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UK SeaMap 2010
Predictive mapping of seabed habitats in UK waters

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Acronyms

BGS - British Geological Survey
BODC - British Oceanographic Data Centre
CCW - Countryside Council for Wales
EUNIS - European Nature Information System
JNCC - Joint Nature Conservation Committee
MCZ - Marine Conservation Zone
MESH - Development of a Framework for Mapping European Seabed Habitats
MNCR - Marine Nature Conservation Review
MPA - Marine Protected Area
MSFD - Marine Strategy Framework Directive
NOC - National Oceanographic Centre
POL - Proudman Oceanographic Laboratory
SNCBs - Statutory Nature Conservation Bodies
WFD - Water Framework Directive

Executive Summary

UKSeaMap 2010 was established to produce an ecologically relevant, full-coverage map of seabed habitats across the entire UK marine area. Predictive seabed habitat mapping is necessary because consistent, high-quality habitat maps from surveys are only available for 6% of the seabed in the UK marine area. Through the combination of physical data describing the marine environment with information from biological sampling, a broadscale predictive map of seabed habitats has been made. A confidence map has been produced to accompany the habitat map. The third component of UKSeaMap is a layer showing coastal physiographic features, which it is not appropriate to map using a predictive approach.

There is a wide range of applications for these products. They can be used in the process of establishing marine protected area networks, for example when a full-coverage habitat map is required to make judgements about whether a marine protected area network meets criteria for representativity. In order to develop marine monitoring programmes, the UKSeaMap 2010 products are essential for stratifying sampling efficiently. Meeting national and regional assessment and reporting obligations more accurately is made possible with these products, for example EC Habitats Directive reporting and Marine Strategy Framework Directive (MSFD) assessments. Broadscale predictive habitat maps also have benefits for marine planning, both to set local data in context and to ensure that Good Environmental Status is maintained under MSFD.

UKSeaMap 2010 builds on previous work to develop predictive habitat models using Geographic Information Systems (GIS), particularly UKSeaMap 2006 and the MESH project. However, in UKSeaMap 2010 confidence is partly integrated into the model as a way of selecting the most likely habitat to occur at a particular location. This method also allows the production of maps showing our confidence in boundaries between habitats. The quality of the data describing the nature of the seabed (type of sediment, rock) has been assessed, since this variable drives many of the habitat predictions. The combination of confidence in boundaries and quality of the seabed substrata data gives an overall confidence map to accompany the predictive habitat map.

The predictive seabed habitat map shows the distribution of 44 habitats across over 858,000km^2 of the UK marine area. The habitats are classified according to the standard European marine habitat classification scheme (EUNIS), with the exception of deep sea habitats for which a new classification is applied. This is necessary because the current structure of EUNIS is too general in this area and does not adequately reflect the huge variation across deep sea zones. It is the first time that a full-coverage confidence map has been produced which takes into account confidence in boundaries and the quality of the data. A comparison has been made with other predictive seabed habitat maps (international and regional), as well as a comparison to maps derived solely from seabed survey data. Data and metadata are made available online for viewing and download at the UKSeaMap webGIS: jncc.defra.gov.uk/UKSeaMap.

Acknowledgements

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Contents

1 Introduction

The seabed is a complex environment, under the influence of a broad range of physical, chemical, geological and biological factors. Physical variables, such as topography, substratum and depth, influence the variation in biological communities. These communities at the seabed are also affected by the nature of the water column above them: variables such as temperature, salinity and the energy exerted by water movements.

The importance of seabed habitat mapping has been increasingly recognised in recent years. Information on seabed habitats is essential both for the development of new economic activities and for assessing the impact of these activities on the marine environment. Management policies and actions, including marine spatial planning, need to be informed by the best-available data if they are to achieve long-term sustainable use and management of the marine environment and its resources.

Mapping of seabed can be achieved in two ways: survey of the seabed (with or without biology), or through predictions using abiotic variables and biological data. Survey methods and technologies have improved dramatically since the 1990s, with advances such as multi-beam echo sounding and side-scan sonar, when combined with high-definition video or still photos able to provide highly detailed information about the seafloor. However, there are still many obstacles to providing full coverage maps of the seabed through these methods alone. Data collection can be prohibitively expensive and time consuming for full coverage mapping of large areas. Hence methods that can use existing data to its highest potential to provide good coverage over areas otherwise poor in seabed habitat data are highly desirable.

1.1 Need for predictive seabed habitat maps

Predictive seabed habitat mapping is necessary because consistent, high-quality habitat maps from surveys are only available for 6% of the seabed in the UK marine area. Acquiring sufficient full coverage acoustic data and biological ground-truthing for widespread direct mapping of ecological communities is possible but is very expensive and would take many years. There is a clear need to create a full coverage map predicting seabed habitats for the entire UK marine area, particularly to contribute to:

- assessing the state of the marine environment as required by the EU Marine Strategy Framework Directive (MSFD);
- designing a robust sampling strategy under the UK Marine Biodiversity Surveillance and Monitoring Programme[1];
- developing an ecologically coherent network of Marine Protected Areas (MPAs) in the UK, as required by the Marine and Coastal Access Act (2009) and the Marine (Scotland) Act (2010); and
- implementing marine planning, as required by the Marine and Coastal Access Act (2009) and the Marine (Scotland) Act (2010), by informing the location and development of new uses of the sea, such as renewable energy.

There is now an implicit requirement for continuous mapping that can be applied across European regions. The MSFD states that, by 2012, “Member States shall make an initial

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[1] JNCC, in partnership with the SNCBs, has started to develop integrated monitoring schemes for benthic habitats, seabirds and cetaceans in the entire UK marine area, including protected sites. This work is all being delivered through UKMMAS and aims to me*et al*l UK monitoring obligations, including the coordinated monitoring programme required of each Member State by the MSFD by 2014.

assessment of their marine waters, taking account of existing data where available and comprising … an analysis of the essential features and characteristics … covering the physical and chemical features, the habitat types, the biological features and the hydro-morphology". Annex III of the Directive defines the list of elements against which the assessments must be made, and with reference to habitats calls for "the predominant seabed and water column habitat type(s) with a description of the characteristic physical and chemical features, such as depth, water temperature regime, currents and other water movements, salinity, structure and substrata composition of the seabed".

UKSeaMap 2010 provides a full coverage predictive seabed habitat map for the sublittoral UK marine area using the EUNIS (2007-11) classification, filling the geographic gaps evident in earlier predictive mapping projects (UKSeaMap 2006 and MESH). Higher resolution environmental data, which were not previously available, have been used to predict these habitats. The higher resolution data were used to investigate the environmental classes (e.g. high, moderate and low energy) and their boundaries. The confidence in the predictive map was assessed using information about the quality of the individual environmental datasets. The UKSeaMap 2010 predictive seabed habitat map was compared both to previous predictive seabed habitat maps and to habitat maps produced from survey data.

UKSeaMap's primary purpose is to provide a national and regional perspective on the UK's marine habitats, including their distribution and extent, to support national and regional scale planning and management requirements. Potential uses are outlined in Table 1.

Table 1. Potential uses of full coverage predictive seabed habitat maps.

Potential Use	Description
Protection of the marine environment	This will be better informed through the availability of holistic ecological maps, allowing all users and managers to have a better understanding of the nature and distribution of marine seabed; this is especially important because the UK has such extensive areas of sea to manage and protect, and this environment is largely hidden from sight. The availability of predictive habitat maps will facilitate the identification of a representative suite of MPAs; this will help fulfil both European (EC Habitats Directive (92/43/EEC), EU MSFD (2008/56/EC), OSPAR[2] Convention) and national obligations (Marine and Coastal Access Act (2010) and Marine (Scotland) Act (2010)).
Monitoring and surveillance programmes	To adequately assess the state of the marine environment, as required by the Marine and Coastal Access Act, the Marine (Scotland) Act, the MSFD and OSPAR, it is necessary to establish programmes which sample across the range of ecological features and have a sound geographical spread of sampling stations. A sampling design (where, what, when and how to sample) for habitats will rely on knowing the distribution and extent of habitats of interest. UKSeaMap 2010 will be one of the layers used by JNCC and partners to develop the sampling design for the Marine Biodiversity Surveillance and Monitoring Programme, covering the UK marine area.
Marine planning	Availability of the marine habitat maps could much better inform the new systems of marine planning provided for in the Marine and Coastal Access Act, the Marine (Scotland) Act and proposed legislation in Northern Ireland. The use of predictive habitat maps in such planning is most appropriate at the regional level, whilst the provision of seabed habitat maps, produced through surveys, will offer a similar benefit at a local level.
Good Environmental Status (GES)	Implementation of the MSFD will be better informed through a full coverage habitat map for the UK marine area. The MSFD requires the description and mapping of marine habitats in each Member State and an assessment of state of the environment.

1.2 Previous work

UKSeaMap 2006 provided the first visualisation of seabed and water column features for the UK marine area using a combination of modelling and delineation of features (Connor *et al* 2006): modelled seabed types only are shown in Figure 1. Box 1 outlines the origin of the habitat modelling approach, first applied in Canada and subsequently in the Irish Sea. Building on the work of the original UKSeaMap project, in 2008 JNCC produced predictive maps of seabed habitat types using the European habitat classification scheme, EUNIS, under the MESH project[3] (Figure 2). The aim of this part of the MESH project was to deliver a consistent map predicting seabed types across north-west Europe. Although the predictive maps resulting from both UKSeaMap 2006 and MESH were derived from similar

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[2] www.ospar.org

[3] Development of a Framework for Mapping European Seabed Habitats (www.searchMESH.net); funded by INTERREG IIIB North West Europe (NWE) Programme (3b.nweurope.eu).

input datasets, the results they present have important differences; both in the concept of the units presented, and in the approach employed to derive these units.

Both projects used broad-scale environmental data to predict broad-scale habitats and validated the maps using habitat data points. Neither UKSeaMap nor MESH provided a full coverage map of the UK marine area. UKSeaMap 2006 used temperature data to designate warm and cold deep water habitats, applied energy classes to sediment habitats only and mapped topographic features and coastal physiographic types. The MESH EUNIS model did not include temperature data, topographic features or coastal physiographic types and only applied energy classes to rock habitats. UKSeaMap 2006 predicted marine landscape types while MESH predicted EUNIS habitat types.

Box 1: Origin of the broad-scale habitat modelling approach

In what is often referred to as a ‘top-down’ approach, it is recognised that the distribution of habitats can be defined by physical variables, and hence the spatial variation of the biological communities they support (Roff & Taylor 2000; Vincent *et al* 2004; Connor *et al* 2006). The concept of marine landscape mapping was developed for Canadian marine habitats (Roff & Taylor 2000), where it was demonstrated that oceanographic and geophysical data could be used to predict ecologically meaningful marine features at a scale where sufficient biological data are not available. Biological data can be used to generate the rules which are then applied to classify the oceanographic and geophysical data. Additionally, independent biological datasets can be used to validate the predictions based on these physical variables.

The development of this broad-scale habitat mapping approach recognised that proper governance of the oceans required mapped information on the nature and distribution of marine features, so that regulation of human activities could be assessed in a more ecologically-meaningful manner and for environmental protection measures to be applied with a national perspective on the resource being managed. Given the high costs of collecting the necessary detailed survey data to produce such maps for large areas of sea, Roff and Taylor developed a more practical approach that could deliver broadscale maps, via modelling of available data, in a realistic timescale.

The first time this approach was used in the UK was in the Irish Sea Pilot, where geophysical and oceanographic data were used to identify seabed and water column landscapes in the Irish Sea (Vincent *et al* 2004). The maps were validated using biological data in order to test the ecological relevance of the maps. The Irish Sea was divided into five coastal and thirteen marine seabed landscape types. Coastal and seabed habitats were modelled using the following physical variables: depth, substrate, bed-stress caused by currents and topography. The Irish Sea Pilot recommended that the marine landscape approach ‘should be adopted as a key element for marine nature conservation and utilised in marine spatial planning and in the management of the marine environment’. The approach taken in the Irish Sea was further developed by UKSeaMap 2006 and the MESH project.

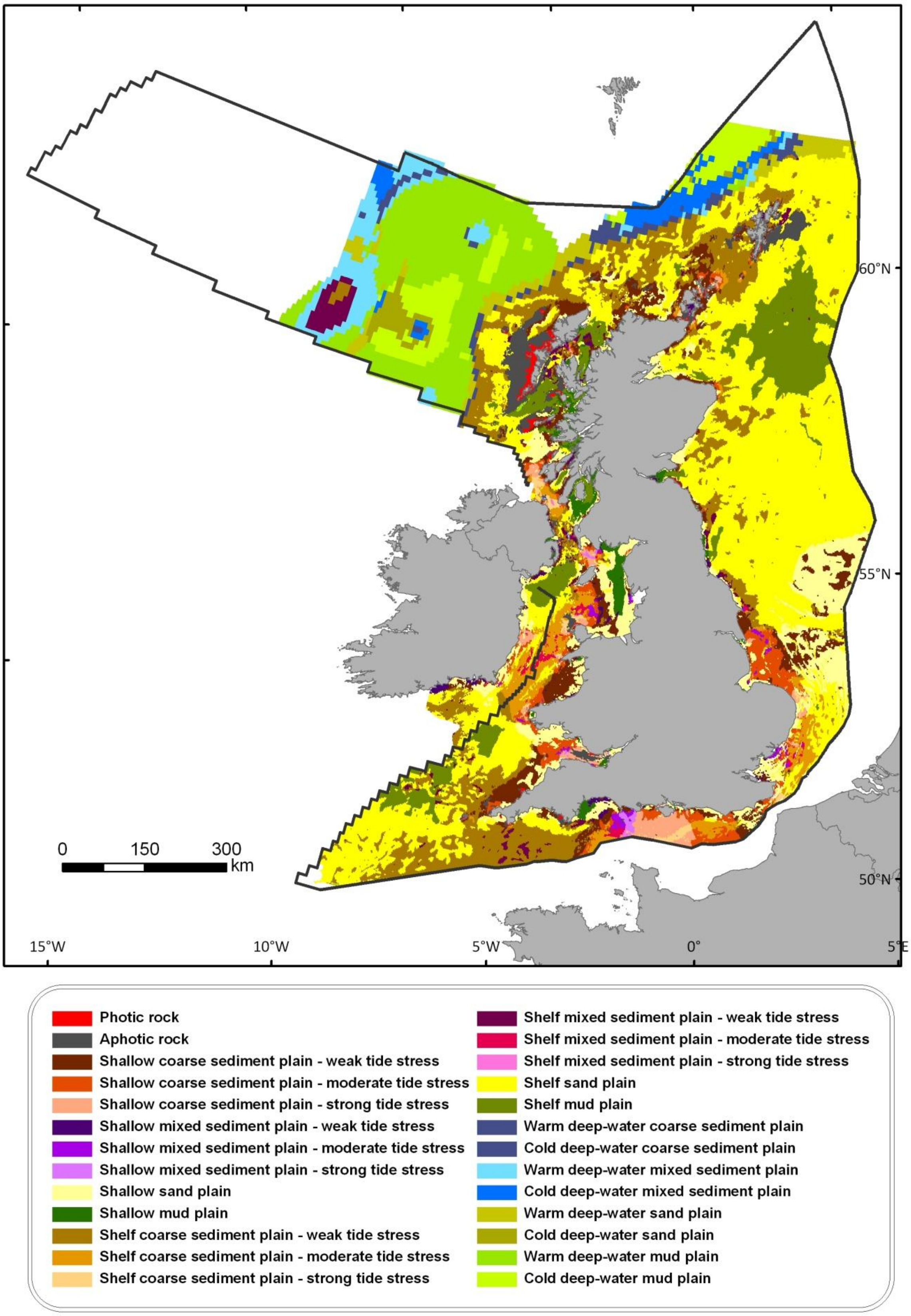

Figure 1. UKSeaMap 2006 modelled seabed types (Connor *et al* 2006). Coastal physiographic and topographic features produced during the project are not shown in this image.

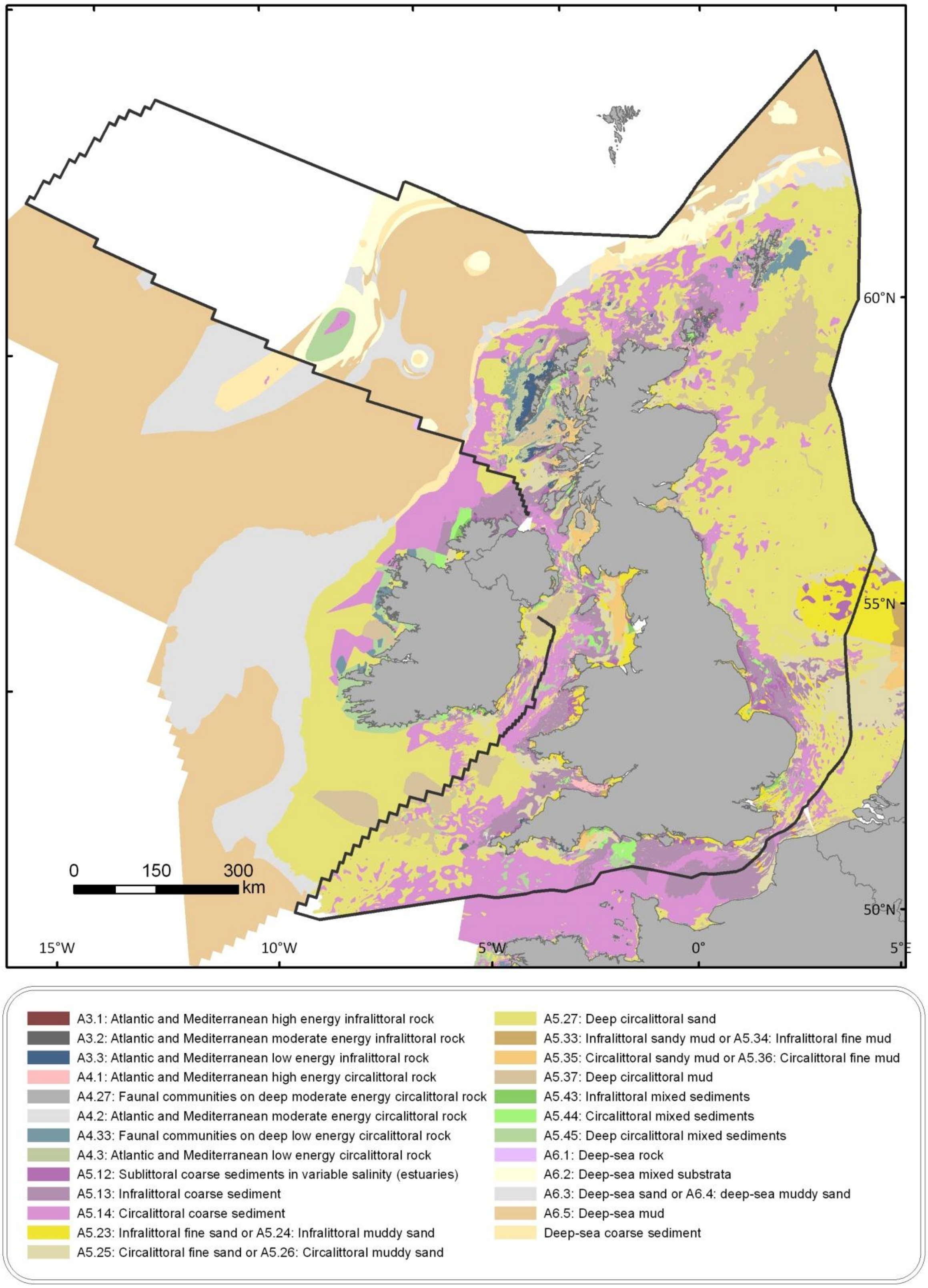

Figure 2. MESH predictive seabed habitat map*.* The map is a mixture of EUNIS Level 3 and 4 habitats, showing the most detailed class available in each location (Coltman *et al* 2008).

1.3 Summary of technical work

The classification of the seabed focused on broad-scale habitats. After assessing the environmental parameters which have most influence on ecological character, and the availability of suitable data, parameters were selected for use in the predictive seabed habitat model (Table 2).

Table 2. Parameters selected for analysis.

Parameter	Description
Seabed substrata	The nature of the substratum (e.g. sand, mud) has a marked influence on the biological communities which live in or on them;
Light penetration	Determines the depth to which macroalgae (e.g. kelp) can grow.
Depth	Increasing depth brings greater stability (in terms of temperature, salinity, wave action) and greater pressure, both parameters to which biological communities respond. Species live within tolerance ranges[4] (pressure, salinity, temperature), beyond those ranges, species may require special adaptations to survive.
Wave-base	The depth to which waves can penetrate the sea and thus disturb the seabed, with marked effects on the resulting communities, and the considerable variation of its communities around the coast.
Energy at the seabed due to waves	Surface waves influence the amount of energy affecting the seabed, particularly in shallow coastal areas and this influences the character of communities with more robust species living in areas of high wave energy.
Energy at the seabed due to tidal currents	Bottom current has a strong influence on both the character of the seabed (sediment type, formation of surface features such as sand waves and ripples) and the biological communities it supports.
Salinity	Salinity is a useful indicator for distinguishing between fully marine and variable salinity areas. Slight reductions in salinity (in the range 33-35‰) leads to loss of some species, with this becoming increasingly marked below 30‰ in the highly variable salinity regimes of estuaries.

In the coastal zone, physiographic features such as estuaries, sealochs and bays have been identified according to definitions developed for the Marine Nature Conservation Review (Defra, 2004) and for application of the EC Habitats Directive. This layer was created during UKSeaMap 2006 and updated as part of UKSeaMap 2010.

GIS physical data layers were prepared for the parameters in Table 2 as grids covering the UKSeaMap 2010 project area, with each grid cell being 0.0025 decimal degrees (about 300m) wide. The resultant datasets were analysed in a supervised classification[5] to derive a

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[4] Tolerance range = Limits of tolerance a species has to an abiotic factor or condition in the environment.

[5] A supervised approach relies on a degree of guidance being provided by the mapping scientist. This guidance draws upon expert judgement and prior knowledge, which means that the process, and often the output, can be

series of habitat types. To assess the confidence of the predictive seabed habitat map, information about the quality of the physical data layers was used to create individual confidence maps, which were then combined to produce a single confidence map for the predictive seabed habitat map. Biological records were not used to assess the confidence of the predictive habitat map as the available records are too sparse and generally aggregated around coastal areas.

1.4 General limitations

As the maps are based on a grid of about 300m, and some of the underlying data are at coarser grids, the maps are unsuitable for fine-scale planning, for example for site-specific new developments. Rather, they are intended to give a broader regional and national perspective on the distribution of these features, and should enable more detailed data to be put in context.

1.5 Related regional & international predictive mapping projects

1.5.1 HABMAP (2004 - 2010)

HABMAP was a joint Irish-Welsh project predicting seabed habitats in the southern Irish Sea, funded by INTERREG IIIA (Robinson *et al* 2009a; Robinson *et al* 2009b). Its aim was to produce predictive seabed habitat maps that could be used for conservation and management in the southern Irish Sea, following the Marine Habitat Classification for Britain and Ireland[6]. HABMAP used seabed substrata, temperature, bathymetry, current, waves, salinity and light attenuation to predict ranges for biotopes, and from these biotope maps, a full coverage seabed habitat map was generated. These biotopes have been translated into EUNIS habitat types by CCW and JNCC so that they can be compared to UKSeaMap 2010.

CCW received funding from Welsh Assembly Government for a further two years, to refine the biotope modelling, extend the maps to cover all Welsh waters and apply the maps to practical problems such as sensitivity mapping, marine spatial planning and impact modelling.

1.5.2 BALANCE (2005 - 2007)

The BALANCE (Baltic Sea Management - Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning)[7] project was a Baltic Sea Region INTERREG IIIB co-funded programme comprised of 27 partners from 10 countries. It mapped marine landscapes and habitats for the Baltic and Kattegat seas and parts of the Skagerrak strait.

The approach used by BALANCE built on the concepts proposed by Roff and Taylor, the Irish Sea Pilot project (2004) and UKSeaMap (2006). The maps developed by BALANCE identified three different broad-scale characterisations of the marine environment: topographic features, such as sediment plains and troughs; physiographic features such as

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more intuitive and less abstract in nature. Although this method may be criticised on the basis of being subjective, it would seem short sighted to not apply the wealth of knowledge and understanding we have about marine ecosystems to the classification process in this project. This method relies on developing broad definitions for each broad-scale seabed habitat type prior to the data analysis stage (i.e. supervising the classification of broad-scale seabed habitat types), recognising that criteria used to define each landscape type have ecological relevance. (Connor *et al* 2006).

[6] http://jncc.defra.gov.uk/page-1584.

[7] http://www.balance-eu.org/

lagoons, estuaries, and archipelagos; and seabed features. This last characterisation used three primary physical data layers (sediment, photic depth and salinity), to spatially describe the seabed in terms of broad habitat conditions (Al-Hamdani and Reker 2007).

1.5.3 EUSeaMap (2008 - 2011)

EUSeaMap has produced predictive seabed habitat maps for over two million square kilometres of European seabed. It built on the seabed modelling work carried out in the MESH and BALANCE projects. EUSeaMap has improved existing maps across the Celtic, North and Baltic Seas, and harmonized them under the EUNIS classification, as well as extending predictive mapping to the western Mediterranean for the first time. A consortium led by JNCC has developed data layers and thresholds. The final maps were made publicly available through a webGIS in early 2011.

The project is funded by the European Commission’s (EC) Directorate-General for Maritime Affairs and Fisheries, with the primary aim to support the implementation requirements of the Marine Strategy Framework Directive (MSFD), specifically the Initial Assessments which all Member States must undertake in 2012. EUSeaMap is itself an integral part of the EC’s preparatory actions for a European Marine Observation Data Network (EMODnet), and the project is a primary customer of many of the new data layers that are being produced by the initiative.

UKSeaMap 2010 and EUSeaMap have worked closely together. Due to differences in timescales and resources some input datasets will differ, e.g. higher resolution light data was only available for EUSeaMap. EUSeaMap also required certain technical differences due to the need to consider both a larger extent and regional differences between the Atlantic, Baltic and western Mediterranean waters. EUSeaMap applied ‘fuzzy’ boundaries rather than using ‘hard’ boundaries between habitats.

2 General methodology

2.1 Modelling approach

Classification of the seabed into habitat types was undertaken using geological, physical and hydrographic characteristics in a manner similar to that adopted in the UKSeaMap 2006 and MESH projects (Connor *et al* 2006; Coltman *et al* 2008). This approach recognises the strong correlation between environmental parameters and ecological character, such that mapping environmental parameters in an integrated manner can successfully be used to produce ecologically-relevant maps. UKSeaMap differs from previous broadscale modelling projects in that it takes account of uncertainty around boundaries in the classification of habitats, and includes this uncertainty as an element in a confidence map to accompany the habitat map.

Figure 3 shows the process employed by UKSeaMap 2010 to produce the predictive habitat map and confidence map. Numbered annotations are as follows:

a In-situ biological data are used to establish the numeric values of physical parameters associated with boundaries between classes in the habitat classification system (e.g. between ‘moderate energy’ and ‘high energy’ classes).

b In-situ physical data are used to assess variation between a physical data layer and a second source, such as independent in-situ measurements of the same parameter.

c The variance of each physical data layer is then used to derive relationships between a given value of a grid cell and the probability that the value is within a class, relative to a single predefined boundary established in Step 1. These measurements of uncertainty therefore vary spatially across the physical data layer. It was not possible to carry out this step for the seabed substrata data layer. Through combining probability layers calculated in Step 2, the probability that a cell falls between two boundaries (defined in Step 1) that define the upper and lower bounds of a class can be calculated. This is the probability that the cell belongs to the class defined by those boundaries.

d Comparing the probability that each cell belongs to each class is then achieved through a process of ‘stacking’ in GIS and the class with the highest probability is selected for each cell, resulting in classified physical data layers.

e The classified physical data layers are combined in GIS, and interpreted with the habitat classification system to determine which habitats are represented by each combination of physical classes.

f The probability associated with each ‘winning’ class that contributes to the final predicted habitat in each grid cell can then be taken as a measure of uncertainty in relation to the boundaries applied in the model.

g Measurements of uncertainty at boundaries are combined with information about the quality of the physical data layers to produce a confidence map to accompany the habitat map. In UKSeaMap 2010 the seabed substrata data layer was the only layer assessed for quality (e.g. taking into account factors such as age, data density, data collection techniques). Confidence is therefore the interaction between how confident we can be that a habitat has been classified into the correct biological zone or energy class (which is caused by how clear or otherwise the boundaries are between these zones or classes, and how good a predictor of any habitat these physical data are), and the quality of the information describing seabed substrata.

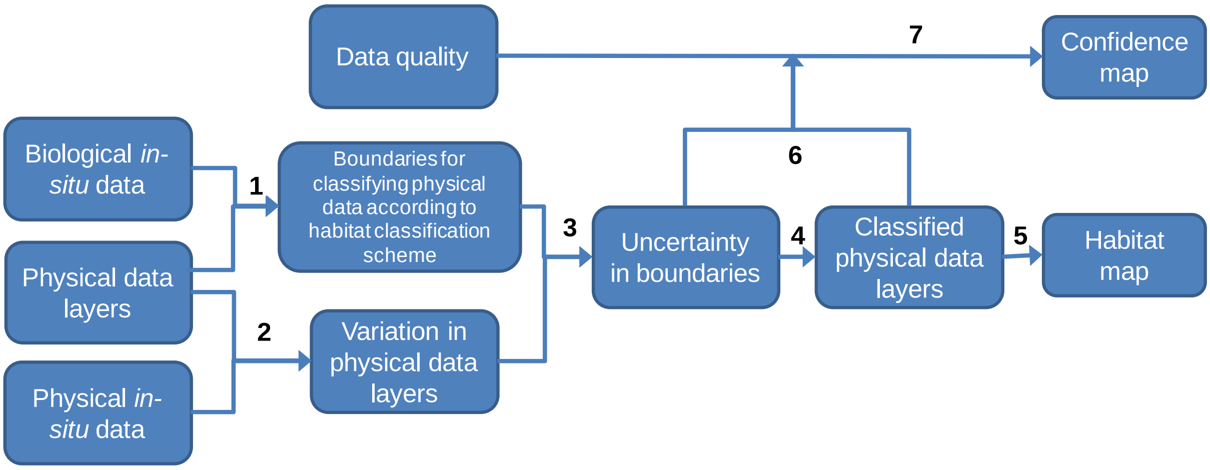

Figure 3. Diagram showing the UKSeaMap 2010 process to predict seabed habitats and assess their confidence.

2.2 Parameters considered

There are a wide range of environmental parameters which influence ecological character; these have varying degrees of influence and lead to differences in ecological character at various scales (e.g. structurally determining habitat type, or determining the communities or individual species which occur in any particular place). Consideration was given to the availability of suitable environmental datasets at a UK level which could be used to predict seabed habitat types, and how such parameters could best be used in a modelling context. Data were derived in a variety of ways, including hydrodynamic modelling, interpolation, satellite observation, remote-sensing and ground-truthing techniques. The environmental datasets used were:

- seabed substrata;
- light attenuation;
- depth;
- waves;
- tidal currents;
- salinity.

These datasets are described in sections 3.1 to 3.5, giving details of their source, technical development and the rationale behind their selection and categorisation. Physical data layers available in 2009/2010 were often of a higher resolution than those used in UKSeaMap 2006 and MESH project (Table 3). All the datasets required considerable further processing to convert them into a suitable format for modelling. Further detail is available in the UKSeaMap 2010 Technical Reports which give details of their technical development and the rationale behind their selection and transformation, as well as a description of their conversion from continuous data into categorical data, with categories relevant to habitat classification. See Appendix 9 for a list of UKSeaMap 2010 Technical Reports.

Table 3. Physical data layers used in the construction of the UKSeaMap 2010 seabed habitat map.

UKSeaMap 2010 physical data layers	Organisation	Source(s)	Resolution	UKSeaMap 2006 & MESH EUNIS model resolutions
Bathymetry	SeaZone	Coastal Digital Elevation Model	30m	Not used
	Intergovernmental Oceanographic Commission (IOC) of UNESCO and IHO[8].	GEBCO[9]	30 second	1 minute
Light	NASA	Aqua MODIS satellite	4km	9km (SeaWiFS)
Seabed substrata	BGS	DigSBS250 v2 (pre-release)	1:250,000	v1, 1:250,000
	NOC[10]	Deep sea substrata	Unknown	Not available
	BGS[11]	Water Framework Directive typology substrata	1nm (coastal waters) & 0.1nm (transitional waters)	Water Framework Directive typology substrata
	BGS	Rock and hard substrata	1:250,000	Not available
Waves	NOC	ProWAM	12.5km	Not used
	DHI	Spectral wave model (from the coast out to 6km from the coast)	~100m	Not available
Currents	NOC (formerly known as POL)	POLCOMS CS20[12] POLCOMS CS3 POLCOMS North East Atlantic	1.8 km (2007 v) 10 km (2007 v) 35 km (2007 v)	1.8 km (2004 v) Not used Not used

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[8] International Hydrographic Organisation

[9] General Bathymetric Chart of the Oceans: www.gebco.net

[10] Formerly known as Proudman Oceanographic Laboratory (POL)

[11] British Geological Survey

[12] Run 5 of the POLCOMS model was used in the original UKSeaMap project and Run 11 of the model from 2007 was used in UKSeaMap 2010.

2.3 Considering boundaries in the habitat classification system

Crucial to the UKSeaMap 2010 habitat modelling process is the structure of EUNIS, which informs the application of ecologically-relevant thresholds to the physical data layers. In some cases the definition of a habitat lends itself naturally to a clearly defined threshold. However, in other cases the definition of what constitutes a particular category in the EUNIS scheme is not well developed in terms of physical measurements. Exploring these thresholds is shown as Step 1 in the modelling process in Figure 3. Thresholds can be determined in a variety of ways: arbitrary, using expert judgement or through analysis.

Table 4 outlines the thresholds used by the original UKSeaMap and MESH projects. The thresholds investigated in UKSeaMap 2010 were chosen due to both their application in EUNIS and the availability of new higher resolution physical data layers with could be used to test the thresholds. Thresholds were investigated by comparing habitat and physical data from the JNCC Marine Recorder database[13] to gridded physical data layers.

Figure 4 shows the series of physical and environmental questions in the modelling process which are used to arrive at different Levels of the EUNIS classification. Habitats were modelled to EUNIS Level 3 and 4 using physical data layers (Figure 4). These modelled habitats fell into four Level 2 habitat types: infralittoral rock or hard substrate (A3), circalittoral rock or hard substrate (A4), sublittoral sediment (A5) and deep sea bed (A6). The model did not take into account pelagic[14] habitats (A7), ice habitats (A8) or intertidal habitats (A1 and A2). There are currently no ice habitats in UK waters. Substrate data were too coarse spatially and qualitatively in intertidal areas to usefully model intertidal habitats.

Howell (2010) identified five separate biological zones in UK deep sea areas which are not currently represented in EUNIS. Here, depth is used as a proxy for environmental variables to define the different deep sea biological zones, resulting in a potential 25 modelled deep sea habitat types. UKSeaMap 2010 also introduced Biogeography into the deep sea classification. The EUNIS classification currently includes biogeography (e.g. Atlantic, Mediterranean and Baltic) but does not include a category for Arctic seabed habitats.

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[13] The Marine Recorder package was developed by JNCC as a collect and collate piece of software designed to hold and manage marine survey data including from Marine Nature Conservation Review surveys. The JNCC database holds benthic sample data from a variety of organisations including the JNCC, the Statutory Nature Conservation Bodies (SNCBs), Marine Environmental Data and Information Network (MEDIN), Seasearch and Local Record Centres.

[14] Pelagic = open water column

Table 4. Thresholds investigated by UKSeaMap 2010, and the thresholds used by the original UKSeaMap project (2006) and MESH. G = gravel, S = sand, M = mud.

Thresholds	Basis		Thresholds						Investigated by UKSeaMap 2010
			UKSeaMap 2006			MESH EUNIS Model			
Infralittoral-circalittoral boundary	Fraction of light reaching the seabed		1%			2.36%			Yes
Circalittoral-deep circalittoral boundary	Wave-base		Equal to half the wavelength			Equal to half the wavelength			No, available data (deep circalittoral habitat points) are too sparse.
Sediment	EUNIS categories	BGS modified Folk categories	Gravel (%)	Sand (%)	Mud (%)	Gravel (%)	Sand (%)	Mud (%)	
	Coarse sediment	G, sG, gS	> 5	< 95	< 20	> 5	< 95	< 20	Yes
	Mixed sediment	mG, msG, gM, gmS	> 5	< 90	< 90	> 5	< 90	< 90	Yes
	Sand & muddy sand	(g)S, S, (g)mS, mS	< 5	> 80	<20	< 5	> 80	<20	Yes
	Mud & sandy mud	(g)M, M, (g)sM, sM	< 5	< 80	>20	< 5	< 80	>20	Yes
Energy	Current models only Weak Moderate Strong		Tidal Shear stress (Nm^{-2}) < 1.8 1.8 - 4 > 4			Tidal Shear stress (Nm^{-2}) < 1.8 1.8 - 4 > 4			Yes

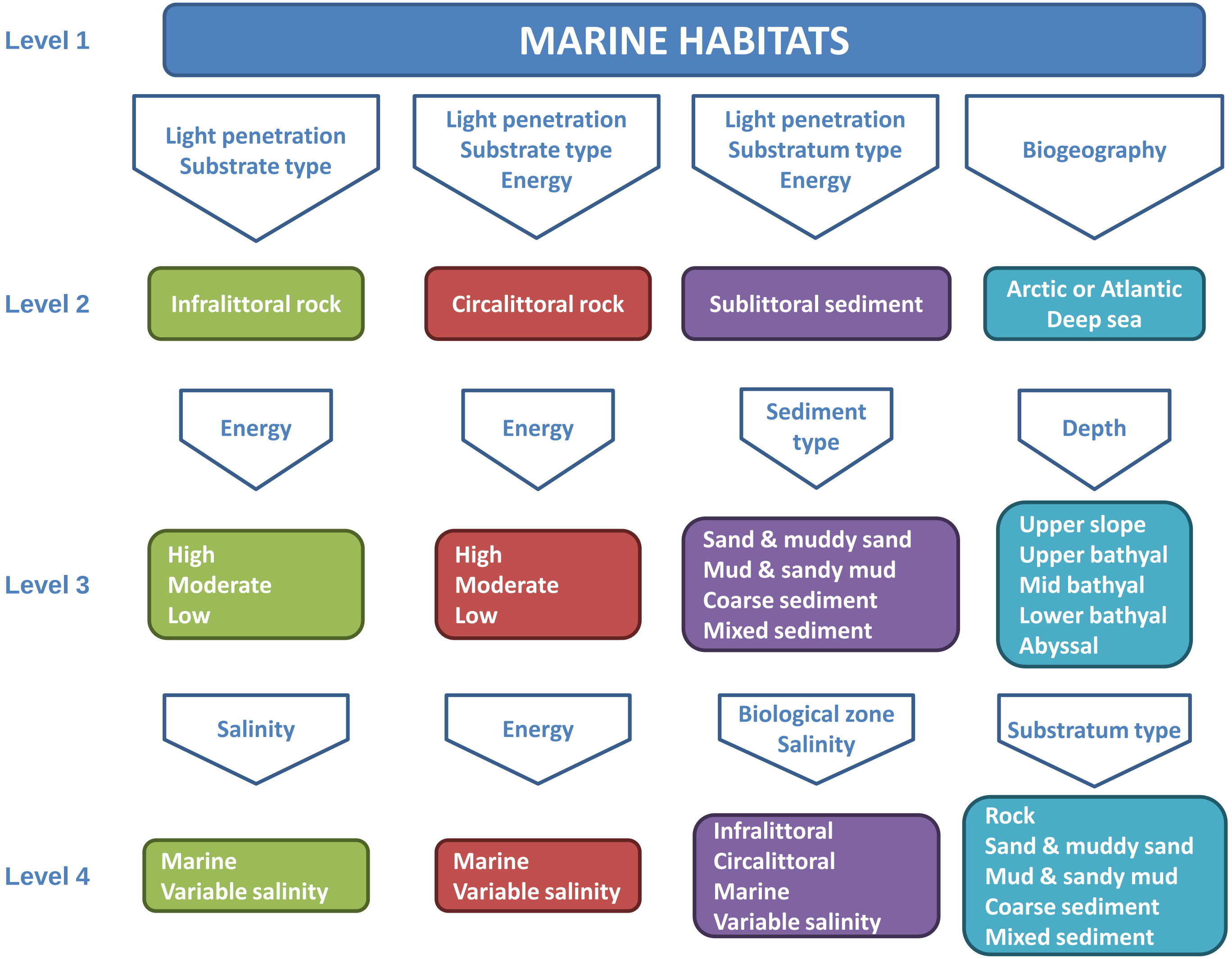

Figure 4. Diagram of the physical data layers (blue arrows) used to predict habitat at different levels of the EUNIS and deep-sea classifications.

2.4 Model resolution and extent

A resolution of 0.0025 decimal degrees (approximately 300m) was selected for UKSeaMap 2010. This was driven by the knowledge that over much of the study area this level of resolution is generally available for the seabed substrate dataset, which plays a major role in the distribution of seabed habitats. In the coastal zone other input data layers are available at this resolution (depth and wave energy), however, it does not hold true in the offshore area where input data layers tend to be found at coarser resolutions.

The map products of UKSeaMap 2010 cover the entire UK subtidal marine area (872,360 km^2). They do not include the intertidal zone, because of a lack of consistent UK-level data for the intertidal area, especially for seabed substrata. The predictive seabed habitat map and associated confidence map were clipped to the British Mean Low Water (MLW) boundary using a JNCC modified version of the OS Boundary-Line[15] product and the UK continental shelf boundary. The OS boundary-Line is based on administrative boundaries which are generally based on the MLW. Some small anomalies, e.g. where boundaries extend to islands were removed.

The marine boundaries between Northern Ireland and the Republic of Ireland are not formally defined in territorial waters (within 12nm of the coast). The maps presented here incorporate both Lough Foyle and Carlingford Lough as they are jointly managed by Northern Ireland and the Republic of Ireland for the Water Framework Directive under the NS Share project[16]. The maps also cover the waters of the Isle of Man, because this area was covered by the physical data and therefore did not incur an additional cost for modelling. The maps therefore cover some areas beyond the jurisdiction of the UK Governments. The area of the maps will be referred to as the project area. Any area calculations will be for the UKSeaMap 2010 project area.

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[15] Boundary-Line is a vector digital mapping product that is a complete set of local government administrative boundaries and electoral boundaries used in local and general election voting. It has been specifically designed to show the area of each administrative or electoral boundary. The administrative boundaries are usually defined by the MLW boundary. Modification had to be made in some areas which contained anomalies.

[16] North South Shared Aquatic resource (NS Share) project: http://www.nsshare.com/

3 Detailed methodology

Recognising the benefits of seabed habitat maps for identifying MPAs and for marine spatial planning, a range of organisations[17] contracted a consortium led by ABP Marine Environmental Research Ltd[18] to access physical and biological data layers to assist MPA identification and spatial planning[19]*.* This included delivery of improved input data layers for modelling and assessing the confidence of seabed habitats*.* The UKSeaMap 2010 team worked closely with ABPmer to develop the layers needed for habitat modelling (Frost et al 2010; Frost & Swift 2010; West *et al* 2010).

The input data layers used by UKSeaMap 2010 are:

- biological zones which reflect the changes in biological communities due to corresponding changes in light, energy and depth;
- seabed substrate which reflect changes in sediment type associated with changes in biological communities;
- energy conditions at the seabed which incorporates information on both wave and tidal current energy; and
- biogeography which uses depth boundaries to divide the project area into Atlantic and Arctic zones.

These data layers are divided into classes which are equivalent to the EUNIS Level 3 (or Level 4 in some cases) seabed habitat types*.* Division is made by using specific thresholds which are defined either from literature and expert judgement or through testing against field data.

3.1 Seabed substrata

Seabed community types are strongly influenced by the physical nature of the seabed substratum, and as such a map of seabed substrata is an essential component of the UKSeaMap 2010 model*.* The original UKSeaMap project and the MESH project used the following simplified classification, which corresponds to broad substratum types used in seabed habitat classifications (Figure 5) (Davies *et al* 2004; Connor *et al* 2004):

- Rock;
- coarse sediment;
- mixed sediment;
- sand and muddy sand;
- mud and sandy mud.

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[17] Department for Environment, Food and Rural Affairs, Joint Nature Conservation Committee, Countryside Council for Wales, Natural England, Scottish Government, Department of Environment Northern Ireland and Isle of Man Government.

[18] Other members of the consortium were POL (now NOC), MarLIN, Bangor University, Cefas and EMU Limited.

[19] Defra biophysical data layers contract MB0102: Accessing and developing the required biophysical datasets and datalayers for Maine Protected Areas network planning and wider marine spatial planning purposes: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=16368. Tasks to improve modelled input layers and confidence were Task 1C and 2E.

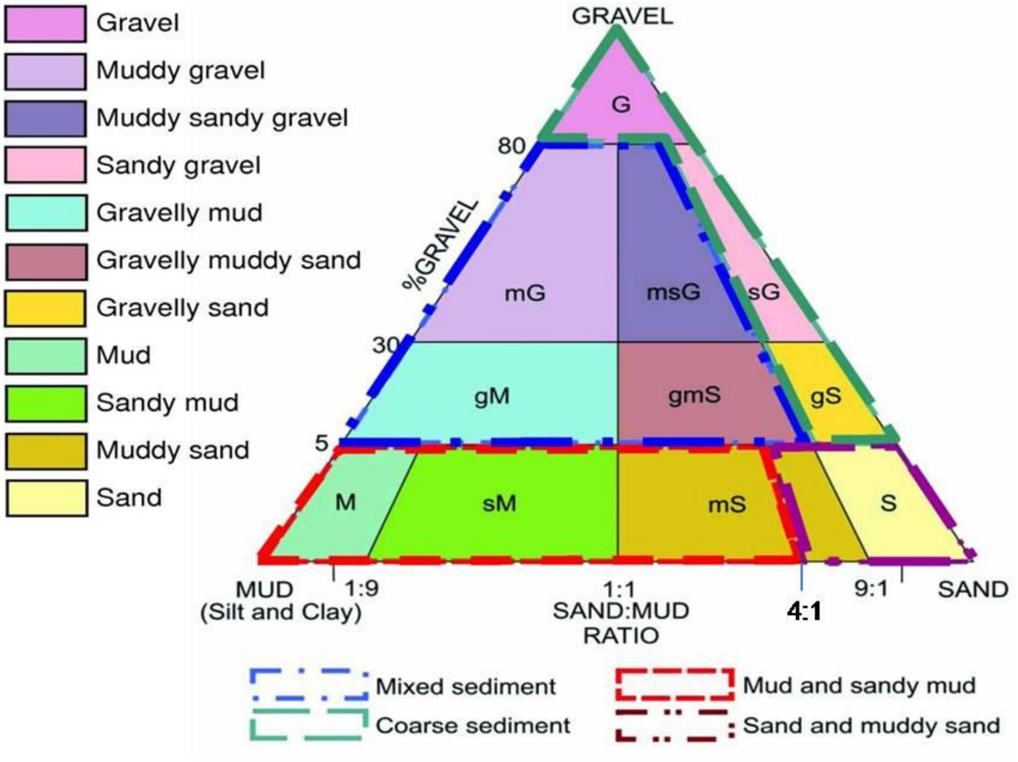

Figure 5. BGS modified Folk sediment trigon, modified to show the aggregation of classes into four main sediment classes (coarse, mixed, sand and muddy sand, mud and sandy mud) for UKSeaMap 2006 (Connor *et al* 2006).

The ecological relevance of the four sediment classes above, and the definition of the boundaries between them, were investigated using habitat data from Marine Recorder, particle size data and sediment descriptions to better describe the relationship between the habitat types and the sediment (for further detail see Technical Report No. 3). This investigation highlighted issues with the both the data in Marine Recorder and the sediment descriptions in the seabed habitat classifications. Where particle size data are available for a sample, they often do not correspond to the sediment descriptions associated with the habitat type assigned to the same sample. Assigning habitat types to samples should take account of physical conditions such as sediment type, but in many cases priority is given to the species composition and the habitat type is assigned solely on the basis of species present. Furthermore, many biotopes were found to occur over a wider range of sediment types than expected. On the basis of these investigations, it was decided that there was at present insufficient evidence to justify further subdividing the current four classes of sediment or to justify changing the current boundaries of the classes.

Four datasets were used in the construction of the UKSeaMap 2010 substrate layer (see Technical Report No. 3 for full details). BGS were contracted to produce a map of seabed substrata for the project area from these datasets: DigSBS250; the hard substrata layer (Gafeira *et al* 2010); the Water Framework Directive (WFD) typology layer (Rogers *et al* 2003); and the NOC deep sea sediment layer (Jacobs and Porritt 2009). Minor gaps between the substrate layer and the mean low water mark were subsequently filled using data from MNCR surveys. Figure 6 shows the final seabed substrata map.

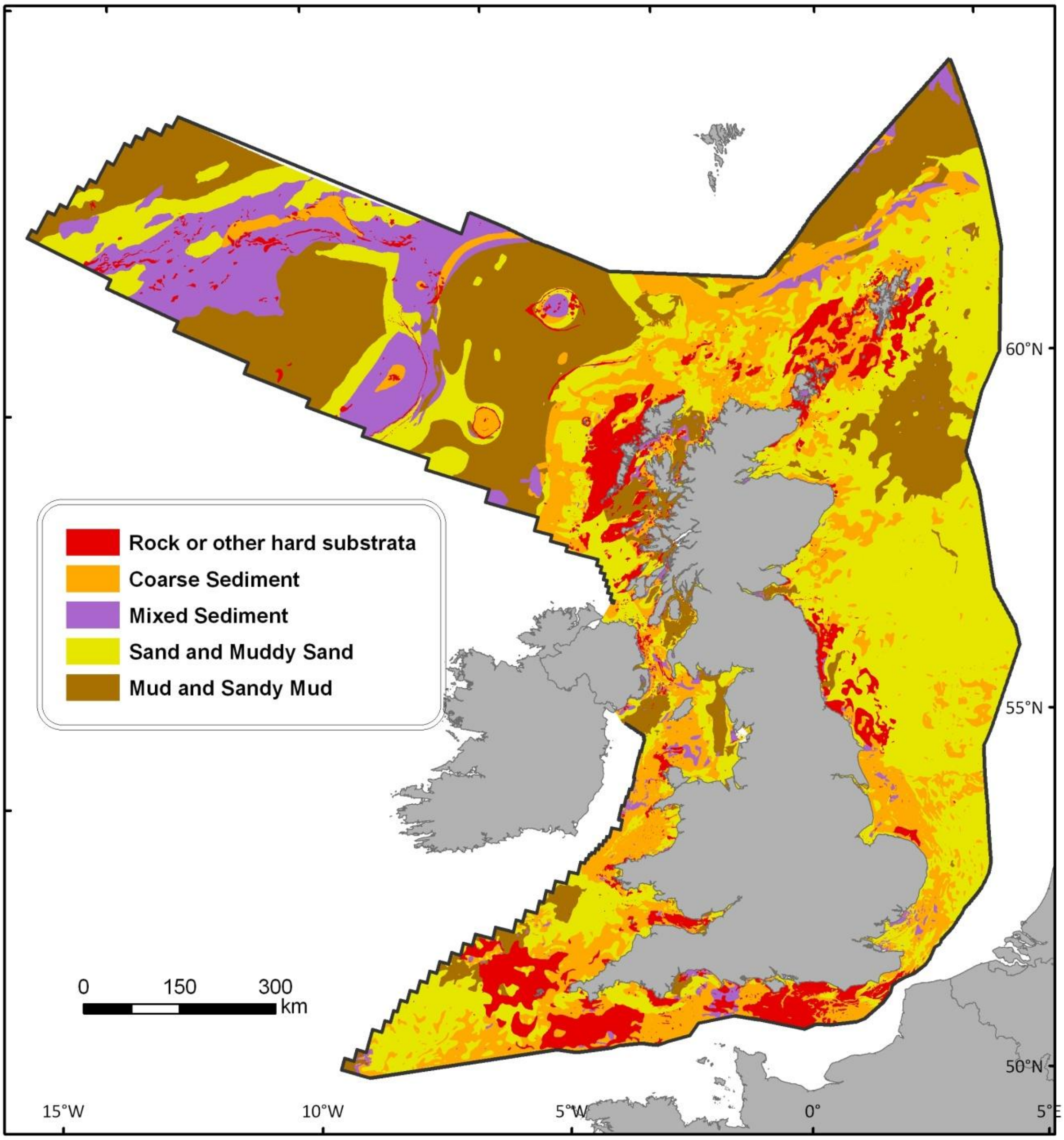

Figure 6. UKSeaMap 2010 seabed substrata, as produced by BGS (Cooper *et al* 2010) and modified by JNCC to include MNCR data.

3.1.1 Confidence in seabed substrata

Confidence was assessed by applying a modified version of the MESH confidence assessment tool for habitats[20] to the UKSeaMap 2010 seabed substrate layer in a contract undertaken by BGS (Cooper *et al* 2010). It is important to note that this tool assess the quality of the data and interpretation methods used to make the seabed substrate map, not the likelihood that a particular substrate occurs in a particular location. The latter would require a far more extensive dataset of seabed samples than is currently available, in order allow a sufficient number of samples which would not be included in the interpretation but which could be used to test the interpretation.

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[20] http://www.searchMESH.net/confidence

The seabed substrate map was first divided into 12 areas in which the same data quality and interpretation methods had been used. The confidence assessment was carried out for each of these 12 areas by scoring factors according to internationally agreed criteria. The factors address three questions:

- How good is the remote sensing?
- How good is the ground-truthing?
- How good is the interpretation of the overall map?

Areas of the map were scored 0 to 3 for each factor (Table 5), from which group scores were calculated and an overall score as an average of the three group scores. For further detail see Technical Report No. 3.

Modifications from the MESH confidence assessment tool to the assessment applied here were as follows:

- The factor Biological Ground-truthing Technique was removed from the assessment because no areas of the seabed substrate map include biological ground-truthing.
- The factor Physical Ground-truthing Sample Density has been modified to include elements of both sample density and sample variability. A sample density map was produced by BGS based on samples which had particle size data or sample descriptions. Sample variability was based on the number of different substrate classes found within a 10km^2 area around the sample. This is used to assign higher confidence to areas where sample density and variability are low, compared to areas where sample density is low and variability is high.

The final map showing confidence for the seabed substrate map is shown in Figure 7.

Table 5. Factors used to assess confidence in the UKSeaMap 2010 seabed substrate layer.

Questions	Factor	Scores	Final value
How good is the remote sensing?	Remote Techniques Remote Coverage Remote Positioning Remote Standards Applied Remote Vintage	Remote score	Overall score
How good is the ground-truthing?	Physical Ground-truthing Technique Ground-truthing Position Ground-truthing Sample Density Ground-truthing Standards Applied Ground-truthing Vintage	Ground-truthing score	
How good is the interpretation of the overall map?	Ground-truthing Interpretation Remote Interpretation Detail Level Map Accuracy	Interpretation score	

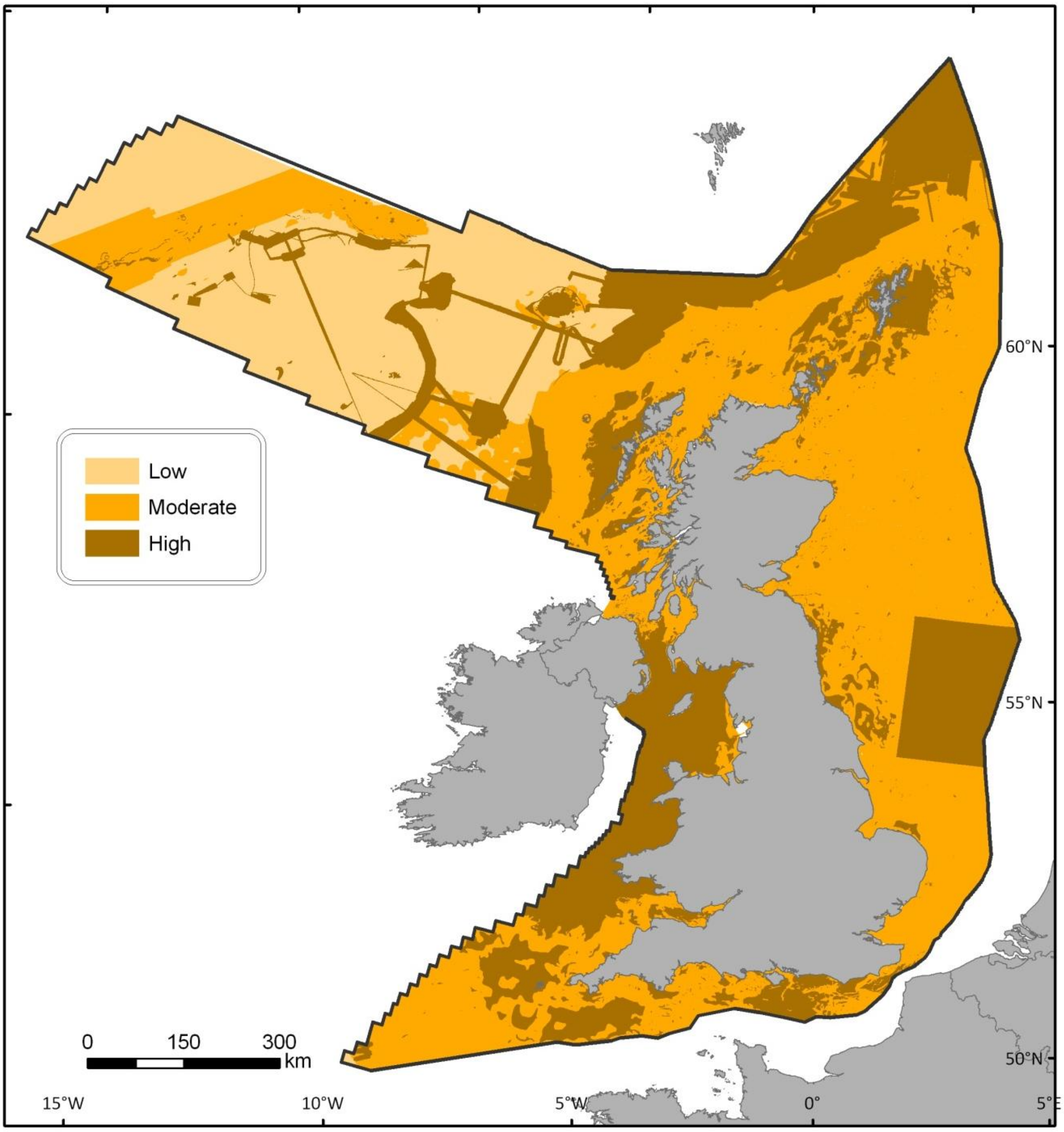

Figure 7. Confidence in seabed substrata - an assessment of the quality of the data.

3.1.2 Recommendations: seabed substrata

In future, with additional co-located substratum information and data describing the biological communities, further investigations of the four broad sediment classes used in seabed habitat classifications should be made.

3.2 Energy regimes at the seabed

Energy exerted on the seabed can be characterised in a variety of ways that account for effects of waves or tidal currents, or their combined effects. For example, waves can be characterised by their height, period, or orbital velocity of water particles that varies with depth. Currents can be characterised by measures such as tidal current magnitude or kinetic energy over a tidal cycle. One variable common in ocean modelling to capture the effects of both waves and tides and also their combined effect on the seabed is bed shear stress. Bed shear stress is a measure of the force exerted by waves and/or currents on sediments by the water movement over the seabed. Bed shear stresses are functions of several wave and current variables, and in addition to sediment information (grain size), fluid dynamic effects, need to be taken into account, such as the creation of near-bed boundary layers. These measures of energy are important factors that determine the stability of the seabed and hence determine its suitability for different communities (Boyd 2002).

Energy regimes resulting from wave action and tidal currents can have similar effects on biological community character. Their relative importance varies significantly from one place to another, being quite different in a macrotidal[21] system such as the Channel compared to wind-dominated areas such as the Western Isles in Scotland. In coastal areas, the two variables typically work together; their separate effects are often difficult to distinguish in the field. For simplicity the EUNIS classification scheme combines them into a single measure of energy. Energy levels are applied only to rocky habitats in the EUNIS classification; because sediment types typically reflect the hydrodynamic regime of an area of sediment (i.e. high associated with coarse sediments, low energy with fine sediments). The influence of waves is greatest on the shore and in the infralittoral zone. In the circalittoral zone tidal currents have a more marked influence. With increasing depth, movement of particles in the water column caused by waves decrease; the depth below which waves have a negligible influence is known as the wave base. Hence below the wave base currents have the only effect.

A method developed by Soulsby (1997) combines wave and current variables to produce bed shear stress[22] values. However, this method was developed for sediments rather than for rock. Since different energy levels are applied only to rocky habitats in the EUNIS classification, UKSeaMap 2010 used peak seabed kinetic energy which measures energy at the seabed without the need for sediment information, and can be applied to both sediment and rock.

3.2.1 Wave energy at the seabed

Wave action affects seabed communities in coastal areas, with variations due to the aspect of the coast (with respect to prevailing winds), the fetch (distance to nearest land), degree of open water offshore and depth of water adjacent to the coast (Hiscock 1996). This can manifest itself either by influencing the type of sediment available (coarse sediments on exposed coasts and fine sediments on sheltered coasts), or by directly affecting epifaunal communities, especially on rocky habitats. Its effects vary both horizontally (along shore from exposed coasts to sheltered inlets) and vertically (dissipating with increased depth). Marked differences in community types result from different wave exposures along rocky coasts. Exposed shores are usually animal-dominated (mussels and barnacles), whilst sheltered shores are algal-dominated (fucoids). Such differences can occur over only tens of metres at certain sites, such as opposite sides of a headland. In the subtidal a similar pattern is exhibited, but is masked by the increasing tidal current influence with increasing depth.

Wave models provide the solution to the need for full-coverage information describing wave parameters. Wave energy layers were built on data from NOC's ProWAM wave model (12.5km resolution) and DHI's MIKE21 spectral wave model[23] (100 - 300m resolution) (West *et al* 2010). The ProWAM wave model results were filtered to remove swell waves (using

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[21] In macrotidal areas the difference between mean high water springs and mean low water springs is between 4m and 6m.

[22] Bed-shear stress is a measure of the force exerted on the substrate by water movement over the seabed.

[23] http://www.mikebydhi.com/upload/dhisoftwarearchive/shortdescriptions/marine/SpectralWaveModuleMIKE21SW.pdf

wave steepness values) leaving only wind-wave results. Swell waves tend to have longer wave periods but shorter wave heights so they disturb the seabed less than wind waves. Data from the ProWAM wave model (Monbaliu *et al* 2000) covered the five year period from 2000 - 2004 and were based on 1-in-5 year peak values (those associated with peak significant wave heights[24] from the model). The higher resolution MIKE21 wave model was used for areas within 6km of the coastline, because this was found to be the approximate distance from the coast at which an approaching wave begins to have an effect on the seabed. Mean High Water Springs (MHWS) defined its inshore boundary. Deep sea areas not covered by either model were assumed to be areas where waves no longer had an effect on the seabed due to the depths involved. These areas were assigned constant zero values based on the premise that they were too deep to be affected by waves (Frost & Swift 2010; West *et al* 2010). Further details can be found in the UKSeaMap Technical Report No.4.

Data from Marine Recorder (wave exposure, habitat and species data) were used to identify numeric boundaries (thresholds) in the seabed kinetic wave energy layer which were equivalent to the energy classes used in the EUNIS habitat classification. EUNIS splits infralittoral and circalittoral rock into three energy classes: high, moderate and low. In order to limit the analysis to those samples found only in areas affected by waves, habitat points from the infralittoral and circalittoral zones only were used.

The 11,698 habitat samples were aggregated to their parent class of low, moderate or high energy, based on the EUNIS hierarchy. After joining these habitat samples to the seabed kinetic wave energy layer, boundaries between classes were selected as the midpoint between the 95% confidence intervals for adjacent classes (Table 6) and these classes applied to the seabed kinetic wave energy layer. Classes were verified using 47,152 site-level recordings wave exposure from coastal locations, extracted from Marine Recorder. High and low energy classes were a better match to the wave exposure data (62% and 79% respectively) than the moderate energy class (49%). These are termed 'performance ratings'.

Table 6. Kinetic wave energy classes

Wave energy	Kinetic energy (Nm^{-2})
High	> 1.2
Moderate	0.21 - 1.2
Low	< 0.21

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[24] Significant wave height is defined by NOAA's national weather service webpage (http://www.weather.gov/glossary/index.php?letter=w) as the average height (trough to crest) of the one-third highest waves valid for the indicated 6 hour period.

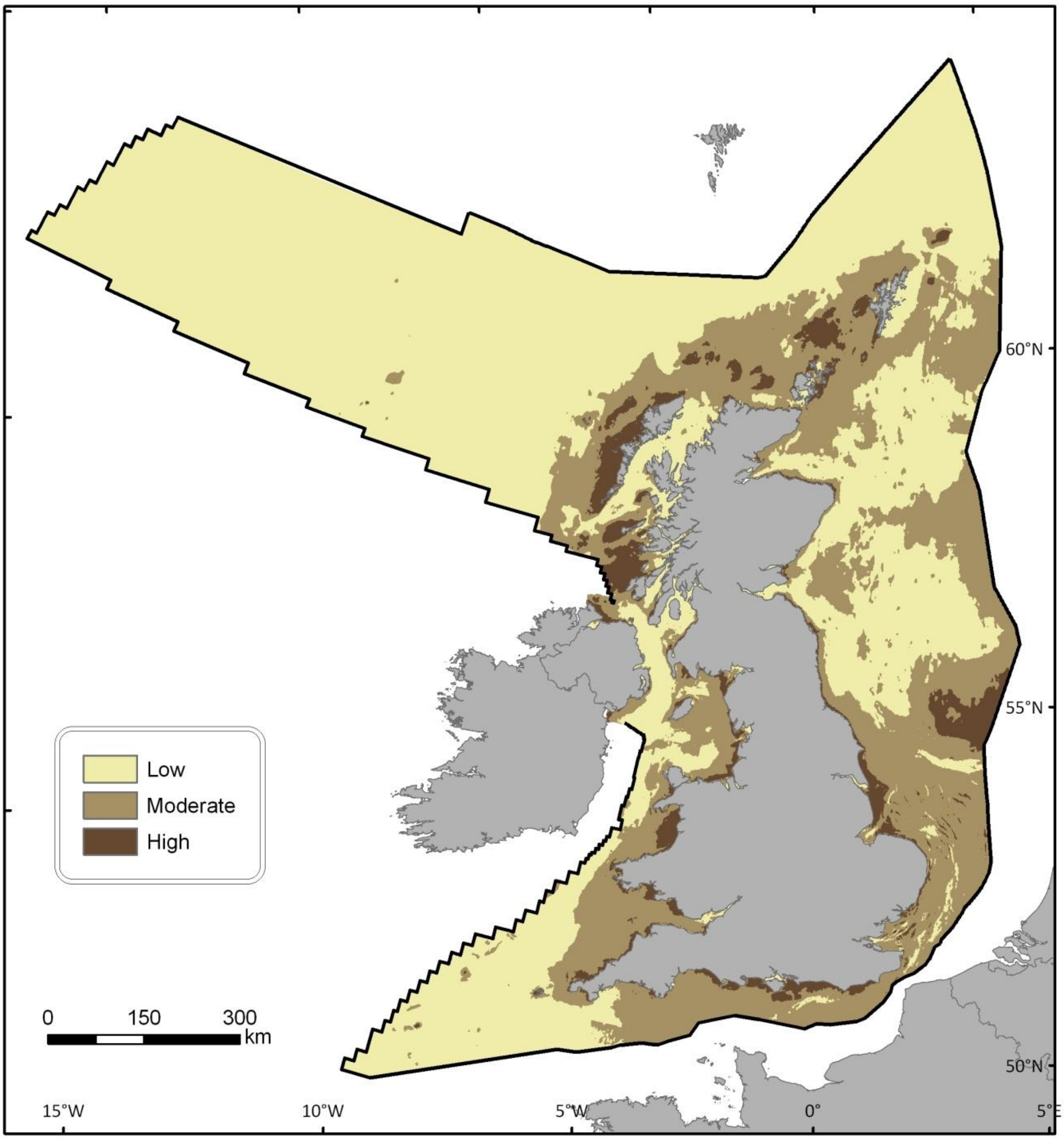

Figure 8. Classified map of peak seabed kinetic energy due to waves.

Uncertainty in the three wave energy classes has three components: uncertainty in the bathymetry data used in the wave model (which is described in section 3.4.1); uncertainty in the wave model outputs; and uncertainty in the position of the class boundaries.

Uncertainty in the wave model used to predict wavelengths was evaluated by comparing time series of wave periods predicted by the ProWAM wave model against quality assured field data from wave buoys reported by Cefas. The Cefas Wavenet datasets consisted of 47 stations with data falling within the temporal window offered by the ProWAM wave model run. Uncertainty in the position of the class boundaries was derived from the performance ratings described above. West *et al* 2010 used these three components to make probability layers for each grid cell. The energy class selected for Figure 8 was that associated with the highest probability in each grid cell. These highest probabilities are shown in Figure 9.

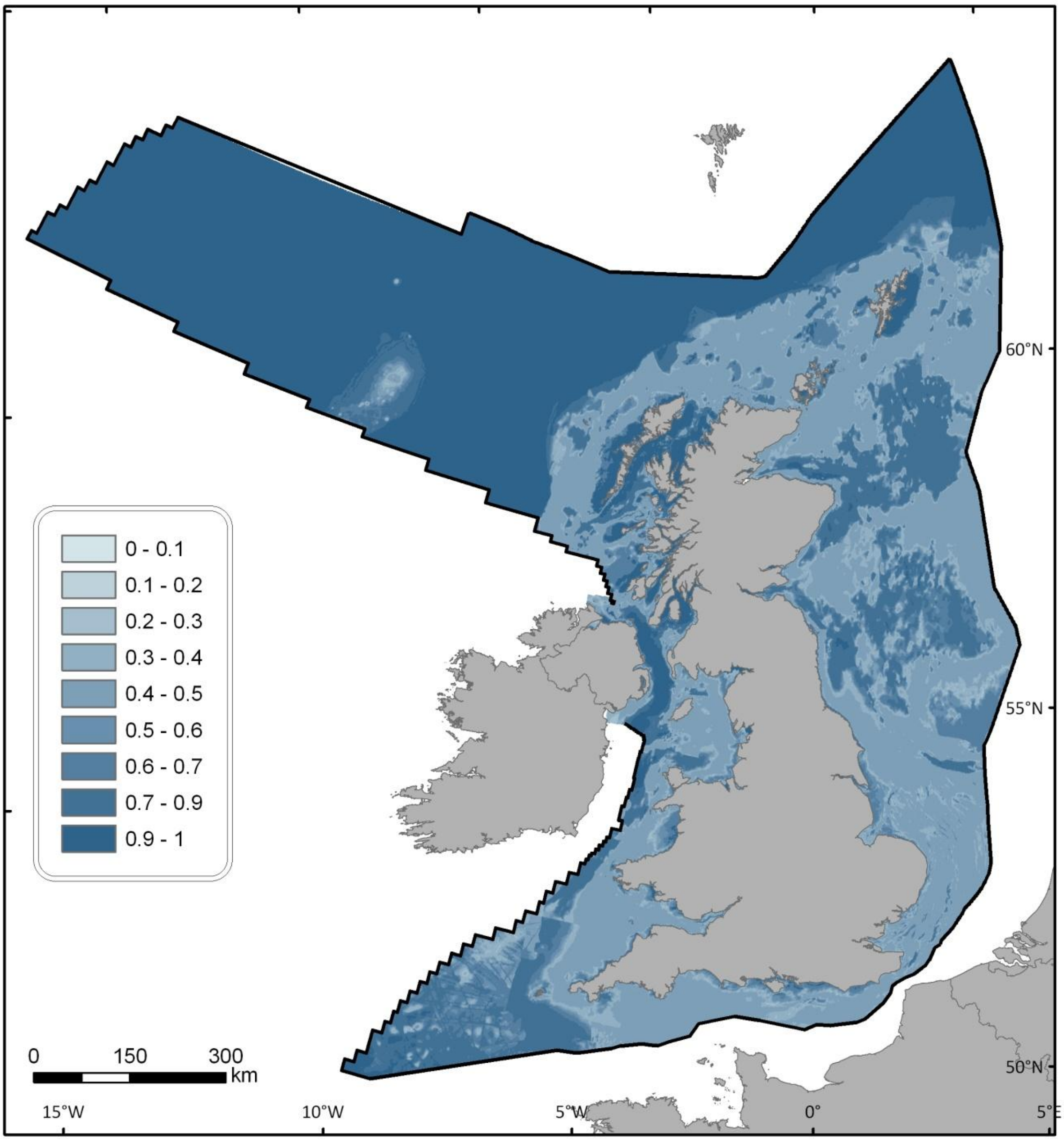

Figure 9. Peak seabed kinetic wave energy confidence - the highest probability associated with an energy class for each cell.

3.2.2 Current energy at the seabed

Strong offshore currents affect many coasts and have a particularly marked influence on communities below the infralittoral zone, with lessening effects in shallow water and on the shore, where the influence of wave action dominates. However, constricted sections of some inlets, particularly the narrows in sealochs, can have very strong currents which affect both the shallow subtidal and the lower shore zones, significantly increasing species richness. In estuaries and sealochs strong currents can lead to coarser sediments than would normally be expected in sheltered areas.

Tidal energy layers were derived from NOC's current models at various resolutions: the High Resolution Continental Shelf model (CS20; 1.8km), the Fine Resolution Continental Shelf model (CS3; 10km) and North East Atlantic model (NEA; 35km)[25]. In areas of overlap, the highest resolution available model was used. Tidal current speeds from all three tidal models were used in the creation of the current energy layers (Technical Report No.4).

Hiscock (1996) divides tidal streams into five categories: very strong, strong, moderately strong, weak and very weak. The category values were converted from tidal current speed (ms^{-1}) to peak seabed kinetic tidal current energy (Nm^{-2}). To equate these tidal stream categories with the three energy categories in the EUNIS classification, very strong and strong tidal streams were combined into the high energy category and weak and very weak tidal streams were combined to represent low energy environments. There were very few areas in the map showing very strong tidal streams, the most obvious being the Pentland Firth, and thus this category was combined with strong tidal streams. Very weak tidal streams were combined with the weak tidal stream category to make a low energy class. Hence the boundary selected between moderate and low kinetic current energy is 0.13 Nm^{-2}, and 1.16 Nm^{-2} between moderate and high kinetic current energy.

Table 7. MNCR tidal stream categories.

Surface Tidal Streams	Speed (Knots)	Speed (ms^{-1})	Kinetic Energy (Nm^{-2})	EUNIS energy category
Very strong	>6	>3	> 4.5	High
Strong	3 - 6	1.5 - 3	1.16 - 4.5	High
Moderately strong	1 - 3	0.5 - 1.5	0.13 - 1.16	Moderate
Weak	< 1	< 0.5	<0.13	Low
Very weak	Negligible	Negligible	Negligible	Low

The ideal method for calculating uncertainties in peak seabed current energy would compare peak predicted values (model outputs) and peak observed values for current speeds. Observed values were not available within the timescales required by this project. Instead, values from Holt *et al* (2005) were used. Holt *et al* (2005) compared POLCOMS outputs with observed data to produce mean error values from which West *et al* (2010) derived means the probability distribution for tidal current speeds. This probability distribution was used to obtain the most likely seabed kinetic current energy class and its associate probability (Figure 10 and Figure 11 respectively).

Because the seabed kinetic current energy confidence layer was calculated using mean error values derived from comparisons between the NOC tidal models and field data (Holt 2005) it is likely to over-estimate confidence in the kinetic current energy layer. In future, the creation of the confidence layer would be improved if simultaneous field data recording current speeds could be obtained for direct comparison to the tidal model outputs (West *et al* 2010).

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[25] The data produced by the tidal models are from the same model run (11) as the data used in the Atlas of UK Marine Renewable Energy Sources (2007): http://www.renewables-atlas.info

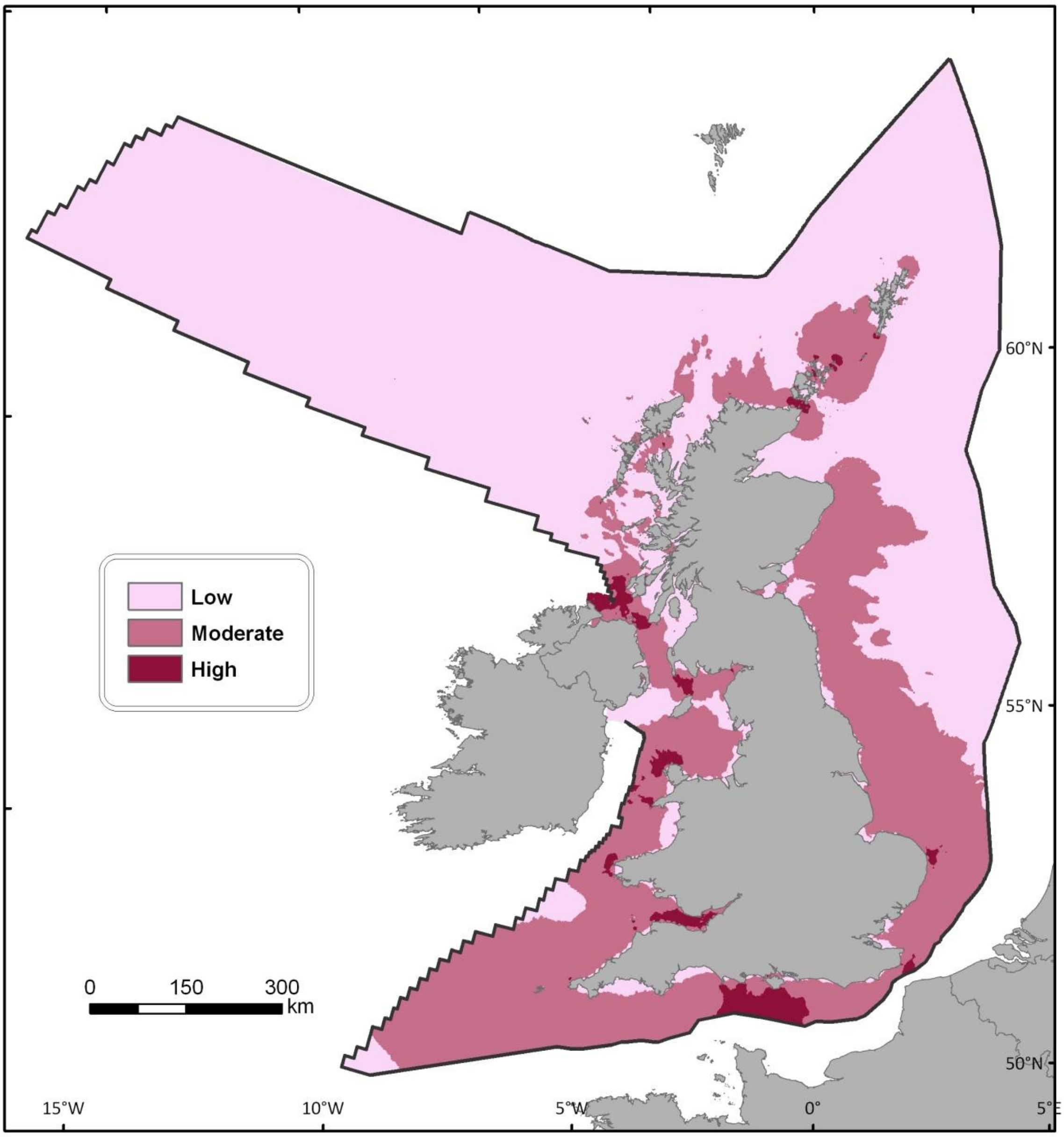

Figure 10. Classified map of peak seabed kinetic energy due to currents.

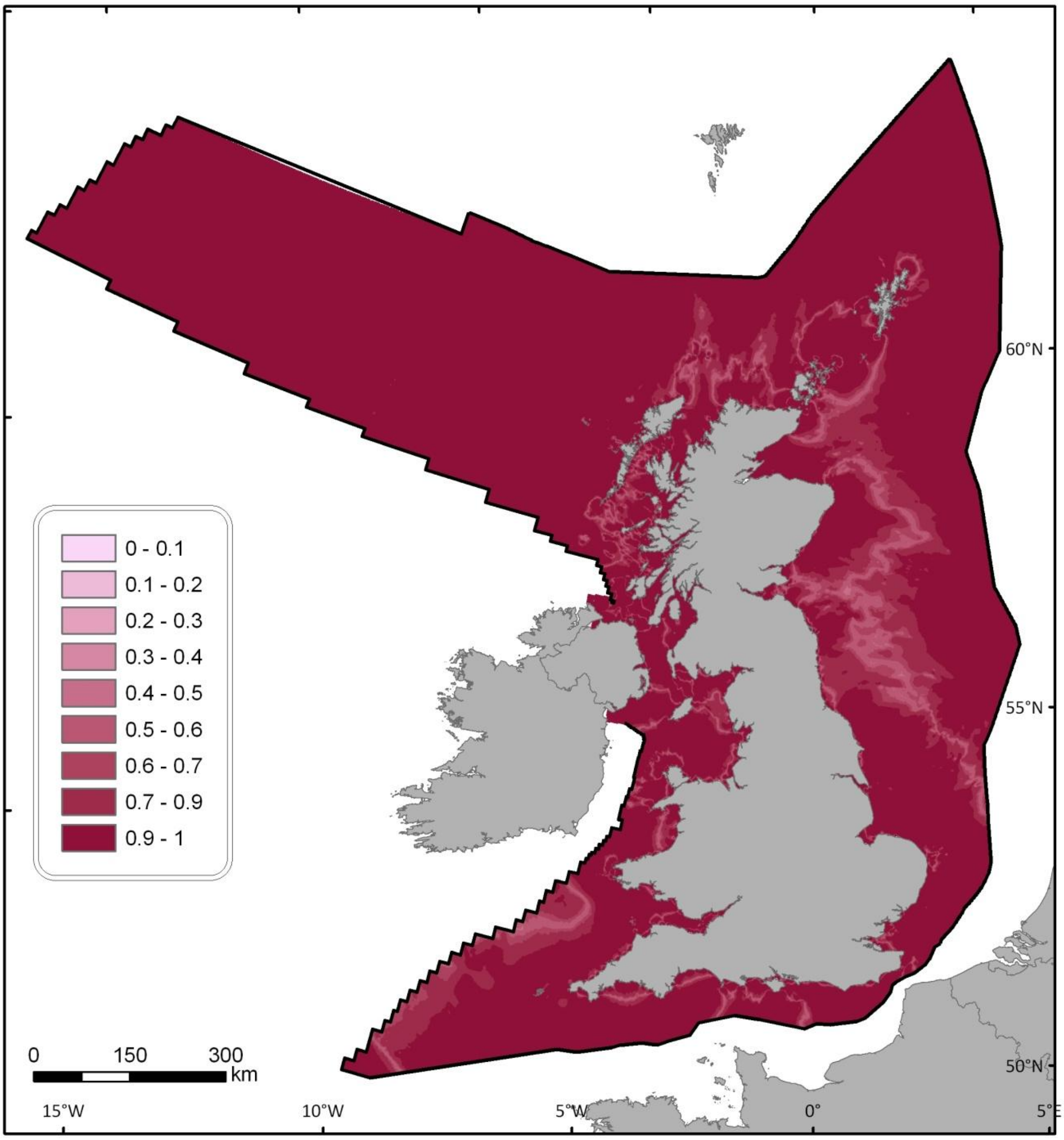

Figure 11. Peak seabed kinetic current energy confidence - the highest probability associated with an energy class for each cell.

3.2.3 Combined effects of waves and currents

There are established methods to numerically combine waves and currents (Soulsby, 1997). However, using UKSeaMap data this method would result in a masking of the effects of currents because the numeric values for seabed kinetic energy caused by currents are lower than the values for seabed kinetic energy caused by waves - as evidenced by the thresholds selected here and the resulting maps. Instead, the approach taken here was first to classify wave and current energy into ecologically meaningful classes, then to combine the classes. This reflects the way energy is handled in the EUNIS classification.

Wave and current energy classes were combined using a rules-based approach. The highest category for each grid cell was selected, e.g. a cell with high wave energy and moderate current energy was assigned to a high energy category; a cell with low wave energy and moderate current energy was assigned to a moderate energy category.

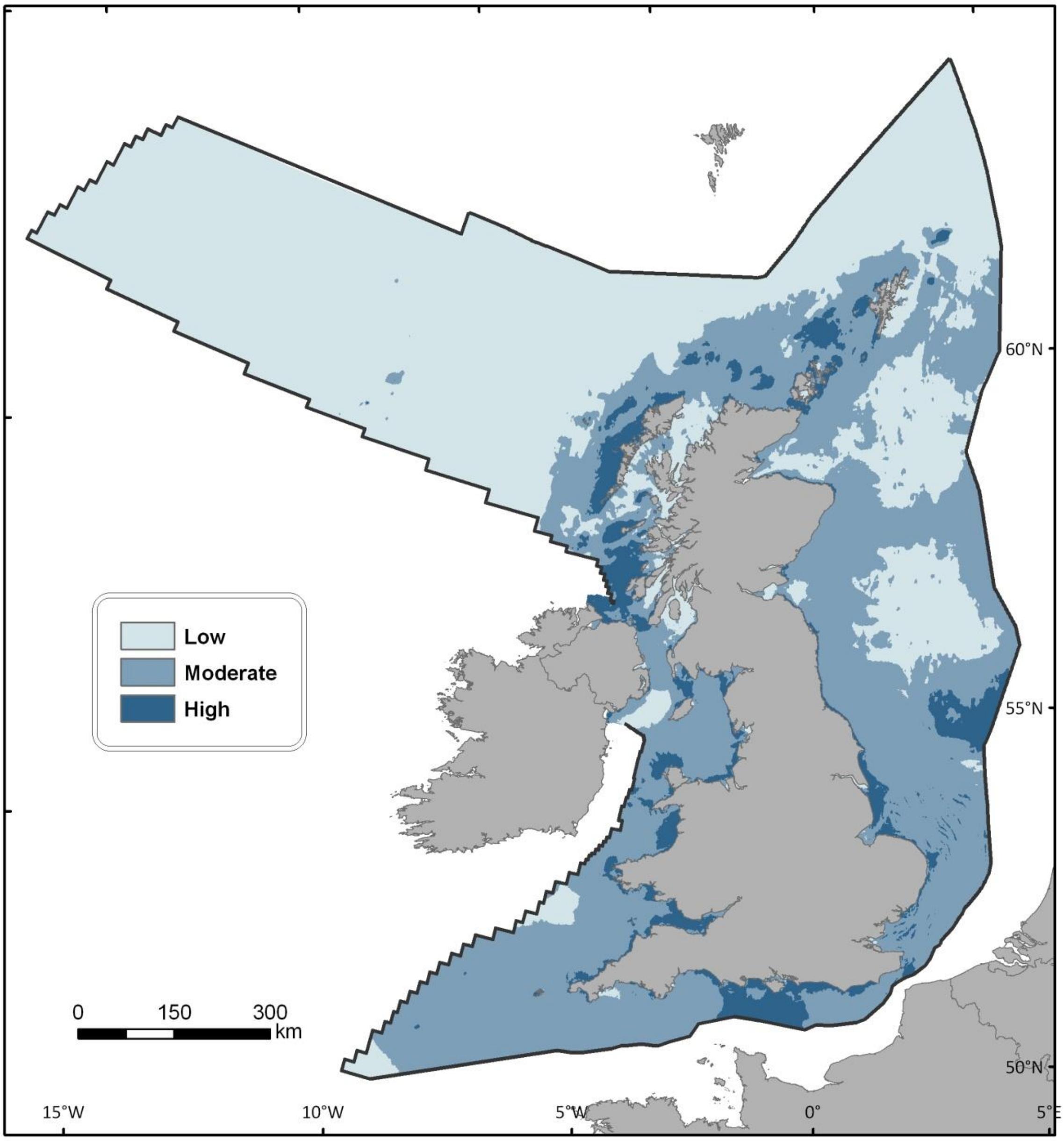

Figure 12. Classified map of combined peak seabed kinetic energy (due to both waves and currents).

3.2.4 Relationship between sediment types and seabed energy

In the EUNIS classification system, rock habitats are divided into groups of habitats which share similar levels of energy. Generally, it is assumed the grain-size of seabed sediments (i.e. whether they are sand/mud/gravel/pebbles) reflects the energy in the environment. For example, fine sediments are unlikely to occur in high energy environments because they are easily picked up and dispersed and therefore would be moved from high energy areas and to low energy areas. To investigate whether data layers available to UKSeaMap 2010 support this assumption, the relationship between sediment type and energy level were investigated (Figure 13).

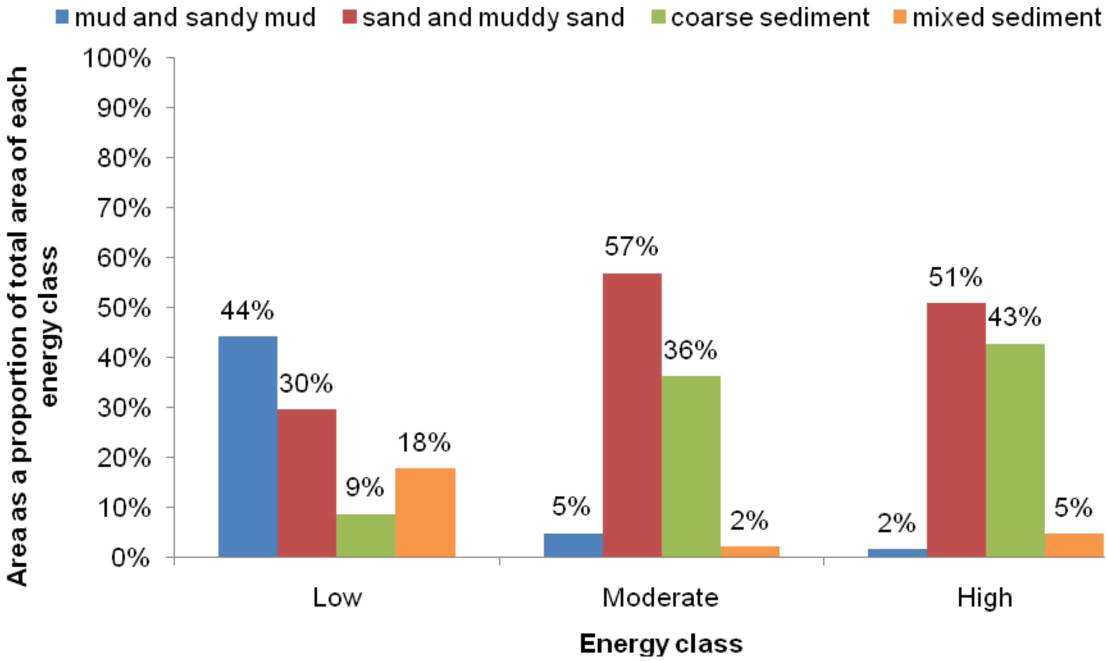

Figure 13. The areas of each sediment type falling in each energy classes.

Examining the pattern of relative abundances of mud and sandy mud, sand and muddy sand, coarse sediment and mixed sediment at each energy level shows roughly what is expected in low energy environments (Figure 13). In low energy environments, the sediment class with the smallest grain size (mud and sandy mud) dominates by area (44% compared to only 9% coarse sediments). A high proportion of the area of mixed sediments is also found in low energy environments (18% compared to 2% and 5% in moderate and high energy areas). This is expected since an area is only defined as mixed sediments if it includes mud as part of the mixture, which therefore restricts mixed sediments to areas where mud has not been moved away.

High energy environments are dominated by sand and muddy sand (51%) but closely followed by coarse sediment (43%). A similar pattern is seen in moderate energy environments, but with an increased difference between these two classes: sand and muddy sand (57%) and coarse sediment (36%).

These results indicate that within the data layers used for UKSeaMap 2010, sediment types well reflect the energy classes applied. The results support the structure of the seabed classification, where energy data are only applied to rocky habitats, with sediment types acting as a proxy for energy regimes. For a more detailed analysis of the relationship between substrate and energy see Technical Report No. 5.

3.2.5 Recommendations: energy at the seabed

The resolution of the energy model needs improving and further validation in places, e.g. in the Firth of Lorn for currents and in Shetland for waves. With only three classes in the EUNIS classification for energy, the overall pattern for kinetic energy is bound to be coarse and miss local variations.

The analysis undertaken by UKSeaMap 2010 has made the first estimates for numeric values of kinetic energy associated with the EUNIS classes of high, moderate and low energy. However, this analysis could be improved if co-located in-situ measurements of seabed habitat and kinetic energy were available. This would increase our understanding of the response of seabed habitats to waves and currents, both separately and in combination.

Recommendations have been made by West *et al* (2010) about how to improve the assessment of kinetic current energy confidence. The method used is likely to over-estimate confidence. Areas in the energy maps which it has been suggested are incorrect, e.g. the Firth of Lorn for currents and in Shetland for waves appear to have high confidence in the respective energy confidence maps. This is likely to be due to the fact that probabilities predict the certainty that cells are assigned to the right category rather than the fact the under-lying data are correct. In future updates of the both the energy layers and the confidence layers, these issues should be addressed. It is important to note that both energy confidence maps may therefore over-estimate the confidence in certain areas, particularly the current confidence map.

3.3 Salinity at the seabed

Salinity distinguishes brackish (stable lowered salinity) and estuarine (unstable variable salinity) conditions, from fully marine conditions. Brackish and estuarine conditions are confined to coastal areas in the project area. Slight reductions in salinity (below fully marine conditions at 35-33‰) lead to loss of some species, with this becoming increasingly marked below 30‰ in the highly variable salinity regimes of estuaries. A series of estuarine 'zones' are described in the literature (McLusky 1993) to reflect the highly variable and increasingly reduced salinity regimes of estuaries, with distinct communities occurring in particular salinity regimes.

Salinity data from the WFD Typology for transitional and coastal waters for UK and Ireland report (Rogers *et al* 2003) were used. The report classifies salinity into five categories: freshwater (<0.5‰), oligohaline (0.5 - < 5‰), mesohaline (5 - <18‰), polyhaline (18 - <30‰) and euhaline (30 - < 40‰). The boundary between the polyhaline and euhaline zones (30‰) was used to define the boundary between marine areas and areas of variable salinity. Areas of reduced salinity (e.g. lagoons) were also not included in the predictive model. Lagoons are included in the coastal physiographic features map.

3.4 Biological zones

The marked zonation of communities with increasing depth, from the top of the shore to the bottom of the deep sea, is one of the most important parameters for defining marine habitats. However, this zonation is not directly related to depth but to a range of linked factors, for example: the amount of wave energy experienced at the seabed dissipates with depth; the degree of thermal stability increases with depth; the proportion of surface light reaching the sea floor decreases with depth. UKSeaMap 2010 used eight biological zones to classify the seabed. The boundary between the infralittoral and circalittoral zone was defined by the minimum amount of light required for kelp growth and the boundary between the circalittoral and deep circalittoral zones was defined by the wave base (see section 3.4.3). Five new deep sea biological zones as recommended by Howell (2010) were incorporated into the model.

Table 8. Biological zones used in the construction of UKSeaMap 2010.

Biological zone	Upper limit	Lower limit
Infralittoral	Mean low water	1% light reaches the seabed
Circalittoral	1% light reaches the seabed	Wave base
Deep Circalittoral	Wave base	200m
Upper slope	200m	750m
Upper Bathyal	750m	1,100m
Mid bathyal	1,100m	1,800m
Lower bathyal	1,800m	2,700m
Abyssal	2,700m	

Classifying physical data layers into these biological zones has three elements, as shown in Steps 1 to 3 in Figure 3. Firstly, biological and physical in-situ data are used to determine thresholds. Secondly, uncertainty in the cell values is calculated (various methods used). Lastly, this uncertainty is applied to calculate the probability that a cell falls between the boundaries used to define the class.

3.4.1 Depth: a base layer

Bathymetry data from the SeaZone coastal 30m Digital Elevation Model (DEM) and from the GEBCO 30 minute grid (~0.76m) were used in UKSeaMap 2010 (Figure 14). Both datasets were gridded to the UKSeaMap 2010 cell size of 0.0025 decimal degrees (Frost & Swift 2010).

It is only for the deep sea zones that depth on its own is used to determine the boundaries between classes. Thresholds for which depth is only one factor (e.g. light penetration and wave disturbance) are discussed in those sections. In the current version of the EUNIS classification scheme (2007-11), the deep sea is a single biological zone, defined as areas deeper than 200m. Recent work has proposed division of the deep sea into five ecologically-relevant zones: upper slope, upper bathyal, mid bathyal, lower bathyal, and abyssal (Howell, 2010; values given in Table 8). Based on data collected around the UK and Ireland, Howell (2010) suggested depth as the best proxy for environmental conditions, such as temperature, pressure, oxygen and food supply, which determine variation in biological communities. These depth thresholds are not intended as absolute values which are applicable to all marine areas. Mapping the depth zone suggested by Howell (2010) gives a level of detail for the deep sea which is more comparable with that of the shelf.

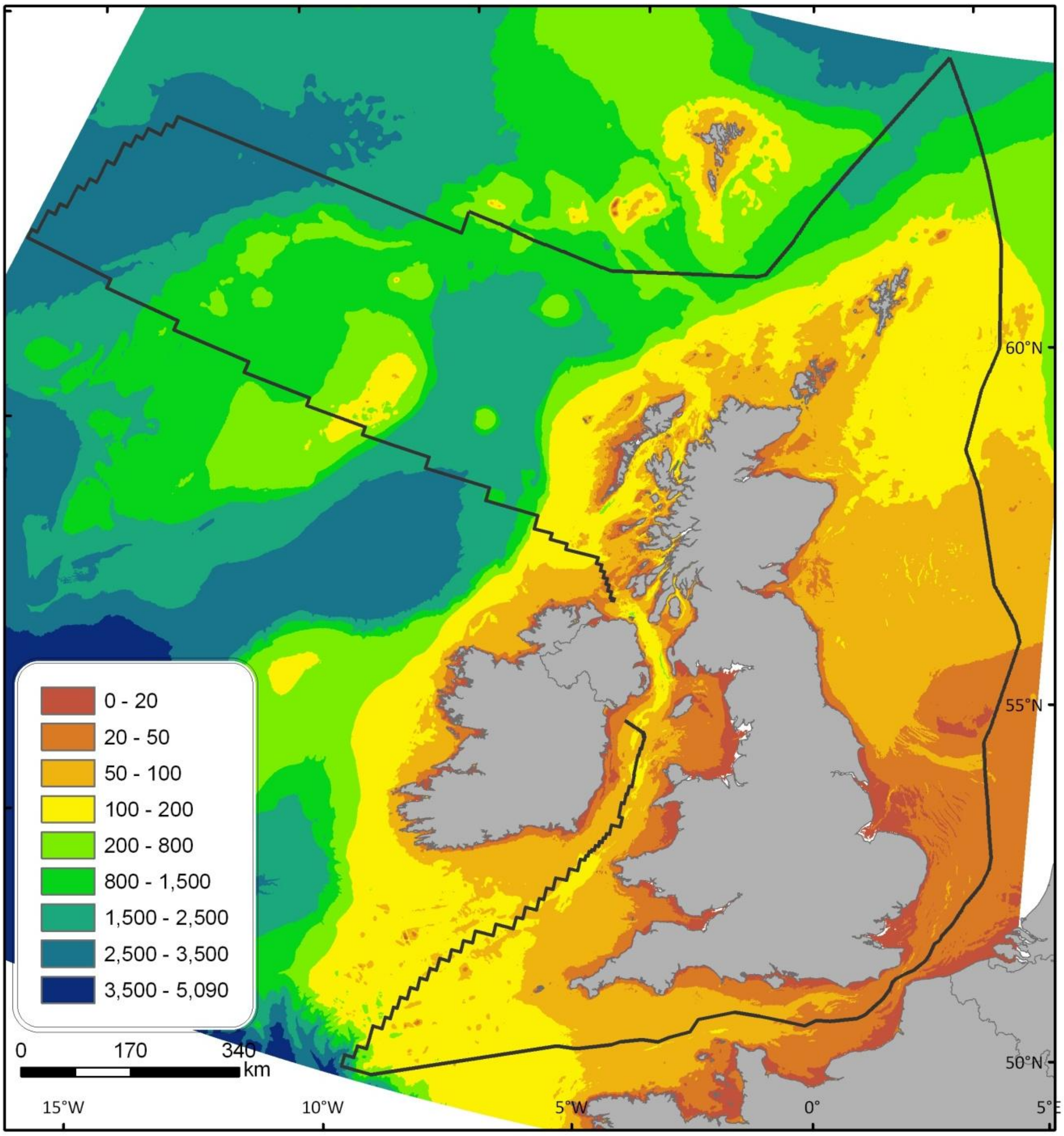

Figure 14. UKSeaMap 2010 bathymetry layer (m).

Two methods were used to describe uncertainty in the bathymetry layer, depending on whether the area was covered by SeaZone data, or by only GEBCO data (Frost & Swift 2010; West *et al* 2010). Variability of depth within the 300m model cells was used to describe uncertainty in the areas covered by SeaZone data, on the basis that the depth ‘measurement errors’ were negligible for the modern survey techniques that had been used to gather the data. For the GEBCO data, the uncertainty was attributed to ‘measurement errors’ and these were derived by obtaining standard deviations of differences between GEBCO and SeaZone, over the areas where the two products overlapped. These standard deviations were found to depend upon the recorded water depth and were used to assess the uncertainty in the GEBCO data in the areas covered by GEBCO alone. More details on the formation of the bathymetry layer can be found in Technical Report No. 1.

These measurements of standard deviation for each cell were used to calculate the probability that each cell falls in a particular deep sea zone. For example, for the deep sea zone of upper slope, depth boundaries have been identified at 200m depth for the shallow limit and 750m for the deep limit. The ‘upper slope probability’ is the probability that a cell falls into this deep sea zone, taking into account uncertainty around the depth value assigned to that cell. Probability maps were constructed for the upper slope, upper bathyal, mid bathyal, lower bathyal, and abyssal. Section 3.4.4 describes how these maps were used to make a map of all the biological zones.

3.4.2 Light reaching the seabed to define the infralittoral-circalittoral boundary

On Atlantic coasts of Europe the decrease in light levels with depth is typically reflected in four zones (Hiscock 1996). This zonation pattern occurs because different macrophyte and algal communities have differing minimum light requirements to photosynthesise and grow. The infralittoral zone is where favourable light conditions allow the growth of macroalgae such as kelp. Kelps are large brown seaweeds which are key structural species in rocky environments.

- Upper infralittoral: dense kelp (e.g. *Laminaria*);
- Lower infralittoral: sparse kelp, dense seaweeds;
- Upper circalittoral: sparse seaweeds;
- Deep circalittoral: encrusting algae only.

Below a certain fraction of surface light, kelp will struggle to grow and rocky areas become dominated by faunal communities rather than macroalgae. The threshold at which this occurs represents the transition from the infralittoral zone to the circalittoral zone. Light intensity decreases with depth due to the attenuating effects of scattering and absorption (by water molecules, suspended particulate matter, phytoplankton and coloured dissolved organic matter) in the water column. This attenuation tends to be higher in coastal waters, due to suspended and dissolved matter being washed down rivers, higher phytoplankton concentrations and suspension of sediment caused by wave action in shallow waters.

Satellite observations are effective for producing maps of light attenuation across very large areas at relatively high spatial resolution. Algorithms are used to derive the diffuse attenuation coefficient of the down-welling spectral irradiance at wavelength 490nm (Kd_{490}) from ocean colour satellite sensors such as the Medium Resolution Imaging Spectrometer instrument (MERIS), the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), and the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument. Most of these existing models have been calibrated on open ocean waters and provide good results in these areas, but tend to underestimate the attenuation of light in turbid coastal waters (Frost et al 2010). UKSeaMap 2010 used 4km resolution light data (Kd_{490} values) from the MODIS instrument on NASA’s Aqua satellite, together with the UKSeaMap 2010 bathymetry layer described in section 3.4.1 to calculate values for the fraction of surface light reaching the seabed.

To investigate the fraction of surface light reaching the seabed which corresponds to the infralittoral zone, the distribution of kelp habitats around the UK coast was examined. Data showing the spatial distribution of kelp habitats were extracted from Marine Recorder. These kelp habitat data were intersected with the data layer showing the fraction of light reaching the seabed, derived from the 4km resolution MODIS data. A first quartile value of 1% of incident light reaching the seabed was found where kelp habitats grow. This 1% threshold was used as the lower limit of the infralittoral zone. A similar analysis by the MESH project identified the same boundary at 2.36% (Coltman *et al* 2008). However, this work used 9km resolution data which may be responsible for the different result.

NASA publishes in-situ data[26] supporting the derivation of the equation used to obtain the value of K_{490} from the satellite measurements of the water-leaving radiances (490 and 555nm). These in-situ data allow the calculation of a probability distribution to accompany the values calculated from satellite measurements. In this case the probability function is not normally distributed. Consequently, to obtain the probability of light penetration in a given water depth, the difference between two normally-distributed random variables cannot be applied and therefore it was necessary to apply numerical integration to obtain the probability of light penetration to the seabed, that is the probability that the depth to which 1% of the surface light penetrates exceeds the water depth, i.e. the probability that a cell falls in the infralittoral zone. The water depth used here takes into account uncertainties as described in section 3.4.1. Therefore, Figure 15 shows the probability of a cell falling in the infralittoral zone, taking into account uncertainties in the bathymetry data and uncertainties in the light data.

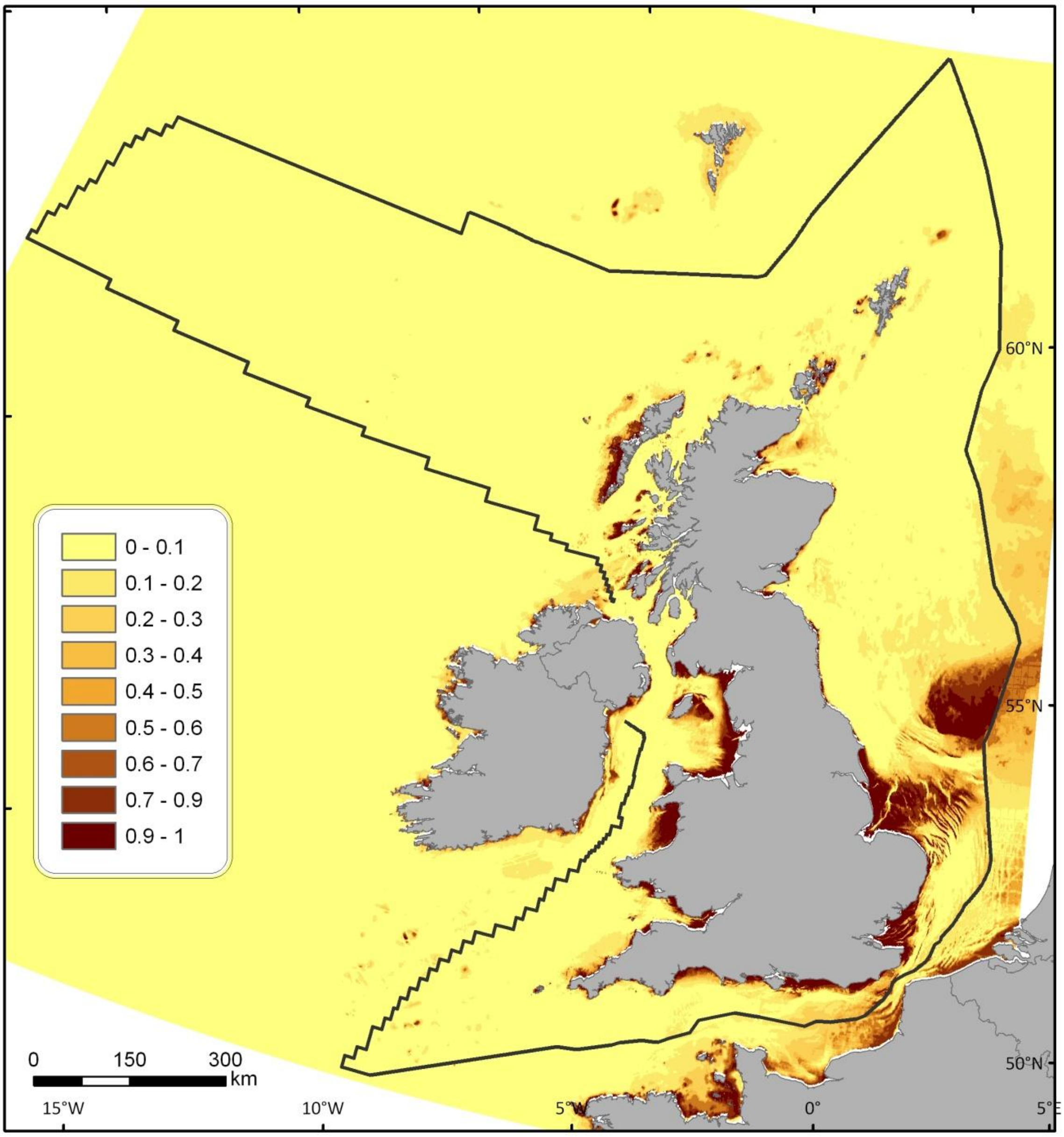

Figure 15. Probability that a cell falls in the infralittoral zone.

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[26] http://oceancolor.gsfc.nasa.gov/REPROCESSING/SeaWiFS/R5.1/k490_update.html

3.4.3 Wave disturbance to define the circalittoral-deep circalittoral boundary

The boundary between the wave-disturbed circalittoral and the undisturbed deep circalittoral is the wave base. Wave base is defined as the maximum depth to which the passage of a wave causes motion in the water column, equal to half the wavelength. Historically, wave base was used to define the Circalittoral and Circalittoral du large 'etages' of Glémarec (1973). It was not possible to further investigate this threshold using data from Marine Recorder because of the scarcity of habitat data at depths close to the intersection of the wave base and the seabed.

The modelled wave data used to determine wave base were the same as described in section 3.2.1. Uncertainty in the wave model used to predict wavelengths was evaluated by comparing time series of wave periods predicted by the ProWAM wave model against quality assured field data from wave buoys reported by Cefas. The Cefas Wavenet datasets consisted of 47 stations with data falling within the temporal window offered by the ProWAM wave model run. The output from this part of the study was a mean and standard deviation of differences between the ProWAM wave model predictions of wave period and Cefas field data. This information was subsequently used to derive the probability distribution of wavelengths, which in turn was applied in combination with the probability distribution of water depths, to obtain the probability that the seabed is disturbed by waves (Figure 16).

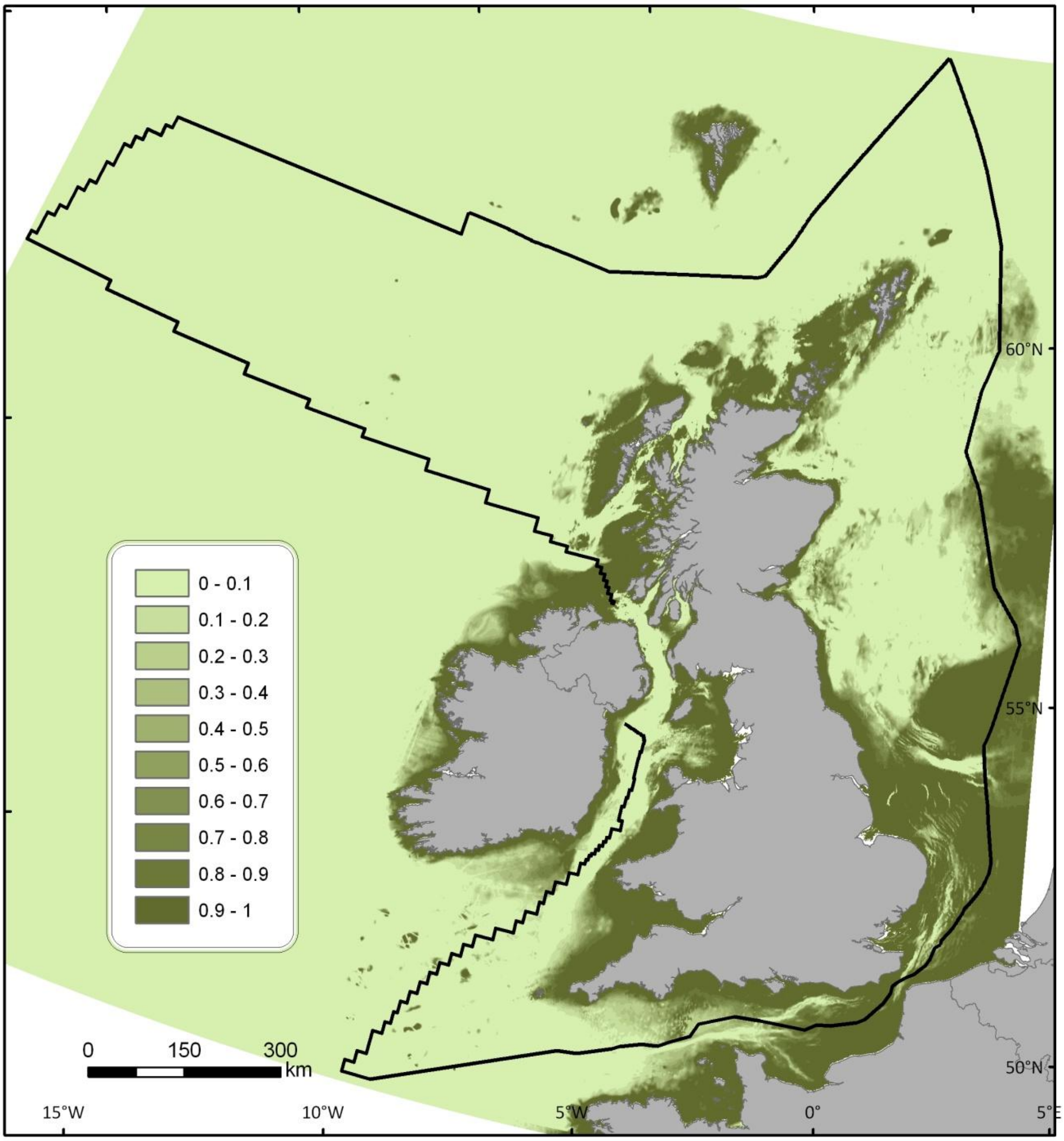

Figure 16. Probability that a cell falls in the wave disturbed zone (circalittoral or infralittoral).

3.4.4 Combining probability maps of each biological zone

Probability layers for every biological zone were combined to produce a biological zones layer for UKSeaMap (Figure 17, Figure 18). Biological zones were classified by identifying the probability layer with the highest score, e.g. if the infralittoral probability score for a cell was 0.9 and the circalittoral probability score was 0.6 and every other probability layer had a score of 0, the cell was classified as being in the infralittoral. The associated highest probability in each cell is shown in Figure 19.

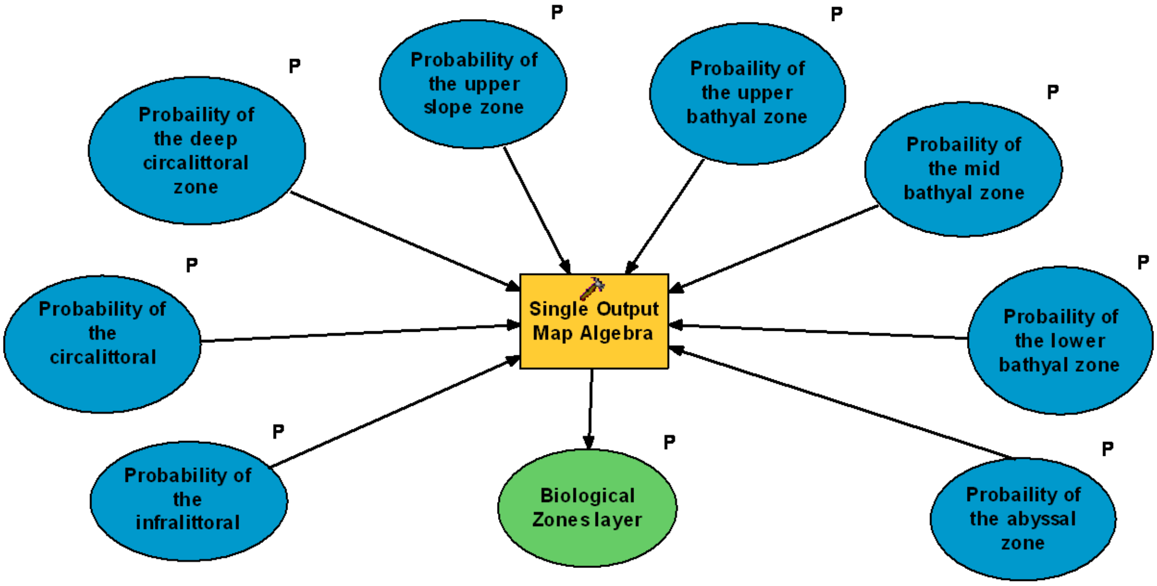

Figure 17. Model used to create a map of the UKSeaMap 2010 biological zones. For each cell in the area covered, the model function (central yellow box) selects the biological zone associated which has the highest probability, and returns that zone as the cell value in the output biological zones layer.

3.4.5 Recommendations: biological zones

Through the work completed by Howell (2010), five deep sea zones have been identified; upper slope, upper bathyal, mid bathyal, lower bathyal and abyssal. It is recommended that these new deep sea biological zones and coarse sediment be included in updates to the EUNIS classification system.

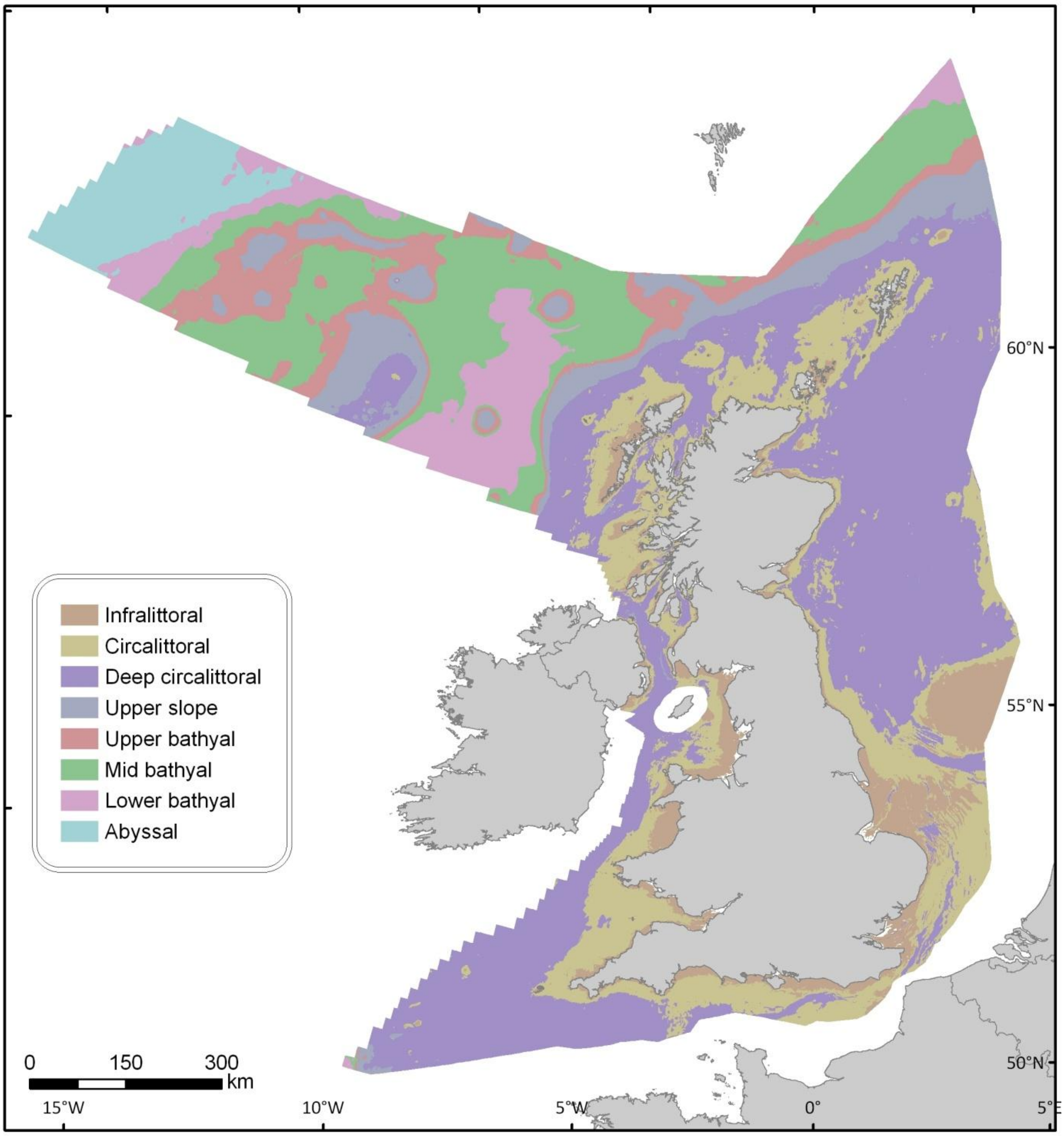

Figure 18. Biological zones map developed for UKSeaMap 2010 (see Table 8 for parameters used to define each zone).

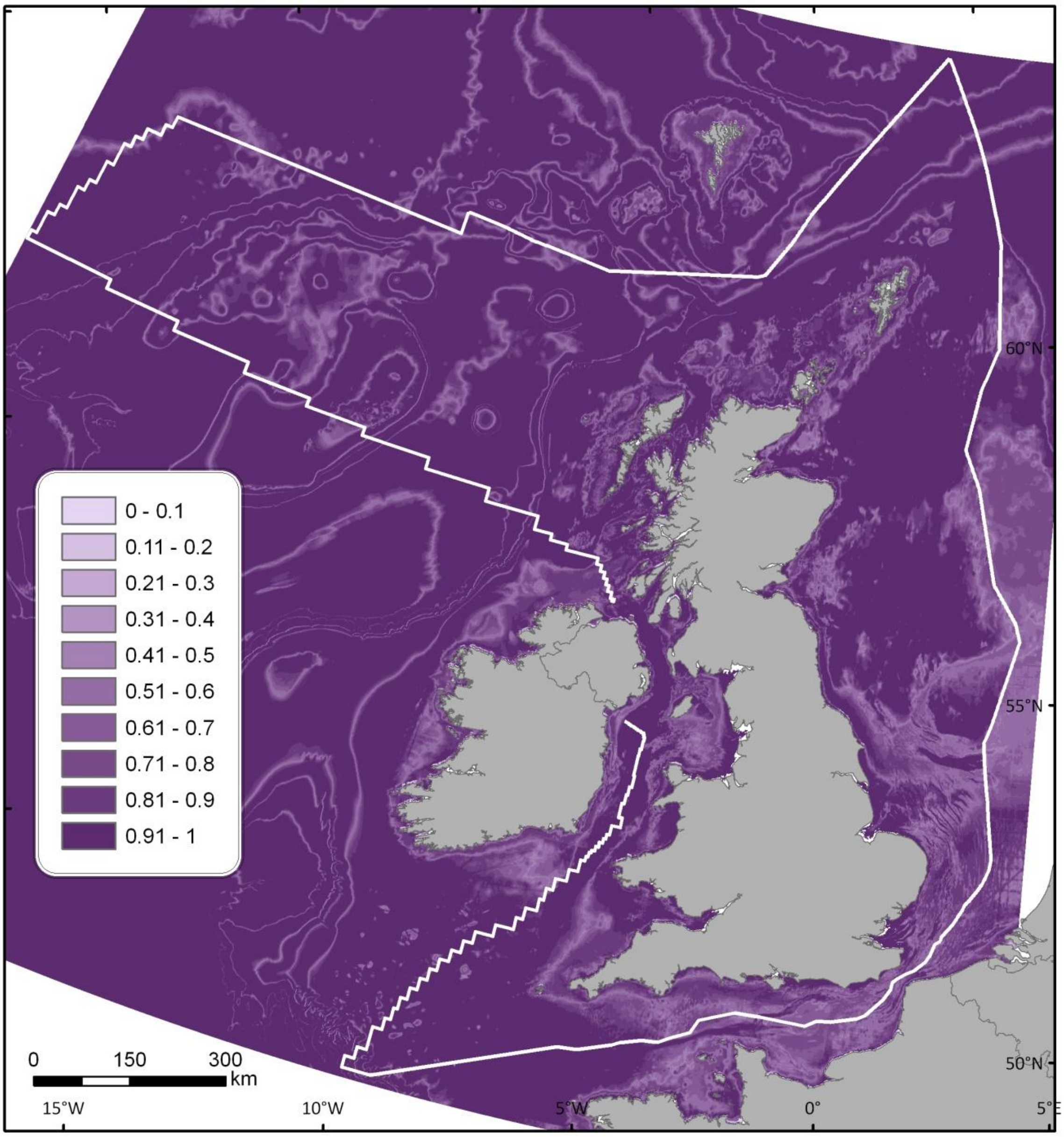

Figure 19. Biological zone confidence: the highest probability associated with a biological zone for each cell.

3.5 Depth to define Atlantic and Arctic biogeographic zones

The project area crosses two distinct biogeographic regions, with the north-east Atlantic, comprising 95% of the total area and Arctic waters comprising the remainder (Dinter 2001; Howell 2010). The boundary between the two regions is delineated by the Wyville-Thompson Ridge, which divides the Rockall Trough from the Faroe-Shetland Channel. The Rockall Trough contains a warm water mass (4.3 to 12°C) from the North East Atlantic and a lower cold water mass originating from the Labrador Sea (1 to 4.3°C). The Faroe-Shetland Channel contains the same upper warm water mass from the North East Atlantic and a lower cold water (Arctic) mass originating from Nordic Seas (-1 to 5°C) (Howell 2010). Zoogeographical differences have been noted between the deep sea fauna of both regions (Dinter 2001; Howell 2010; Howell *et al* 2010).

Howell (2010) recommends the 500m depth contour as the boundary between Arctic and Atlantic waters. Furthermore, the 500m depth contour extracted from the UKSeaMap 2010 bathymetry layer was compared to seabed temperature data from the Met Office's Atlantic Margin model (2002 - 2008)[27] and was found to correspond relatively closely to a transition zone where the temperature drops rapidly from 9°C to less than 0°C (Figure 20). Therefore, the Atlantic and Arctic zones were created using the 500m depth boundary, from the UKSeaMap 2010 bathymetry layer.

3.5.1 Recommendations: Atlantic and Arctic biogeographic zones

UK waters contain both Atlantic and Arctic waters, but there is currently no Arctic section of the EUNIS classification system for seabed habitats. The introduction of the Arctic as a biogeographic region at a high level in EUNIS is recommended. Howell *et al* (2010) have identified suitable Arctic deep sea biotopes for inclusion in the EUNIS habitat classification scheme which could be used to populate this suggested area of the classification.

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[27] This dataset was provided to JNCC by the Met Office in June 2008. The resolution of the data is 12km (40N-60N; 20W-13E).

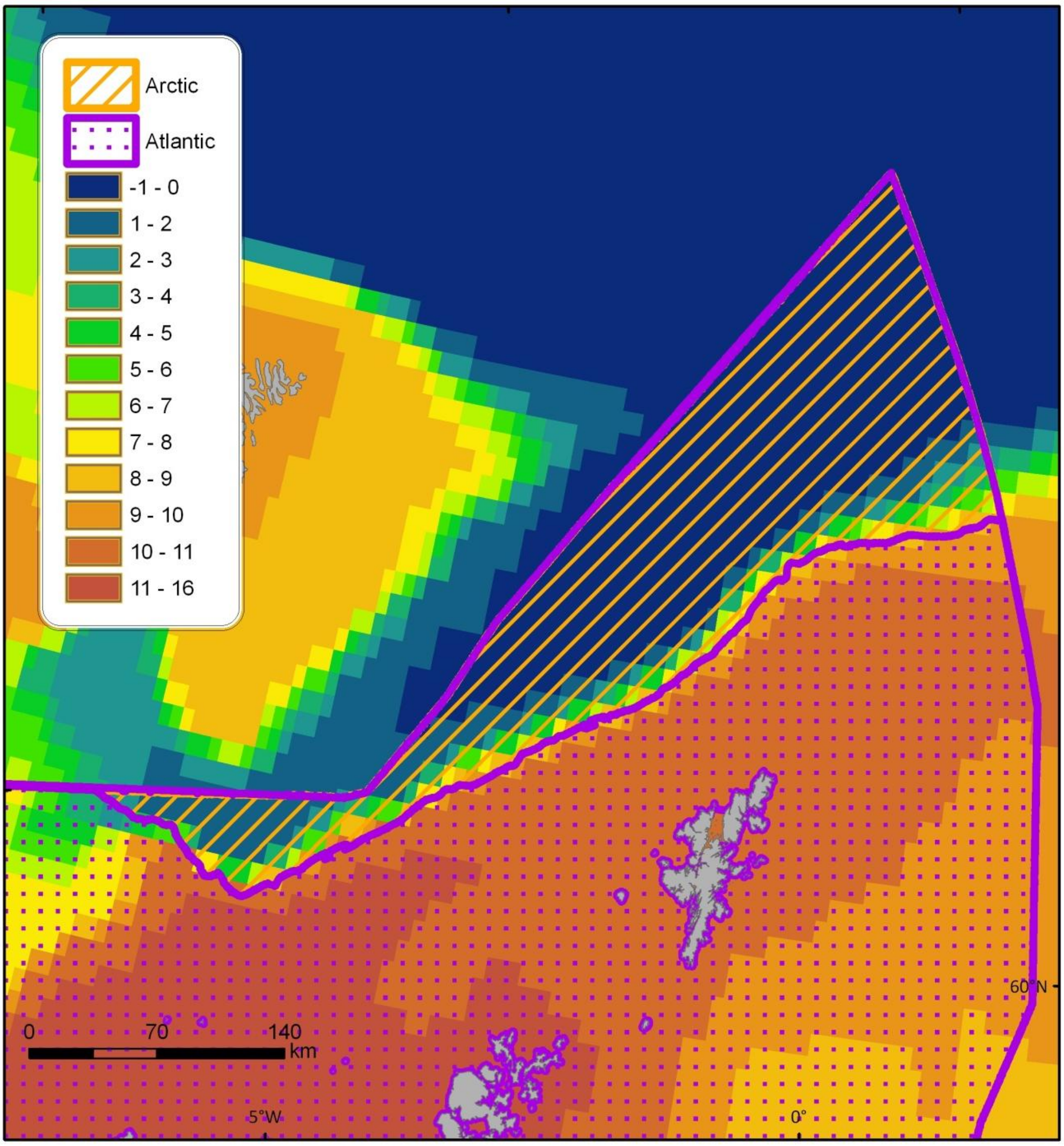

Figure 20. The 500m depth contour (purple line) overlain on modelled annual mean seabed temperature data (°C), from the MET Office Atlantic Margin model (2002 - 2008) for the Faroe Shetland Channel.

3.6 Combining classified physical data layers

Different classified data layers can easily be ‘stacked’ to construct combinations of their classes, in the form of a code for each grid cell. These codes can be translated to a EUNIS habitat code where appropriate, since the primary layers equate to the variables used at the top levels of EUNIS. Data processing was performed using raster (gridded) data in ESRI™ ArcMap 9.2 with Spatial Analyst extension. Datasets in raster format (rather than vector format) are used because they are much more economical in terms of data storage. Processing times to combine rasters are significantly reduced compared to combining of vector data with a similar level of detail.

The model combined five input raster layers to produce a code for each cell. The codes were then translated to the most detailed EUNIS habitat types or deep sea habitat descriptions using translation tables to obtain the most detailed classification possible (Table

9, Table 10 and Table 11). These translation tables were derived by inspecting the habitat classification. For some combinations of environmental variables, it was not possible to identify a unique habitat type found in those conditions. Where two habitat types occurred in for a particular combination of environmental variables, both these habitat types were included in the translation tables. For example, for low energy rock found in the infralittoral zone and in variable salinity, there are two possible habitat types at EUNIS level 4: Kelp in variable salinity on low energy infralittoral rock (A3.32) and Faunal communities in variable or reduced salinity infralittoral rock (A2.36). In cases where more than two habitat types are possible for a particular combination of environmental variables, the parent code was used in the translation table.

Table 9. EUNIS habitat codes for rock habitats (does not include the deep-sea habitats).

		Rock		
		Marine	Variable salinity	
Biological zone	Infralittoral	A3.31	A3.32 or A3.36	Low energy
	Circalittoral	A4.31		
	Deep circalittoral	A4.33		
	Infralittoral	A3.2 except A3.22	A3.22	Moderate energy
	Circalittoral	A4.2 except A4.27		
	Deep circalittoral	A4.27		
	Infralittoral	A3.1		High energy
	Circalittoral	A4.11 or A4.13		
	Deep circalittoral	A4.12		

Table 10. EUNIS habitat codes for sediment habitats (does not include deep-sea habitats).

		Sediment type			
		Coarse	Sand	Mud	Mixed
Biological zone & salinity	Variable salinity	A5.12	A5.22	A5.32	A5.42
	Infralittoral	A5.13	A5.23 or A5.24	A5.33 or A5.34	A5.43
	Circalittoral	A5.14	A5.25 or A5.26	A5.35 or A5.36	A5.44
	Deep circalittoral	A5.15	A5.27	A5.37	A5.45

Table 11. Habitat names for the new deep sea habitats.

		Seabed substrata						
		Rock	Coarse	Sand	Mud	Mixed		
Biological zone	Upper slope	Atlantic upper slope rock	Atlantic upper slope coarse	Atlantic upper slope sand	Atlantic upper slope mud	Atlantic upper slope mixed	Atlantic	Biogeography
	Upper bathyal	Atlantic upper bathyal rock	Atlantic upper bathyal coarse	Atlantic upper bathyal sand	Atlantic upper bathyal mud	Atlantic upper bathyal mixed		
	Mid bathyal	Atlantic mid bathyal rock	Atlantic mid bathyal coarse	Atlantic mid bathyal sand	Atlantic mid bathyal mud	Atlantic mid bathyal mixed		
	Lower bathyal	Atlantic lower bathyal rock	Atlantic lower bathyal coarse	Atlantic lower bathyal sand	Atlantic lower bathyal mud	Atlantic lower bathyal mixed		
	Abyssal	Atlantic abyssal rock	Atlantic abyssal coarse	Atlantic abyssal sand	Atlantic abyssal mud	Atlantic abyssal mixed		
	Upper slope	Arctic upper slope rock	Arctic upper slope coarse	Arctic upper slope sand	Arctic upper slope mud	Arctic upper slope mixed	Arctic	
	Upper bathyal	Arctic upper bathyal rock	Arctic upper bathyal coarse	Arctic upper bathyal sand	Arctic upper bathyal mud	Arctic upper bathyal mixed		
	Mid bathyal	Arctic mid bathyal rock	Arctic mid bathyal coarse	Arctic mid bathyal sand	Arctic mid bathyal mud	Arctic mid bathyal mixed		
	Lower bathyal	Arctic lower bathyal rock	Arctic lower bathyal coarse	Arctic lower bathyal sand	Arctic lower bathyal mud	Arctic lower bathyal mixed		
	Abyssal	Arctic abyssal rock	Arctic abyssal coarse	Arctic abyssal sand	Arctic abyssal mud	Arctic abyssal mixed		

3.7 Coastal Physiographic Features

The UK coastline consists of a complex environment of marine inlets and linear coast formed by landform process, such as glaciations, over millions of years. This has led to a diverse range of coastline physiographic features which provide different types of habitats for a huge range of marine communities. The habitats of coastal physiographic features substantially differ in their environmental conditions, including substrate type, temperature, salinity, tidal range, and wave exposure. These diverse conditions provide unique niches for an abundance of marine life in the UK. The importance of several of these coastal physiographic features is defined by legislation. Estuaries, lagoons, and shallow inlets and bays are listed on Annex I of the EC Habitats Directive, which requires the establishment of Special Areas of Conservations (SACs) to ensure their protection.

The original UKSeaMap project produced a map identifying eight types of coastal physiographic feature, largely from manual digitisation (Table 11). A review of this map was carried out which considered: the mapping of additional categories of feature; the creation of feature subtypes for certain features; and the addition of individual features. Other corrections were made to deal with minor errors caused by re-projection and coastline issues, and to add missing attributes to some records.

Tide-swept channels and were suggested as an additional category to include in the list of coastal physiographic features. As the UKBAP[28] definition of tide-swept channels is likely to be reviewed by the SNCBs in the near future it is reasonable to wait until the definition is clarified.

As part of the 2010 update, sealochs were divided into four subtypes, following definitions in the MNCR and Coastal Geology of Great Britain: open sealochs; fjords; fjards and voes. The subtypes were assigned as attributes based on classifications from the MNCR reports and the Scottish sealoch catalogue (Edwards and Sharples 1986; Dipper and Johnston 1999; Howson 1999; Beaver and Dipper 2002; Dipper and Beaver 2005; Dipper *et al* 2008) (Table 12). There was insufficient information to assign subtypes to all of the sealochs.

Classifying saline lagoons into the sub-types identified by Bamber *et al* (2001) was also considered. After discussion with the SNCBs, it was decided that this would not be appropriate as the UK Saline Lagoon Working Group expect to change the lagoonal classification in the near future.

In the original UKSeaMap coastal physiographic features map, mapped data showing the location of lagoons, estuaries and sealochs for Northern Ireland were not available. For UKSeaMap 2010, these features were added using GIS data delineating the features which were collated for the Favourable Conservation Status (FCS) report (Joint Nature Conservation Committee 2007). Individual estuaries, sealochs and bays missing from the original dataset for other areas were manually digitised (Buck 1993a; Buck 1993b; Buck 1993c; Buck 1996) (Appendix 4 and Appendix 5). Where lagoons overlapped with other larger coastal physiographic features such as bays, the overlap was eliminated by removing the lagoonal area from the larger features so that the lagoons could still be seen. For this reason, it is not valid to carry out area calculations of the larger features from this layer.

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[28] UK Biodiversity Action Plan

Table 12. Definitions of the coastal physiographic features used in UKSeaMap 2010 and modifications made to the map since UKSeaMap 2006.

Coastal type	Description	Modifications since UKSeaMap 2006
Bay	An area of open coast bounded by headlands, which provide some shelter from along-shore winds, but which is predominantly open to onshore winds (compare 'embayment').	Two bays added (Scotland)
Sound or strait	Channels between the mainland and an island, or between two islands which are open at both ends to the open coast (excludes similar features or narrows within marine inlets such as sealochs).	72 sounds or straits added (Scotland, England)
Barrier beach	Coastal features caused by long-shore drift of sediment resulting in submerged sheltered areas behind the features.	None
Embayment	An enclosed area of coast in which the entrance provides shelter from onshore winds for the major part of the coast inside, but which is not a sealoch, voe, ria, estuary or lagoon.	None
Sealoch	Glacially-formed inlets (fjords, fjards) of western Scotland and Ireland, including the voes of Shetland. Typically elongate and deepened by glacial action with little freshwater influence. Often with narrows and sills dividing the loch into a series of basins. For sub-type definitions, see Howson *et al* (1994).	Four subtypes added to 93% of features and three sealochs added (Scotland)
Ria	Drowned river valleys of south-west Britain. Often with a greater presence of rock and more marine in character than estuaries.	None
Estuary	Downstream part of a river where it widens to enter the sea. Often with significant freshwater influence and predominantly comprising sediment habitats.	13 estuaries added (Scotland, Wales, Northern Ireland)
Lagoon	Enclosed bodies of water, separated or partially separated from the sea by shingle, sand or sometimes rock and with a restricted exchange of water with the sea, yielding varying regimes of reduced salinity.	30 lagoons added (all Northern Ireland)

Many sounds or straits were not included in UKSeaMap 2006, particularly in north-west Scotland, the Shetland, Orkney and Hebridean Islands, because of lack of time in that project to identify them manually. Missing sounds and straits were manually digitised using the Ordnance Survey maps (1:50,000) as a backdrop. Some features labelled as sounds or straits on the Ordnance Survey maps were excluded because they were judged not sufficiently narrow, relative to their length, to cause accelerated current speeds. A full list of all new features can be found in Appendix 5.

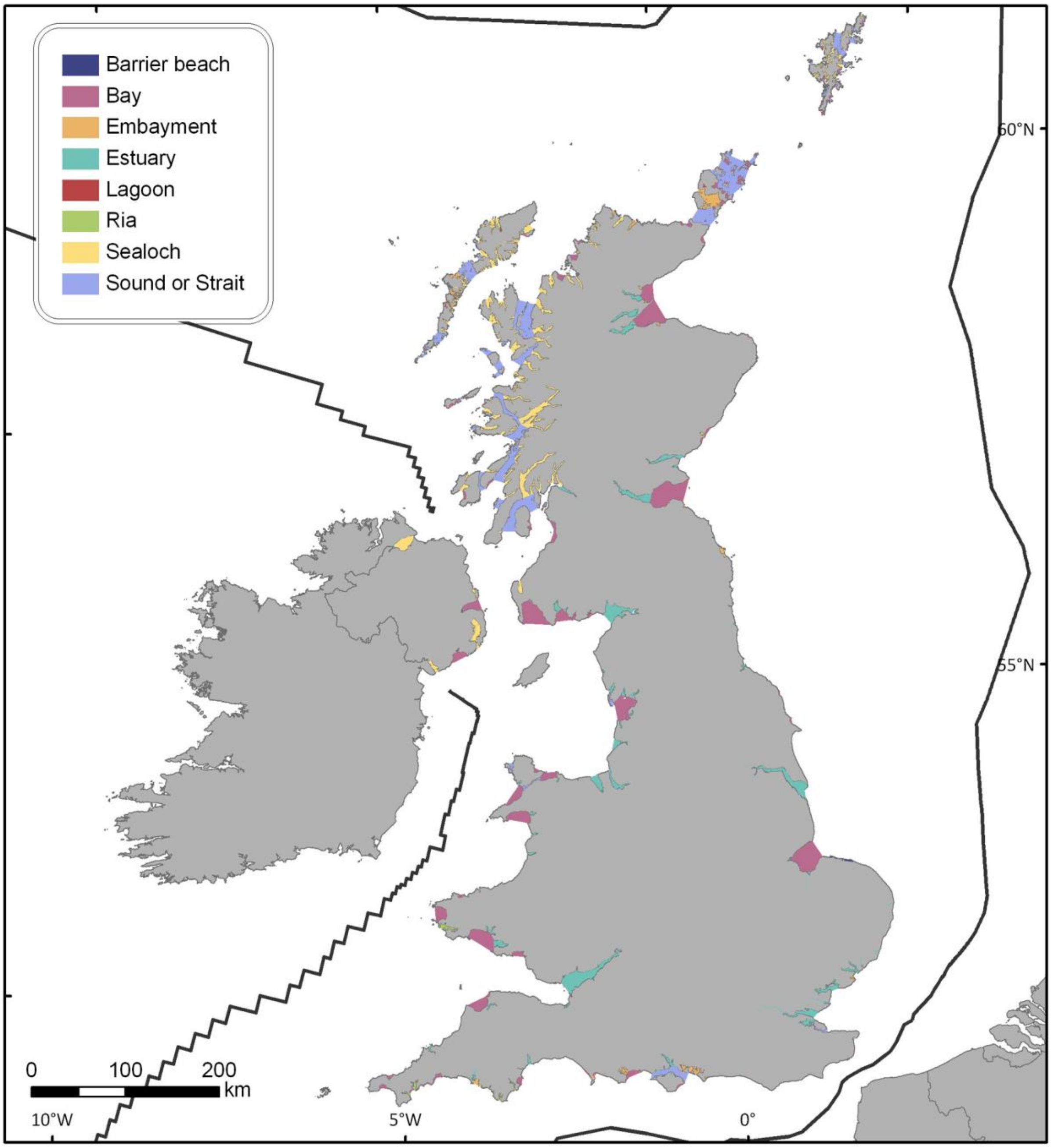

Figure 21. UKSeaMap 2010 coastal physiographic features.

3.8 Topographic features

The UK has an extensive continental shelf area extending to about 200m depth, followed by the continental slope which leads down to the deep sea. Major topographic features of the seabed, such as canyons and seamounts, represent the valleys and mountains of the marine environment. The importance of topographic features is highlighted by their inclusion in the OSPAR List of threatened and declining species and habitats, the UK Biodiversity Action Plan List of Priority Species and Habitats[29] and Annex 1 of the EC Habitats Directive (e.g. seamounts, carbonate mounds, sandbanks slightly covered by seawater all of the time respectively).

The UKSeaMap 2006 project used bathymetric data to identify and map the main topographic features based on slope (GEBCO 1 minute grid, SeaZone 250m DEM and BGS's DigBath250 bathymetric contour data[30]. The relatively low resolution of GEBCO prevented the identification of the small- to medium-sized topographic features, and major anomalies were found in the SeaZone DEM.

Two recent contracts have taken significant steps to deliver maps of topographic features: MB0102 - Report No 8, Task 2A. Mapping of Geological and Geomorphological Features (Brooks *et al* 2009) and MB0105 Deep sea habitats - contributing towards completion of a deep-sea habitat classification scheme (Jacobs and Poritt 2009). The first of these reports identified, categorised and mapped geological and geomorphological features on the UK seabed (Brooks *et al* 2009). The aim of the latter report was to contribute towards the development of a deep-sea habitat classification. This involved the production of three features layers for the UK deep sea area: physiographic; deposit; and modifier features. An equivalency table between the features classified in the original UKSeaMap project, the Jacobs and Porritt (2009) and Brooks *et al* (2009) has been created in Appendix 6. With the availability of these products, topographic features were not updated as part of UKSeaMap 2010.

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[29] http://www.ukbap.org.uk

[30] www.bgs.ac.uk/products/digbath250

4 Results

4.1 Predictive seabed habitat map

A predictive seabed habitat model for the UKSeaMap 2010 project area was constructed from five pre-classified input datasets; seabed substrata, energy, salinity, biological zones and biogeography (Figure 22 and Figure 23). The map which the model produced follows the EUNIS classification system, with additional categories in deep sea areas. The map covers the sublittoral zone only because of the higher variability of habitats in the littoral zone and the lack of detailed seabed substrata maps. The cell size in the map is 0.0025 decimal degrees (~300m).

Using ModelBuilder in ArcGIS improves the repeatability of the process as new or more detailed datasets become available they can be incorporated into the model to produce new versions of the predictive map. The map can be updated when higher resolution data becomes available in the future or when the EUNIS classification is updated.

The final raster map was converted to a shapefile and clipped to the UKSeaMap 2010 extent. Attributes have been created to enable the user to view EUNIS Level 3 habitats, EUNIS Level 4 habitats, or the most detailed classification (combining the best available EUNIS classes and the deep sea zones which are currently not part of EUNIS).

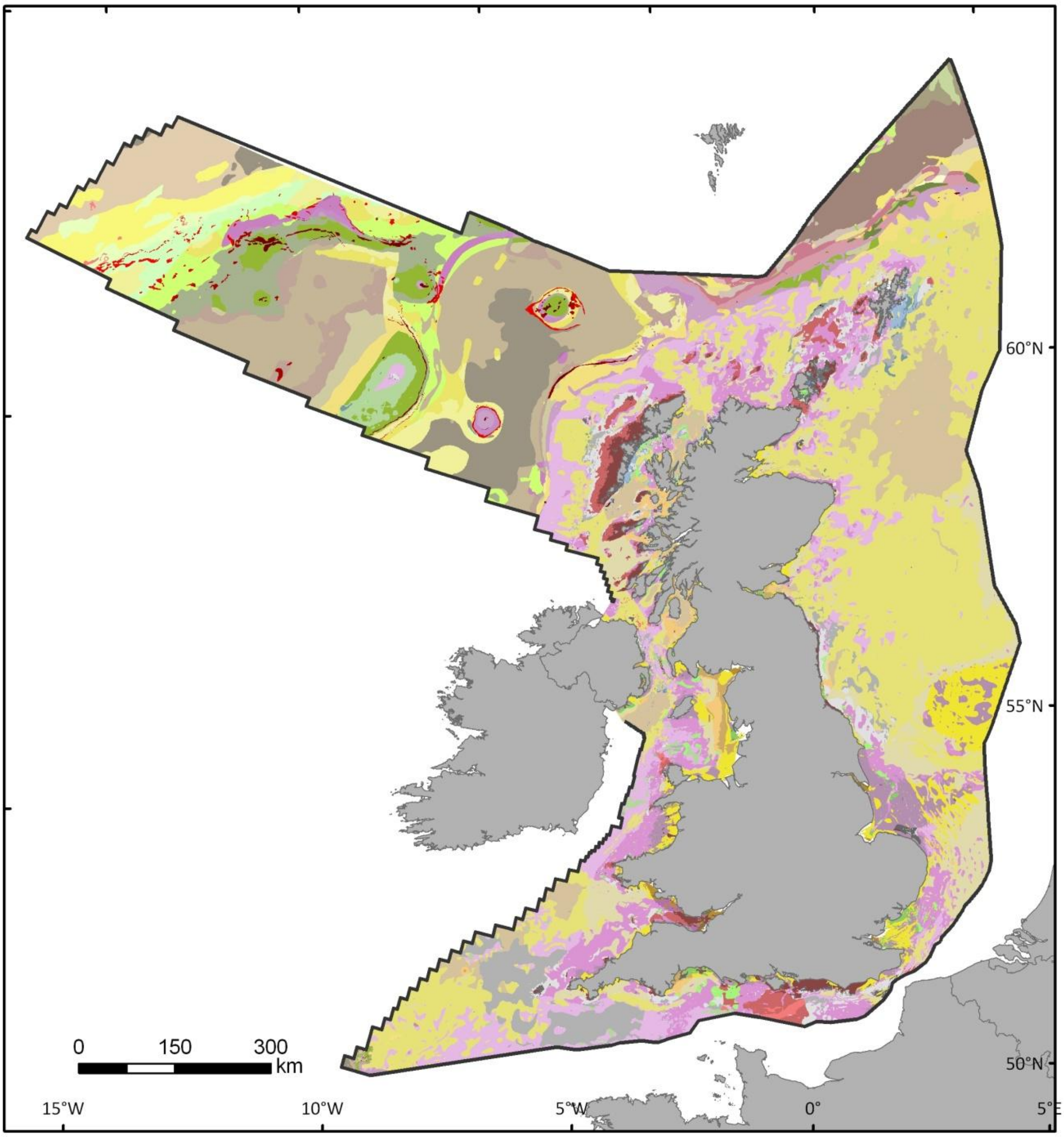

Figure 22. UKSeaMap 2010 predictive seabed habitat map - most detailed habitats (see Table 13 for legend).

Table 13. Legend showing the most detailed classes in the UKSeaMap 2010 predictive seabed habitat map.

🟫	A3.1: Atlantic and Mediterranean high energy infralittoral rock	🟨	Arctic mid bathyal sand and muddy sand
⬛	A3.2: Atlantic and Mediterranean moderate energy infralittoral rock	🟨	Arctic slope mud and sandy mud
⬜	A3.22: Kelp and seaweed communities in tide-swept sheltered conditions	🟫	Arctic upper bathyal mud and sandy mud
🟦	A3.31: Silted kelp on low energy infralittoral rock with full salinity	🟫	Arctic mid bathyal mud and sandy mud
🟦	A3.32 Kelp in variable salinity on low energy infralittoral rock or A3.36: Faunal communities on variable or reduced salinity infralittoral rock	🟫	Arctic lower bathyal mud and sandy mud
🟥	A4.11: Very tide-swept faunal communities on circalittoral rock or A4.13: Mixed faunal turf communities on circalittoral rock	🟩	Arctic slope mixed sediment
🟥	A4.12: Sponge communities on deep circalittoral rock	🟩	Arctic upper bathyal mixed sediment
⬜	A4.27: Faunal communities on deep moderate energy circalittoral rock	🟩	Arctic mid bathyal mixed sediment
⬜	A4.2: Atlantic and Mediterranean moderate energy circalittoral rock	🟩	Arctic lower bathyal mixed sediment
🟦	A4.31: Brachiopod and ascidian communities on circalittoral rock	🟥	Atlantic slope rock or reef
🟦	A4.33: Faunal communities on deep low energy circalittoral rock	🟥	Atlantic upper bathyal rock or reef
🟪	A5.12: Sublittoral coarse sediments in variable salinity (estuaries)	🟥	Atlantic mid bathyal rock or reef
🟪	A5.13: Infralittoral coarse sediment	🟥	Atlantic lower bathyal rock or reef
🟪	A5.14: Circalittoral coarse sediment	🟥	Atlantic abyssal rock or reef
🟪	A5.15: Deep circalittoral coarse sediment	🟪	Atlantic slope coarse sediment
🟫	A5.22: Sublittoral sand in variable salinity (estuaries)	🟪	Atlantic mid bathyal coarse sediment
🟨	A5.23: Infralittoral fine sand or A5.24: Infralittoral muddy sand	🟪	Atlantic lower bathyal coarse sediment
🟨	A5.25: Circalittoral fine sand or A5.26: Circalittoral muddy sand	🟪	Atlantic upper bathyal coarse sediment
🟨	A5.27: Deep circalittoral sand	🟨	Atlantic slope sand and muddy sand
🟫	A5.32: Sublittoral mud in variable salinity (estuaries)	🟨	Atlantic upper bathyal sand and muddy sand
🟫	A5.33: Infralittoral sandy mud or A5.34: Infralittoral fine mud	🟨	Atlantic mid bathyal sand and muddy sand
🟧	A5.35: Circalittoral sandy mud or A5.36: Circalittoral fine mud	🟨	Atlantic lower bathyal sand and muddy sand
🟫	A5.37: Deep circalittoral mud	🟨	Atlantic abyssal sand and muddy sand
🟩	A5.42: Sublittoral mixed sediment in variable salinity (estuaries)	🟨	Atlantic slope mud and sandy mud
🟩	A5.43: Infralittoral mixed sediments	🟫	Atlantic upper bathyal mud and sandy mud
🟩	A5.44: Circalittoral mixed sediments	🟫	Atlantic lower bathyal mud and sandy mud
🟩	A5.45: Deep circalittoral mixed sediments	🟫	Atlantic mid bathyal mud and sandy mud
🟦	Arctic slope rock or reef	🟫	Atlantic abyssal mud and sandy mud
🟦	Arctic upper bathyal rock or reef	🟩	Atlantic slope mixed sediment
🟥	Arctic slope coarse sediment	🟩	Atlantic upper bathyal mixed sediment
🟥	Arctic upper bathyal coarse sediment	🟩	Atlantic mid bathyal mixed sediment
🟥	Arctic mid bathyal coarse sediment	🟩	Atlantic lower bathyal mixed sediment
🟨	Arctic slope sand and muddy sand	🟩	Atlantic abyssal mixed sediment
🟨	Arctic upper bathyal sand and muddy sand		

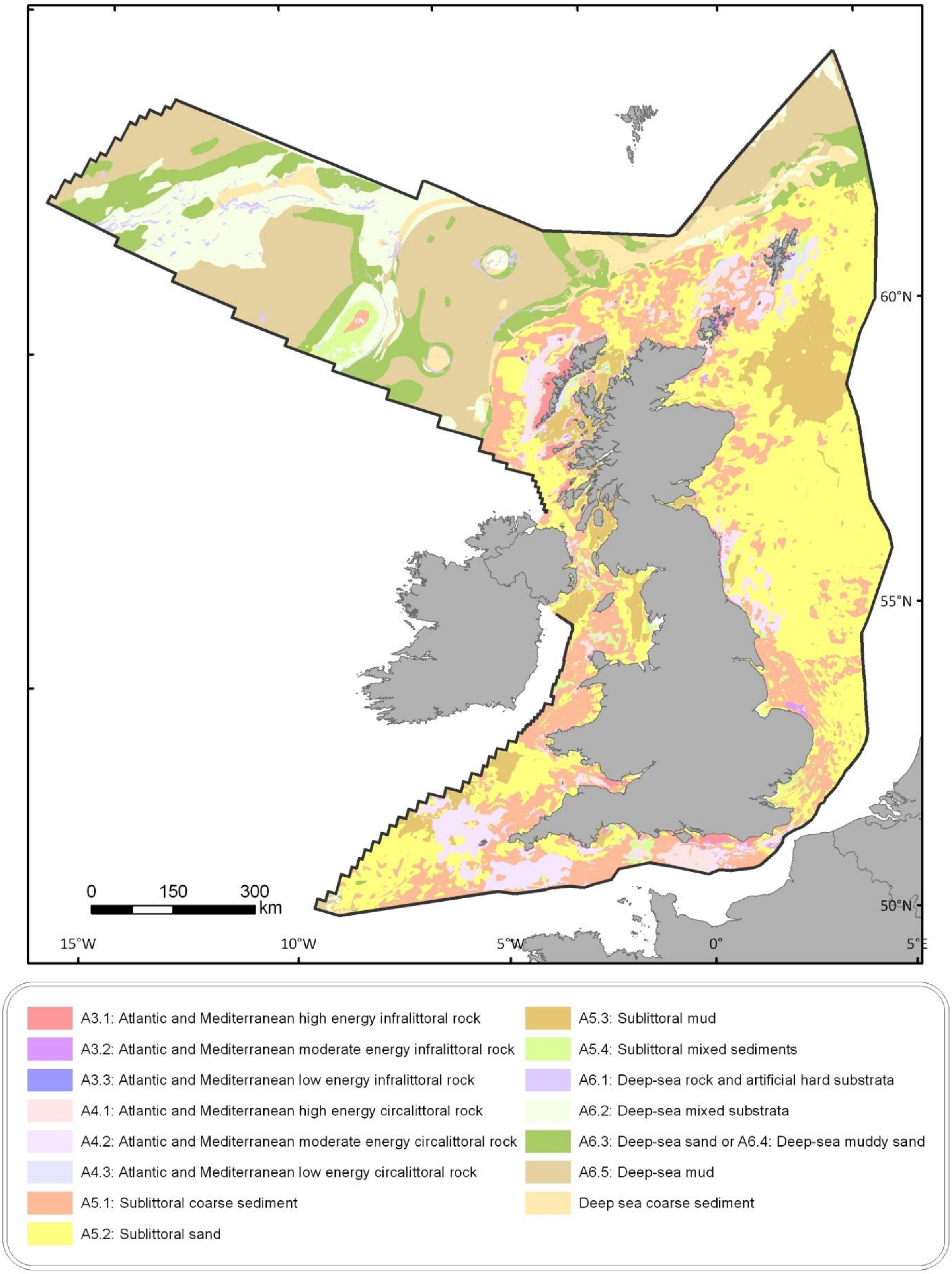

Figure 23. UKSeaMap 2010 predictive seabed habitat map - EUNIS Level 3 habitats.

Figure 24 shows the 12 regional seas in the UK marine area. Figure 25 to Figure 36 show the most detailed classification for each regional sea. Table 14 is provided to show percentage of habitat both for the UK and for each regional sea.

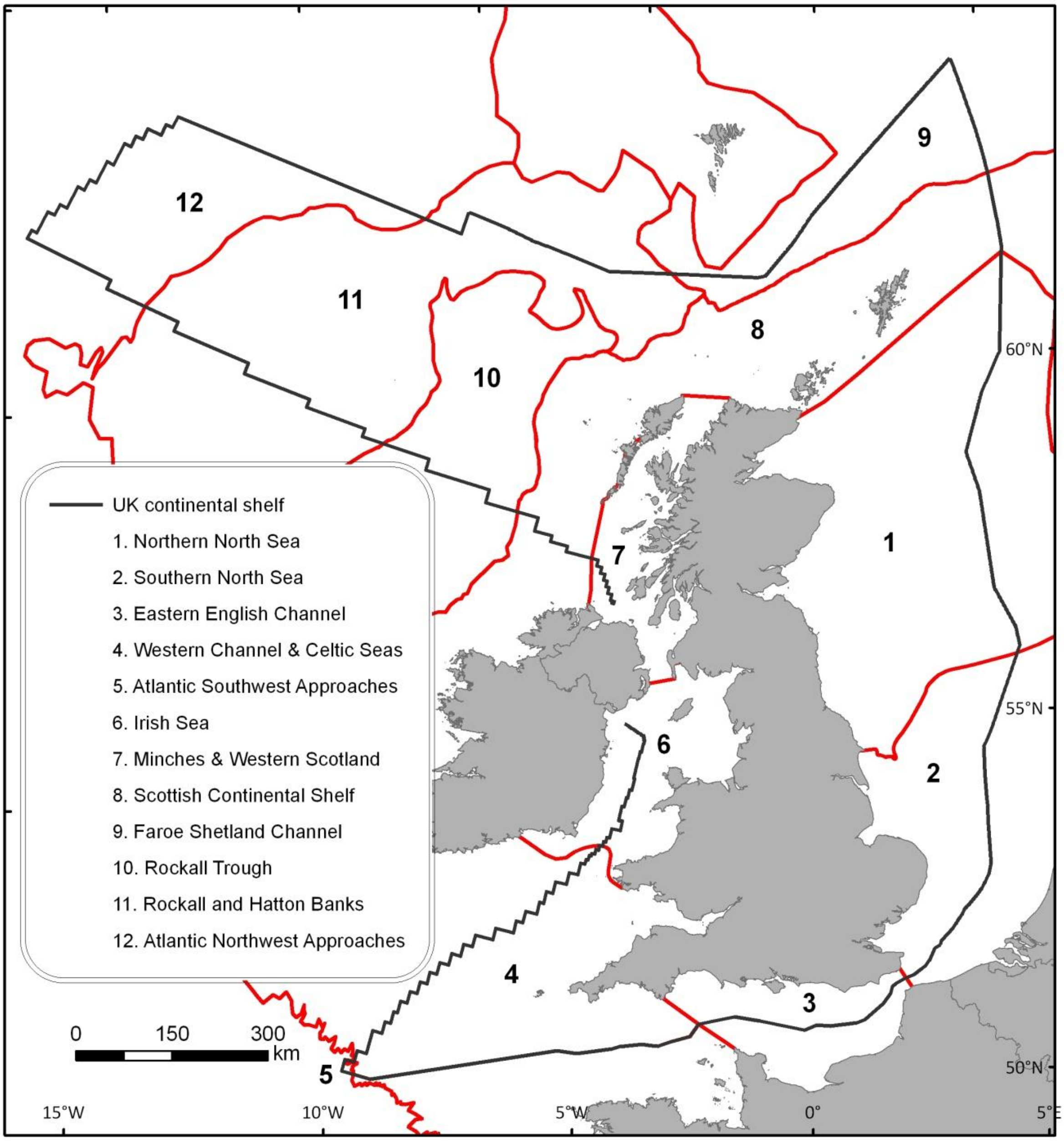

Figure 24. Draft regional sea boundaries for the UK waters.

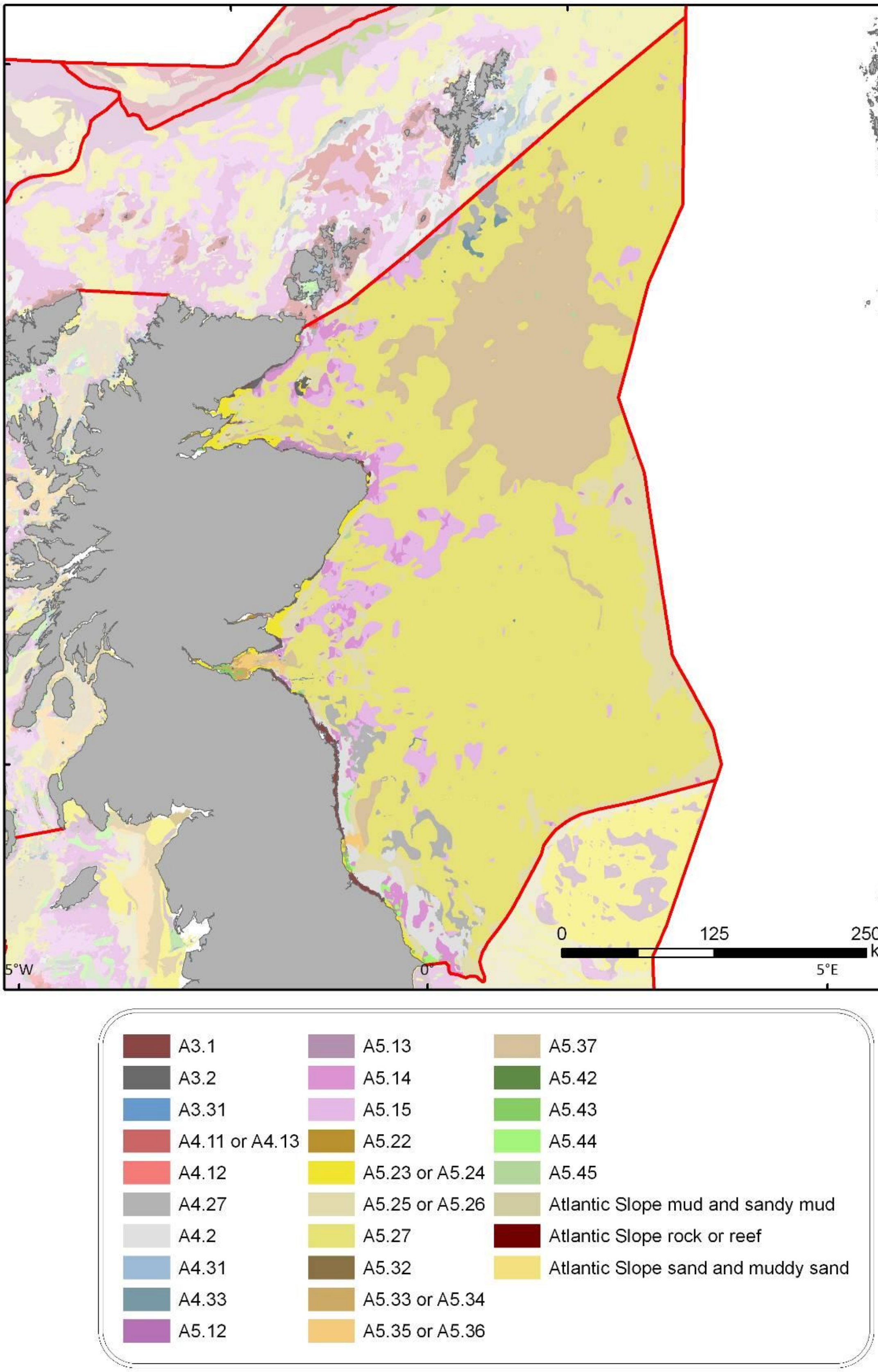

Figure 25. Regional Sea 1: Northern North Sea.

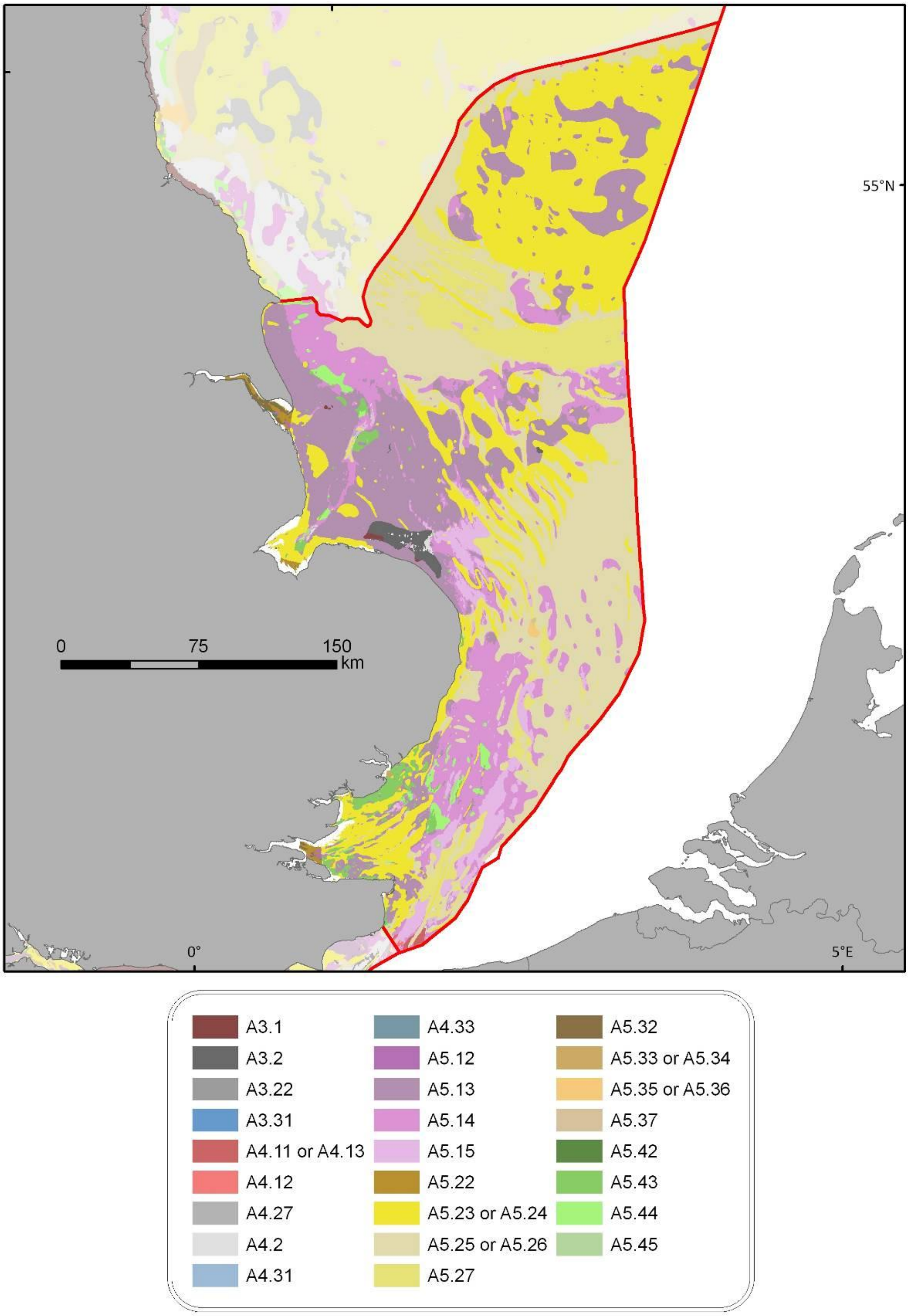

Figure 26. Regional Sea 2: Southern North Sea.

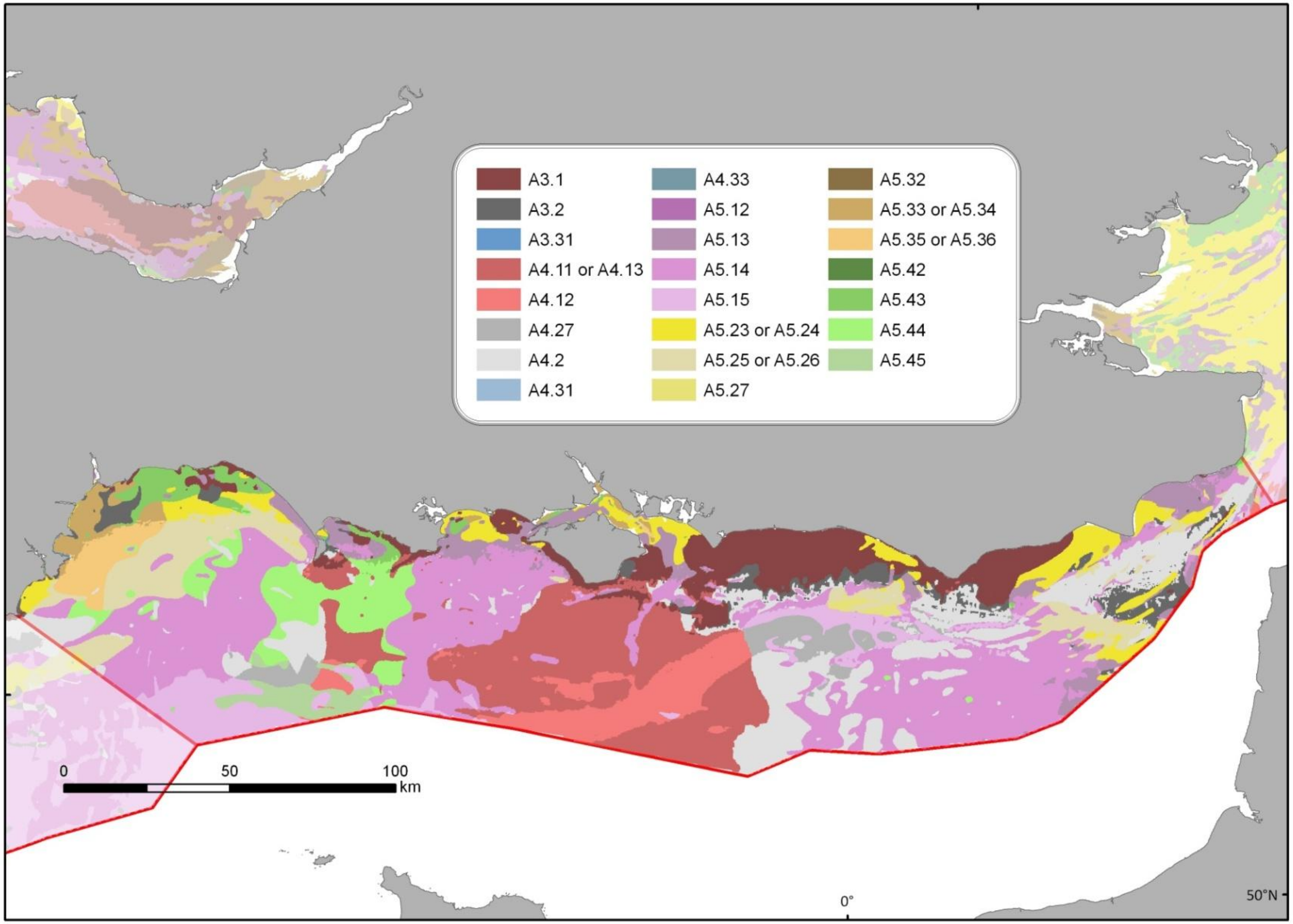

Figure 27. Regional Sea 3: Eastern English Channel.

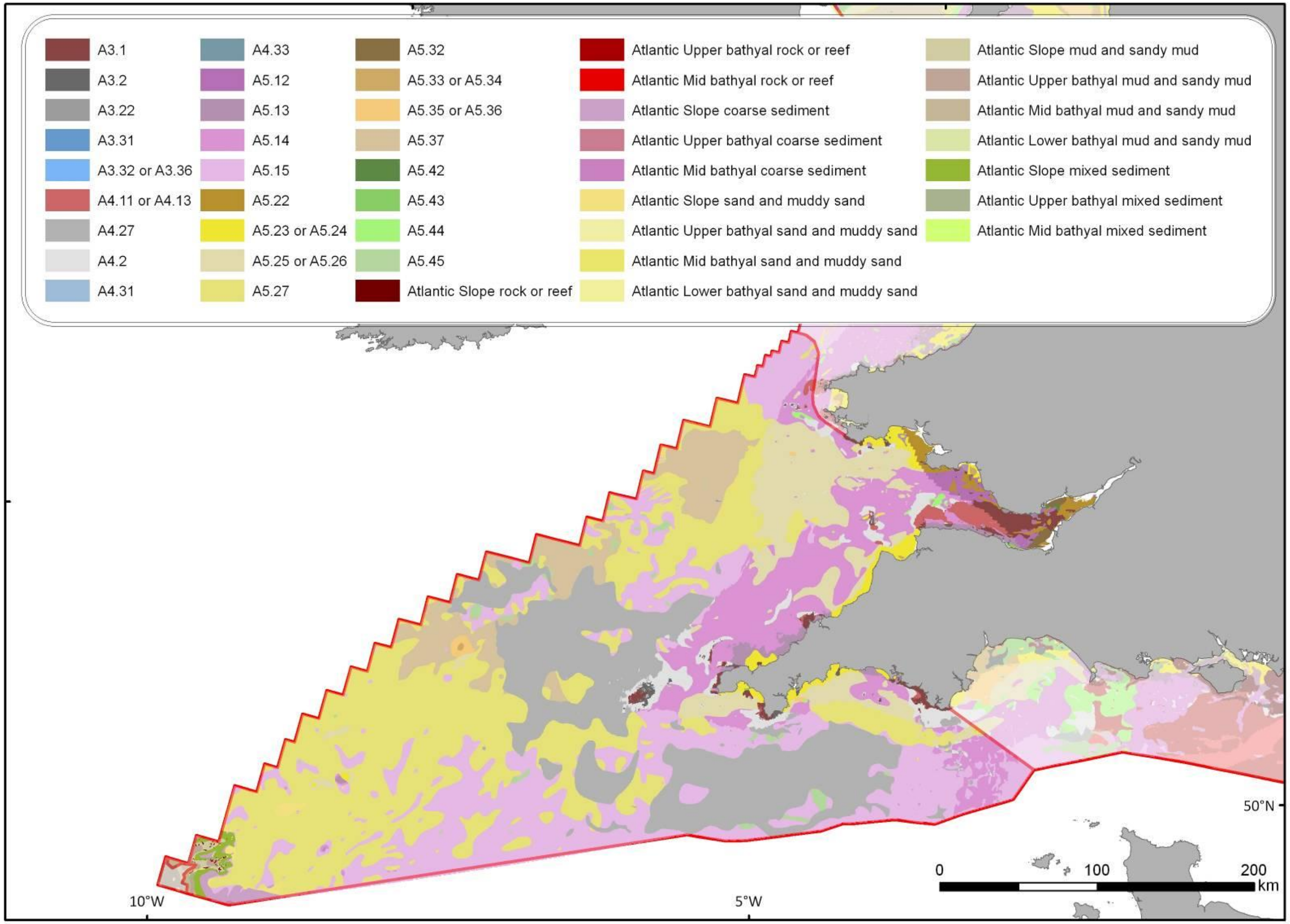

Figure 28. Regional Sea 4: Western Channel and Celtic Seas.

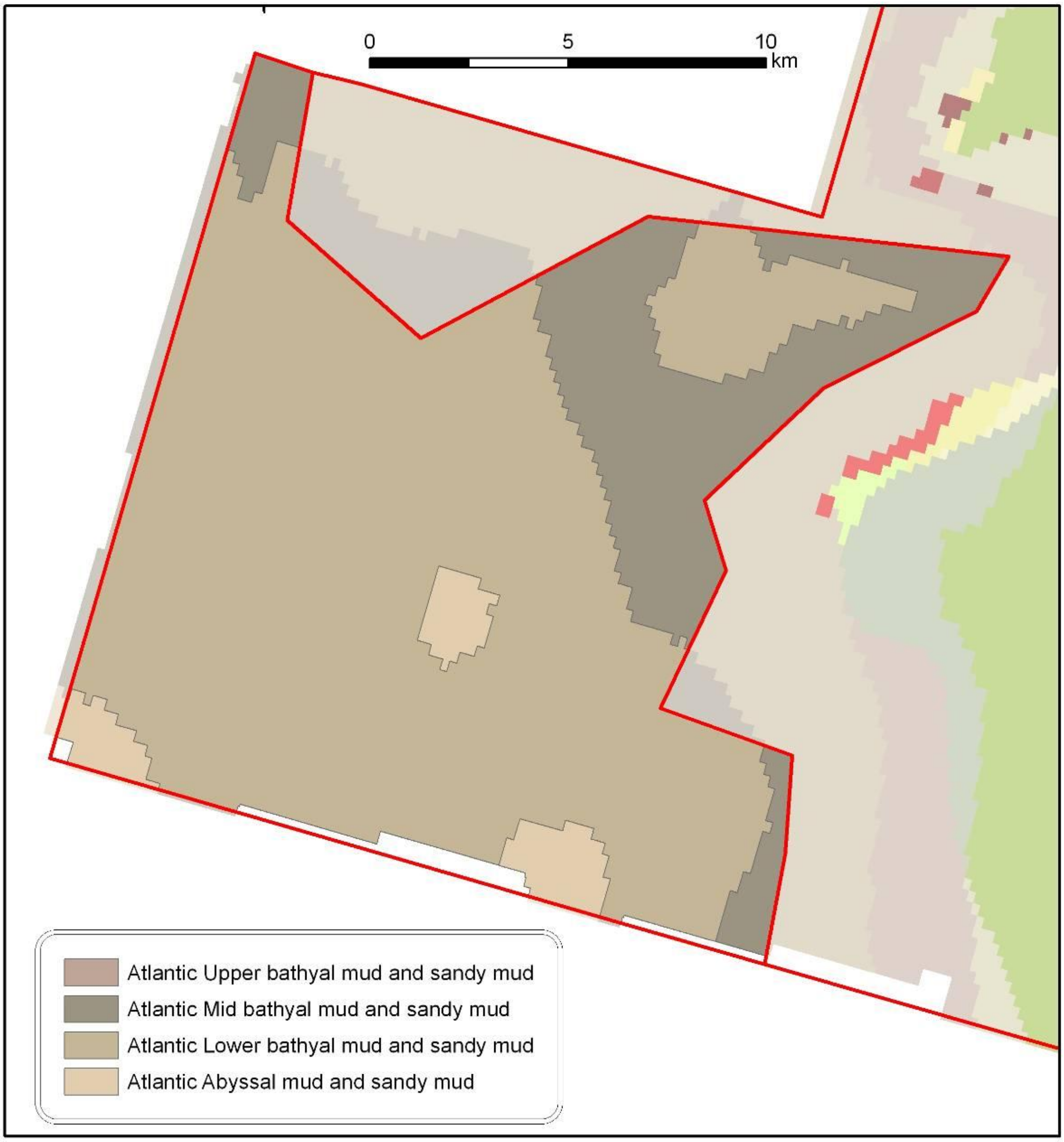

Figure 29. Regional Sea 5: Atlantic Southwest Approaches.

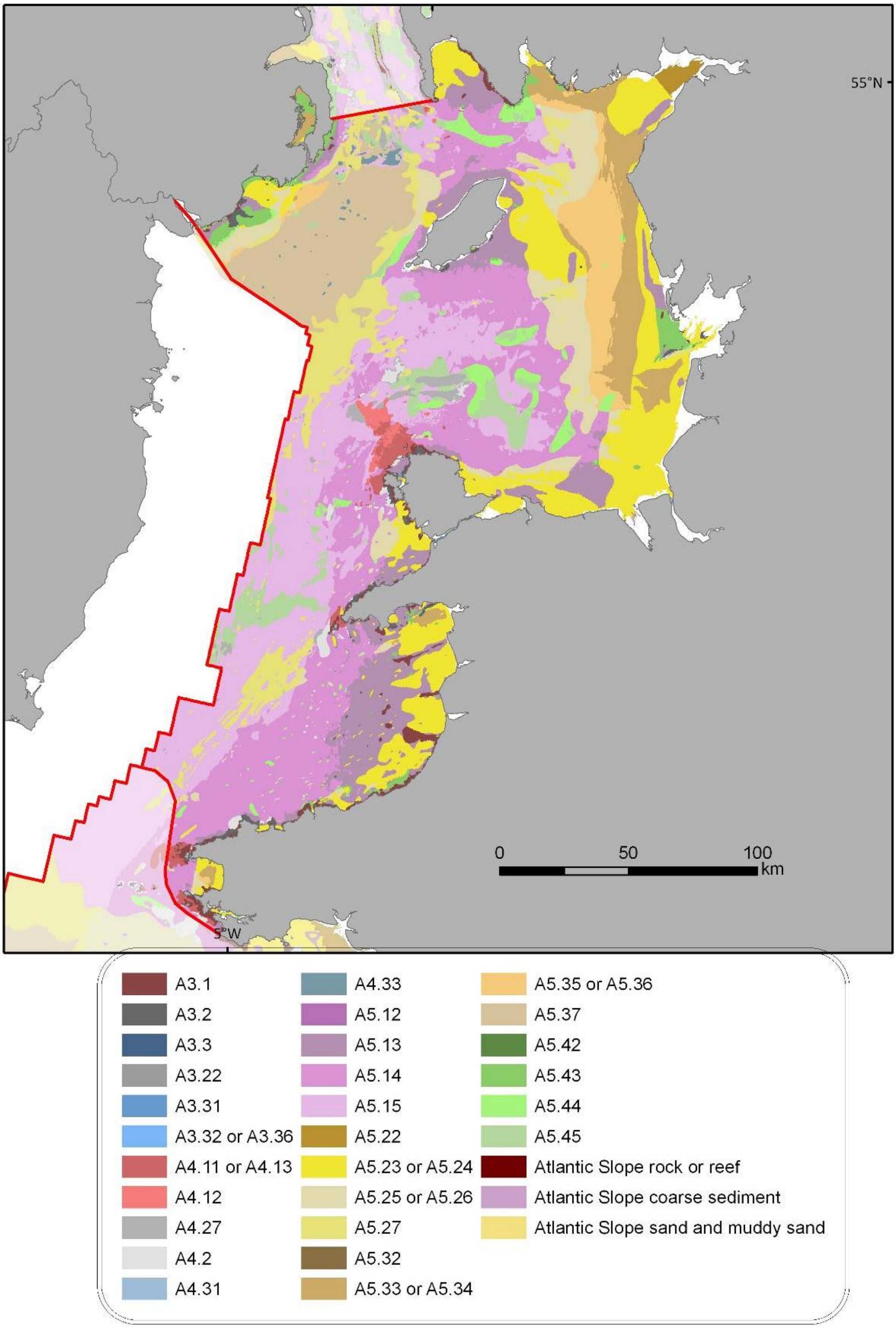

Figure 30. Regional Sea 6: Irish Sea.

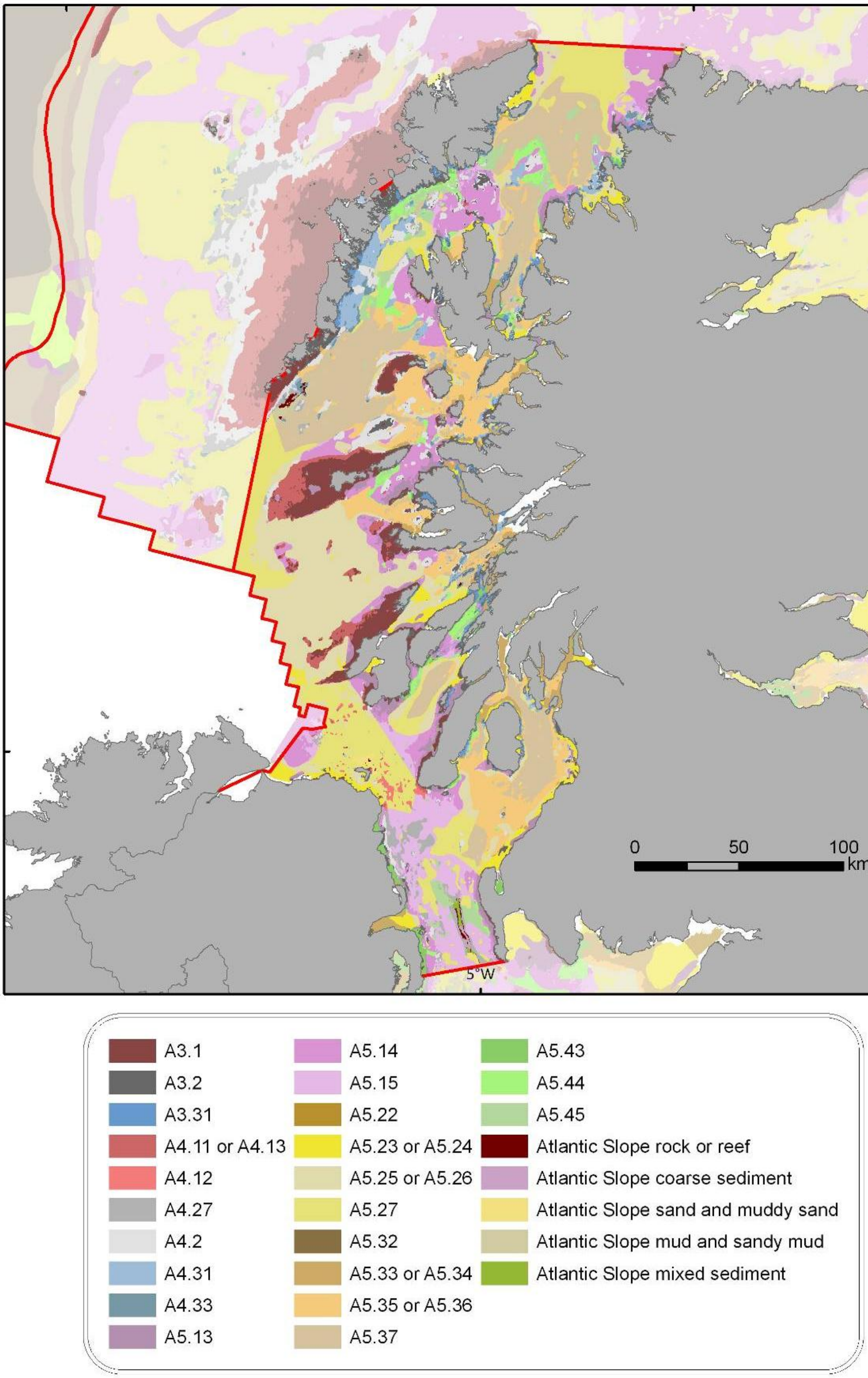

Figure 31. Regional Sea 7: Minches and Western Scotland.

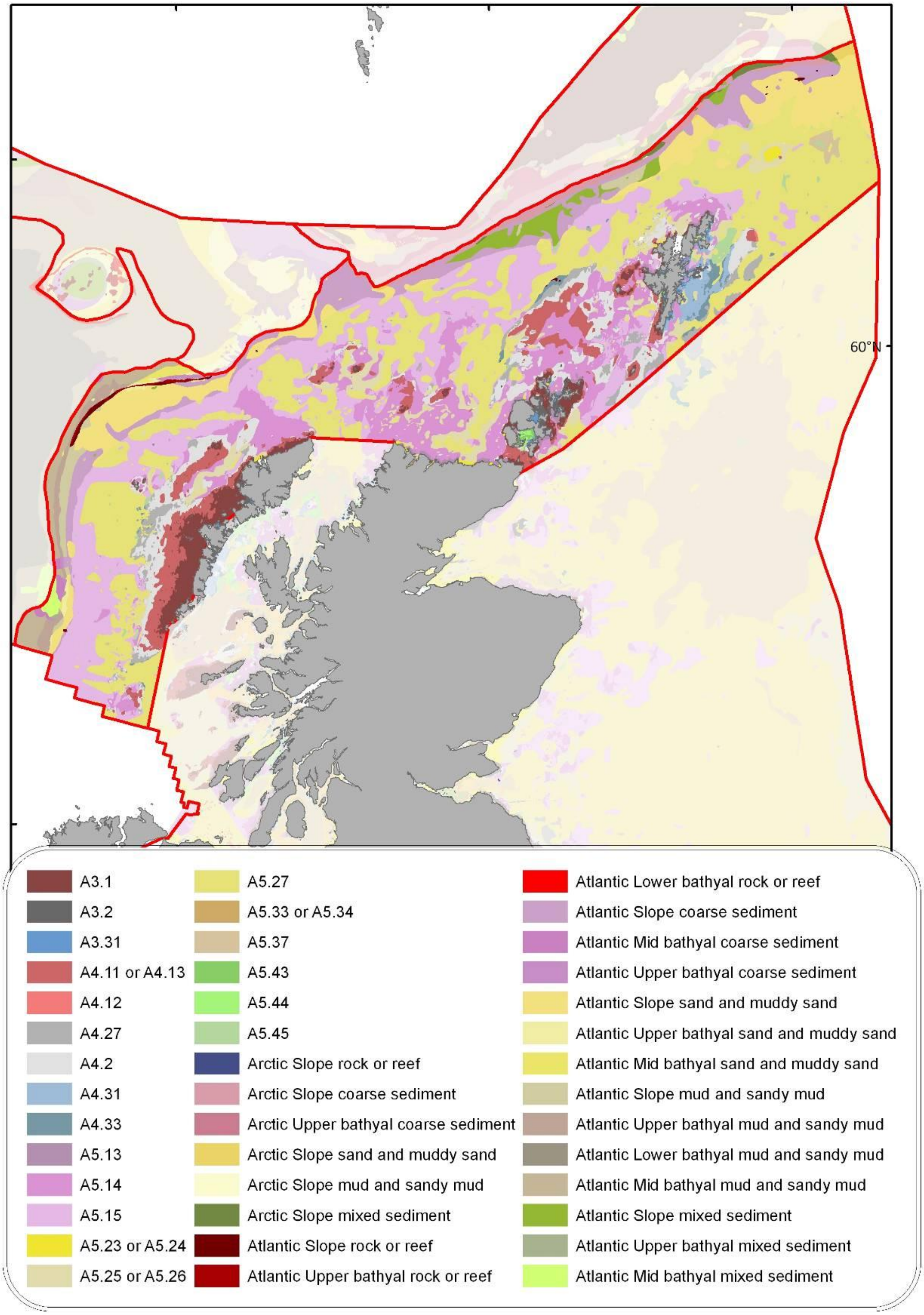

Figure 32. Regional Sea 8: Scottish Continental Shelf.

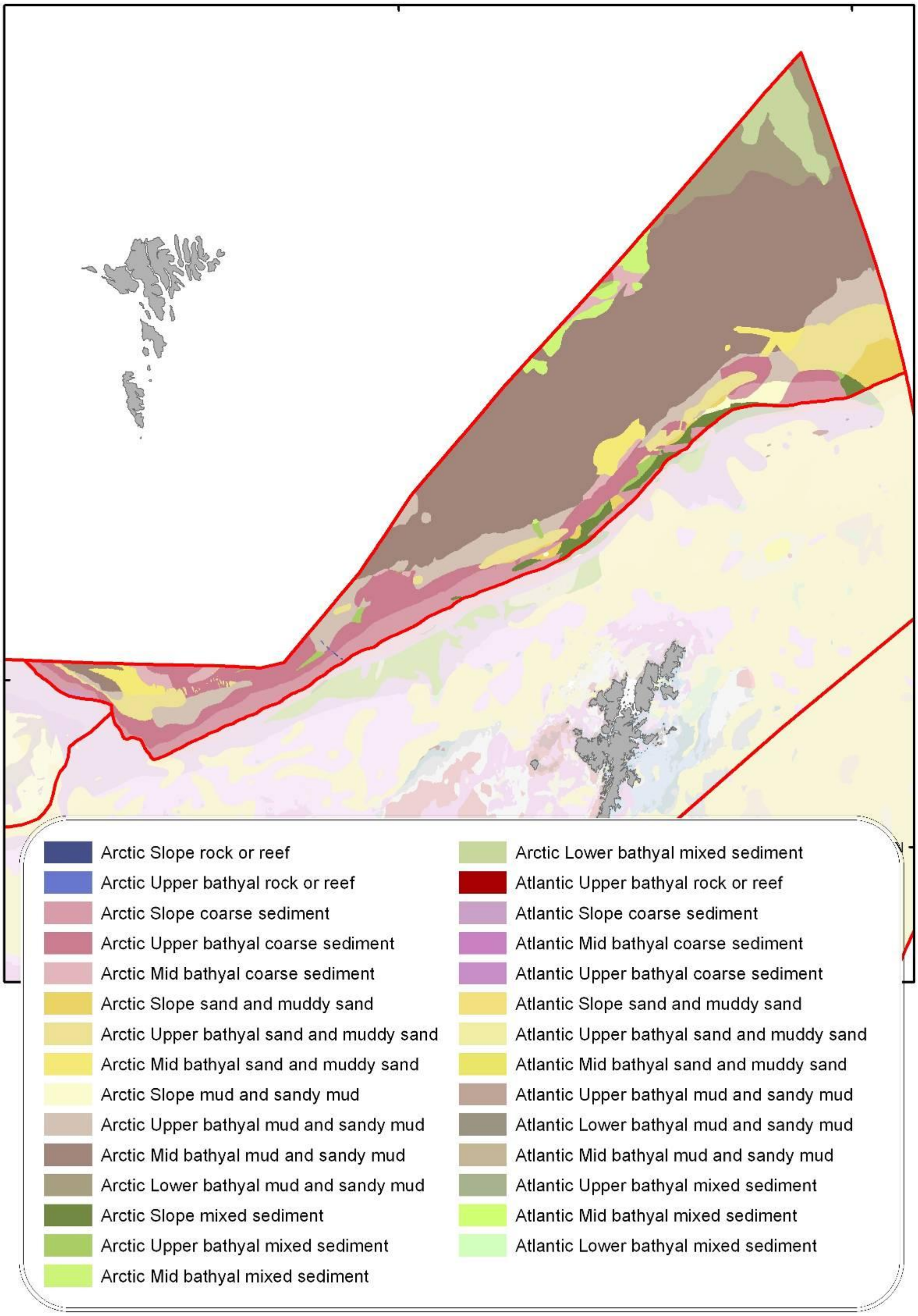

Figure 33. Regional Sea 9: Faroe Shetland Channel.

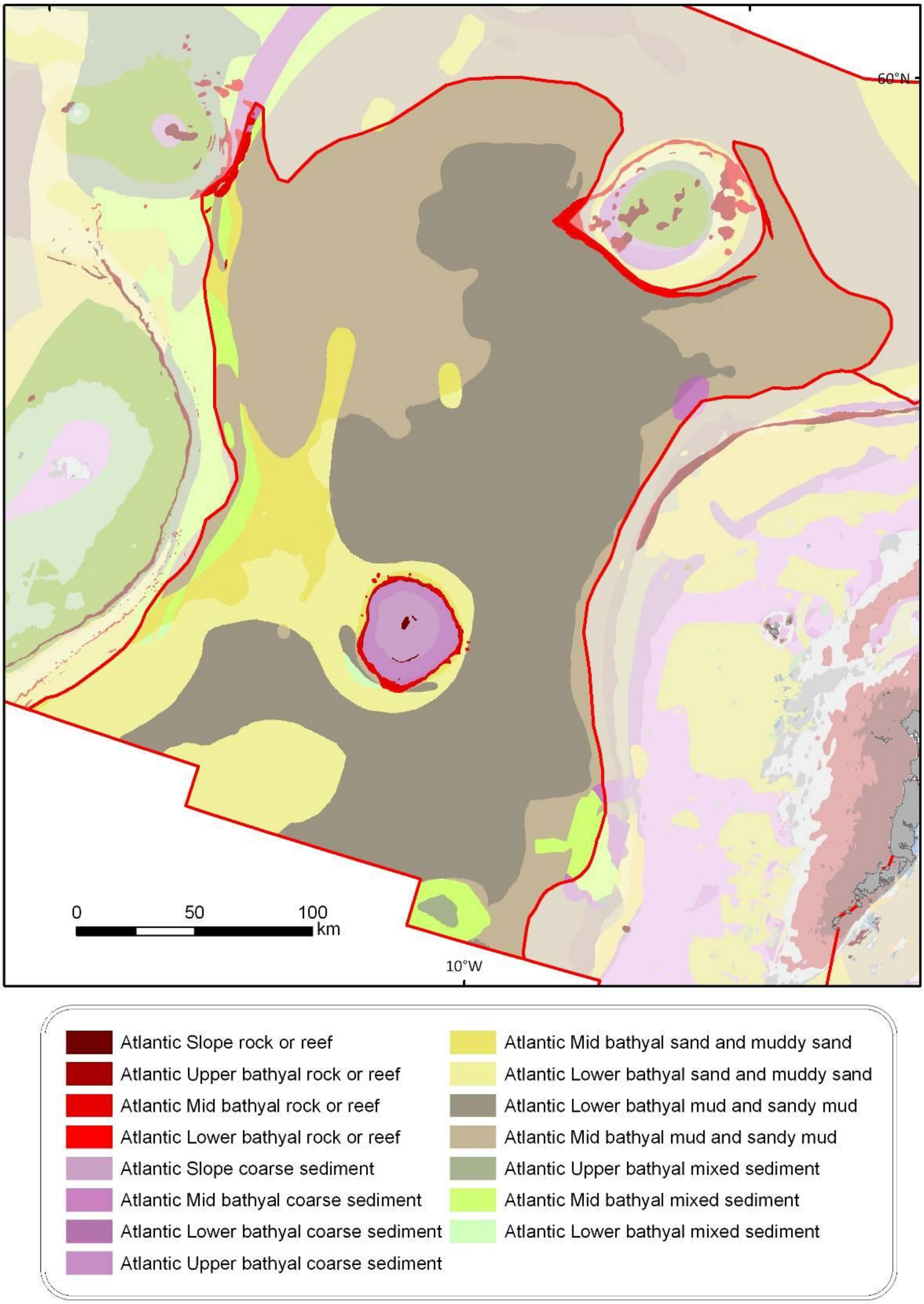

Figure 34. Regional Sea 10: Rockall Trough.

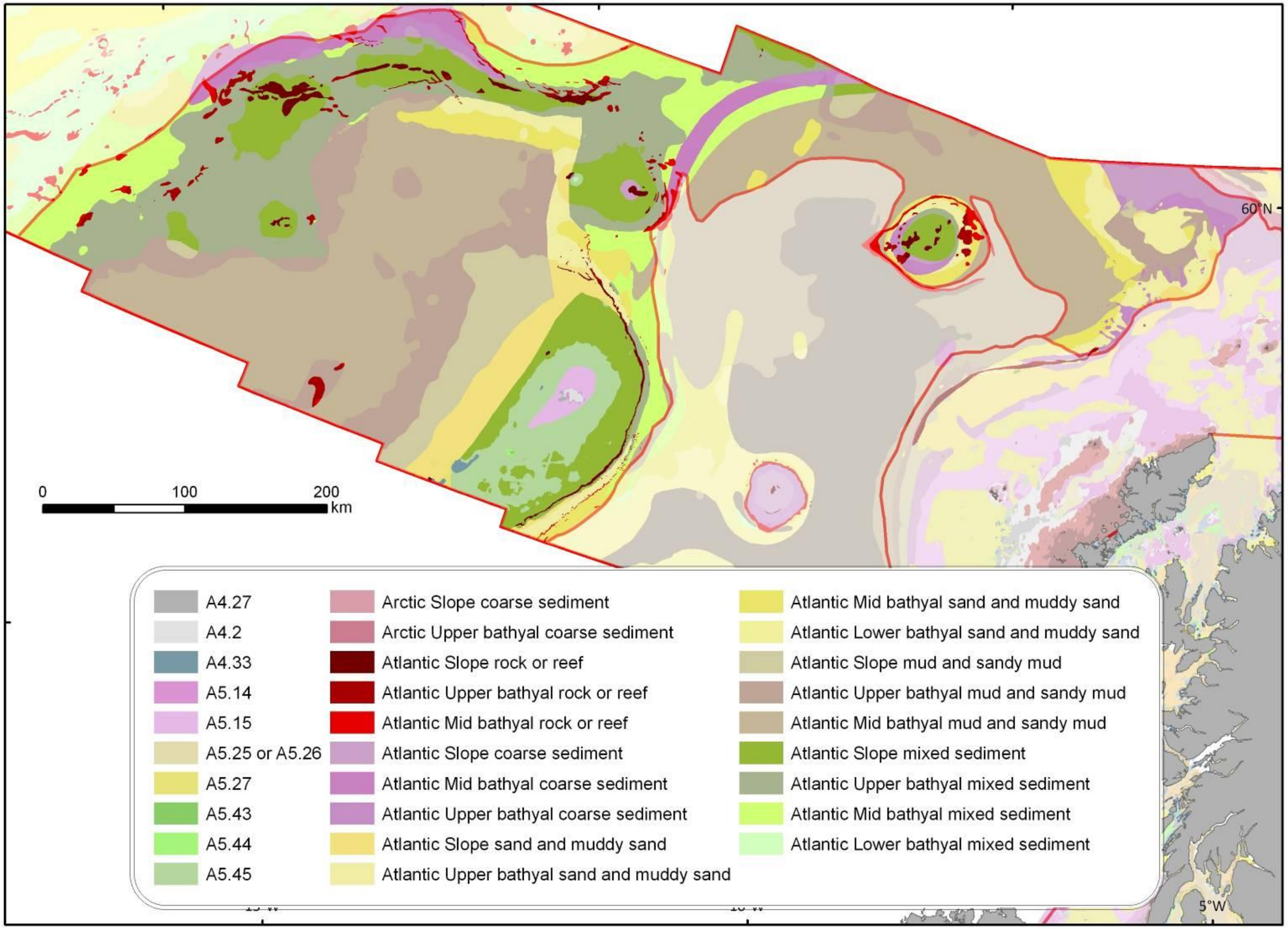

Figure 35. Regional Sea 11: Rockall and Hatton Bank.

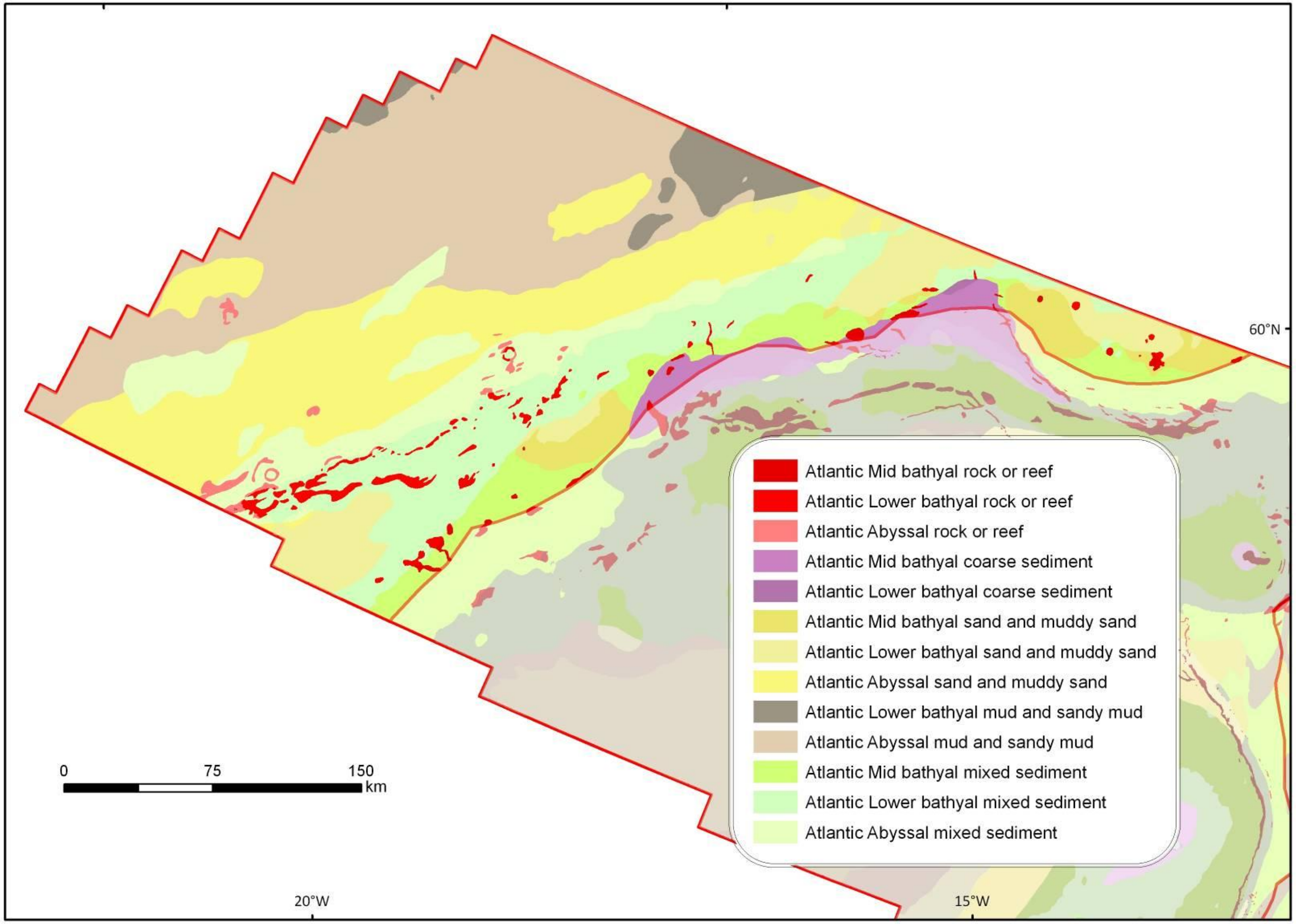

Figure 36. Regional Sea 12: Atlantic Northwest Approaches.

Table 14. Total area and proportion of the UK marine area covered by each habitat, and the proportion of each habitat within each of the 12 regional seas. Habitats are reported as codes or abbreviations to save space, with full habitat names given in Table 15.

Habitat	Total area (km^2)	Total area (%)	Percentage of each habitat within each of 12 regional seas											
			1	2	3	4	5	6	7	8	9	10	11	12
A3.1	7,286	0.85	0.07	0.06	7.70	0.74	0	0.74	4.47	2.46	0	0	0	0
A3.2	2,234	0.26	0.24	0.70	2.76	0.11	0	0.33	1.27	0.17	0	0	0	0
A3.22	25	0.00	0	0	0	0.03	0	0	0	0	0	0	0	0
A3.31	315	0.04	<0.01	0	<0.01	<0.01	0	0	0.48	0.12	0	<0.01	0	0
A4.1	165	0.02	0	0	0	0.18	0	0	0	0	0	0	0	0
A4.11/A4.13	11,136	1.30	0.02	0.09	13.83	0.70	0	0.92	2.22	4.98	0	0	0	0
A4.12	1,359	0.16	0.01	0.02	4.95	0	0	0.49	0.36	0.02	0	0	0	0
A4.2	16,016	1.87	1.81	0.11	12.11	2.13	0	0.64	3.71	5.33	0	0	0.06	0
A4.25	<1	<0.01	0	0	0	<0.01	0	0	0	0	0	0	0	0
A4.27	24,637	2.87	2.10	0.03	2.49	18.53	0	1.02	1.72	2.20	0	0	0.02	0
A4.31	1,791	0.21	0.01	0	0	<0.01	0	<0.01	2.43	0.78	0	0	0	0
A4.33	1,265	0.15	0.17	0	0	<0.01	0	0.21	0.49	0.47	0	0	0.09	0
A5.12	487	0.06	0	0.03	0	0.52	0	0	0	0	0	0	0	0
A5.13	16,351	1.91	0.14	18.58	3.85	0.57	0	8.36	2.15	0.15	0	<0.01	<0.01	0
A5.14	49,678	5.79	2.01	12.81	25.40	10.08	0	20.91	9.64	10.76	0	0	0.01	0
A5.15	63,861	7.44	5.67	3.51	5.22	20.12	0	17.84	5.56	18.36	0	0	0.57	0
A5.22	455	0.05	0	0.10	0	0.43	0	0.01	0	0	0	0	0	0
A5.23/A5.24	22,708	2.65	0.56	25.54	4.21	0.99	0	11.90	1.68	0.14	0	0	0.01	0
A5.25/A5.26	50,467	5.88	7.18	28.70	6.34	7.80	0	6.51	16.46	4.17	0	0	<0.01	0
A5.27	178,007	20.75	62.94	7.50	0.31	28.41	0	6.47	13.88	26.96	0	0	0.08	0
A5.32	93	0.01	0	0.04	0	0.08	0	0	0	0	0	0	0	0
A5.33/A5.34	2,071	0.24	0.08	0.04	1.06	0.04	0	4.75	0.29	0.01	0	0	0	0
A5.35/A5.36	5,661	0.66	0.29	0.06	1.68	0.18	0	4.07	10.54	0	0	0	0	0
A5.37	41,199	4.80	16.39	0.02	0	5.96	0	7.82	16.86	0.32	0	0	0	0

Habitat	Total area (km^2)	Total area (%)	Percentage of each habitat within each of 12 regional seas											
			1	2	3	4	5	6	7	8	9	10	11	12
A5.42	21	<0.01	0	0.01	0	0.02	0	0	0	0	0	0	0	0
A5.43	1,597	0.19	0.04	1.10	1.72	0.01	0	1.16	0.22	0.03	0	0	<0.01	0
A5.44	3,509	0.41	0.19	0.87	4.83	0.12	0	2.22	2.24	0.08	0	0	0.02	0
A5.45	9,232	1.08	0.06	0.10	1.52	0.65	0	3.58	2.33	0.44	0	0	3.95	0
AtSI rock	1,760	0.21	<0.01	0	0	0.02	0	<0.01	0.16	0.19	0	0.03	0.98	0
AtSI cs	11,581	1.35	0	0	0	0.50	0	0.02	0.06	5.93	0.15	0.96	1.82	0
AtSI s&ms	15,211	1.77	0.01	0	0	0.28	0	0.02	0.29	7.56	0	0	3.41	0
AtSI m&sm	7,597	0.89	0.01	0	0	0.14	0	0	0.37	0.93	0	0	4.25	0
AtSI ms	16,972	1.98	0	0	0	0.36	0	0	0.10	1.45	0	0	10.22	0
AtUB rock	1,494	0.17	0	0	0	0.01	0	0	0	0.14	0	0.04	0.89	0
AtUB cs	3,469	0.40	0	0	0	0.01	0	0	0	0.13	0	1.00	1.84	0
AtUB s&ms	6,741	0.79	0	0	0	<0.01	0	0	0	0.21	0	0	4.50	0
AtUB m&sm	15,994	1.86	0	0	0	0.09	0.04	0	0	0.84	0	0	10.29	0
AtUB ms	20,596	2.40	0	0	0	0.03	0	0	0	0.01	0	0.23	14.18	0
AtMB rock	1,727	0.20	0	0	0	<0.01	0	0	0	0	0	0.91	0.56	0.46
AtMB cs	4,861	0.57	0	0	0	0	0	0	0	0.23	0	0.37	2.27	1.47
AtMB s&ms	12,170	1.42	0	0	0	<0.01	0	0	0	0.25	0	4.94	4.17	3.70
AtMB m&sm	63,284	7.38	0	0	0	0.11	20.78	0	0	1.77	0	31.35	28.19	0
AtMB ms	17,167	2.00	0	0	0	<0.01	0	0	0	0.23	0	3.06	7.51	5.72
AtLB rock	994	0.12	0	0	0	0	0	0	0	0	0	0.18	0	1.23
AtLB cs	107	0.01	0	0	0	0	0	0	0	0	0	0.08	0	0.08
AtLB s&ms	12,781	1.49	0	0	0	0	0	0	0	0	0	11.17	0.02	7.75
AtLB m&sm	31,944	3.72	0	0	0	0.02	75.47	0	0	0.01	0	45.53	0	3.20
AtLB ms	9,438	1.10	0	0	0	0	0	0	0	0	0	0.16	0	13.09
AtA rock	436	0.05	0	0	0	0	0	0	0	0	0	0	0	0.61
AtA s&ms	16,115	1.88	0	0	0	0	0	0	0	0	0	0	0	22.59
AtA m&sm	22,104	2.58	0	0	0	0	3.70	0	0	0	0	0	0	30.94

Habitat	Total area (km^2)	Total area (%)	Percentage of each habitat within each of 12 regional seas											
			1	2	3	4	5	6	7	8	9	10	11	12
AtA ms	6,523	0.76	0	0	0	0	0	0	0	0	0	0	0	9.14
ArSl rock	5	<0.01	0	0	0	0	0	0	0	<0.01	0.01	0	0	0
ArSl cs	5,198	0.61	0	0	0	0	0	0	0	1.57	7.27	0	0.04	0
ArSl s&ms	981	0.11	0	0	0	0	0	0	0	0.19	1.74	0	0	0
ArSl m&sm	287	0.03	0	0	0	0	0	0	0	<0.01	0.67	0	0	0
ArSl ms	1,286	0.15	0	0	0	0	0	0	0	0.42	1.75	0	0	0
ArUB rock	5	0.00	0	0	0	0	0	0	0	0	0.01	0	0	0
ArUB cs	4,074	0.47	0	0	0	0	0	0	0	<0.01	9.54	0	0.01	0
ArUB s&ms	2,713	0.32	0	0	0	0	0	0	0	0	6.42	0	0	0
ArUB m&sm	3,289	0.38	0	0	0	0	0	0	0	0	7.76	0	0	0
ArUB ms	285	0.03	0	0	0	0	0	0	0	0	0.66	0	0	0
ArMB cs	706	0.08	0	0	0	0	0	0	0	0	1.62	0	0	0
ArMB s&ms	1,004	0.12	0	0	0	0	0	0	0	0	2.37	0	0	0
ArMB m&sm	21,298	2.48	0	0	0	0	0	0	0	0	50.35	0	0	0
ArMB ms	697	0.08	0	0	0	0	0	0	0	0	1.59	0	0	0
ArLB m&sm	2,245	0.26	0	0	0	0	0	0	0	0	5.19	0	0	0
ArLB ms	1,246	0.15	0	0	0	0	0	0	0	0	2.91	0	0	0
All	858,014	100	19.6	7.0	2.4	10.6	0.03	3.8	3.6	15.3	4.9	7.5	16.8	8.3

Table 15. Habitat names for codes and abbreviations used in Table 14.

EUNIS code/ Abbreviation	Full name	Abbreviation	Full name
A3.1	Atlantic and Mediterranean high energy infralittoral rock	AtUB cs	Atlantic Upper bathyal coarse sediment
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	AtUB s&ms	Atlantic Upper bathyal sand and muddy sand
A3.22	Kelp and seaweed communities in tide-swept sheltered conditions	AtUB m&sm	Atlantic Upper bathyal mud and sandy mud
A3.31	Silted kelp on low energy infralittoral rock with full salinity	AtUB ms	Atlantic Upper bathyal mixed sediment
A4.1	Atlantic and Mediterranean high energy circalittoral rock	AtMB rock	Atlantic Mid bathyal rock or reef
A4.11/A4.13	Very tide-swept faunal communities on circalittoral rock or Mixed faunal turf communities on circalittoral rock	AtMB cs	Atlantic Mid bathyal coarse sediment
A4.12	Sponge communities on deep circalittoral rock	AtMB s&ms	Atlantic Mid bathyal sand and muddy sand
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	AtMB m&sm	Atlantic Mid bathyal mud and sandy mud
A4.25	Circalittoral faunal communities in variable salinity	AtMB ms	Atlantic Mid bathyal mixed sediment
A4.27	Faunal communities on deep moderate energy circalittoral rock	AtLB rock	Atlantic Lower bathyal rock or reef
A4.31	Brachiopod and ascidian communities on circalittoral rock	AtLB cs	Atlantic Lower bathyal coarse sediment
A4.33	Faunal communities on deep low energy circalittoral rock	AtLB s&ms	Atlantic Lower bathyal sand and muddy sand
A5.12	Sublittoral coarse sediments in variable salinity (estuaries)	AtLB m&sm	Atlantic Lower bathyal mud and sandy mud
A5.13	Infralittoral coarse sediment	AtLB ms	Atlantic Lower bathyal mixed sediment
A5.14	Circalittoral coarse sediment	AtA rock	Atlantic Abyssal rock or reef
A5.15	Deep circalittoral coarse sediment	AtA s&ms	Atlantic Abyssal sand and muddy sand
A5.22	Sublittoral sand in variable salinity (estuaries)	AtA m&sm	Atlantic Abyssal mud and sandy mud
A5.23/A5.24	Infralittoral fine sand or Infralittoral muddy sand	AtA ms	Atlantic Abyssal mixed sediment
A5.25/A5.26	Circalittoral fine sand or Circalittoral muddy sand	ArSl rock	Arctic Slope rock or reef
A5.27	Deep circalittoral sand	ArSl cs	Arctic Slope coarse sediment
A5.32	Sublittoral mud in variable salinity (estuaries)	ArSl s&ms	Arctic Slope sand and muddy sand
A5.33/A5.34	Infralittoral sandy mud or Infralittoral fine mud	ArSl m&sm	Arctic Slope mud and sandy mud
A5.35/A5.36	Circalittoral sandy mud or Circalittoral fine mud	ArSl ms	Arctic Slope mixed sediment
A5.37	Deep circalittoral mud	ArUB rock	Arctic Upper bathyal rock or reef

EUNIS code/ Abbreviation	Full name	Abbreviation	Full name
A5.42	Sublittoral mixed sediment in variable salinity (estuaries)	ArUB cs	Arctic Upper bathyal coarse sediment
A5.43	Infralittoral mixed sediments	ArUB s&ms	Arctic Upper bathyal sand and muddy sand
A5.44	Circalittoral mixed sediments	ArUB m&sm	Arctic Upper bathyal mud and sandy mud
A5.45	Deep circalittoral mixed sediments	ArUB ms	Arctic Upper bathyal mixed sediment
AtSl rock	Atlantic Slope rock or reef	ArMB cs	Arctic Mid bathyal coarse sediment
AtSl cs	Atlantic Slope coarse sediment	ArMB s&ms	Arctic Mid bathyal sand and muddy sand
AtSl s&ms	Atlantic Slope sand and muddy sand	ArMB m&sm	Arctic Mid bathyal mud and sandy mud
AtSl m&sm	Atlantic Slope mud and sandy mud	ArMB ms	Arctic Mid bathyal mixed sediment
AtSl ms	Atlantic Slope mixed sediment	ArLB m&sm	Arctic Lower bathyal mud and sandy mud
AtUB rock	Atlantic Upper bathyal rock or reef	ArLB ms	Arctic Lower bathyal mixed sediment

4.2 Confidence map for predictive seabed habitat map

An important part of the UKSeaMap 2010 project is to provide an assessment of confidence in the final predictive habitat map. Two key principles are used to derive a measure of confidence: uncertainty and data quality. Where possible, the uncertainties associated with the contributing data layers were analysed statistically to obtain a quantitative, probabilistic measure of confidence. For the seabed substrata layer, confidence was assessed qualitatively.

Mapping uncertainty has a dual purpose in UKSeaMap 2010. It is used for selecting the most likely classification of habitats and then for visualising the probability associated with this classification. A cell on a boundary of a biological zone will be assigned to one of the zones, but with a lower probability than a cell falling far from the boundary of its biological zone. For biological zones and energy classes, probability maps were made by comparing interpolated or modelled physical data layers produced during UKSeaMap 2010 with measurements of the same physical characteristics in the field. The spatial variation in differences between these data sources was then used to create the probability maps.

As a categorical and interpreted parameter, seabed substrate required a different approach. It was not possible to compare seabed samples with the substrate classes in the map, since these samples were themselves all used in the process to make the map. The assessment of confidence in seabed substrates used a modified version of the MESH confidence assessment method, applying a qualitative assessment to the remote-sensing, ground-truthing and interpretation methods used to make the map. These methods varied in different parts of the map, and the resulting assessments were combined to produce a single confidence map for the seabed substrate layer.

The overall predictive seabed habitat confidence map was created by multiplying confidence scores for the main input layers: biological zones; seabed substrata; wave energy and tidal current energy (Figure 37). Biogeography and salinity were not included in the confidence model. For each cell, the confidence scores that were multiplied depended on the final predicted habitat as not all input layers are required for all habitat types. For example, the prediction of A5.43 (Infralittoral mixed sediments) requires only biological zones and substrate data and not kinetic energy. Table 16 indicates which input layers were multiplied in the calculation of the final confidence scores for different habitat types.

Table 16. Contributing input layers for groups of habitats. A tick below the name of an input layer indicates that it was used in predicting the habitats in a particular group and its confidence score was therefore used to calculate the values for the final confidence layer.

Habitat group	Biological Zone	Tidal energy	Wave energy	Substrate
Infralittoral & circalittoral rock	✓	✓	✓	✓
Deep circalittoral rock	✓	✓		✓
Deep-sea rock (below 200 metres)	✓			✓
Sediment	✓			✓

Towards the final stages of the project, an external review of the methods used to assess confidence in UKSeaMap was undertaken (see Technical Report No. 7). Recommendations from this review were applied to the final version of the model.

Many patterns clearly visible in the seabed substrata confidence map appear in the final confidence map. This can be explained because the transitions between different confidence scores for the seabed substrate map are often sharp, for example where multibeam backscatter data have been used adjacent to an area of otherwise low data quality (e.g. with few samples). Transitions between confidence scores in the biological zone confidence and energy confidence layers are smoother. Added to this, in these areas of sharp transitions there is often no contribution from energy confidence derived from waves, because the areas are undisturbed by waves.

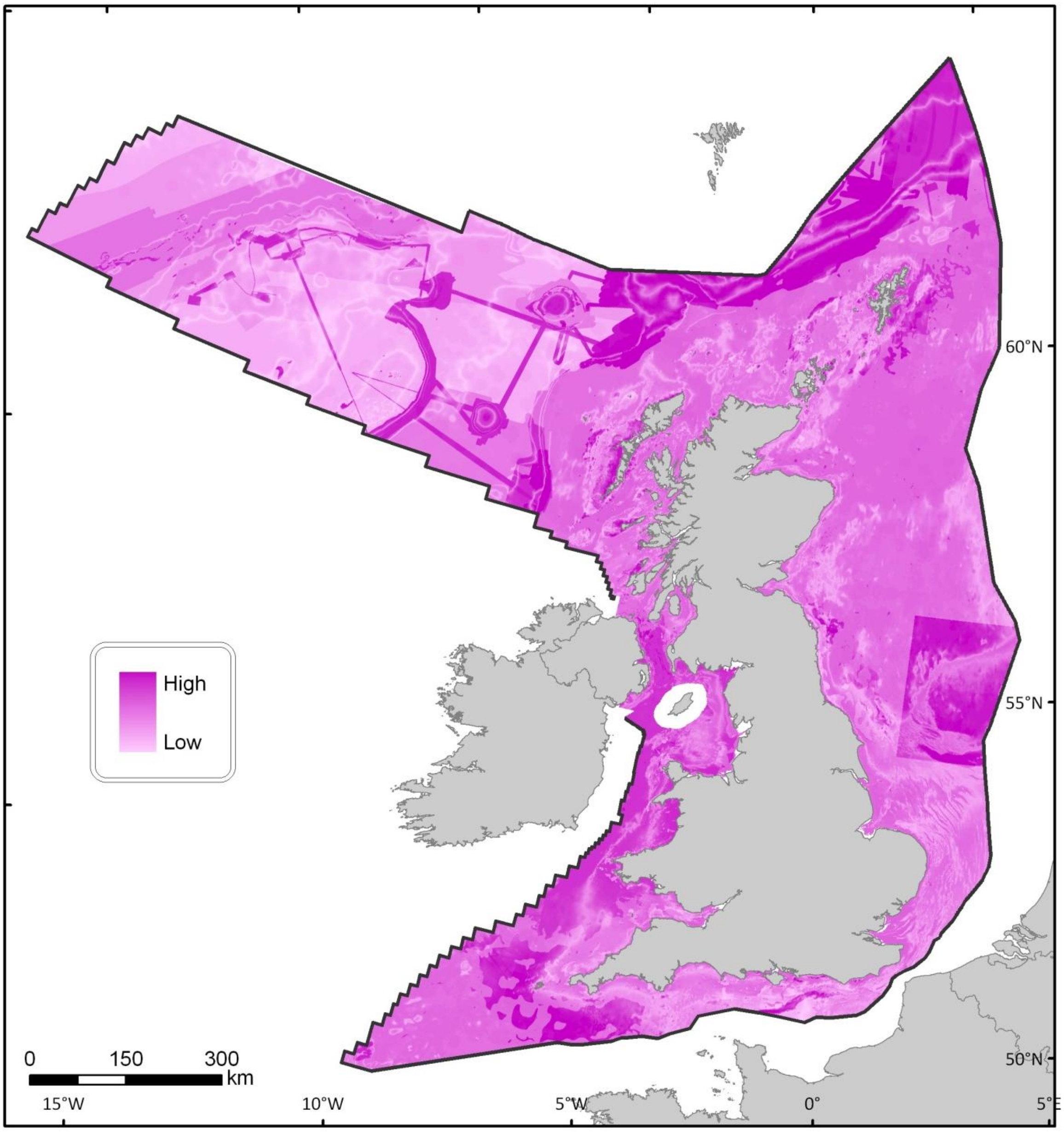

Figure 37. UKSeaMap 2010 confidence map.

It is important to note the different approach necessary for assessing confidence in seabed substrata, compared to assessing confidence in biological zones and energy classes. For seabed substrata, a low confidence score means that the data quality in this area is lower than in other areas, but it does not mean that we are unsure about the habitat present. In the Northern North Sea, we are certain that there are muddy habitats since there is a fishery targeting these habitats. However, the data for this area are of relatively low quality compared to other areas. Conversely, for many deep sea areas the biological zone confidence and energy confidence maps show high scores. This is because we are certain that - based on the data available - a cell falls in a particular zone or class, usually because it its physical environment is far from boundary conditions. However, we currently do not have a way to spatially assess the outputs from satellites or hydrodynamic models and compare them to alternatives.

5 Discussion

5.1 Comparisons with other predictive seabed habitat maps

Multiple predictive seabed habitat maps are now available for parts of UK waters; it is important to compare these outputs to indicate how different modelling approaches affect the habitat predictions, and hence their suitability for different situations. The approaches used in UKSeaMap 2010 are more closely aligned with those applied in the MESH project, than with those used in UKSeaMap 2006 or HABMAP. Therefore, in comparing the map outputs of UKSeaMap 2010 with the MESH predictive seabed habitat map (henceforth the MESH predictive map), the effect of improved input data is likely to be the main factor in any differences. Comparing UKSeaMap 2010 to UKSeaMap 2006 or HABMAP outputs is likely to highlight differences in modelling approach as well as input data. A summary of modelling approaches and input data used by various broadscale predictive mapping projects in the UK is given in Table 17. A more detailed discussion of the differences and similarities between UKSeaMap 2010 and the MESH and HABMAP predictive maps are provided in Technical Report 6.

5.1.1 UKSeaMap 2010 compared to the MESH EUNIS model

Data resolution and/or number of sources have increased in UKSeaMap 2010 for all of the physical input layers. The main differences in modelling technique, as seen in Table 17 are:

- UKSeaMap 2010 uses seabed kinetic energy caused by waves and currents to classify high, moderate and low energy environments while the MESH EUNIS model used shear stress caused by currents.

- UKSeaMap 2010 uses an additional five biological zones to classify deep sea areas. The UKSeaMap 2010 analysis also considers two biogeographic zones (Arctic and Atlantic) which were not part of the MESH EUNIS model. Note: for comparison purposes, the additional biological zones were aggregated to one “deep sea” class, which is the zone used in the MESH model, while the biogeographic zones were not included in the comparison.

The effect of these differences can be seen in Table 18 which shows the extent to which EUNIS codes and input datasets match in the overlapping study area. The total area differs for EUNIS Level 4 because some areas in each model are only classified at Level 3.

The degree of agreement between habitat components indicates the relative roles of biological zones, substrate types and energy classes in determining the overall match between the models. Energy is only used for classifying infralittoral and circalittoral rocky habitats; therefore, the matching area for energy levels was only calculated for areas mapped as rock and infralittoral or circalittoral in UKSeaMap 2010. The energy classes only match in 29% of these habitats, which will contribute to some of the mismatch between models at EUNIS Level 3; however, this area is only 6% of the total overlapping study area and there must therefore also be other effects. This discrepancy in the extent of matching energy classes between the two models reflects the change in energy modelling techniques and assignment of thresholds in UKSeaMap 2010 compared to the MESH EUNIS model.

Table 17. Comparison of the methods and input data used by broadscale predictive seabed habitat mapping projects in the UK.

	UKSeaMap (2004 - 2006)	MESH (2004 - 2008)	HABMAP (2004 - 2010)	UKSeaMap (2009 - 2010)
Classification system	Broadscale habitats (not EUNIS)	EUNIS	Marine Habitat Classification of Britain & Ireland	EUNIS
GIS approach	Vector net (standard polygon size & shape)	Raster	Vector (unrestricted polygons)	Raster
Equivalent EUNIS level	3 or 4	3 or 4	4 or 5	3 or 4
Resolution	Fine - 0.02° Coarse - 0.5°	0.0025°	Variable polygon sizes	0.0025°
Seabed substrata	5 classes	5 classes	43 classes	5 classes
Salinity	Not used	Not used	6 classes	2 classes
Biological zones	Aphotic Photic Shallow Shelf	Infralittoral Circalittoral Deep circalittoral Deep sea	Infralittoral Circalittoral Offshore[31]	Infralittoral Circalittoral Deep circalittoral Slope Upper bathyal Mid bathyal Lower bathyal Abyssal
Energy	Shear stress Currents	Shear stress Currents	Shear stress Waves Currents	Kinetic energy Waves Currents
Biogeography	Warm deep-water Cold deep-water	Not used	Not used	Arctic Atlantic
Citation	Connor *et al* (2006)	Coltman *et al* (2008)	Robinson *et al* (2009)	McBreen *et al* (2010)

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[31] Offshore is the term used in the Marine Habitat Classification of Britain & Ireland, and is exactly equivalent to the deep circalittoral zone, which is the term used in the EUNIS classification system.

Table 18. Extent to which the UKSeaMap 2010 and MESH predictive maps match at three EUNIS levels and with three components used to develop the models.

		Total area (km^2)	Area of matching codes (km^2)	Area of matching codes (% of total area)
EUNIS level	2	701,912	626,870	89
	3	701,912	580,963	83
	4	483,702	359,657	74
Habitat component	Biological zone	701,912	600,563	86
	Substrate type	701,912	600,681	86
	Energy class	701,912	307,900	44
	Energy class (infralittoral or circalittoral rock only)	43,064	12,554	29

One of the contributors to the mismatch between biological zones is the use of a different light penetration value to define the threshold between the infralittoral and circalittoral zones. The UKSeaMap 2010 model uses values of ≥1% light penetration at the seabed to define the infralittoral zone; whereas the MESH model used values of ≥2.36% (see Technical Report 2). The result is a 50% increase in the extent of the infralittoral zone.

The MESH EUNIS model predicted a large area of A5.1 (sublittoral coarse sediment) and A5.2 (sublittoral sand) where UKSeaMap 2010 predicts A3 and A4 (infralittoral and circalittoral rock of all energies). This may be explained by the increase in extent of rock in the substrate dataset since the MESH EUNIS model was built. Gafeira *et al* (2010) explain that much of the previous dataset was based primarily on samples, with particle size analysis used to assign a sediment type. However, the procedure did not account for the poor recovery of rock samples and therefore underestimated the total amount of rock. As a result, the proportion of rock in overlapping study areas has gone up from 3% in MESH to 10% in UKSeaMap 2010 (see Technical Report 6).

The MESH EUNIS model predicted a large area of A6.5 (deep sea mud) where UKSeaMap 2010 predicts A6.1 (deep sea rock) and “A6.3 or A6.4” (deep sea sand or muddy sand). MESH predicted a large area of A6.2 (deep sea mixed sediment) where UKSeaMap 2010 has predicted A6.1 (deep sea rock) and deep sea coarse sediment. Since the conclusion of the MESH project, substrate data for the offshore area have improved substantially - in terms of quality and quantity of data - as a result of the inclusion of deep sea NOC survey data (Jacobs and Porritt 2009) and the BGS hard substrate layer (Gafeira *et al* 2010).

UKSeaMap 2010 uses improved higher resolution data and improved thresholds for light and energy data compared with the MESH EUNIS model. UKSeaMap 2010 is therefore an improvement on the MESH predictive map for UK waters and it is advised that the former be used as the most accurate broadscale EUNIS habitat map for UK seas. While these analyses examine the percentage of agreement between the maps it is important to highlight that reasons for disagreement have not been fully investigated.

5.1.2 UKSeaMap 2010 compared to the HABMAP model

As opposed to the ‘top-down’ approach of UKSeaMap 2010, the overall approach to HABMAP can be seen as ‘bottom-up’, using physical data to apply rules derived from biological samples. The process is less rigid than that of UKSeaMap and as a result, biological information for an area may override the physical data when defining the presence of biotopes beyond EUNIS Levels 3 and 4. The main differences in modelling technique in terms of the physical datasets used in UKSeaMap 2010 can be seen in Table 17.

An overview of how well the two models agree is given in Table 19, which shows the extent to which EUNIS codes and habitat components match in the overlapping study area. Habitat components for HABMAP were derived from EUNIS habitats; as a result, the total area differs between components varies - biological zones, substrate type and energy class are not always explicit in EUNIS habitat descriptions.

Table 19. Extent to which data from the UKSeaMap 2010 and HABMAP predictive maps match at three EUNIS levels and with three components used to develop the models.

		Total area (km^2)	Area of matching codes (km^2)	Area of matching codes (% of total area)
EUNIS level	2	29,603	27,003	91
	3	29,603	10,364	35
	4	27,885	5,683	20
Habitat component	Biological zone	29,327	16,004	55
	Substrate type	29,327	11,423	39
	Energy class	1,370	253	18
	Energy class (infralittoral or circalittoral rock only)	1,116	156	14

The degree of agreement between input datasets indicates the relative roles of biological zones, substrate types and energy classes in determining the overall match between the models. The highest level of agreement between the two models is for biological zones (55%). Levels of agreement between substrate types (39%) and energy (14%) are low.

The differences between energy classes may be due to the different energy data used. HABMAP used wave and tidal bed shear stress while UKSeaMap 2010 uses wave and tidal seabed kinetic energy. However, note that the extent of infralittoral and circalittoral rock for which energy is used to classify is less than 4% of the total overlapping study area and therefore differences in biological zone and substrate type must have a greater effect on the differences in predicted EUNIS habitats. The way in which HABMAP uses substrate data involves linking sediment samples that often occurs in the same region as particular biotope points. However, a sediment sample used in HABMAP may not have been used to decide the original position of the biotope in the EUNIS classification and may differ from the sediment types listed as being associated with the biotope. HABMAP also used a sediment map with 43 classes, which differs from the sediment classes used in the EUNIS classification and therefore UKSeaMap 2010 (see section 3.1).

There is more than 50% agreement in three of the nine habitats predicted by UKSeaMap 2010, A.52: sublittoral sand and muddy sand, A5.3: sublittoral mud and sandy mud and A5.4: sublittoral mixed sediment (see Technical Report 6). The potential reasons for mismatch for individual habitats are discussed in more detail below.

HABMAP has predicted a large proportion of A5.4 (sublittoral mixed sediment) where UKSeaMap 2010 has predicted A5.1 (sublittoral coarse sediment). In the HABMAP modelling technique, biological data can take precedence over physical data in defining biotopes for areas where a specific biotope is not clear. In this case, this observation may be explained by a combination of two phenomena:

- sediment was incorrectly mapped as coarse when it is in fact mixed;

- it may be that mixed sediment biotopes were the best fit biologically despite being found in coarse sediment areas (Ramsay, K., Pers. Comm., 2010; see Technical Report No. 6 for more details).

HABMAP has predicted a lot of A5.4 where UKSeaMap has predicted A3 and A4 (infralittoral and circalittoral rock - all energies). This may be because areas classed as rock in the substrate data were actually rock or hard substrate at or within 50cm of the seabed (Gafeira *et al* 2010). Therefore, if the rock is buried by 50cm of sediment, the biological communities at the seabed will be best described by a sediment biotope.

HABMAP has predicted a lot of A4.2 (moderate energy circalittoral rock) where UKSeaMap has predicted A3.1 (high energy infralittoral rock) and A4.1 (high energy circalittoral rock). In the overlapping study area HABMAP has more area mapped as circalittoral than UKSeaMap. This may be explained by the resolution of light penetration data used by HABMAP (9km) in comparison with UKSeaMap (4km) or may be that HABMAP circalittoral biotopes were the best fitting biotopes based on the biological data.

HABMAP used point data to construct its predictive model for the southern Irish Sea (Robinson *et al* 2009). Where samples were sparse, the predicted biotopes were awarded low confidence scores. It has previously been suggested that the HABMAP approach could be applied to the UK marine area. To scope the feasibility of this approach at a UK scale, UKSeaMap 2010 created sample density maps. This allows a visual comparison of the density of habitat samples in the HABMAP area (southern Irish Sea scale; Figure 38 (a)) and the density of samples at a UK scale (Figure 38 (b)).

Figure 38 (a) contains the locations of samples used in HABMAP (Robinson *et al* 2009). Figure 38 (b) contains sample point data from the following sources:

- JNCC marine recorder database;
- Environment Agency;
- National Marine Monitoring Programme;
- Irish Seabed Image Archive;
- CEFAS ME3112 data points;
- Data obtained from Emu Ltd. - English and Welsh coasts and offshore;
- Data obtained from ABPMer - English coast;
- Data obtained from MES - English and Welsh coasts and offshore.

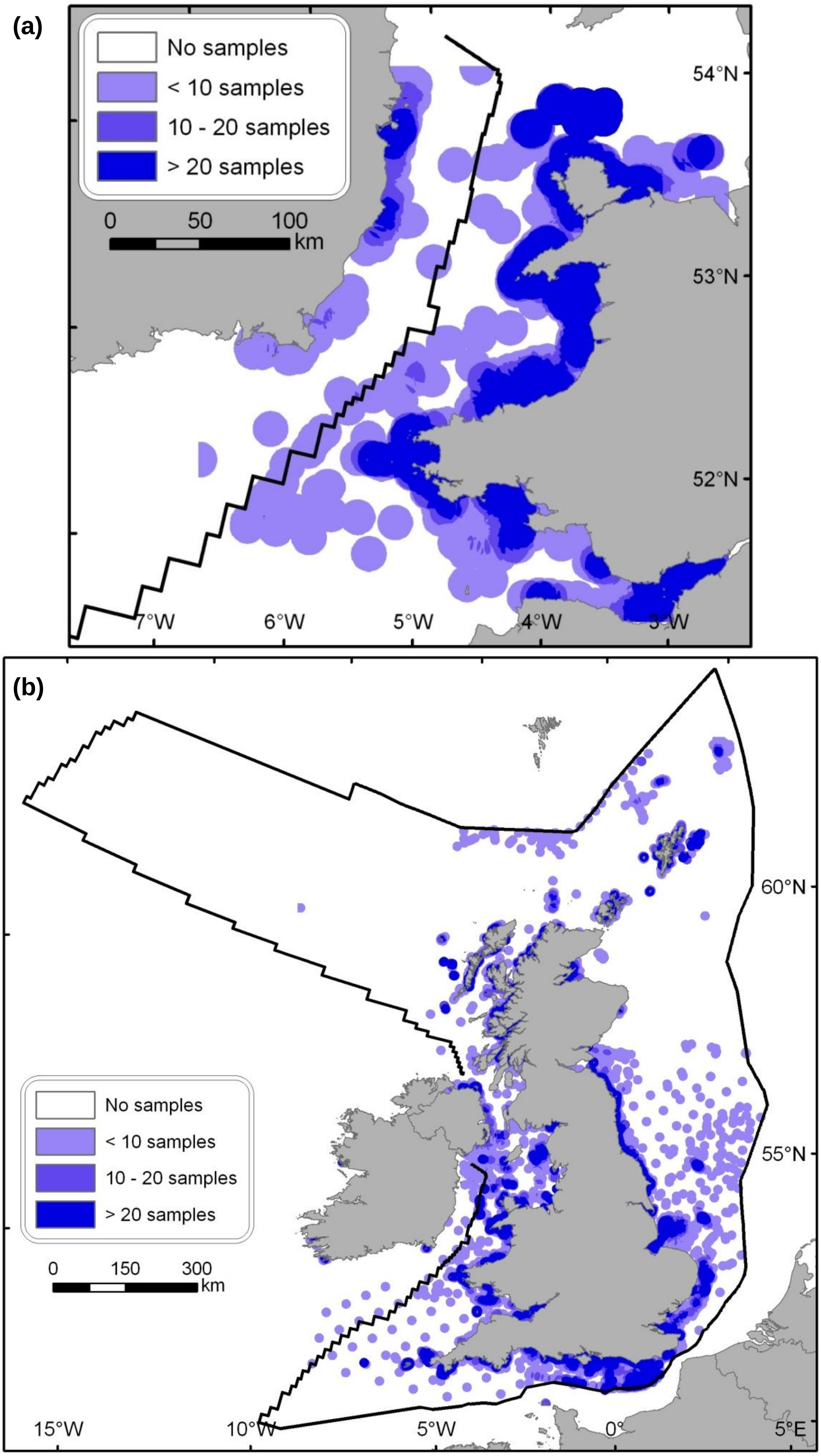

Figure 38. Sample density (as number of samples per 10km2) for samples interpreted to habitats (a) used in the HABMAP project to build the predictive seabed habitat model in the Southern Irish Sea, and (b) available across the UK marine area.

These sample density maps demonstrate why it is not currently appropriate to use the sample-based, ‘bottom-up’ approach for the UK marine area, because the sample density in offshore areas is too low to drive a reliable habitat model using the methods of the HABMAP project, particularly in the Northern North Sea and in the North-West Approaches.

HABMAP predicted detailed biotopes beyond EUNIS levels 3 and 4 based on relationships between physical and biological information that are not necessarily consistent with the physical attributes listed as part of biotope definitions, whereas UKSeaMap predicts broadscale level 3 and 4 habitats based on physical information only. For this reason, significant divergence between the model outputs is to be expected.

5.2 Comparison with MESH survey maps

The UKSeaMap 2010 predictive habitat map was compared to EUNIS habitat data derived from habitat surveys, which are freely available to download from the MESH website: www.searchMESH.net/webGIS. Only survey maps with overall confidence scores higher than 58% were included in this analysis as we can be certain that maps with these scores were derived using both remote sensing and ground-truthing data. The resolution of the data is generally much higher than the resolution used in the UKSeaMap model. The survey maps can therefore map seabed habitats at a much finer scale than is possible with predictive modelling. This comparison is included partly to illustrate that maps produced for use at different scales are unlikely to fully agree. A more detailed discussion of the differences and similarities between UKSeaMap and maps derived from surveys is given in Technical Report No. 6.

An overview of the agreement between EUNIS habitats and habitat components in the overlapping area between MESH survey maps and the UKSeaMap predictive map is given in Table 20. It must also be remembered that as with the predictive maps areas of disagreement maybe be very minor, e.g. small difference in percentages of sand, gravel or mud which will result in areas falling into a different class.

Table 20. Extent to which data from UKSeaMap 2010 and MESH survey maps match at three EUNIS levels and for three habitat components.

		Total area (km^2)	**Area of matching codes (km^2)**	**Area of matching codes (% of total)**
EUNIS level	2	27,887	20,952	75
	3	27,887	10,071	36
	4	24,076	4,363	18
Habitat component	Biological zone	23,678	13,010	55
	Substrate class	23,687	9,782	41
	Energy class	3,305	2,031	61
	Energy class (infralittoral or circalittoral rock only)	2,089	1,302	62

The level of agreement between the energy classes in rocky areas is much higher (62%) than with the MESH (29%) or HABMAP modelled maps (14%), although this area is only 6% of total overlapping study area. There is less agreement with biological zones (55%) and substrate (41%). More than half of UKSeaMap rocky habitats are found as sedimentary habitats in the MESH survey maps.

James *et al* (2010) compared modelled points to survey points from the South Coast Regional Environmental Characterisation. They investigated the discrepancies between modelled and survey data and found that the reasons lay in six main categories, three of which related to sediment data, including the vertical resolution of sediment thickness at the seabed. It is likely that this plays a role in the rock-sediment mismatch between UKSeaMap 2010 and MESH survey maps, particularly because the rock class in UKSeaMap may be covered by up to 0.5m of sediment.

5.3 Summary of recommendations

5.3.1 Seabed substrata

In future, with additional co-located substratum information and data describing the biological communities, further investigations of the four broad sediment classes used in seabed habitat classifications should be made.

5.3.2 Energy at the seabed

The resolution of the energy model needs improving and further validation in places, e.g. in the Firth of Lorn for currents and in Shetland for waves. With only three classes in the EUNIS classification for energy, the overall pattern for kinetic energy is bound to be coarse and miss local variations.

The analysis undertaken by UKSeaMap 2010 has made the first estimates for numeric values of kinetic energy associated with the EUNIS classes of high, moderate and low energy. However, this analysis could be improved if co-located in-situ measurements of seabed habitat and kinetic energy were available. This would increase our understanding of the response of seabed habitats to waves and currents, both separately and in combination.

Recommendations have been made by West *et al* (2010) about how to improve the assessment of kinetic current energy confidence. The method used is likely to over-estimate confidence. Areas in the energy maps which it has been suggested are incorrect, e.g. the Firth of Lorn for currents and in Shetland for waves appear to have high confidence in the respective energy confidence maps. This is likely to be due to the fact that probabilities predict the certainty that cells are assigned to the right category rather than the fact the under-lying data are correct. In future updates of the both the energy layers and the confidence layers, these issues should be addressed. It is important to note that both energy confidence maps may therefore over-estimate the confidence in certain areas, particularly the current confidence map.

5.3.3 Biological zones

Through the work completed by Howell (2010), five deep sea zones have been identified; upper slope, upper bathyal, mid bathyal, lower bathyal and abyssal. It is recommended that these new deep sea biological zones and coarse sediment be included in updates to the EUNIS classification system.

5.3.4 Atlantic and Arctic biogeographic zones

UK waters contain both Atlantic and Arctic waters, but there is currently no Arctic section of the EUNIS classification system for seabed habitats. The introduction of the Arctic as a biogeographic region at a high level in EUNIS is recommended. Howell *et al* (2010) have identified suitable Arctic deep sea biotopes for inclusion in the EUNIS habitat classification scheme which could be used to populate this suggested area of the classification.

6 Making data available

This UKSeaMap 2010 report and associated Technical Reports are available for download from the JNCC website (jncc.defra.gov.uk/UKSeaMap). The UKSeaMap 2010 seabed habitat map, its associated confidence map and the updated coastal physiographic features layer are freely available to view and download from the UKSeaMap webGIS at jncc.defra.gov.uk/page-5534. By requiring users to enter their email address when they download data, users can be contacted if changes are made to the data layers and new versions become available. The original UKSeaMap webGIS has been updated to make it more user-friendly and to increase its functionality. Layer files are provided to enable users to use UKSeaMap 2010 EUNIS colour schemes (see Appendix 8 for a description of the field names).

Efforts have been made to ensure that the data used in UKSeaMap 2010 are accessible. Where possible, input data layers are made available through the UKSeaMap webGIS. Any shapefiles or raster layers available through the UKSeaMap webGIS have associated metadata describing the origin and ownership of the data. Where input data layers are not available through the UKSeaMap webGIS, details of alternative access are given in Table 21.

Table 21. Availability of input and output data layers.

Data layers	View on UKSeaMap webGIS?	Download from UKSeaMap webGIS?	Alternative access?
Seabed substrata	Yes	No	Contact JNCC or BGS
Current energy at seabed	Yes	No	BODC website
Wave energy at seabed	Yes	No	BODC website
Combined energy at seabed	Yes	Yes	UKSeaMap webGIS
Bathymetry	No	No	BODC website
Light penetration	Yes	No	BODC website
Wave base	Yes	No	BODC website
Biological zones	Yes	Yes	UKSeaMap webGIS
Variable salinity areas	Yes	Yes	UKSeaMap webGIS
Biogeographic regions	Yes	Yes	UKSeaMap webGIS
Predicted seabed habitats	Yes	Yes	UKSeaMap webGIS
Seabed substrata confidence	Yes	Yes	UKSeaMap webGIS
Wave energy confidence	Yes	No	BODC website
Current energy confidence	Yes	No	BODC website
Biological zone confidence	Yes	Yes	UKSeaMap webGIS
Confidence in predicted seabed habitats (overall)	Yes	Yes	UKSeaMap webGIS
Coastal physiographic features	Yes	Yes	UKSeaMap webGIS

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Appendix 1

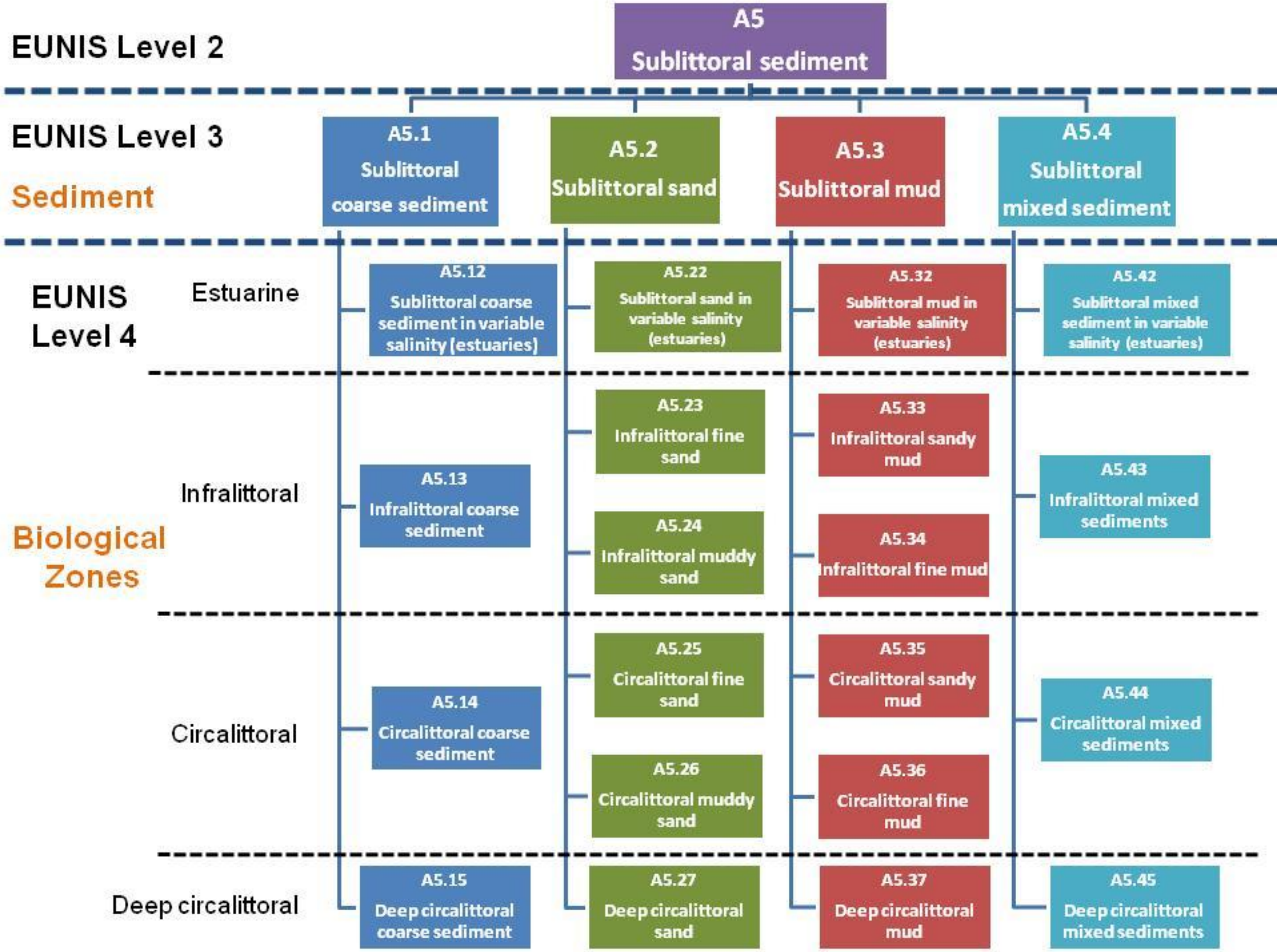


Diagram of the sublittoral sediment habitats which it is possible to predict using the UKSeaMap methodology.

Appendix 2

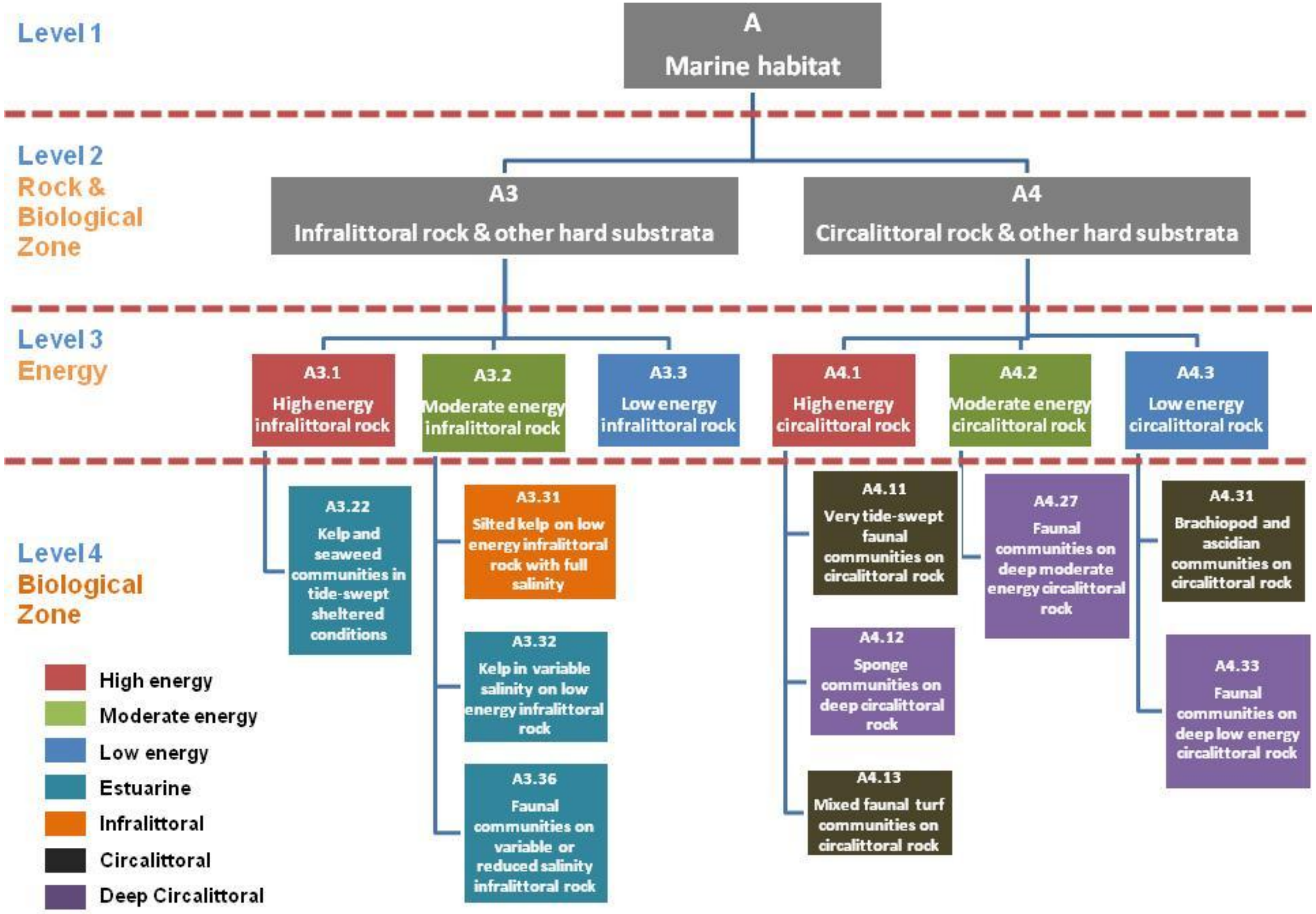


Diagram of the sublittoral rock habitats which it is possible to predict using the UKSeaMap methodology.

Appendix 3

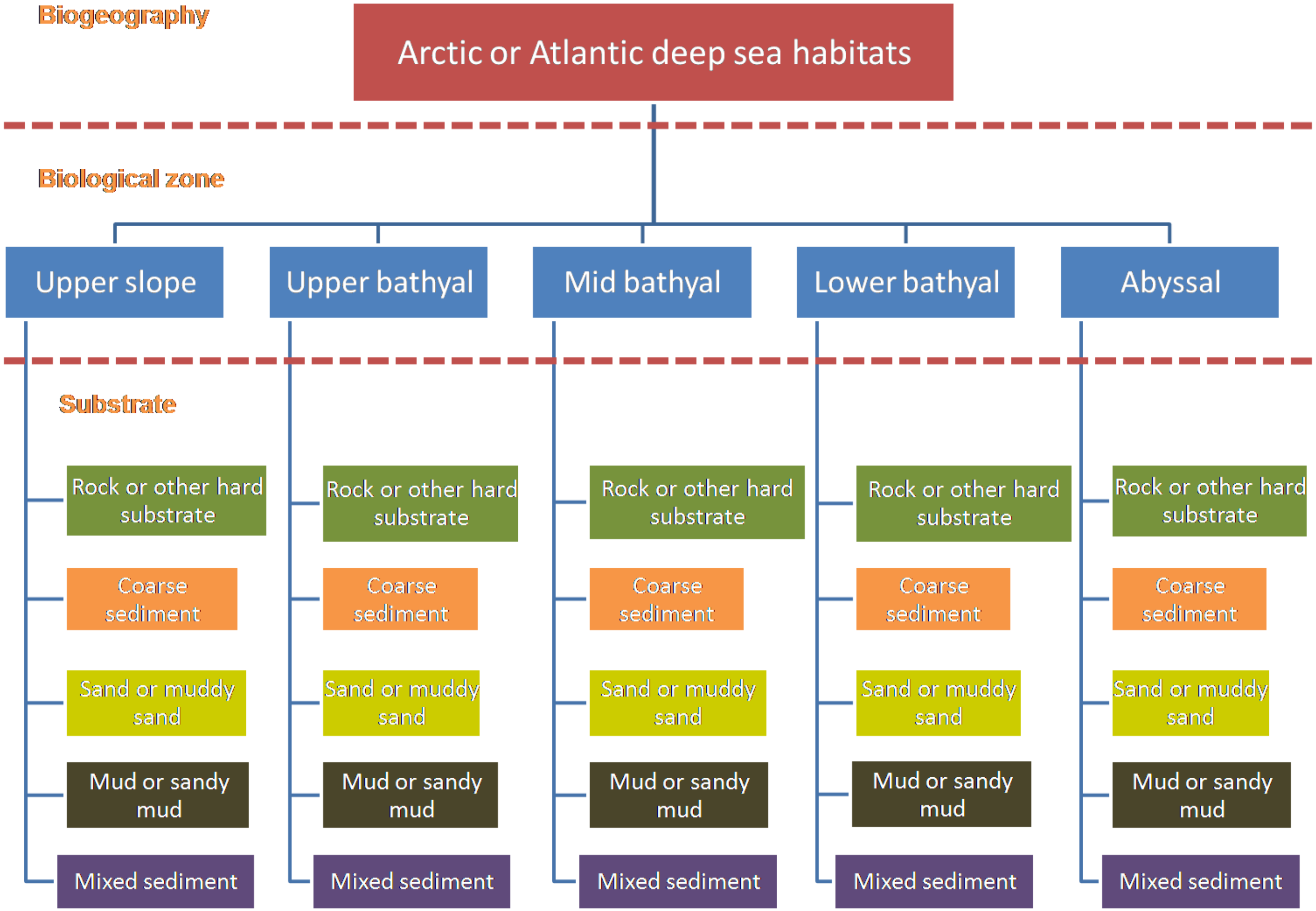
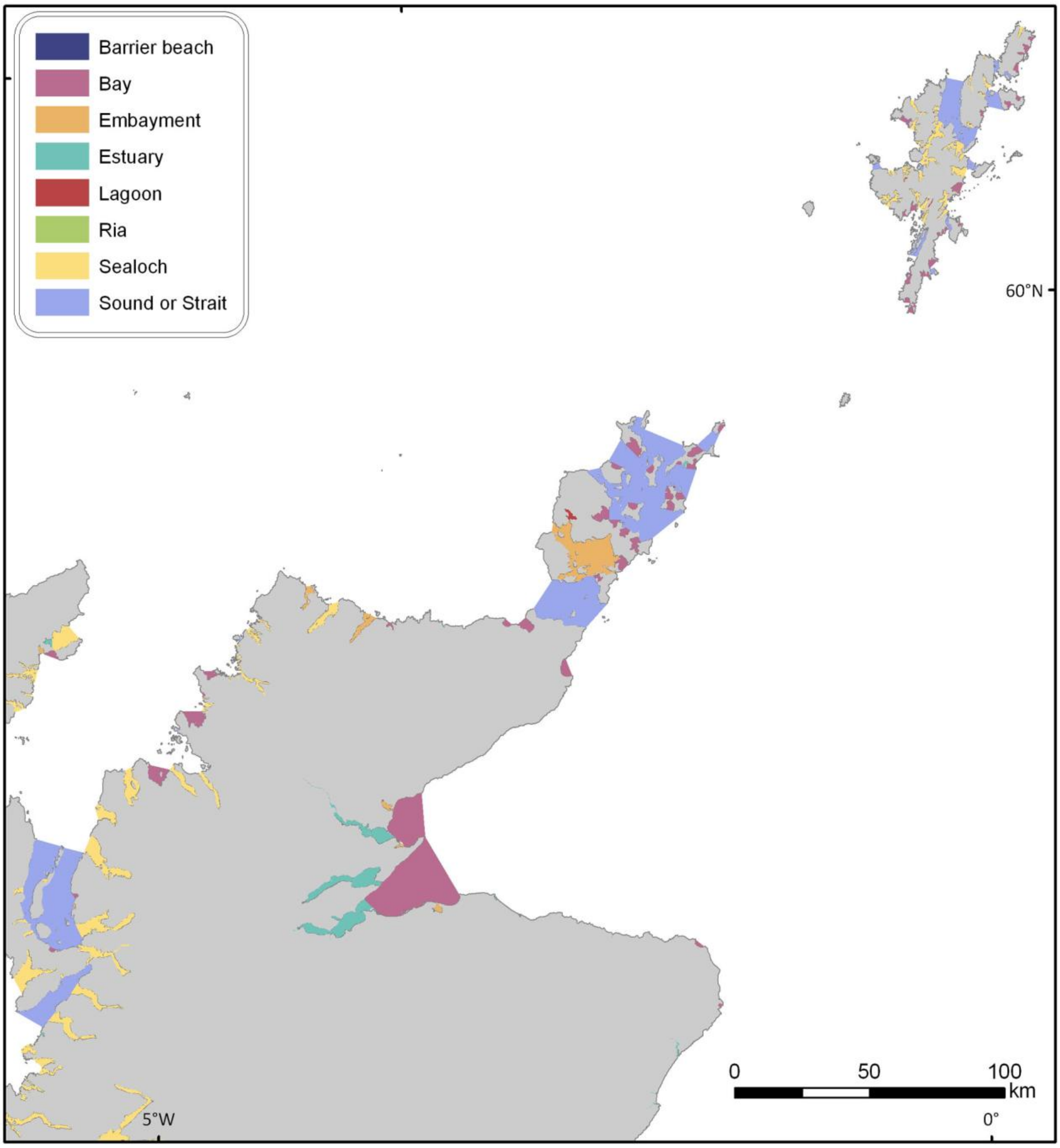
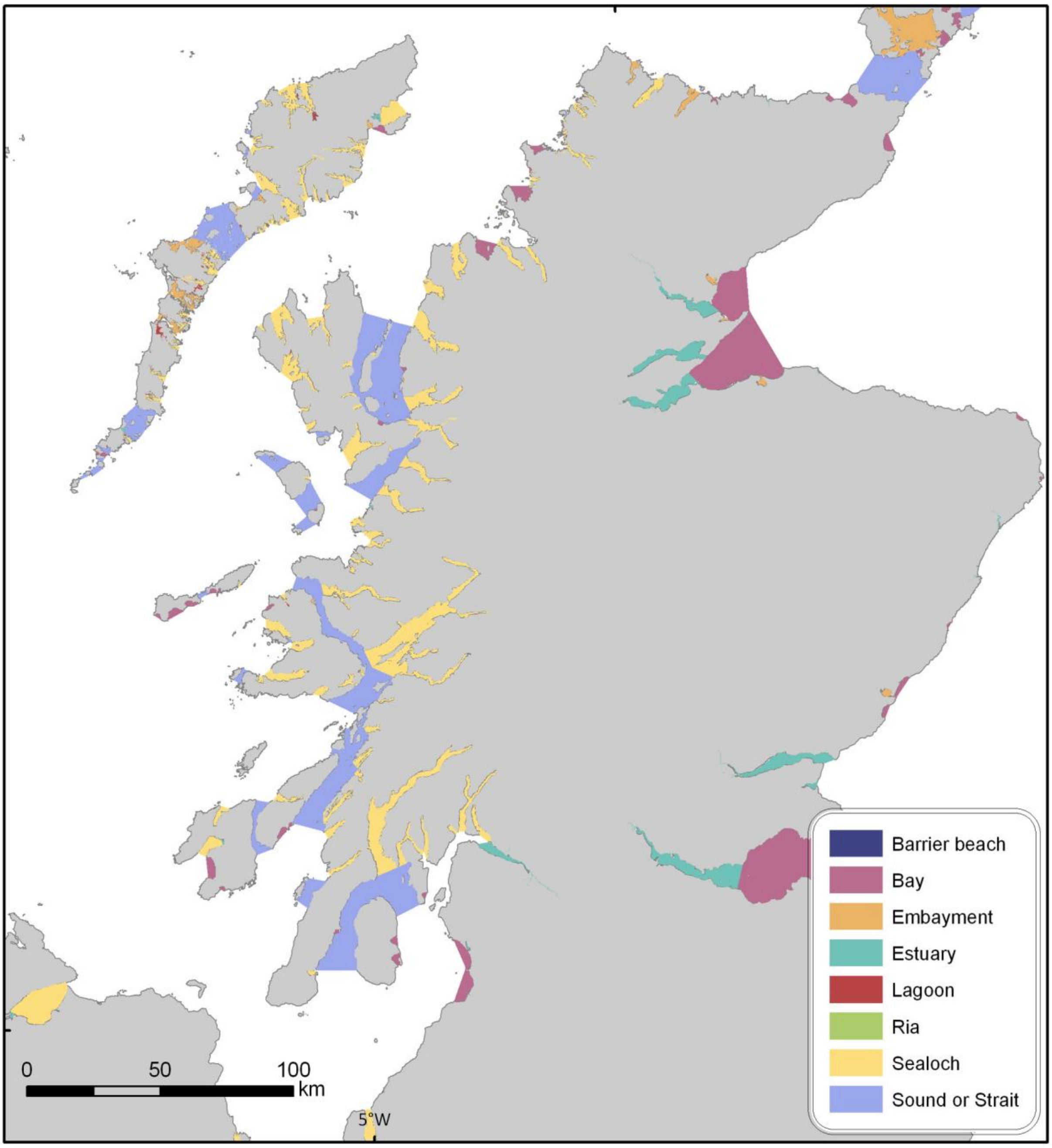


Diagram of the deep sea habitats which it is possible to predict using the UKSeaMap methodology.

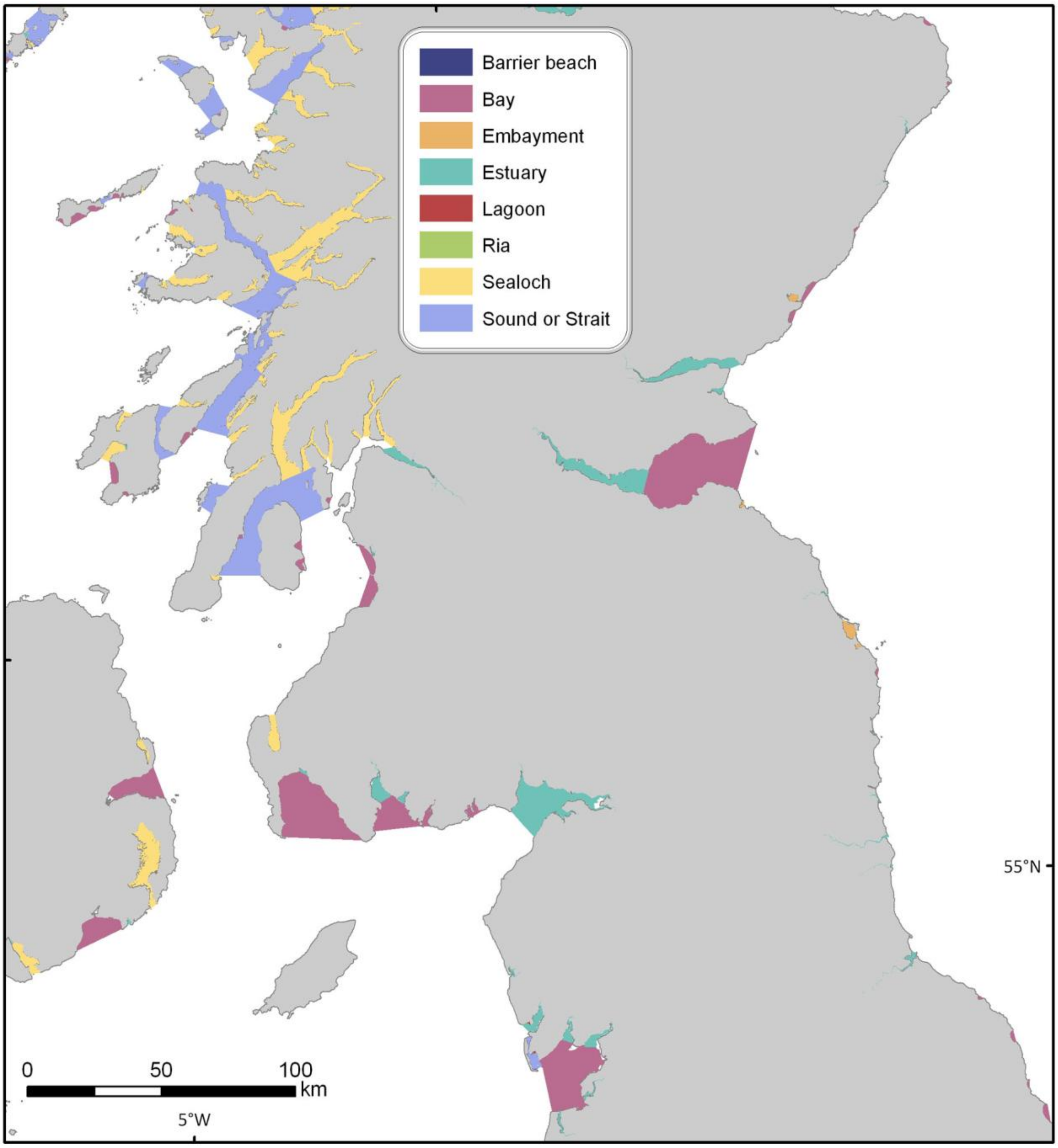
Appendix 4. Detailed maps of the coastal physiographic features layer



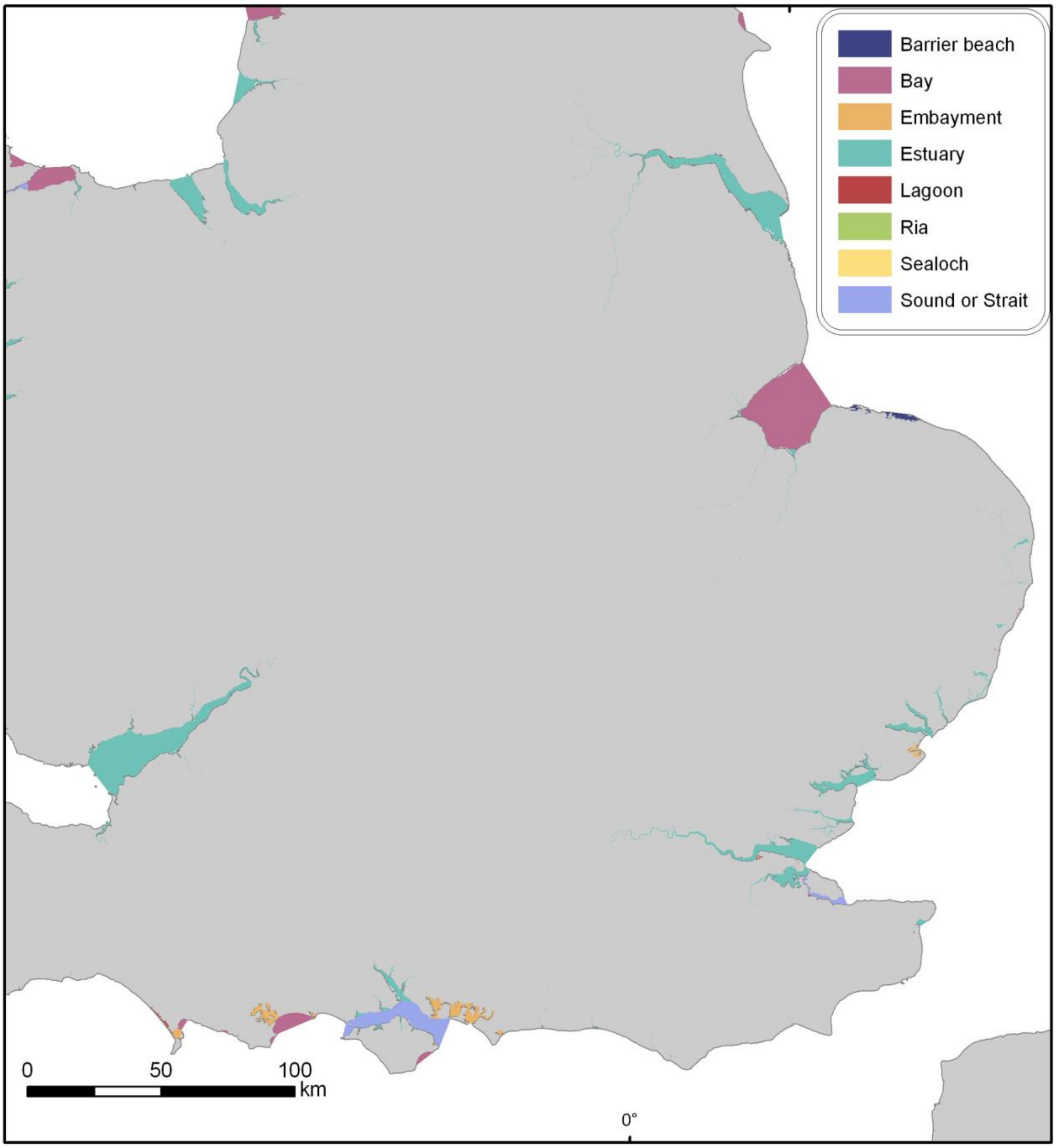
Coastal Physiographic Features of Orkney, Shetland and northern Scotland



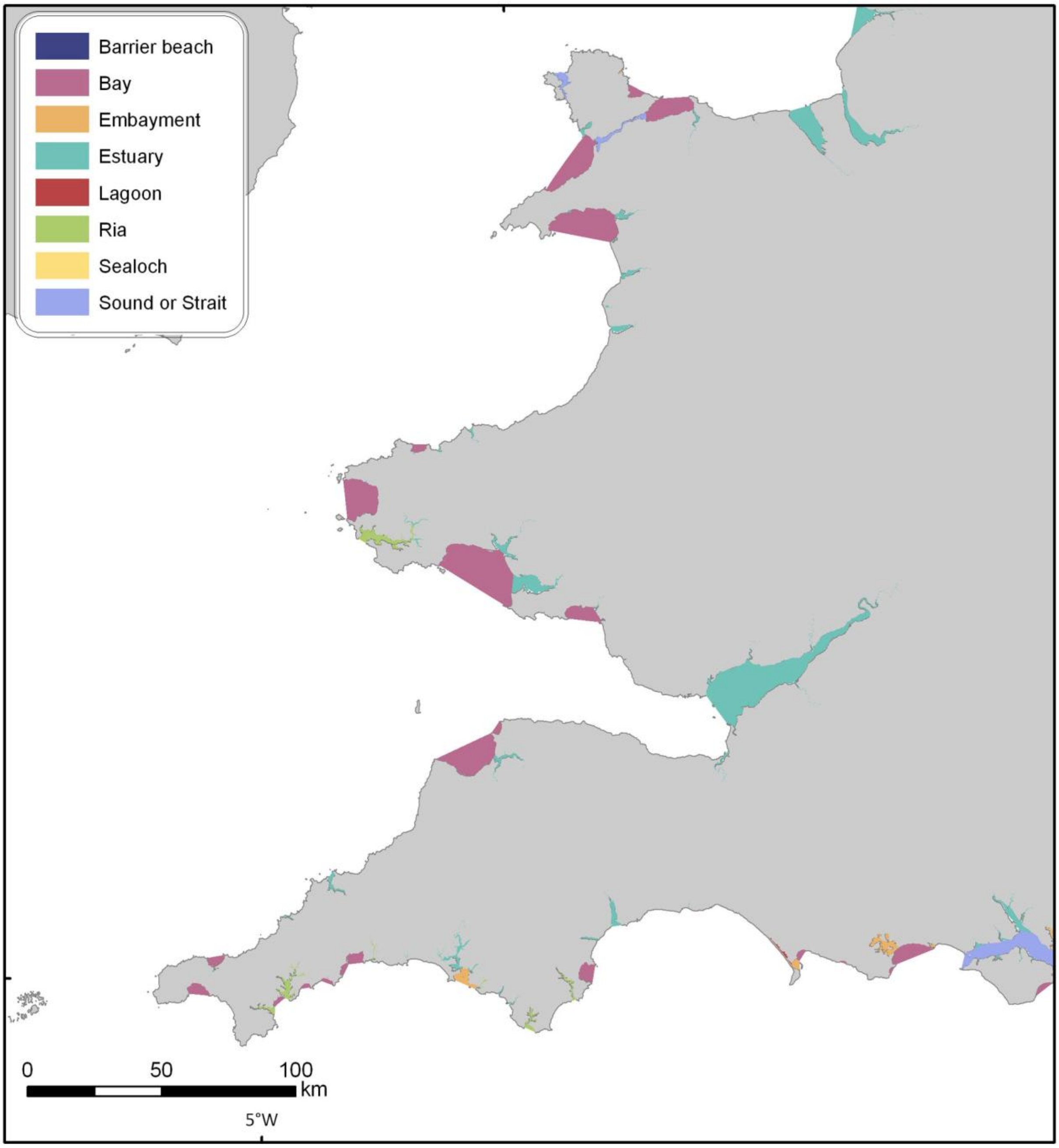
Coastal Physiographic Features of the Minches and western Scotland



Coastal Physiographic Features of southern Scotland, northern England and Northern Ireland



Coastal Physiographic Features of eastern and southern England



Coastal Physiographic Features of Wales and south-western England

Appendix 5. New physiographic features added to UKSeaMap 2010

Feature Name	Country	Physiographic Type	Source
Campbelltown Loch	Scotland	Sealoch	(Dipper *et al* 1999)
West Lock Tarbet	Scotland	Sealoch	(Beaver *et al* 2002)
Loch Tuath	Scotland	Sealoch	(Davies, 1990)
Outer Dornoch Firth	Scotland	Bay	Manually digitised
Firth of Forth	Scotland	Bay	Manually digitised
Killough harbour	Northern Ireland	Estuary	(Buck, 1996)
Conns Water Estuary	Northern Ireland	Estuary	FCS
Newry Estuary	Northern Ireland	Estuary	FCS
Quoile estuary	Northern Ireland	Estuary	FCS
Cata Sand	Scotland	Estuary	(Buck, 1993c)
Melvich Bay	Scotland	Estuary	(Buck, 1993c)
Ketlletoft Bay	Scotland	Estuary	(Buck, 1993c)
St. Cyrus	Scotland	Estuary	(Buck, 1993c)
Traigh Mhor	Scotland	Estuary	(Buck, 1993b)
Laxdale estuary	Scotland	Estuary	(Buck, 1993b)
Trsigh Cill-a-Rhubha	Scotland	Estuary	(Buck, 1993b)
Dornoch Firth	Scotland	Estuary	Manually digitised
Foryd Bay	Wales	Estuary	(Buck, 1993a)
Cadew Point	Northern Ireland	Lagoon	FCS
Quarterland	Northern Ireland	Lagoon	FCS
Mahee Point	Northern Ireland	Lagoon	FCS
Rathgorman	Northern Ireland	Lagoon	FCS
Castleward	Northern Ireland	Lagoon	FCS
Blackcauseway	Northern Ireland	Lagoon	FCS
East Down Yacht Club A	Northern Ireland	Lagoon	FCS
East Down Yacht Club B	Northern Ireland	Lagoon	FCS
Larne	Northern Ireland	Lagoon	FCS
Glynn A	Northern Ireland	Lagoon	FCS
Glynn B	Northern Ireland	Lagoon	FCS
Oldmill	Northern Ireland	Lagoon	FCS
Ballycarry	Northern Ireland	Lagoon	FCS
Gransha	Northern Ireland	Lagoon	FCS
Blackbrae	Northern Ireland	Lagoon	FCS
Donnybrewer	Northern Ireland	Lagoon	FCS
Longfield	Northern Ireland	Lagoon	FCS
Ballykelly	Northern Ireland	Lagoon	FCS
Myroe	Northern Ireland	Lagoon	FCS
Ballyaghran	Northern Ireland	Lagoon	FCS
Whitehouse	Northern Ireland	Lagoon	FCS
Belfast Harbour Lagoons	Northern Ireland	Lagoon	FCS
Victoria Park	Northern Ireland	Lagoon	FCS
Castle Espie Lagoons	Northern Ireland	Lagoon	FCS
Anne's Point	Northern Ireland	Lagoon	FCS
Rosemount	Northern Ireland	Lagoon	FCS
Granagh	Northern Ireland	Lagoon	FCS

Dundrum South	Northern Ireland	Lagoon	FCS
Strand Lough	Northern Ireland	Lagoon	FCS
The Dorn	Northern Ireland	Lagoon	FCS
The Solent	England	Sound or Strait	Ordnance Survey map (1:50,000)
Bressay Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Caol Mór	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Caol Rhona	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Caolas Eilean Ristol	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Caolas an Fhuraidh	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Clift Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Colgrave Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Cuan Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Easdale Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Linga Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Loch na Cairidh & Caolas Scalpay	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Mousa Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Muckle Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Narrows of Raasay & Sound of Raasay	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Noss Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Seil Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Shuna Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Soay Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Canna	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Eigg	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Handa	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Havra	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Hoy	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Insh	Scotland	Sound or Strait	Ordnance Survey

			map (1:50,000)
Sound of Iona	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Islay	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Kerrera	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Luing	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Mull	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Orfasay	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Papa	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Rúm	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Ulva	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
South Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Stream Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Whisle Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Yell Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Bluemull Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Hascosay Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Roe Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Houbansetter	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Uyea & Skuda Sounds	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Lang Sound & South Voe	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Luning Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Gigha	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Gulf of Corryveckan	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Jura	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sanday, Spurness, Huip, Eday, Calf & Lashy Sounds	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)

Sound of Faray & Rapness Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Papa Sound (Westray)	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Shapinsay Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Smithy Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Eynhallow, Rousay, Gairsay, Wyre & Howie Sounds	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Caolas an Eilein	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Caolas an Scarp	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Gunna Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Caolas Shandraigh	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Western, Wide & Stronsay Firths	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
North Ronaldsay Firth	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Pentland Firth	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
The North Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Harris & Caolas Bhearnaraigh & Phabaigh	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Barra & Caolas Eirisgeigh	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Sleat	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Caolas Phabaigh	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Caolas Mhiughlaigh	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Caolas Bhatarsaigh	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Kilbrannan Sound & Sound of Bute	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Inner Sound	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Firth of Lorne	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)
Sound of Taransay	Scotland	Sound or Strait	Ordnance Survey map (1:50,000)

Appendix 6. Features equivalency table (Connor *et al* 2006; Jacobs & Porritt 2009; Brooks *et al* 2009)

UKSeaMap 2006	Jacobs & Porrit 2009	Brooks *et al* 2009
Subtidal sediment Bank		Tidal banks Sand Gravel Mud Unknown
Shelf mound or pinnacle	Pinnacle Seamount	
Shelf trough		
Pockmark field	Pockmark	Pockmarks
Continental slope	Continental slope	Continental slope
Iceberg plough-mark zone	Iceberg ploughmarks	Iceberg ploughmark field
Canyon	Canyon	Continental slope canyon
Deep ocean rise	Ridge	Deep ocean rise
Carbonate mounds		Carbonate mound
Deep-water mound		Ice rafted sediment mounds Irish sea mounds Seabed mound or pinnacle Darwin mounds
	Basin	
	Continental shelf	
	Escarpment	
	Hole	
	Mud diapir	Mud diapir
	Spur	
	Contourite	
	Fan	
	Sediment slide deposit	Slide deposit
	Sediment waves	Tranverse bedform features Sand wave field Gravel wave field Sediment wave field Longitudinal bedform features Sand ribbon field Sand stringers Gravel furrow field Longitudinal bedform field
Gully		Gully
Diapir halo		Diapir halo
Landslide scar	Slide scar	Landslide scar

UKSeaMap 2006	Jacobs & Porrit 2009	Brooks *et al* 2009
	Moat	Scour moat Erosional scour field Tidal scour field
	Scours	Glacial lake outburst-flood scour feature
	Polygonal faults	
		Grounded ice seamarks
		Nunatak
		Roche Moutonnée field
		Drumlin field
		Flute field
		Moraine
		Prograding wedge
		Esker field
		Sandur
		Periglacial patterned ground
		Pingo
		Bedform field (other)
		Roll over field
		Turbidite accumulation
		Submerged peat/forest beds
		Submerged river terrace
		Buried Dune field
		Submerged cliffline
		Palaeo lagoon
		Submerged/partially submerged sea caves
		Precambrian rock outcrop
		Ledge
		Parasitic Cone
		Rock conretions
		Lopheila reef
		Maerl bed
		Modiolus bed
		Sabellaria reef
		Carbonate cemented reef
		Cold seep structures
		Sediment drift

Appendix 7. Classes associated with codes in input layers

Input layers	Codes	Classes
Combined energy	1 2 3	Low Moderate High
Substrate	10 20 30 40 50	Rock or reef Coarse sediment Sand or muddy sand Mud or sandy mud Mixed sediment
Biological zones	100 200 300 400 500 600 700 800	Infralittoral Circalittoral Deep circalittoral Upper slope Upper bathyal Mid bathyal Lower bathyal Abyssal
Salinity	1,000 2,000	Marine Variable salinity
Biogeography	10,000 20,000	Atlantic Arctic

Appendix 8. Description of the field names in the UKSeaMap predictive seabed habitat map shapefile.

Attribute field name	Attribute field description
GRIDCODE	Predictive model code
GUI	Globally Unique Identifier
Polygon	Polygon number
Biozone	Biological zone
Combenergy	Combined energy class
Level3	EUNIS 2007-11 Level 3 code
Level3_des	EUNIS 2007-11 Level 3 description
Level4	EUNIS 2007-11 Level 4 code
Level4_des	EUNIS 2007-11 Level 4 description
EUNIScomb	Most detailed level EUNIS code
EUNIScombD	Most detailed level EUNIS code description
Allcomb	Most detailed level EUNIS code or deep sea description
Allcombdes	Most detailed level EUNIS code description or deep sea description

Appendix 9. Summary of UKSeaMap Technical Reports.

Table 22. Summary of UKSeaMap Technical Reports. These can be downloaded from jncc.defra.gov.uk/UKSeaMap.

Technical Report Number	Technical Report Name
1	Bathymetry
2	Light penetration
3	Substrate
4	Energy
5	Analysing the relationship between substrate and energy data
6	Comparison of the UKSeaMap 2010 predictive habitat map with other predictive habitat maps and maps derived from surveys
7	External review of confidence assessment methods