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Title:	**Habitat mapping at different scales as predictors of socio-economic activity: Highland Shellfish Management**
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Summary:	This case study presents the results of a 'top-down' GIS project undertaken to offer support to the Highland Shellfish Management Organisation (HSMO) in its review of inshore fisheries management. Stock assessment for all the relevant species is combined with physical, sedimentary and biological data to build-up a thorough understanding of the environment that supports the target species. This is viewed as an essential prerequisite to successful, sustainable management of those species. The GIS was intended to assist HSMO in its management functions by providing a broad environmental overview of the area, its natural heritage features and the interactions that exist between the relevant fisheries and these features.
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1. Introduction: Using assessment of resources to underpin inshore fishery management

1.1. Background

This case study presents the results of a GIS project undertaken to offer support to the Highland Shellfish Management Organisation (HSMO) undertaking a review of inshore fisheries management. The HSMO had commissioned a stock assessment for all the relevant species. However, a good understanding of the environment that supports the target species was viewed as an essential prerequisite to successful, sustainable management of those species. This environmental assessment was therefore complimentary to the stock assessment. The GIS was intended to assist HSMO in its functions by providing a broad environmental overview of the area, its natural heritage features and the interactions that exist between the relevant fisheries and these features. Initially, this will involve the collation and integration of both fishery information (i.e. the stock assessment) with wider environmental information, where it exists (i.e. bathymetry, distribution of species and habitats, the occurrence of sites designated for natural heritage purposes etc).

There are a number of European Marine Sites located within the HSMO area for which schemes of management are in the process of being developed and implemented. The output from this project was needed to assist the HSMO in its contributions to these schemes of management and for the ongoing management of relevant fisheries within these sites.

Because fisheries are not the only human activity occurring in inshore waters, information is also required on these activities so that their affect on the quality of the supporting environment (or interaction with the relevant fisheries) can be taken into account. These are varied in character and scale and include aquaculture, civil engineering, renewable energy developments and so on, and it is hoped that these may be incorporate in further phases of the project.

This assessment was intended to inform the establishment of any initial management measures and underpin the ongoing management of the relevant fisheries.

1.2. Goals of Mapping

a) To produce a broad scale seabed-type/habitat map for the HSMO area utilising the best available information, and provide an overview of seabed-types/habitats relevant to individual HSMO fisheries/species;

b) To produce an inventory of all environmental designations and features of natural heritage interest that are relevant to the HSMO area;

c) To evaluate interactions (possible and actual) between fisheries for relevant species and the natural heritage features/designated sites;

d) To assess interactions between the relevant fisheries and other activities/sectors that may impact upon the quality of these fisheries' supporting environment (e.g. aquaculture, major civil engineering operations – cables, renewable energy sites etc);

e) To develop an information system that will inform HSMO's management decisions and also to facilitate input to SAC schemes of management;

f) To identify gaps in knowledge and potential areas for further research or investigation.

1.3. Pilot Sites

The area covered includes the entire environment of the west and east coasts of the Highland Region of Scotland. These have been well described and summarized in a number of publications. The nature of the coasts and seas around the Region vary greatly from east to west. The west coast is extensively dissected with glacial valleys, fjards, deep fjords and numerous islands and archipelagos. The shores are generally steep with deep water and sediment sea floors often found close to the shoreline. In contrast, the east coast has a more open coast with extensive rocky wave-cut platforms interrupted by occasional sandy bays.

The physical conditions of the west coast range across the extremes of wave exposure, tidal currents and wind speeds resulting in habitats ranging from extremely exposed to extremely sheltered environments. Together with the indented coastline and varied topography, this has created a very diverse environment and high biodiversity. The conditions are less varied on the east coast and diversity is lower.

1.4. Methods Summary

1.4.1. Project Objectives

The project aimed to bring together data on physical geography, environment, habitats and biotopes, shellfish resources and fishing effort, infrastructure and conservation interests in the form of a GIS for management use by HSMO. Geographic information systems are tools for storing, manipulating and displaying primarily spatial data. Their main inputs are also spatial data, but non-spatial data are used to help interpretation of maps.

1.4.2. Data layers

Data layers included;

- Physical environment – seabed substrates
- Biodiversity – biotopes
- Various other activities
- Fishery Information

These are discussed in greater depth later in the case study.

2. The characteristics of the habitat type

The GIS project presents an overview of a very wide area. It does not pretend to show fine detail, be comprehensive or to be accurate at a fine scale: such a GIS would be a massive undertaking and, besides, the input data available would not support it. Nevertheless, information at too broad a scale would have limited use and, therefore, an attempt has been made to present information at an intermediate range of scales.

By its nature this project therefore incorporates the whole range of habitats found in the HSMO region (see Figure 1, below). This region covers different areas of the Highlands depending upon the fishery. In most cases, this is from low water to 6 nm but is from high water for cockles and the proposed area for scallops is restricted to three areas of the coast.

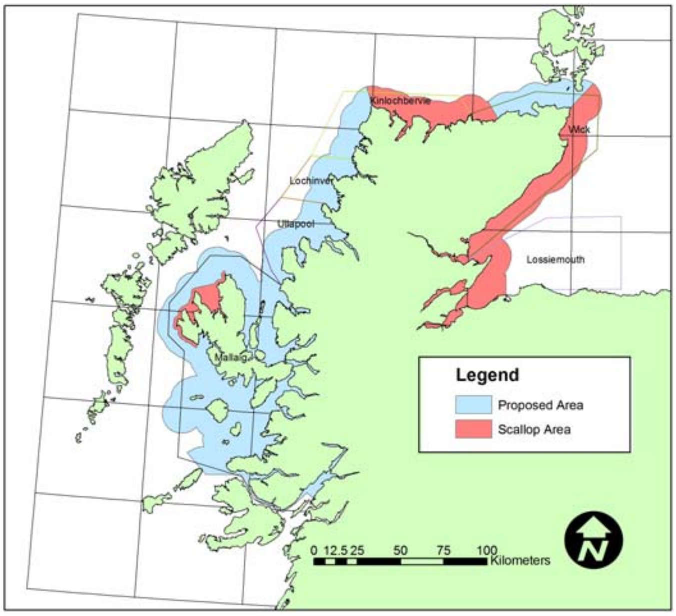

Figure 1: The HSMO Region

3. Summary of Data used

In line with the project aim to make best use of existing information, the sources used are as follows. A brief description of each is provided.

3.1. Physical Data

3.1.1. Bathymetry and coastline

The BGS DIGBATH 250 contour map converted into a grid was used to provide bathymetric data. The straight coastline and gently sloping sea floor of the east coast contrasted with the indented west coast with its fjords, deep glacial troughs and numerous islands.

3.1.2. Topography

The gridded bathymetric data was used to derive a thematic layer highlighting topography. This shows the steep coasts in the west. There are numerous deep troughs in the sea lochs and between Mull and the mainland. The topography of the east coast is far simpler, with the only deep troughs of significance being in the Moray Firth and the entrance to the Cromarty Firth.

3.1.3. Physiographic regions

The topography and shape of the coastline (particularly the degree of enclosure) defines the physiographic units. These have been variously defined and the physiographic thematic map is an attempt at a comprehensive catalogue for the Highland Region. Once again it illustrates the shallow estuaries and firths of the east coast (there are relatively few small estuaries on the west coast). The indentations on the west coast are varied with narrow, sheltered fjords branching off from fjards and open sea lochs.

3.1.4. Tidal currents

Tidal currents and wave exposure are two of the physical factors that are available, although at a low resolution. Nevertheless, the tidal current thematic map shows the accelerated currents around headlands, between islands and particularly between the larger islands (Skye and Orkney and the mainland).

3.1.5. Wave heights

Wave heights are expressed as the maximum heights which are exceeded only a given percent of the year. The heights exceeded 10% of the time are shown in the GIS.

The north west of the Region (Cape Wrath) is exposed to Atlantic storm waves. The Hebrides offers some shelter to Skye and the south western shores. The long sea lochs are sheltered although the steep, narrow glens can funnel winds and short, steep waves can build up.

The east coast is much less exposed to waves despite the lack of shelter on the open coast.

3.1.6. Exposure

Wave and bathymetry can be used to define the exposure to water movement on the sea floor due to wave energy. The thematic map of exposure shows a simple three-level, MNCR classification of exposure/water movement.

3.1.7. Current speed

Current speed will also contribute to the bedload stress on the sea floor. Locally, this energy will need to be considered alongside wave exposure. The relationship between surface current speed and stress at the sea floor has not been modelled, but the exposure rating between Duncansby Head and Orkney has been increased by one category in an attempt to accommodate current speed.

3.1.8. Stratification

Stratification is included as a facet of the hydrography of the area but has not been included in any modelling of biotope distribution.

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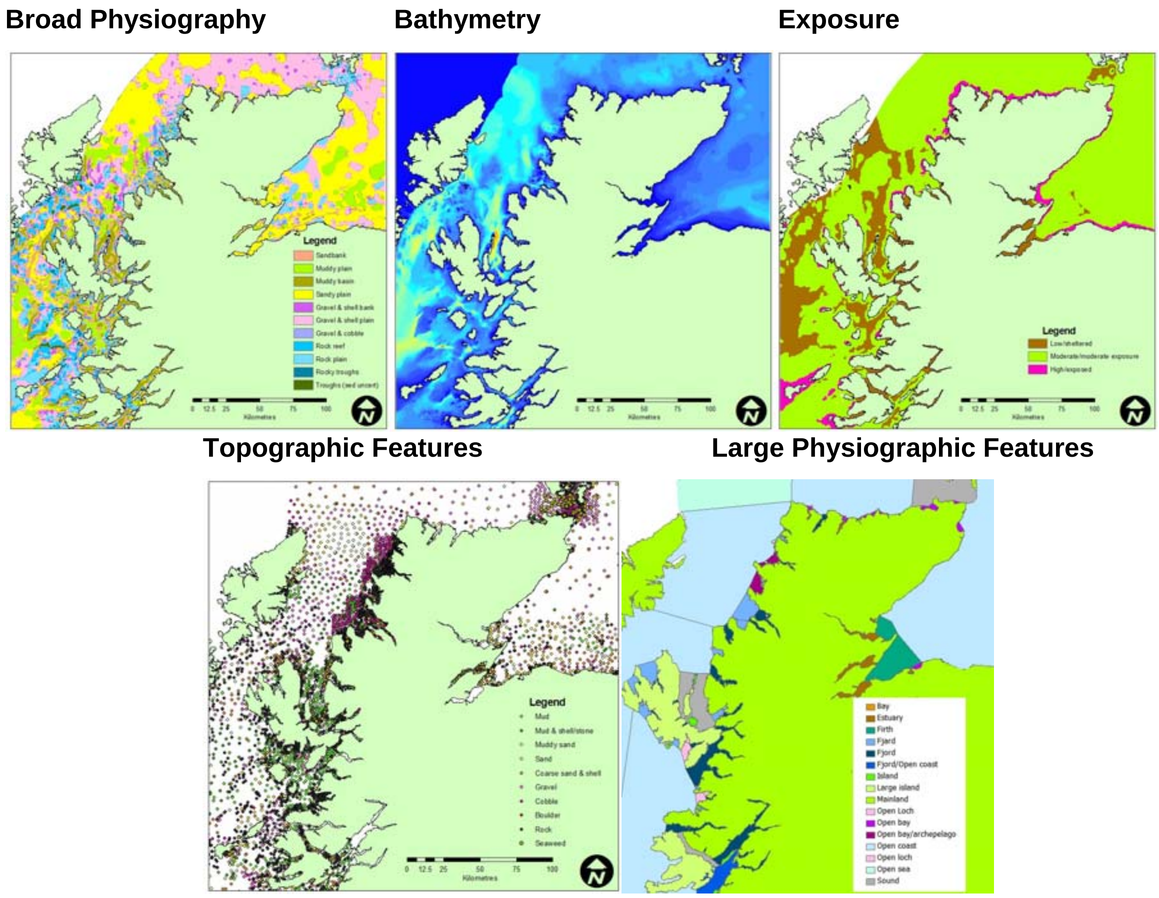


Figure 2: Samples of Data Layers integrated into the HSMO GIS

3.2. Seabed sediment:

3.2.1. British Geological Survey

The surficial sediments have been mapped by the British Geological Survey and is available as vector polygon data (sources: BGS DIGIBATH SB250). The sediments are classified according to the modified Folks triangle.

The coverage is incomplete, especially inshore on the west coast with notable gaps in the sea lochs and between Mull and the mainland.

It should also be noted that the maps are based on varied and scattered data on surficial sediments and rocky substrata are underrepresented.

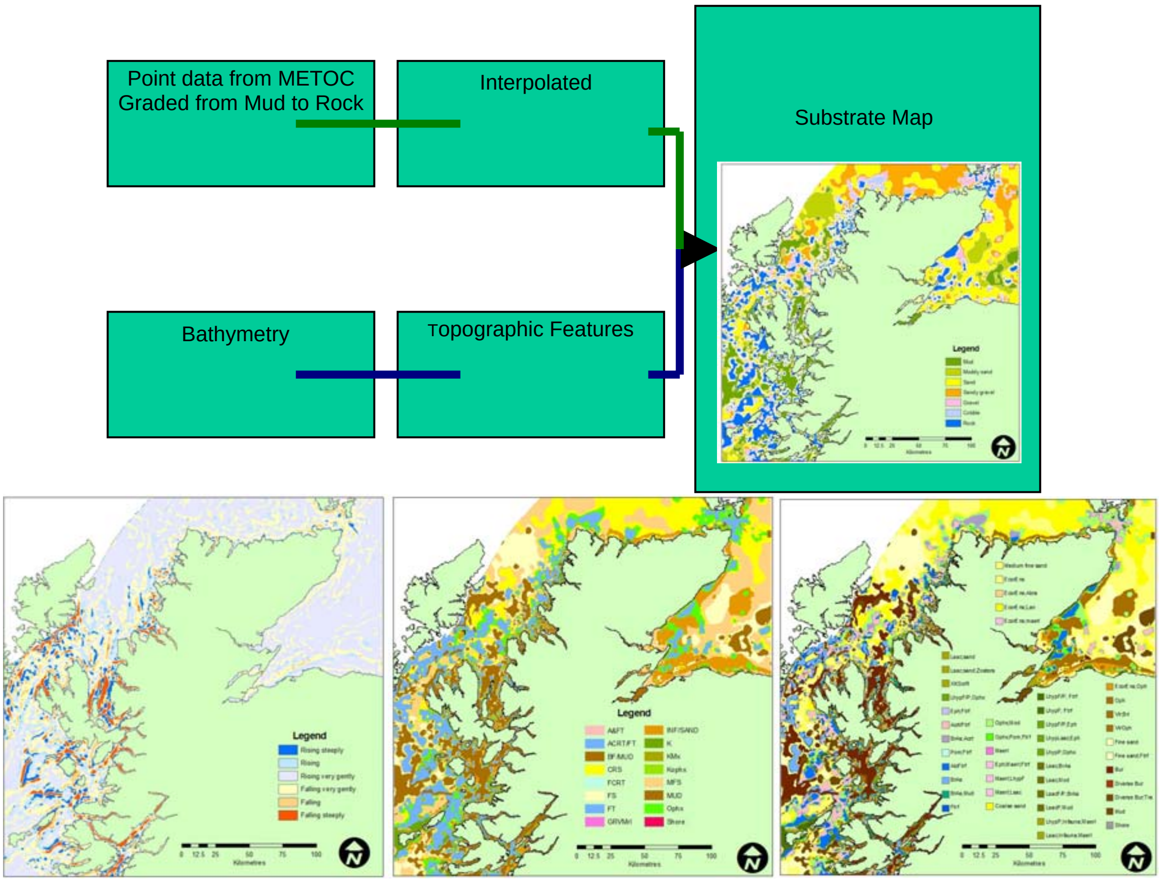
3.2.2. Admiralty Chart data

An alternative source of sediment data is available from the Hydrographic charts (METOC). These vector charts have sediment notation. There are a large range of notations used to describe the sediment and these have been transformed into a simple 7 point, linear scale (roughly based on the Phi scale) which have been interpolated. Additional information was also taken from the topology theme.

This map places greater emphasis on the rocky habitats than the BGS maps, but the areas of mud show a similar distribution.

3.2.3. Sediment Model

The sediment information from the METOC source and the topographic maps were combined to show major sea floor physiographic features, such as muddy basins, sand banks and rocky reefs.



METOC Points → BGS Sediments → Substrates

Figure 3: Derivation of the Substrate Map

This process showed that the METOC sediment data fitted to the topography quite well with a few areas that were anomalous. For example, deep troughs with rock are considered unlikely and most often was an error due to interpolation of the METOC point data (see 'troughs – uncertain' in the legend). There were no records in these troughs to suggest anything other than mud should be expected. Since the information on sediment is derivative, it must be regarded as predictive.

There are extensive areas of varied rocky topography to the west between Mull and Skye, the Minch, off Clashnessie and Eddrachillis Bay and in the Pentland Firth. There are also rocky platforms extending from the shores of the east coast and Tarbet Ness. The deep troughs of the west coasts are muddy basins and their relative shelter must make these sinks for fine sediment and organic matter. The east coast has onshore sandy sediments whilst the sediments of the north coast are more gravelly.

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3.3. Biotopes

Biotopes are defined by the predominant, conspicuous and keystone species that are found in particular conditions of environmental conditions, particularly (1) substratum, (2) water depth (and depth-related factors such as light), and, (3) water movement (wave and tidal energy). The distribution of biotopes should be predictable, at least at higher levels in the biotope classification hierarchy, through knowledge of the distribution of these key environmental factors. Prediction cannot be precise since (1) more than one biotope can share the same habitat conditions and (2) it is likely that the source data will have low spatial precision so that very different habitats might be attributed to the same location.

3.3.1. Analysis of Biotope Data

The approach taken for the analysis of the biotope data was

1. Sort all records in the HSMO region (and slightly beyond) into broad categories according to depth zones, sea floor substratum and exposure
2. Count frequency of occurrence of each biotope in each of the above categories and rank them accordingly
3. Characterise the categories by commonly recurring biotopes by predominant biotope, suite of biotopes (if this represents the character more faithfully) or sediment type where there is a paucity of data.

Lists of all biotopes found in depth/exposure/sediment categories (ranked in order of decreasing likelihood) were used to create summary table of main biotope characteristics used for mapping (See Figure 4, below).

This method required modification because of the biases in the data. Data for the east coast were supplemented by including records from the east coast of Scotland as a whole. Also, there are certain biogeographic trends in distribution and it is unlikely that some of the west coast biotopes occur commonly on the east coast. Thus, some of the broad habitat categories were modified to exclude some biotopes in the east.

The 126 habitat categories were then recoded to show biotopes categories (as in Table above). The habitat category data and the biotope category map (and the full description of component biotopes) were used to derive the habitat suitability map for the shellfish

The net effect is that a particular set of environmental conditions will be characterised by the predominant biotopes which may also be associated with a whole suite of other biotopes. In practical terms, this means that a map showing predicted biotopes really indicates the most likely biotopes to be found, but that a whole range of other biotopes might also be expected. The biotope thematic map must be seen in this light. Biogeographic trends must also be considered.

The biotope map is illustrated in Figure 5, below.

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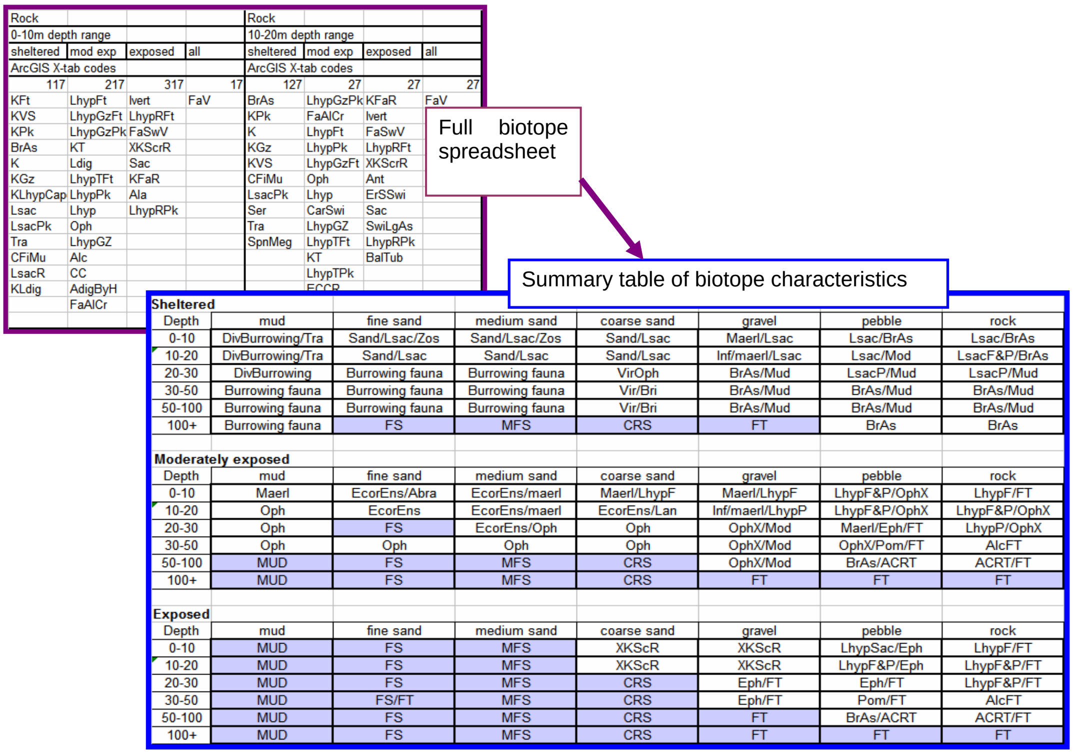

Rock				Rock			
0-10m depth range				10-20m depth range			
sheltered	mod exp	exposed	all	sheltered	mod exp	exposed	all
ArcGIS X-tab codes				ArcGIS X-tab codes			
117	217	317	17	127	27	27	27
KFt	LhypFt	Ivert	FaV	BrAs	LhypGzPk	KFaR	FaV
KVS	LhypGzFt	LhypRFt		KPk	FaAlCr	Ivert	
KPk	LhypGzPk	FaSwV		K	LhypFt	FaSwV	
BrAs	KT	XKScrR		KGz	LhypPk	LhypRFt	
K	Ldig	Sac		KVS	LhypGzFt	XKScrR	
KGz	LhypTFt	KFaR		CFiMu	Oph	Ant	
KLhypCap	LhypPk	Ala		LsacPk	Lhyp	ErSSwi	
Lsac	Lhyp	LhypRPk		Ser	CarSwi	Sac	
LsacPk	Oph			Tra	LhypGZ	SwiLgAs	
Tra	LhypGZ			SpnMeg	LhypTFt	LhypRPk	
CFiMu	Alc				KT	BalTub	
LsacR	CC				LhypTPk		
KLdig	AdigByH				ECCR		
	FaAlCr						

Sheltered

Depth	mud	fine sand	medium sand	coarse sand	gravel	pebble	rock
0-10	DivBurrowing/Tra	Sand/Lsac/Zos	Sand/Lsac/Zos	Sand/Lsac	Maerl/Lsac	Lsac/BrAs	Lsac/BrAs
10-20	DivBurrowing/Tra	Sand/Lsac	Sand/Lsac	Sand/Lsac	Inf/maerl/Lsac	Lsac/Mod	LsacF&P/BrAs
20-30	DivBurrowing	Burrowing fauna	Burrowing fauna	VirOph	BrAs/Mud	LsacP/Mud	LsacP/Mud
30-50	Burrowing fauna	Burrowing fauna	Burrowing fauna	Vir/Bri	BrAs/Mud	BrAs/Mud	BrAs/Mud
50-100	Burrowing fauna	Burrowing fauna	Burrowing fauna	Vir/Bri	BrAs/Mud	BrAs/Mud	BrAs/Mud
100+	Burrowing fauna	FS	MFS	CRS	FT	BrAs	BrAs

Moderately exposed

Depth	mud	fine sand	medium sand	coarse sand	gravel	pebble	rock
0-10	Maerl	EcorEns/Abra	EcorEns/maerl	Maerl/LhypF	Maerl/LhypF	LhypF&P/OphX	LhypF/FT
10-20	Oph	EcorEns	EcorEns/maerl	EcorEns/Lan	Inf/maerl/LhypP	LhypF&P/OphX	LhypF&P/OphX
20-30	Oph	FS	EcorEns/Oph	Oph	OphX/Mod	Maerl/Eph/FT	LhypP/OphX
30-50	Oph	Oph	Oph	Oph	OphX/Mod	OphX/Pom/FT	AlcFT
50-100	MUD	FS	MFS	CRS	OphX/Mod	BrAs/ACRT	ACRT/FT
100+	MUD	FS	MFS	CRS	FT	FT	FT

Exposed

Depth	mud	fine sand	medium sand	coarse sand	gravel	pebble	rock
0-10	MUD	FS	MFS	XKScR	XKScR	LhypSac/Eph	LhypF/FT
10-20	MUD	FS	MFS	XKScR	XKScR	LhypF&P/Eph	LhypF&P/FT
20-30	MUD	FS	MFS	CRS	Eph/FT	Eph/FT	LhypF&P/FT
30-50	MUD	FS/FT	MFS	CRS	Eph/FT	Pom/FT	AlcFT
50-100	MUD	FS	MFS	CRS	FT	BrAs/ACRT	ACRT/FT
100+	MUD	FS	MFS	CRS	FT	FT	FT

Figure 4: Biotope Analysis Methodology. Grey cells indicate no biotope records in category and sediment type used as default

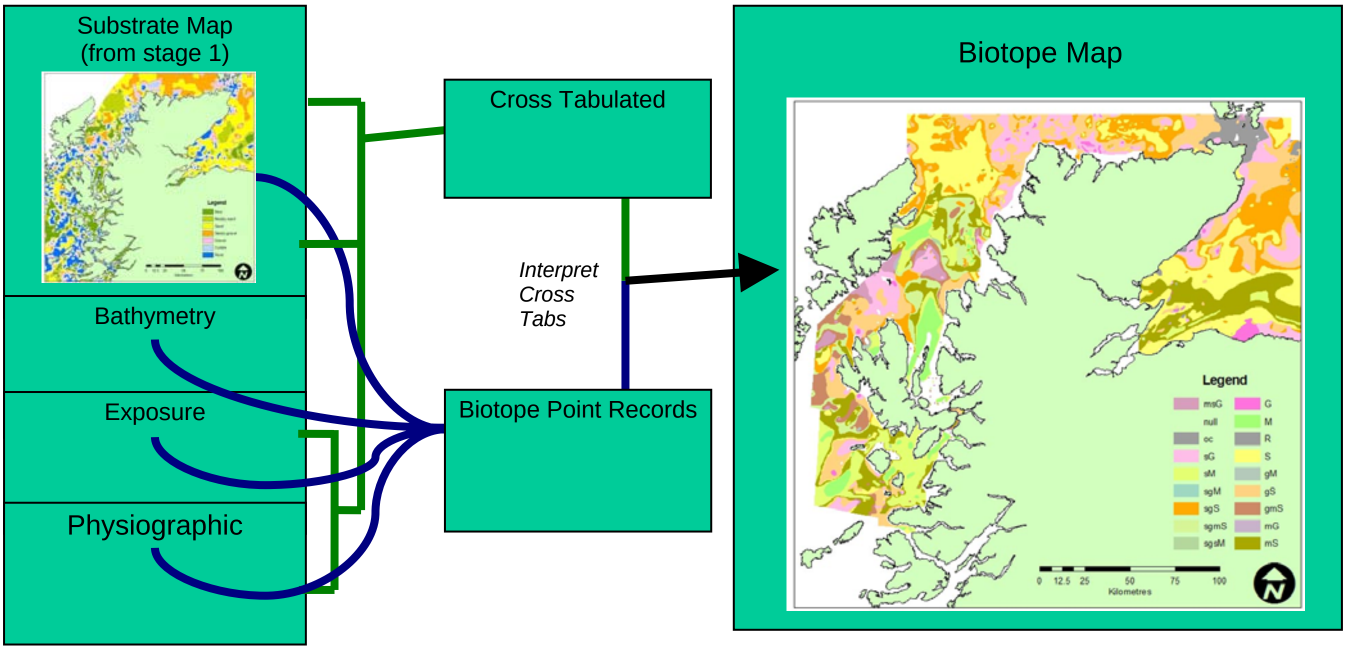

Figure 5: Derivation of the Biotope Map

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The primary source of biotope data is the JNCC database Marine Recorder. The data from this source have a number of fields containing biological and environmental information. The data are given point locations, although these must be considered approximate. The majority of locations also have more than one associated record; presumably because the position as given marks the central location for a series of dives. This adds considerable complication to the use of these data since in very many cases the biotopes recorded at a single location can differ markedly (e.g., kelp forest, cliffs and deep sediment may have been co-located).

The other difficulty with the data is the obvious bias towards the sea lochs and the paucity of records from the east coast.

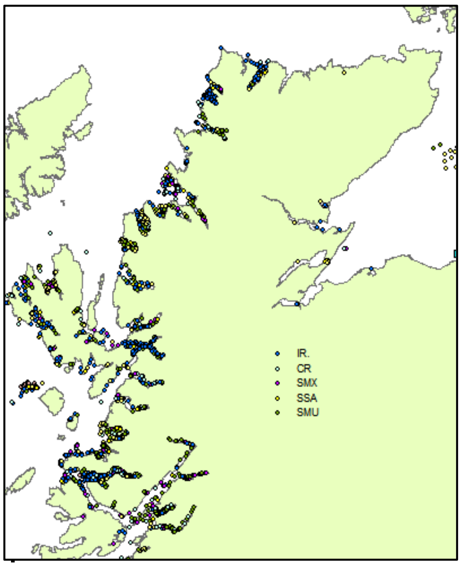

Figure 6: Illustration of the bias in data available from the Marine Recorder database.

3.4. Assessing distribution of seabed habitats for each relevant species

Once obtained, these data could then be applied in the fisheries context. The information on shell fish habitat preferences came from a variety of sources. For example, distribution information is available on the MarLIN website. The Marine Recorder data (see above) also had information on the occurrence of many of the commercial species within the biotope framework. This information was combined with the habitat category matrices to show the relative suitability of each habitat category. These were reduced to a simple 3-class system of 'unsuitable', 'low suitability' and 'suitable' for display purposes.

4. Fisheries Management

4.1. Distribution of fishing effort over essential shellfish habitats

Distribution of target species can then be predicted through the combination of further layers.

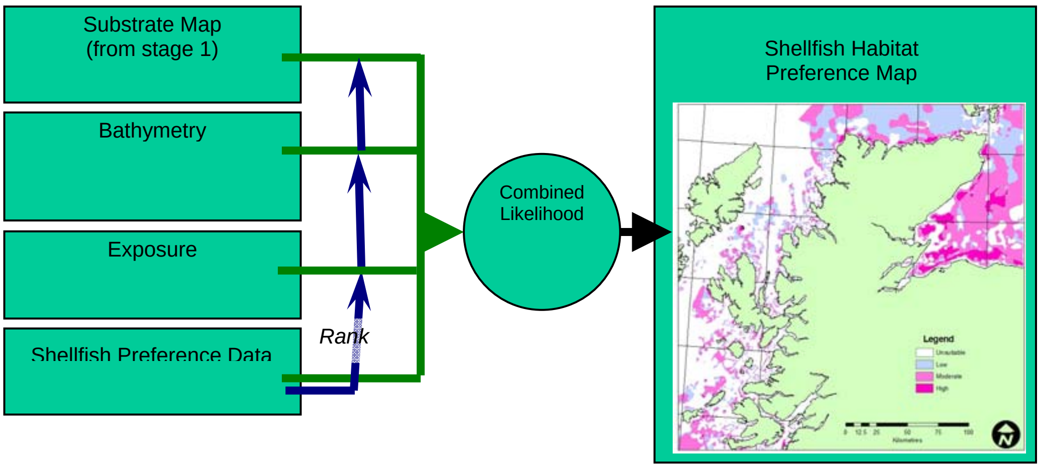

Figure 7: Derivation of Shellfish Habitat Preference Maps

4.2. *Fisheries interactions with habitats and species*

4.2.1. Intensity of fishing gear usage

Fishing activities mainly impact on the environment through abstraction of species (target and non-target species) and, perhaps more importantly, physical damage to the habitat from the use of fishing gear.

The same type of fishing gear can be used for more than one fishery. Often there is one primary target species but other species caught whilst fishing for the primary species also have commercial value. For the purpose of assessing the potential impact of fishing gear on the environment, the fisheries have been classed by the major methods for capture

Fishing data is very limited in terms of spatial resolution. However, we can use the data to make some maps of possible fishing intensity, based on habitat preferences (Figure 7, above) and fisheries data.

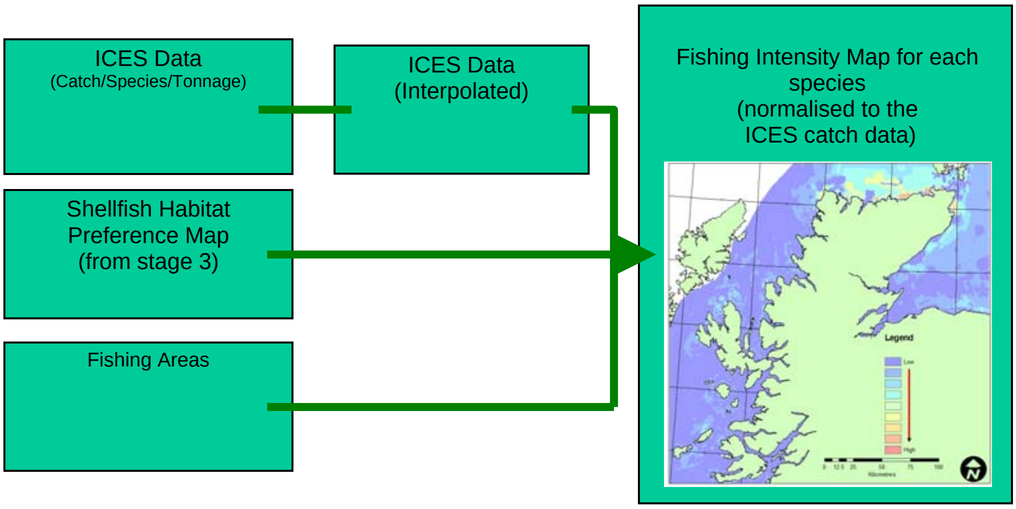

Figure 8: Fishing Intensity Map for each species

4.2.2. Creeling

The largest fisheries using creeling are brown crabs, velvet crabs, Nephrops and whelks. These fisheries seem to be geographically separated with Nephrops largely in the west, brown crabs on the north coast and whelks on the north east and east coasts. Velvet crabs would appear to be fished patchily throughout the area. The sum total of creeling effort is, therefore, quite widespread although the effort for fisheries except Nephrops are north and east coast based.

4.2.3. Dredging

The largest fisheries employing dredging are for scallops and mussels, both very geographically distinct. All other fisheries using dredging are very small in comparison. The impacts for dredging are, therefore, best summarised by the individual fisheries effort maps.

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4.2.4. Trawls and seines

The Nephrops fishery dwarfs all the other species fisheries and the individual maps of species effort are the best summary maps of trawl/seine effort.

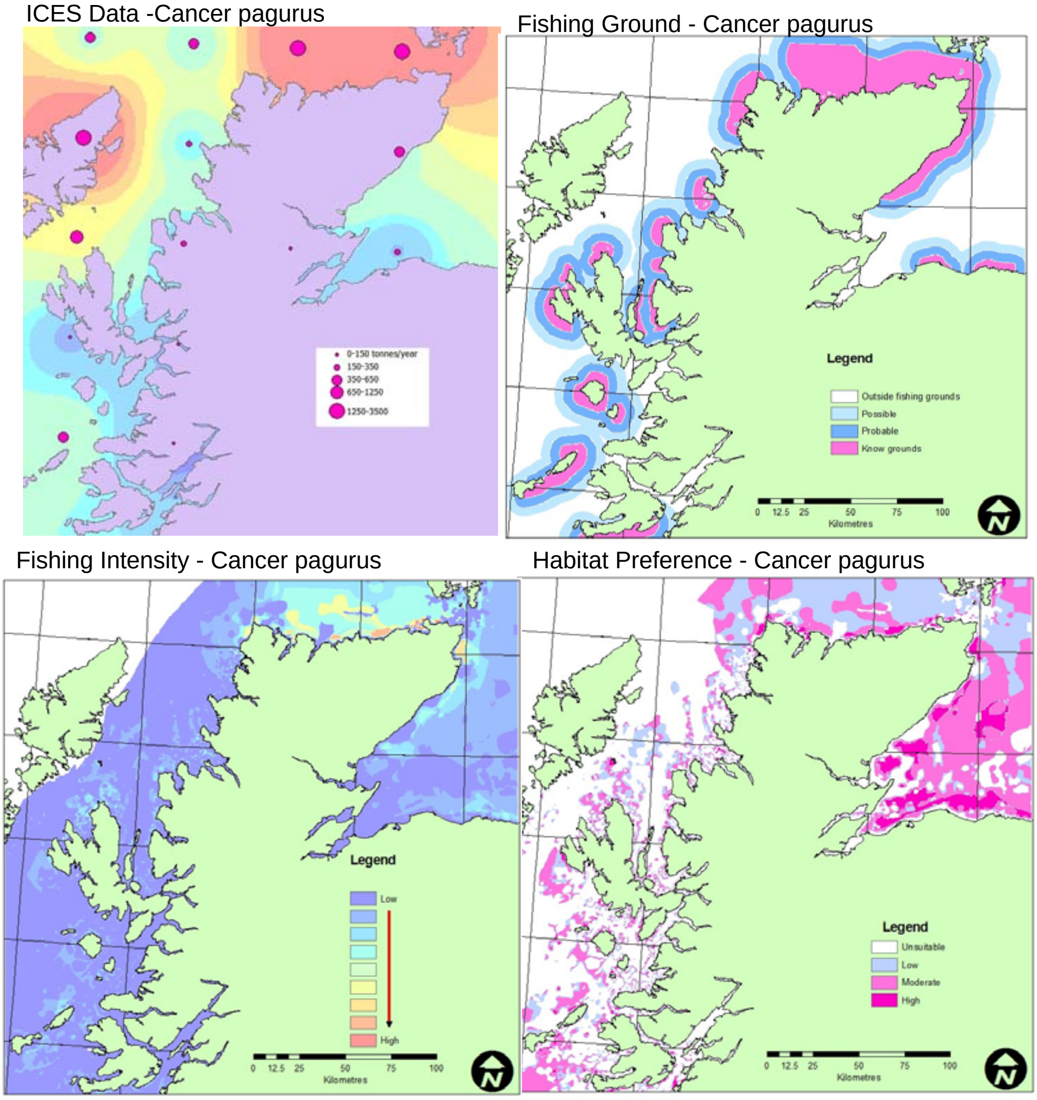


Figure 9: Priority Habitat for Cancer pagurus

4.3. Distribution of biotopes and priority habitats

Priority habitats are defined by combinations of depth zones, sediment type, key biotopes (or species) and physiographic units. For most of these habitats, therefore, it is not simply a case of selecting a habitat feature from a single thematic layer. Instead, the priority habitats must be selected using specific queries and associated model (as shown in Section 5.1, below).

The process of relating biotopes to habitat data (as described above) is based on generalisation. Each combination of habitat characteristics has been related to many biotopes and the most commonly recurring biotopes have been used to draw up a broad-brush description. Clearly, not all of the biotopes will be found in every pixel where the habitat is suitable. The most recurrent biotopes will be the most likely to be found and rare biotopes will have a much lower likelihood of occurrence. There may also be geographic trends in likelihood that will mean that certain biotopes will be more or less likely to occur in a certain location that the overall frequency for the whole HSMO area. For example, maerl is much less likely to occur on the east coast than the west coast. Thus, the predicted biotope distribution must be viewed with a high degree of caution.

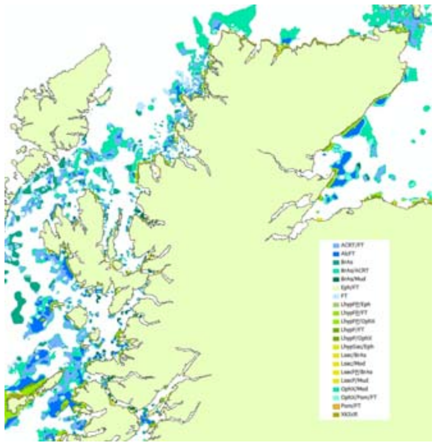
5. Management Queries

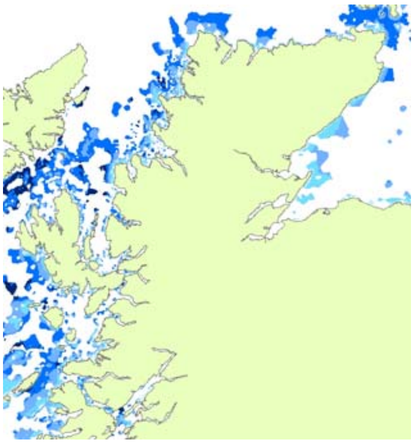
However, the data collated, even at this spatial resolution, can be highly useful for management applications. The GIS maps can be used to provide outputs for queries designed to address specific issues. The following show some examples of query output.

5.1. GIS Queries

We can use the biotope data to map possible distributions of Annex 1 Habitats based on JNCC guidelines. Although these are broadly defined, the distribution maps show marked geographical trends.

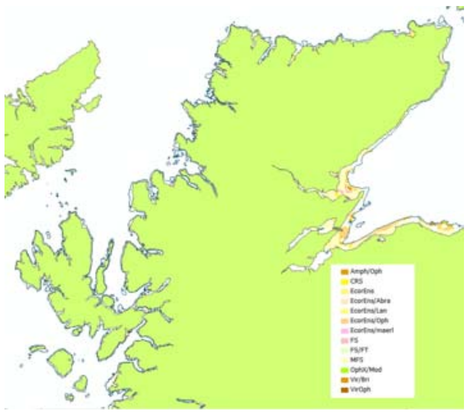
5.1.1. Predicted distribution of biotopes that constitute Annex 1 Reef Habitat





5.1.2. There are east/west geographic trends in reef habitats that are best shown by the reef depth zones.

5.1.3. Predicted distribution of biotopes that constitute Annex 1 Sublittoral Sandbank Habitat



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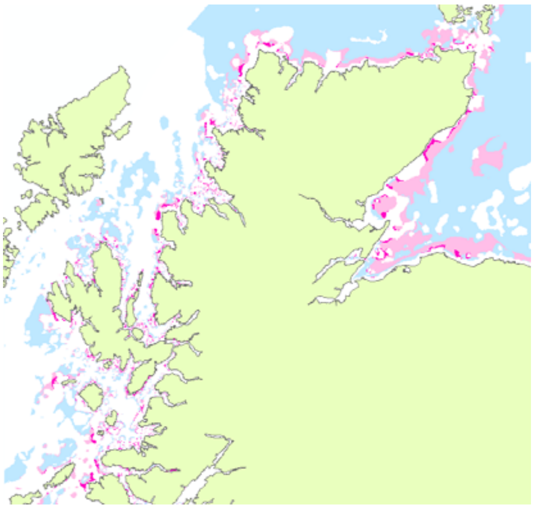
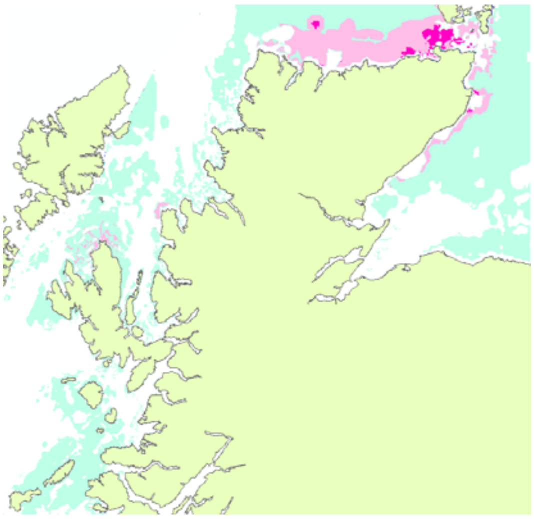
5.2. Management-related Queries

Other types of queries can be made to investigate fisheries data



5.2.1. Predicted where scallop ground might overlap with favourable brown crab ground

5.2.2. Predicted where scallop fishing activity might overlap with favourable brown crab fishing ground



6. Conclusions

The biotope map is derived from the modelling of many source data sets, many of which are not ideal for the task and some of the modelling processes used were 'rough and ready'. For example, the biotope records lack spatial precision and there is poor coverage for the Highland Region. Modelling exposure was not a sophisticated process and the exposure classes were not exactly defined. It would be possible to upgrade data sets and refine the modelling processes to achieve a more confident prediction of the biotope distribution and higher resolution, although this would require considerable effort. However, the case study still demonstrates considerable utility for such 'top-down' models.

In terms of fisheries, the data is limited and the resulting spatial resolution is low. Though this does provide meaningful analysis at the broadest scale, e.g. areas of fisheries conflicts can be successfully predicted, data is required at a scale relevant to the HSMO management framework. There is a large scope for integrating fisher's knowledge into this new framework, which may also provide sufficient data at the required resolution.

The biodiversity data remains inconsistent, but is continually being improved. The main problem, in this respect, remains the lack of data from the northern and eastern areas. Generally, biotope predictions are good at the broader scales, and the system houses the potential for the addition of fine detail as real data becomes available.

From a management perspective, the systems can help set priorities and focus resources, at a regional scale. By visualising the body of data, initial assessment of issues can be made more effective and accessible to a wider audience. In general the results obtained reinforce the value of an ‘area’ management approach for inshore fisheries. The main strengths of the system are the cost effective use that is made of existing data. It also has the potential to support SEA and EIA and can help facilitate management integration.

In conclusion, this ‘top-down’ mapping has shown considerable potential for fisheries applications, and at the very least has stimulated debate amongst both fisheries managers and fishers. It has also provided a tool which the HSMO have used to focuses attention and resources.

7. Acknowledgements

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