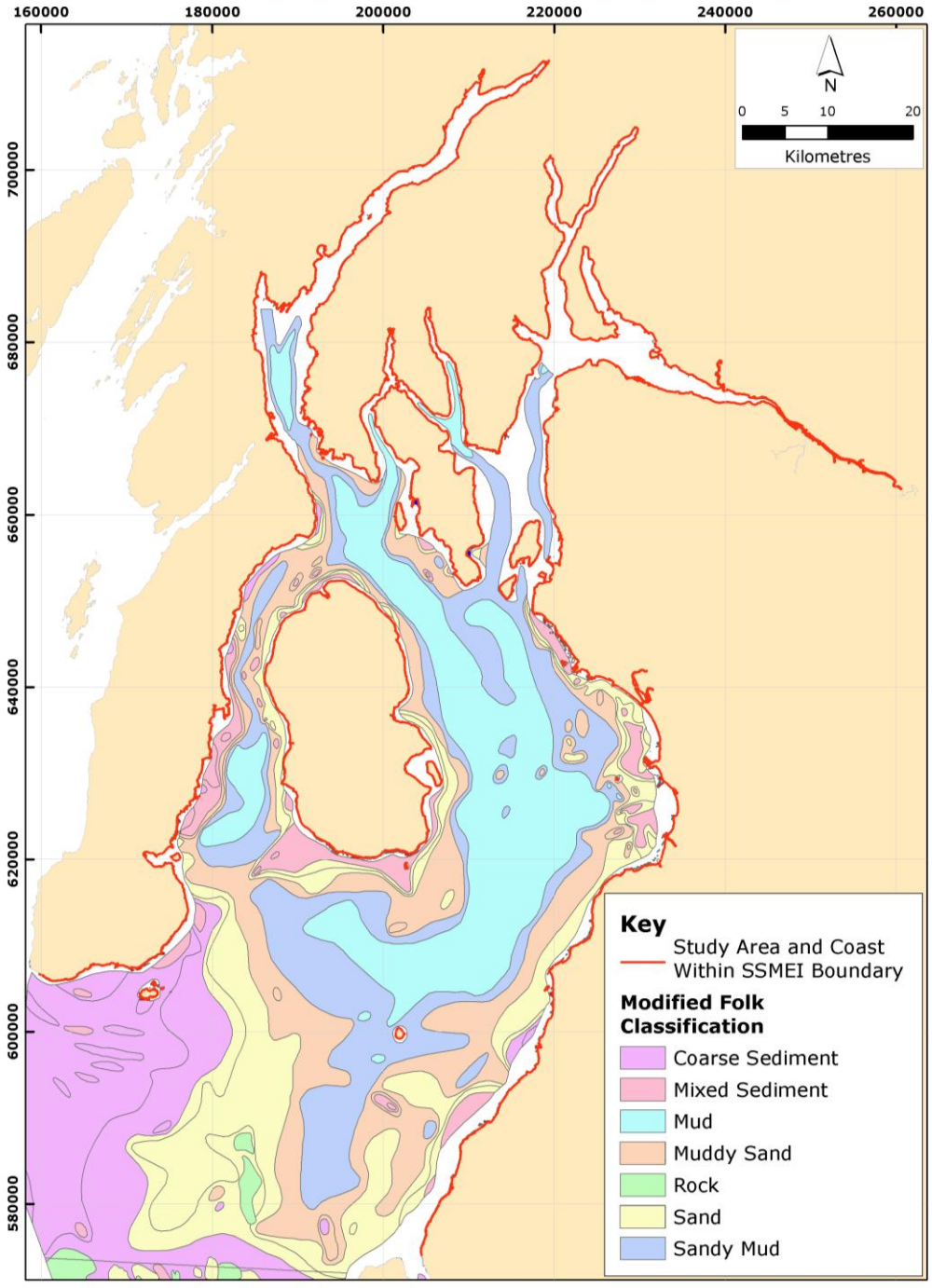


Table 3.2 shows the values used for matching the DigSBS250 BGS Rock_D value to the EUNIS classification divisions

ROCK_D Value	Modified Folk Classification (EUNIS)
Gravel [Marine sediment]	Coarse Sediment
Gravel, Muddy, Sandy [Marine sediment]	Mixed Sediment
Gravel, Sand and Silt	Mixed Sediment
Gravelly Mud [Marine sediment]	Mixed Sediment
Gravelly Muddy Sand [Marine sediment]	Mixed Sediment
Gravelly Sand [Marine sediment]	Coarse Sediment
Mud	(Fine) Mud
Muddy Gravel [Marine sediment]	Mixed Sediment
Muddy Sand [Marine sediment]	Muddy Sand
Sand [Marine sediment]	(Fine) Sand
Sandy Gravel [Marine sediment]	Coarse Sediment
Sandy Mud [Marine sediment]	Sandy Mud
Slightly Gravelly Muddy Sand [Marine sediment]	Muddy Sand
Slightly Gravelly Sand [Marine sediment]	Sand
Undifferentiated Bedrock Lithology	Rock

After reclassification, the data were converted from vector to raster data of cell size $22m^2$ within the ArcGIS environment and incorporated into the model combined dataset.

3.2.1.2 Admiralty Data Integration

The Admiralty Chart data provides a more complete geographic coverage however is based on a range of historical collection methodologies that may not be as accurate or their results validated as well as the more modern techniques that the BGS data is potentially based upon.

A method of creating areas from the point data was required to use these data in the model.

Interpolation was ruled out because sediment is not a contiguous, ratio scale but rather a nominal scale. No distinct relationship exists in being able to mathematically state that a mud area will become sand which will become rock. Since they can all exist as discrete areas within and neighbouring one another with no causal relationship on where the boundaries are, it is not possible to apply an interpolation method that would effectively derive new data from the existing data points.

The method used was to derive a polygon dataset modelled from the point data using the Thiessen, aka Voronoi, method. This constructs polygons by associating any given point within a particular polygon the value of the nearest known input data point being modelled, thus creating polygons of individual values.

This method more faithfully observes the original data however it results in a dataset that is very fragmented and necessarily representative of the geographic spread of the original data since it uses every data point in the source, ie there is no smoothing out of the data.

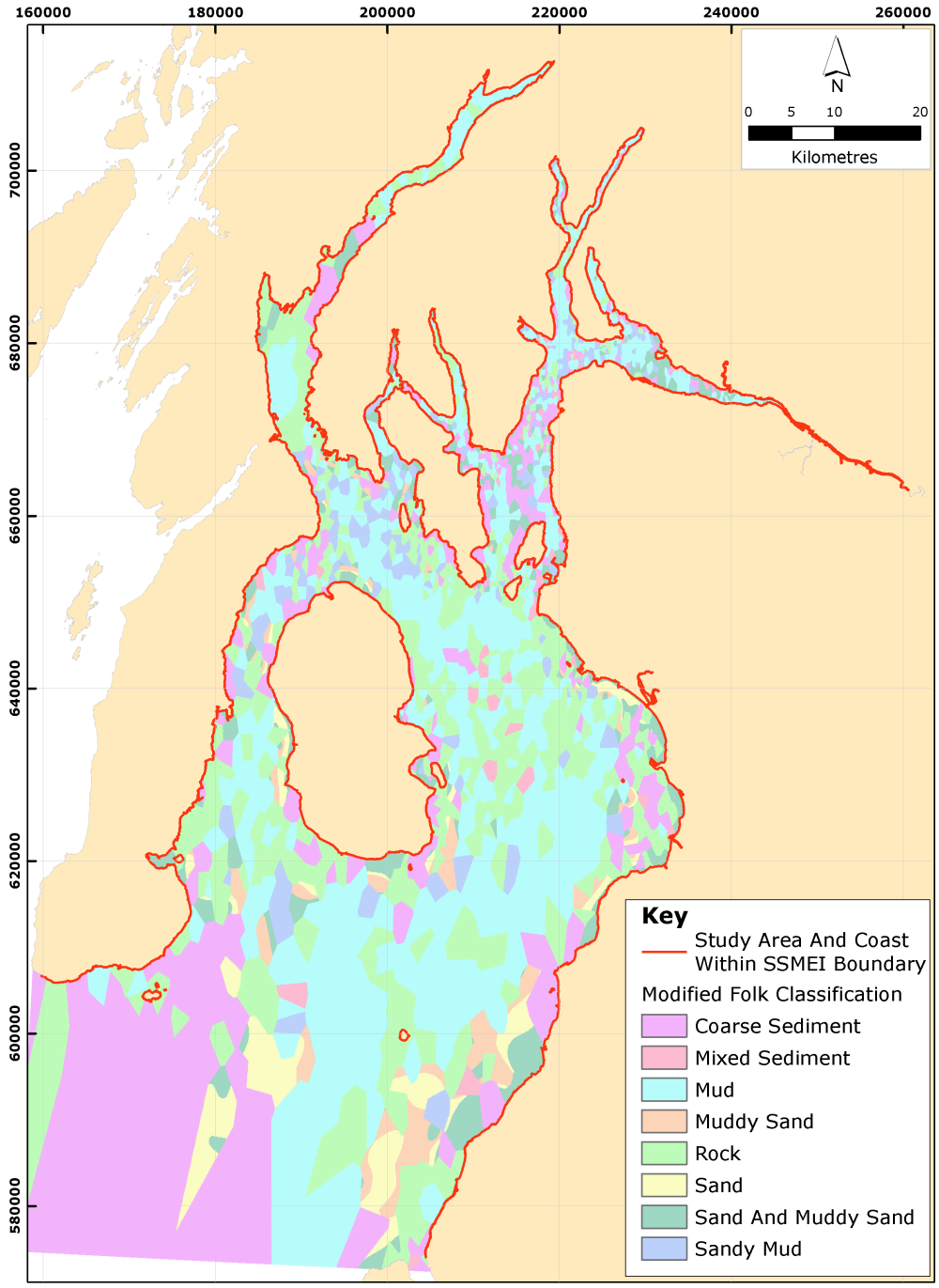
There was more variety in the dataset regarding the sediment/seabed attribute data of each record than in the BGS data and the assumptions made in the reclassification of the data are shown in Table 3.3 and mapped in Figure 3.6.

After reclassification the data were converted from vector to raster data of cell size $28m^2$ within the ArcGIS environment and incorporated into the model combined dataset.

Table 3.3 Reclassification values of Admiralty Chart geology points to Modified Folk Classification

Admiralty NATSUR value	Modified Folk Classification (EUNIS)	Admiralty NATSUR value	Modified Folk Classification (EUNIS)
boulder	Rock	mud,silt	(Fine) Mud
clay	Mud	mud,stone	(Fine) Mud
cobbles	Coarse Sediment	mud,stone,sand	(Fine) Mud
gravel	Coarse Sediment	pebbles	Coarse Sediment
gravel,pebbles	Coarse Sediment	pebbles,shells	Coarse Sediment
gravel,rock	Coarse Sediment	rock	Rock
gravel,rock,cobbles	Coarse Sediment	rock,shells	Rock
gravel,shells	Coarse Sediment	sand	(Fine) Sand
gravel,shells,pebbles	Coarse Sediment	sand,boulder	Mixed Sediment
mud	(Fine) Mud	sand,cobbles	Mixed Sediment
mud,clay	(Fine) Mud	sand,gravel	Coarse Sediment
mud,gravel	Mixed Sediment	sand,gravel,stone	Coarse Sediment
mud,gravel,sand	Rock	sand,pebbles	Mixed Sediment
mud,gravel,stone	Rock	sand,rock	(Fine) Sand
mud,pebbles	Mixed Sediment	sand,rock,gravel	Coarse Sediment
mud,pebbles,gravel	Mixed Sediment	sand,rock,pebbles	Coarse Sediment
mud,pebbles,sand	Mixed Sediment	sand,shells	Coarse Sediment
mud,rock	Rock	sand,shells,gravel	Coarse Sediment
mud,rock,pebbles	Mixed Sediment	sand,shells,pebbles	Coarse Sediment
mud,rock,sand	Mixed Sediment	sand,shells,pebbles,gravel	Coarse Sediment
mud,sand	Sandy Mud	sand,shells,rock	Coarse Sediment
mud,sand,clay	Sandy Mud	sand,shells,stone	Mixed Sediment
mud,sand,silt	Sandy Mud	sand,stone	Mixed Sediment
mud,shells	(Fine) Mud	shells	Coarse Sediment
mud,shells,gravel	(Fine) Mud	silt	(Fine) Mud
mud,shells,gravel,sand	(Fine) Mud	silt,sand	(Fine) Mud
mud,shells,pebbles	(Fine) Mud	silt,shells	(Fine) Mud
mud,shells,pebbles,gravel	(Fine) Mud	silt,shells,stone	(Fine) Mud
mud,shells,pebbles,sand	(Fine) Mud	silt,stone,sand	(Fine) Mud
mud,shells,sand	(Fine) Mud	stone	Coarse Sediment
mud,shells,stone	(Fine) Mud	stone,cobbles	Coarse Sediment
mud,shells,stone,sand	(Fine) Mud	stone,pebbles	Coarse Sediment
Continued		stone,shells	Coarse Sediment

Figure 3.6 Thiessen polygon creation and reclassification of Admiralty Chart geology points (Derived from Seazone Hydrospatial Dataset, 2007)



3.2.2 Intertidal (littoral) dataset

SSMEI were able to provide access to the Multi-Agency Geographic Information for the Countryside (MAGIC) Intertidal Substrate Foreshore (England and Scotland) from the Coastal and Marine Resource Atlas. It is a dataset that classifies the foreshore composition and was collated as a desk study intended for oil spill response planning. It is intended to be representative in terms of location.

3.2.2.1 Intertidal (littoral) Data Integration

The intertidal dataset was supplied in a readily accessible vector format.

It was reclassified to values shown in Table 3.4 to create equivalence with the EUNIS classification and the dataset then clipped to the universal coastline vector used in the modelling process.

Table 3.4 Reclassification values for intertidal dataset to EUNIS classification hierarchy

Intertidal Foreshore Description	EUNIS Level Reclassification
Boulders/Loose rock	Rock
Gravel	Coarse Sediment
Made Ground (Man Made)	N/A
Mud	Mud
Mud & Gravel	Mixed Sediment
Not Present	N/A
Rock Platform	Rock
Rock Platform with banks of Gravel	Rock
Rock Platform with Boulders/Loose Rock	Rock
Sand	Sand
Sand & Gravel	Mixed Sediment
Sand & Mud	Mixed Sediment

These results were then reduced in width from 450m from the coast to some 150m, the distance varies depending on the spatial difference between the OS Meridian coast the data was originally digitised to and the coast vector it was clipped to in this project.

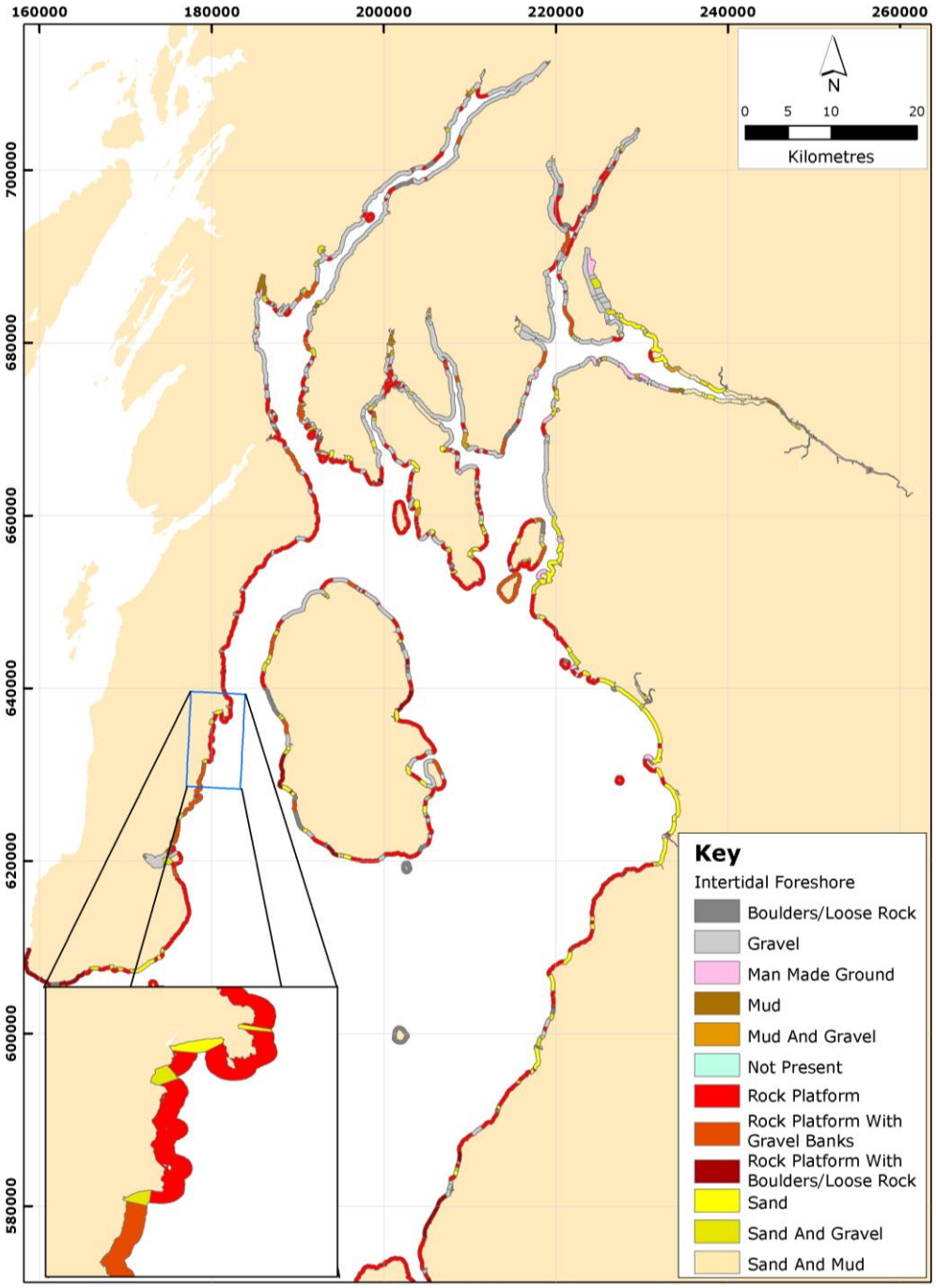
This derives a dataset that is representative of the intertidal area and an extended subtidal "indicative" area that is not covered by the BGS dataset.

The data was converted from vector to raster dataset of cell size $28m^2$ and incorporated into the model.

The data are polygons buffered 450m out from MHW from the OS Meridian dataset and were interpreted from a mixture of sources including; OS raster mapping, BGS Geological mapping, various reports, SNIFFER projects and internally held local knowledge. Figure 3.4 displays the data in its native format.

While acknowledging the provisos stated above by the data providers, the data are still considerably advantageous to the model as the intertidal zone would otherwise have been notably lacking in coverage. These data had a medium level of confidence associated with them since the method of their derivation is a based on sound practice & good, accurate underlying data.

Figure 3.7 Intertidal Substrate Foreshore dataset (DEFRA, 2004)



3.2.3 Energy Regime

This data is required within the EUNIS classification to characterise different environments in terms of being in high, moderate or low energy areas that the scheme differentiates biotopes by.

An energy regime can be classed and defined as a combination of several factors, for instance the exposure of a coastline to prevailing wind and wave action, the tidal current and/or the wave action/energy stress at the seabed. At the outset there was no set method of describing the energy regime to aim for since it was anticipated to be determined by data availability.

Obtaining these data on the scale and resolution demanded by the project proved to be problematic for a number of reasons.

- The UK Digital Marine Atlas (UKDMAP) provides access to some of the datasets required, such as wave heights and current speeds. However, these were at insufficient spatial resolution to be of effective use within the model and so this option was rejected.

- Other sources of tidal current data include Admiralty Chart tidal diamonds from which the maximum speed and directions can be taken. This data was assessed to be at too low a spatial resolution (ie locations too spread out) and anticipated to take a significant amount of time to work into a meaningful dataset so this option was not considered realistic within the confines of the project.

- The British Oceanographic Data Centre (BODC) has tidal current data available although at considerable cost and again, this would require manipulation into a useful dataset. Equally, the Met Office also holds data on wind direction however these proved cost prohibitive. Due to ERT (Scotland) Ltd being a commercial organisation access to these data at anything less than standard commercial rates was not easily forthcoming despite the work being undertaken on behalf of the Scottish Government.

- Computational models do exist that are specific to determining the tidal regime and the output from these would have been one of the most ideal inputs to the model. These are held both by commercial organisations and within SEPA. The former would have been too costly to commission and the latter were unsure whether the resolution they are able to realistically output results at it would be useful to the model.

3.2.3.1 Energy Regime Data Integration

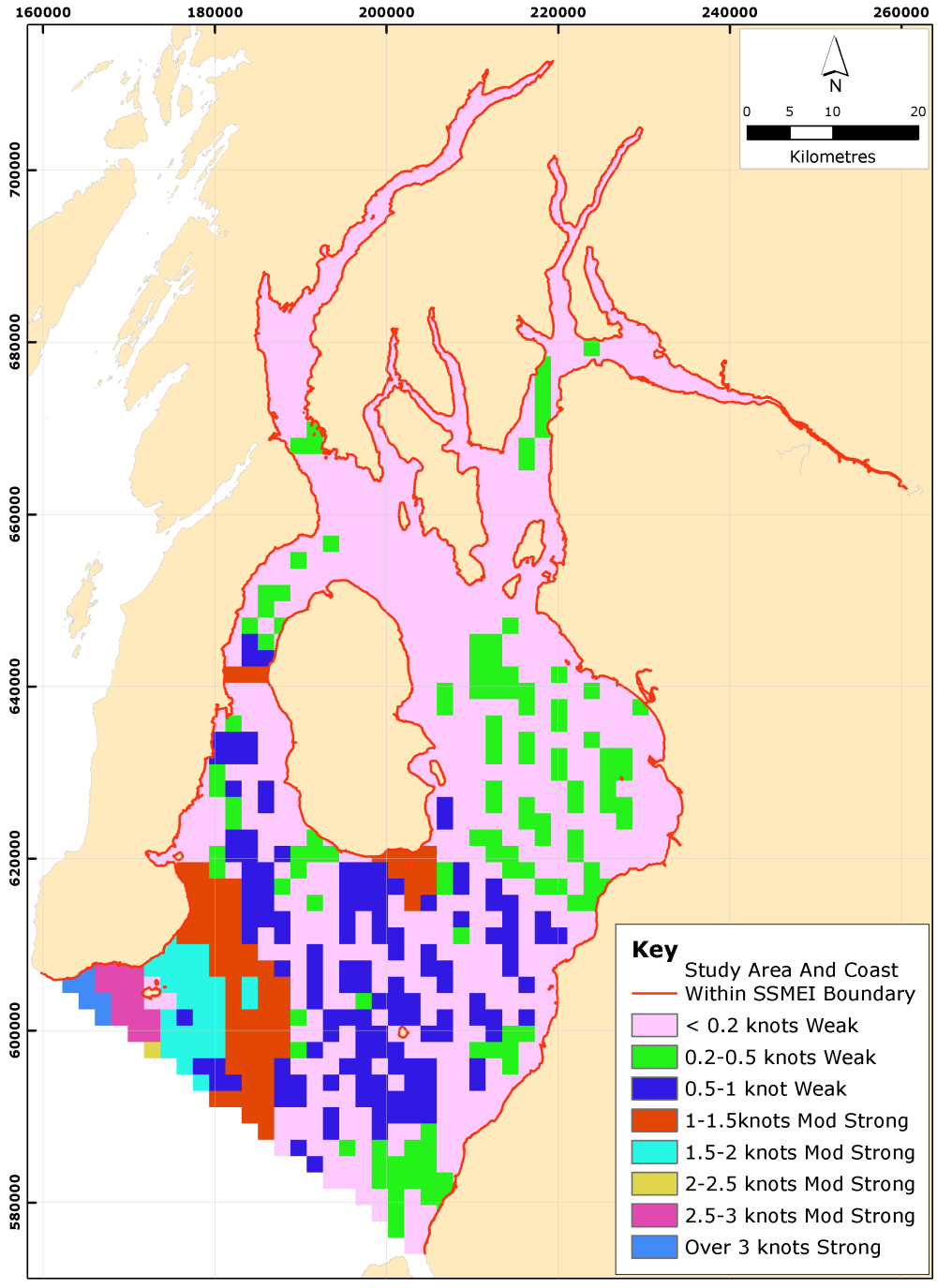
Having identified, but rejected for a range of reasons, a number of sources of digital data pertaining to the energy regime in the Clyde attention was focussed on finding or creating non-digital datasets.

Of these the most useful was determined to be the “Atlas of UK Marine Renewable Energy Resources” (DTI, 2004) which contains data on peak flows (current speed). Although they are at a relatively low spatial resolution and

"less robust 1km close to land" there was sufficient confidence in the data that the datasets were digitised for use in the model. This dataset is shown in Figure 3.8.

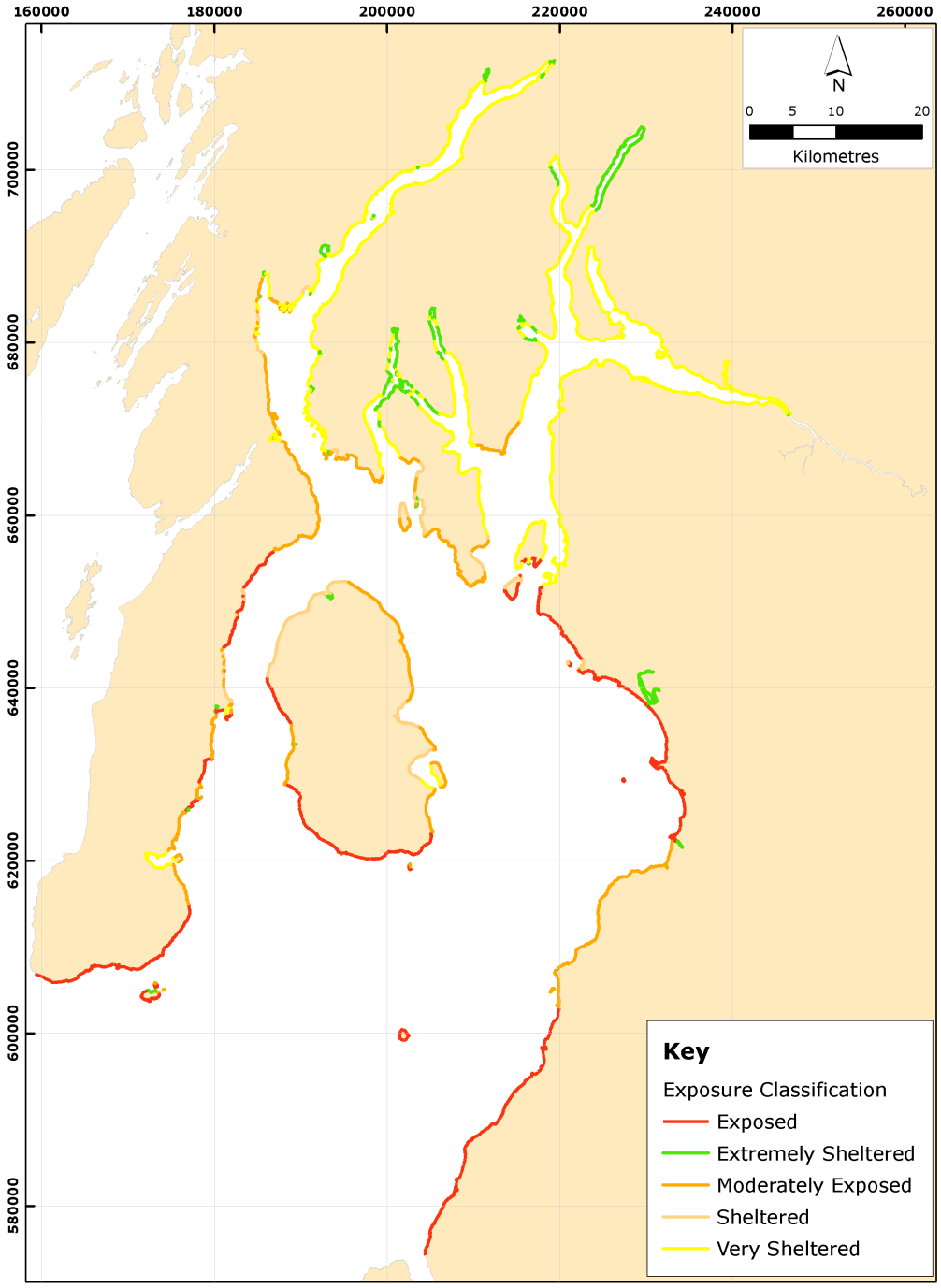
Determining the energy regime for the intertidal zone was achieved by a manual process of measuring the fetch to 500m sections of the coastline and assigning an exposure value to the section. Ideally the prevailing current and/or wind would also be incorporate but for the reasons already described this was not possible. The data is shown in Figure 3.9.

Figure 3.8 Peak flow in the study area (DTI, 2004)



These data can be considered a medium degree of confidence associated with then since they are, as noted, lacking elements that would describe the energy regime of the coastline in the greatest and most accurate detail.

Figure 3.9 Exposure classification based on fetch to 500m sectors of coastline



While the peak flow and significant wave height data were digitised and anticipated to be included in the model this was decided against. Their spatial resolution was appraised to be too low to be of effective use within the model.

The exposure dataset was converted from vector line to raster and then expanded to 500m from the coastline on the assumption that it could also be used to an extent to classify the infra and circalittoral biotopes *in lieu* of unavailable current speed data.

As described the fetch to the coastline was measured and exposure values (shown in Table 3.5) assigned to each 500m long sector. The exposure values were reclassified to the EUNIS high, medium and low energy regime values firstly by classifying to MNCR wave exposure and then to EUNIS.

Table 3.5 Fetch length and corresponding MNCR and EUNIS equivalents

Fetch Length	MNCR Equivalent	EUNIS Energy Regime
>100 km	Exposed	High
100 - 30 km	Moderately exposed	Medium
30 – 20 km	Sheltered	Low
20 – 3 km	Very sheltered	Low
<3 km	Extremely sheltered	Low

3.2.4 Biology

This data is required within the EUNIS classification to characterise different environments in terms of the characterising species that the scheme differentiates biotopes by.

Biological data was sourced from the Marine Nature Conservation Review (MNCR) dataset. This comprehensive marine dataset consists of point locations from a range of surveys carried out in past and submitted to the JNCC for inclusion in the database.

The data is comprehensive in content and includes biotopes at a large number of georeferenced locations (Figure 3.10 displays the locations of the MNCR records and data) and has a high degree of confidence associated with the attribute data contained in the dataset, however a third of the dataset contained records not associated with a JNCC biotope but instead a text description, which meant they were discarded from the dataset.

Spatially there are elements of uncertainty associated with the dataset for two reasons.

- Due to the structuring of the data one point location has many biotope records associated with it (from the same survey) with no way of determining exactly where a surveyed biotope is located.
- The data themselves do not have a comprehensive or consistent geographic distribution resulting in some areas being very well covered while others are notably lacking. In these latter areas this means that

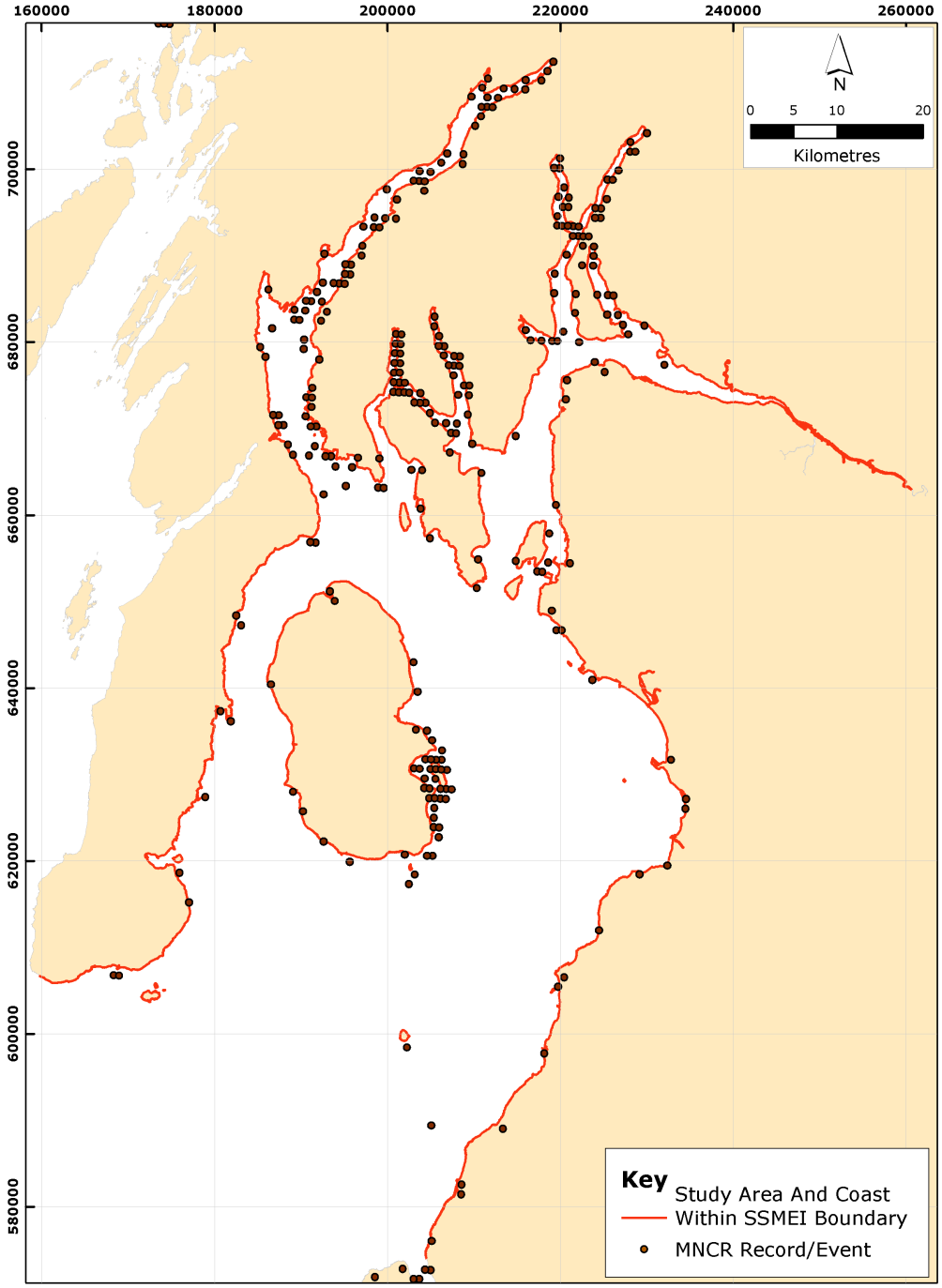
ground-truthing, i.e. the assessing of the model against real, observed values, is simply not possible

The MNCR dataset is certainly the most apt for use in the modelling process, since it uses the JNCC biotope classification that forms the basis of the EUNIS scheme. Other biological and ecological datasets were identified but would have required time consuming data validation and biotope tagging to be able to relate to the EUNIS classifications.

3.2.4.1 Biology Data Integration

The MNCR records were easily plotted out from the coordinates associated with the data and presented no issues to the validation process, in which they were used, except for assigning the individual records (each survey using one location but making more than one observation around that location) to their likely locations.

Figure 3.10 MNCR record locations (JNCC, 2007)



3.2.5 Salinity

This data is required within the EUNIS classification to characterise different environments in terms of being in variable, low or full salinity regimes that the scheme differentiates biotopes by.

Salinity data was not considered intrinsic to the model principally because to use it effectively depended on having better resolution in the other datasets. That is to say, the effects of salinity on the EUNIS classification are at EUNIS

levels 5 and 6 and from the outset of the project the model was limited in its ability to refine to that level. Any effects of salinity were used in the supervised classification analysis, drawing on expert knowledge of the area under consideration.

Another reason for the non inclusion of salinity data was the subject of cost. The data is available from the BODC at commercial rates and this fell outside the scope of the project, particularly when assessed in combination with the above.

3.2.6 Other data reviewed

A number of other datasets considered but not used in the final analysis. A dataset derived from the bathymetry data that quantified the topography of the area showed little potential in adding value to the model. The seabed topography in the area is reasonably uniform with no anomalous or unusual features identified to be considered necessary to include or influence the model output.

Physiogeographically the area consists of sea-lochs, bay and estuarine areas. These are easily identified but within the model itself they are not defining characteristics of sub-division into habitat classes. They were noted during the supervised classification however.

Many of the data sources used in previous similar applications of the methodology, such as temperature, bed stress, light penetration, are at insufficient resolution for directly applicable use in this project. While clearly sufficient for the modelling of marine landscapes, they are less applicable to the development of a model that is determining a biotope classification.

For instance, UKSeaMap incorporated a number of datasets of variables with large ranges at the geographic extent of the whole of the UK waters. Focussing more specifically on the Firth of Clyde area itself many of these parameters fall into single classes within the UKSeaMap classification; the area is “warm” in temperature, it is broadly “shallow”, it is mainly aphotic in nature away from the shore, it has a weak tidal bed stress regime. Given that these data possess insufficient resolution to further break down the classification they were not incorporated in the model.

Data is available from the British Oceanographic Data Centre (BODC) and/or Centre for Fisheries and Aquaculture Science (CEFAS) for a number of further parameters, such as nutrients and pH, in addition to many of those already mentioned. These were not obtained as within the confines of this project they would have been costly and are extremely low ranking influential (if at all) factors in the modelling process.

Notably, the EUNIS biotope classification itself does not incorporate some of the data determinants mentioned as defining characteristics or, if they *are* influential then in view of the lack of good quality ground-truth data available to qualify the model results then their non-inclusion has not reduced the validity of the model output.

3.2.7 Species habitat preference parameters

3.2.7.1 Edible crab (*Cancer pagarus*)

Found on bedrock including under boulders, mixed coarse grounds, and offshore in muddy sand. Lower shore, shallow sublittoral and offshore to about 100 m. Substratum preferences: cobbles, pebbles, gravel / shingle, muddy gravel, coarse clean sand, fine clean sand, sandy mud, muddy sand, bedrock. Tidal strength preferences: Weak (< 1 kn) to moderately strong (1-3 kn). Wave exposure preferences: Exposed, moderately exposed

3.2.7.2 Common lobster (Homarus gammarus)

Found on all British and Irish coasts. It is found on rocky substrata, living in holes and excavated tunnels from the lower shore to about 60 m depth.

3.2.7.3 Norway lobster (Nephrops norvegicus)

Substratum preferences: mud, muddy sand, sandy mud. Tidal strength preferences: very weak (negligible) weak (< 1kn). Wave exposure preferences: Sheltered, Very Sheltered, Extremely Sheltered, Ultra Sheltered. Depth: 20-800m.

3.2.7.4 Great scallop (*Pecten maximus*)

Substratum preferences: coarse clean sand, fine clean sand, sandy mud, muddy sand, gravel / shingle. Tidal strength preferences: moderately strong (1-3 kn), weak (<1 kn). Wave exposure preferences: sheltered, very sheltered, extremely sheltered, exposed. Depth: 10-110 m

3.2.7.5 Queen scallop (Aequipecten opercularis)

Found around all British and Irish coasts. The queen scallop is found between tidemarks, to depths of 100 m and on sand or gravel, often in high densities. It also occurs amongst beds of horse mussels *Modiolus modiolus*.

3.2.8 Potential Marina Locations

3.2.9 Potential Mariculture Locations

3.2.10 Software and geodetic considerations

The software employed in the project was ESRIs ArcGIS and Spatial Analyst extension.

The output was developed to the British National Grid co-ordinate system and in addition, the outputs were projected to WGS84 Lat/Long. This is to provide the greatest scope of use for the habitat map.

Data output was exported to ESRI Shapefile and ESRI Personal Geodatabase, along with an associated .mxd document, enabling the data to be easily accessed in future.

Raster cell sizes for each dataset were created as close as possible to one another within the constraints of the software.

4 Results and Discussion

4.1 Results

4.1.1 Seabed Habitat Maps

As expected the modelled results from the two subtidal substrate datasets are dissimilar.

Figure 4.1 shows the output from the BGS data and Figure 4.2 shows the modelled output from the Admiralty Chart seabed data.

After the combined dataset of all variables was constructed it was queried for each individual biotope. Each record in Table 4.1 corresponds to the output of an SQL query that was constructed to identify that particular biotope.

These biotopes were reclassified into integer value datasets for ease of display, management and manipulation and the values for this reclassification are shown in Table 4.1 although there is no significance to the value associated with a biotope.

Note that two of the classifications (Infralittoral Sand and Muddy Sand and Circalittoral Rock Deep No Specific Energy Regime) are for areas that either do not fall within a distinct EUNIS biotope or are based on a merged substrate type that does not correlate directly to a specific EUNIS biotope. They have been given a generic term to ensure that they are included within the model output. (This only applies to the Admiralty Chart based output)

Pink records are Level 2 Biotopes; Dark blue records are Level 3 Biotopes; Light blue records are Level 4 Biotopes

Table 4.1 Model values and their associated EUNIS Code and text habitat description

Model Value	EUNIS Code	Habitat Description
1	Infralittoral Sand And Muddy Sand	Infralittoral Sand And Muddy Sand
2	A3	Infralittoral rock and other hard substrata
3	Circalittoral Rock Deep No Specific Energy Regime	Circalittoral Rock Deep No Specific Energy Regime
4	A4	Circalittoral rock and other hard substrata
5	A4.1	Atlantic and Mediterranean high energy circalittoral rock
6	A4.3	Atlantic and Mediterranean low energy circalittoral rock
7	A4.2	Atlantic and Mediterranean moderate energy circalittoral rock
8	A3.1	Atlantic and Mediterranean high energy infralittoral rock
9	A3.3	Atlantic and Mediterranean low energy infralittoral rock
10	A3.2	Atlantic and Mediterranean moderate energy infralittoral rock
11	A1.1	High energy littoral rock
12	A1.3	Low energy littoral rock
13	A1.2	Moderate energy littoral rock
14	A2.11	Shingle (pebble) and gravel shores
15	A2.3	Littoral mud
16	A2.4	Littoral mixed sediments
17	A2.2	Littoral sand and muddy sand
18	A5.13	Circalittoral coarse sediment
19	A5.12	Infralittoral coarse sediment
20	A5.14	Deep circalittoral coarse sediment
21	A5.3	Sublittoral mud
22	A5.36	Circalittoral fine mud
23	A5.35	Circalittoral sandy mud
24	A5.34	Infralittoral fine mud
25	A5.33	Infralittoral sandy mud
26	A5.37	Deep circalittoral mud
27	A5.4	Sublittoral mixed sediments
28	A5.44	Circalittoral mixed sediments
29	A5.43	Infralittoral mixed sediments
30	A5.45	Deep mixed sediments
31	A5.2	Sublittoral sand
32	A5.25	Circalittoral fine sand
33	A5.26	Circalittoral muddy sand
34	A5.23	Infralittoral fine sand
35	A5.24	Infralittoral muddy sand
36	A5.27	Deep circalittoral sand

Figure 4.1 Results of cartographic modelling using BGS DigSBS250 sediment dataset

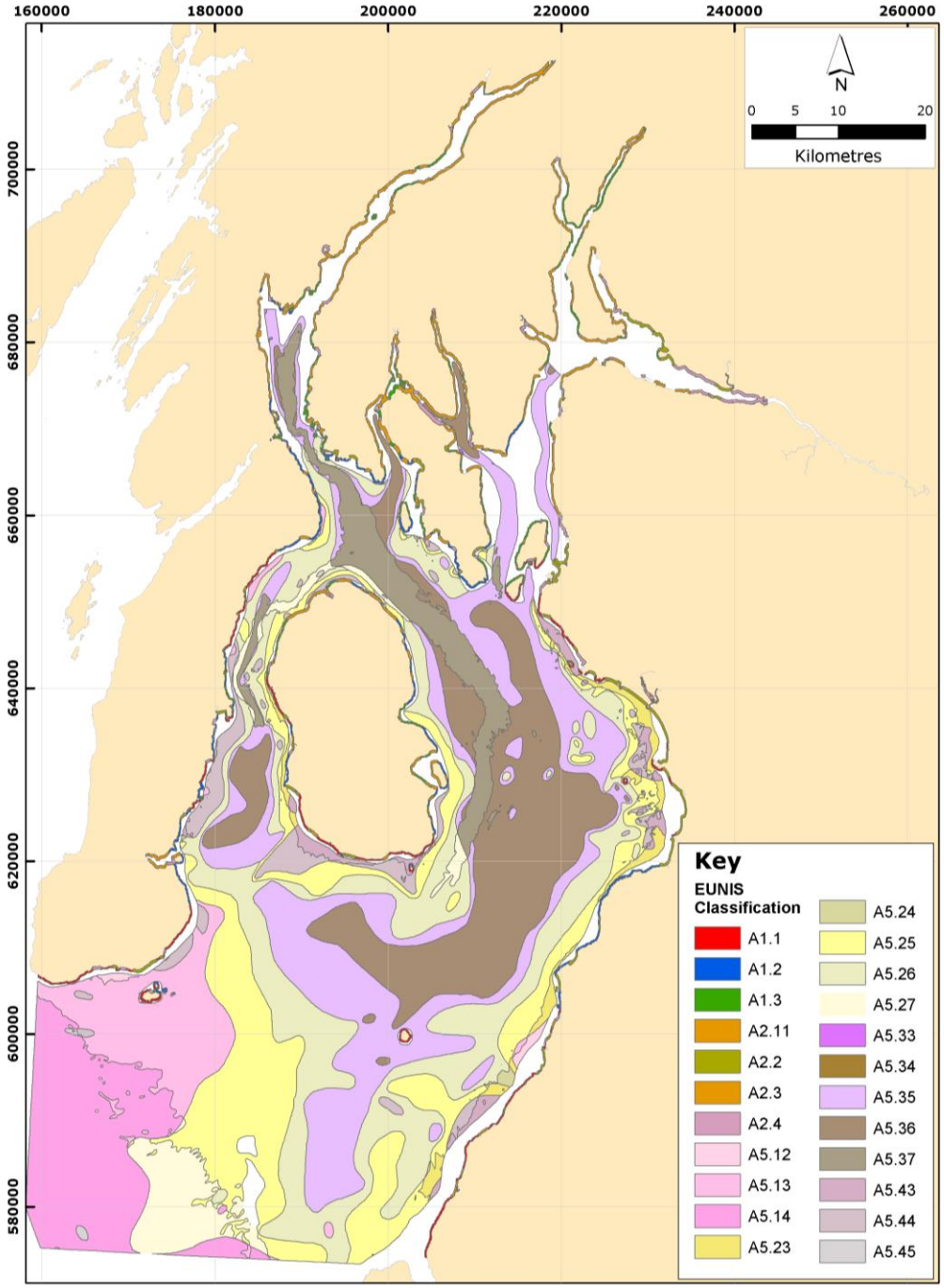
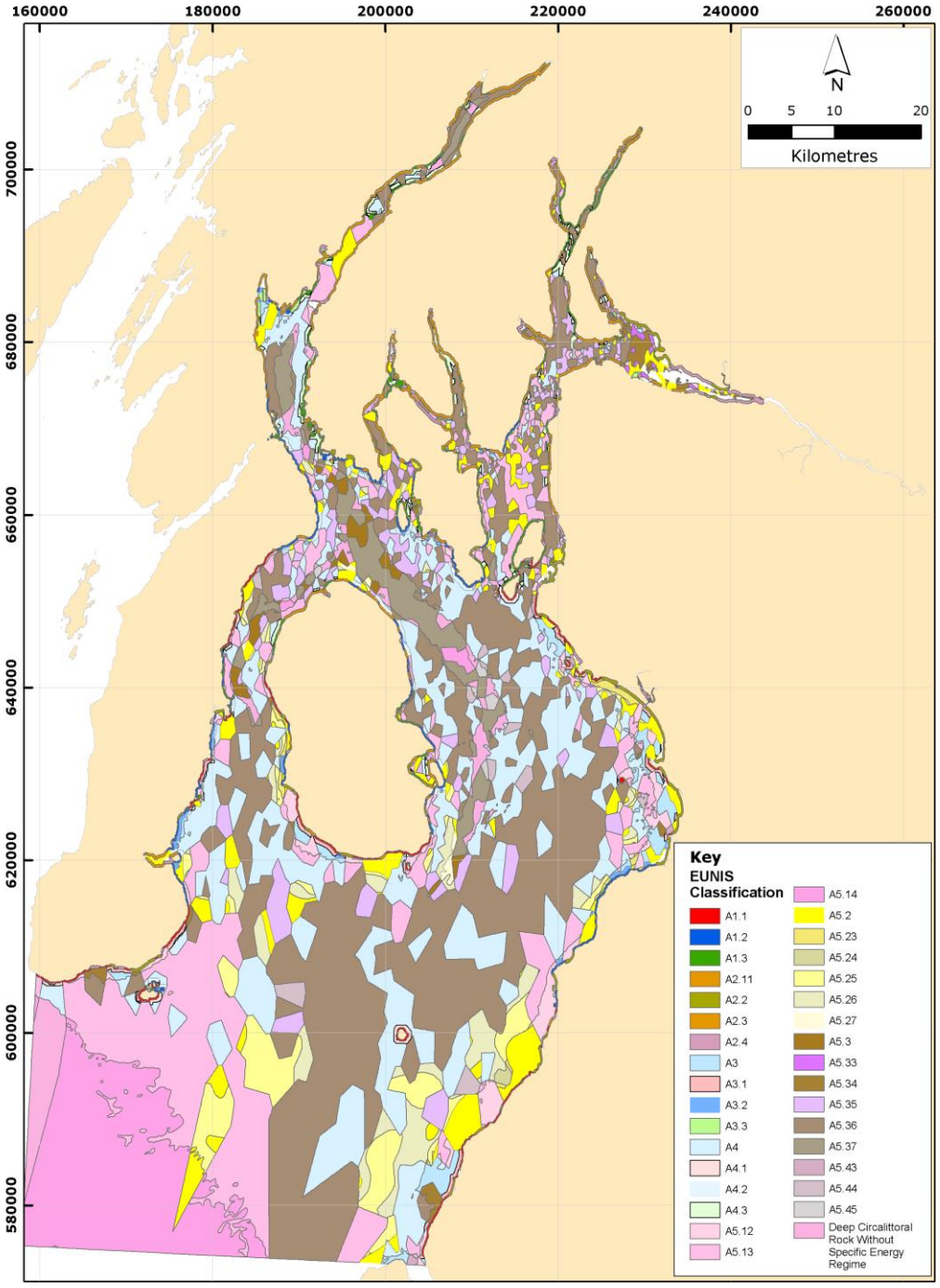


Figure 4.2 Results of cartographic modelling using Admiralty Chart geology point sediment dataset



4.1.2 Species Habitat Maps

Figure 4.3 Modelled Edible crab (*Cancer pagarus*) habitat preference

Figure 4.4 Modelled Common lobster (*Homarus gammarus*) habitat preference

Figure 4.5 Modelled Norway lobster (*Nephrops norvegicus*) habitat preference

Figure 4.6 Modelled Great scallop (*Pecten maximus*) habitat preference

Figure 4.7 Modelled Queen scallop (*Aequipecten opercularis*) habitat preference

Figure 4.8 Potential Marina Locations

Figure 4.9 Potential Mariculture Locations

4.2 Discussion

4.2.1 Modelling Method and Data

The methodology proposed was sound and robust, with the model returning the anticipated results in the expected locations, ie mud based biotopes in the mud defined areas etc.

For all its advantages the technique is not without drawbacks however.

The process of forming a raster grid or altering of data structure (e.g. converting polygon data to a raster grid) and the reclassification of the raster data, e.g. grouping large number of seabed types into broader categories, do present issues with regard to data accuracy. There are inevitable losses of information and/or accuracy when undertaking these procedures; however they are essentially unavoidable and necessary functions of the methodology. These processes are not considered to be of concern to the accuracy of the model output particularly when other more fundamental factors, such as the accuracy of the data, are significantly more influential on the model overall.

Given the resolution of the output the impact of these working practices on the results was considered minimal, particularly in view of the use to which the results shall be used.

It should be noted that although the hierarchical nature of the EUNIS classification lends itself well to cartographic modelling there are aspects of it that are constrained by the nature of the data that comprise a "biotope".

Physical variables such as bathymetry, substrate, salinity or exposure can usually be incorporated into the modelling process with relative ease due to the manner in which the data is captured or formatted. Historically the data has been observed and collated for a long period of time by systematic *in situ* observations and usually over a wide geographic area.

Approaches to collating biological and ecological data is usually no less rigorous but they frequently exist in point location observations with a limited geographic distribution. This means it is less easy to model the biological data with any degree of confidence since their spatial influence limited to a particular locale.

A functional issue in "cleaning" the vector data did arise in the modelling process due to limitations imposed by the level of ArcGIS licence possessed by ERT, however these were overcome by using MapInfo v8.5. Cleaning the data does make a few small alterations, most notably removing sliver polygons and/or gaps (of less than 0.01km^2) and snapping edges/nodes. Impact on the final result is extremely limited.

However, a number of issues arose during the modelling procedure that impacted on the observed results. In the main these issues are based around the data that was used in the modelling process. They relate either to the data

themselves, their accuracy and precision or availability, or to their processing treatment within the modelling methodology.

4.2.2 Bathymetry/Height Data

As noted previously, the bathymetry/height data was generally considered fit for the purposes of this model. The only area in which the dataset may be lacking is its precision in the intertidal zone with certain geographic locations not being covered, possibly because of the interpolation and resolution of the data. This was not a significant issue for the purposes of the model but should be noted for models of finer resolutions.

4.2.3 Sediment Data

The seabed sediment datasets benefit from more scrutiny concerning their fitness for purpose within the context of the required output. It is certainly not an issue to access the data, the BGS make their data easily available and the Admiralty Chart data is contained in the Seazone Hydrospatial product.

While the purpose of the project was not to compare and contrast the two substrate datasets it is worth noting that in areas that should be the same due to the similarity of the seabed data at that point then the model does return the same results from both datasets.

When using the BGS seabed data, this project refines the work in UKSeaMap and MESH and, by using finer resolution bathymetry data and defining more specific sediment classes. This reduces the ambiguity that can be witnessed in the MESH data where some areas have been assigned to be “either/or” biotopes.

The Admiralty Chart derived data provides an interesting alternative view of the seabed sediment and the overall patterns are broadly similar with the BGS results. Question marks inevitably arise concerning the accuracy of the data, and how valid its method of collection, and also of the reclassification that was used. This reclassification was performed from a common sense interpretation of text descriptions within the data and is not closed to criticism.

Fundamentally however question marks exist over the validity of the BGS data and its fitness for purpose in the project. Being produced by geological professionals it possesses a higher degree of confidence than the Admiralty Chart derived data however it is still derived from a “limited” number of point source sample locations.

An “issue” found in the UKSeaMap and in common with this project is that between the Admiralty Chart and BGS data there was the under-representation of rock within the BGS when compared with Admiralty data. A potentially useful technique to update the seabed data is suggested in the UKSeaMap where areas of rock identified in the Admiralty Chart point dataset were incorporated into the DigSBS250 dataset when they were found in sufficient spatial density. Ultimately it is not possible to say which of either, or none, of the datasets is more “correct” than the other and it was decided not to merge

the two datasets within this current project to preserve the integrity of the two distinct datasets.

This however leads to the question of which dataset to use and when. Ultimately the model output based on the BGS dataset uses professionally validated substrate data, with the data quality assurances associated with that dataset compared with the Admiralty Data and method as used in the project.

However, with respect to the current data holdings of the BGS, the organisation is seeking to undertake work on improving the seabed sediment data through multi-beam survey and also in creating a new intertidal dataset. Pilot projects have been successfully trialled for both but the funding and timescales for full or larger scale work are unknown at this time.

The results of these initiatives would improve the output and more specifically the confidence in the output, of any cartographic modelling process immeasurably.

4.2.4 Intertidal Zone

The extension of the modelling process to the intertidal zone is a definite benefit of the current model output over the MESH programme that appears to simply extrapolate seabed data to the shoreline.

Clearly, qualified and quantified data does exist for the intertidal area and using it in the model has, without a doubt, benefited the overall result, however the original reason and caveats in its creation should not be overlooked.

The dataset does not align spatially with the other data used and realistically should be viewed as being indicative of the shoreline. Following the decision to create the intertidal zone as a 150m area from MHW the spatial extent of overlap of the intertidal biotopes into the infra and circalittoral zones varies according to the varying mismatch between the source data the intertidal dataset was derived from and the Seazone Hydrospatial bathymetric data. Potentially this can be resolved by a manual process of redrawing the data to a spatial basis the same as Hydrospatial but for this project it was sufficiently correct. As mentioned above, the BGS are seeking to address this dataset and provide a more comprehensive and spatially consistent product in the future.

Access to the data proved problematic initially due to it being in a legal limbo between DEFRA, the dataset owners, and the BGS who are the custodians. However, SSMEI were persistent in pursuing this and ultimately successful in facilitating access to the dataset.

4.2.5 Energy Regime

Of the remaining data requirements identified the ones needed to derive an accurate energy regime for the area proved the most problematic with access to the data being the principal issue.

Wave, tide, current and wind data are all available but need manipulating and modelling to derive outputs that are of direct use to the type of modelling seen in this project. UKSeaMap and the work undertaken for the production of "The Atlas of UK Marine Renewable Energy Resources" were large scale initiatives with many partners involved in the overall process, each working in their field of expertise. "Off the shelf" products of the type required for cartographic modelling do not exist in the public arena.

Known repositories of data exist within organisations such as UKHO, BODC, Met Office and CEFAS however the organisations charge a fee for access to these data. Despite this project being an intra-governmental exercise the impression and understanding was that the data would still be charged for and these costs would have proven prohibitive within the project budget. Initiatives such as Marine Data Interoperability Programme (MDIP) seek to address this access issue and significantly improve the availability; however cost and funding issues for potential users of the data may persist.

Alternative sources for energy regime related information lie in the private sector and these, again, involve a cost to purchase although access is less of an issue since they are commercial concerns providing a service. Additionally, the data itself is more likely to be available in a form more suitable for input into the cartographic model since the supplier can undertake the actual tidal regime modelling.

It is considered that these difficulties in gaining access to data are not insurmountable providing funding and time is available.

4.2.6 Biological Data

With respect to the biological aspect of biotope definition, in terms of actual quality of data the biological/ecological dataset is extremely good since it is administered and captured by professionals. Access to the data, via the SSMEI project officer, was open, speedy and did not present an issue at all.

The data did suffer from being insufficiently spread and the nature of its capture means it can be difficult to interpret. As distinct from the high confidence associated with the data itself, the spatial coverage of the biological data is less useful to the validation of the model as a whole. For instance, in the northern sea lochs there are a high number of records that are associated with field habitat mapping exercises that have taken place. The problem still remains that the data observations are not spread evenly across the whole Clyde area but are concentrated in specific areas. There are large areas where no observations have been recorded and this means those areas are significantly under-reported, limiting the effectiveness of using the MNCR data as a validation tool in this particular area.

Ground-truthing can take place after the model results are produced in ongoing collaboration with users of the area and this is proposed as a further step in the process.

The MNCR data is professionally administered and records are assigned relevant biotope however there are also further sources of data records that have been gathered in other exercises, for example SeaSearch. These are data that have been recorded in "non-biotoped" format and in the majority of cases they have not yet been assigned a biotope however, an initiative is underway to retrospectively "tag" these records which will serve to increase the geographic availability of data records and observations.

4.2.7 Cartographic Modelling

With respect to cartographic modelling, the assigning of biotopes to spatially discrete point location records should enable their eventual incorporation into a model as a independent dataset. It is important to note that the biotope tagging is the key to easing this process since it describes a single, common foundation with which to integrate the data together.

4.3 Conclusion

Due to the nature of the similarity in methodology, the results from this project are broadly similar to the outputs from the UKSeaMap and MESH projects. In comparison with them both these results are at a higher resolution both spatially and from the breakdown of the attribute data, enabling a greater degree of precision to be modelled.

As a management tool the project delivers a more accurate habitat map than was previously available, both in spatial terms and the level to which the output has been resolved under the EUNIS classification.

However, it is oft stated that the results from any model are directly related to the quality of the data used to generate and create them. The principal methodology used in the project was successful in producing the anticipated results however the accuracy of these results is heavily influenced by the quality of the available data.

No criticism is implied to any data supplier by the following statement but only one input dataset (bathymetry) can realistically be regarded as having a high degree of confidence associated with it. Asking the question of whether the remaining data used in the model was "fit for purpose" realistically yields the answer of "not ideally" but they are the best and most easily available at the current time and are a measurable yardstick for future reference.

By no means should this be regarded as a surprise or failing since cartographic habitat modelling, the computational means and the political drivers for doing carrying it out on a "large" scale are a relatively new phenomenon. Naturally, the process suffers where there is a lack of data having been gathered historically because the need for it or method of calculation at sufficiently high resolution has not previously been present, eg seabed sediment or tidal current.

The successful application of cartographic modelling demonstrated by this, and similar projects, underlines the effectiveness of the *potential* of the tool in the marine environment. However, it is clear that there exists a gap between the

current position and realising that potential fully that can only be filled by the capturing of good quality data on the physical and biological variables that are currently missing. Once this gap is filled there is no reason that the technique cannot confidently inform decision making at all levels, as it does in the terrestrial environment.

5 References