Firth of Forth OSWF: Phase 1 & ECR Habitat Mapping Analysis

Firth of Forth OSWF Habitat Mapping

Envision Mapping Ltd
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NOTES:

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A. Glossary of terms

Classification: The process of conversion of numerical data from a survey (species abundance records or particle size data) to a number of discrete classes. The resulting biota classes can be referred to as a local classification system and have been cross referenced to the JNCC biotope classification, The Marine Habitat Classification for Britain & Ireland (v04.05).

Clusters: Sample records that are statistically similar to each other and distinct from other records.

Ground truth: Sample records that are used in statistical interpretation of remotely sensed images. In the context of this report, the ground truth points are tagged with habitat class and sediment class.

Habitat classes: A local classification of the sample records based on statistical analysis of the infaunal data (the clusters), but modified through amalgamation and combining with other data, to create a system that supports the biological interpretation of the locality. In the context of this report they have added significance as they also underpin the ground truth points crucial for successful integrated analysis.

Integrated analysis: Method of statistical interpretation of the geophysical (remotely sensed) data using ground truth samples as training sites.

Training sites: Small areas of known habitat (or sediment) class superimposed on the geophysical images and used to extract data from the images for creating statistical signatures for a habitat class. In these analyses the training sites consisted of a small buffer zone around each sample point.

B. Executive summary

1. Envision have undertaken a biological interpretation of the geophysical data from the Phase 1 and Export Cable Route. The strategy for this interpretation was to integrate sample records and the geophysical remotely sensed images to produce distribution maps. This follows the strategy that has been established within the EU through the MESH program.
2. The geophysical data required processing and transformation in order to render the images suitable for integrated analysis.
3. Suitable ground truth data assigned to habitat classes is vital for integrated analysis and this necessitated Envision undertaking the analysis of the sample records to derive a locally relevant list of biota classes and these have been cross referenced to classes in the Marine Habitat Classification for Britain & Ireland (v04.05).
4. The analyses have been detailed and the full list of habitat classes described. The habitat class distribution map has been presented.
5. The modified Folk sediment classes have also been used in a parallel analysis of the geophysical data to produce a sediment distribution map.
6. The distribution of the habitats is discussed. The biota is typical of moderately exposed (moderately disturbed) gravelly sandy sediments in the North Sea.
7. There were no species or habitats on the draft list of Priority Marine Features in Scottish Territorial Waters.
8. There was no indication that *Sabellaria* biogenic reefs occur in the area.

C. Introduction

The purpose of the analyses was the biological interpretation of the geophysical and sample data and to provide evidence on the distribution of habitats and species within the Phase 1 area and the Export Cable Route (ECR). The main outputs are descriptions of habitats and distribution maps. The overarching strategy for the interpretation was to combine information from the spatially continuous geophysical data with the point sample data using image processing and statistical analysis. This process uses the sample data to 'ground truth' the geophysical data, a strategy is described in the MESH documentation (http://www.searchmesh.net/default.aspx?page=1654) from which Figure 1 is taken. The geophysical and ground truth data required considerable processing prior to integration so that the data were in a suitable format for the mathematical analyses.

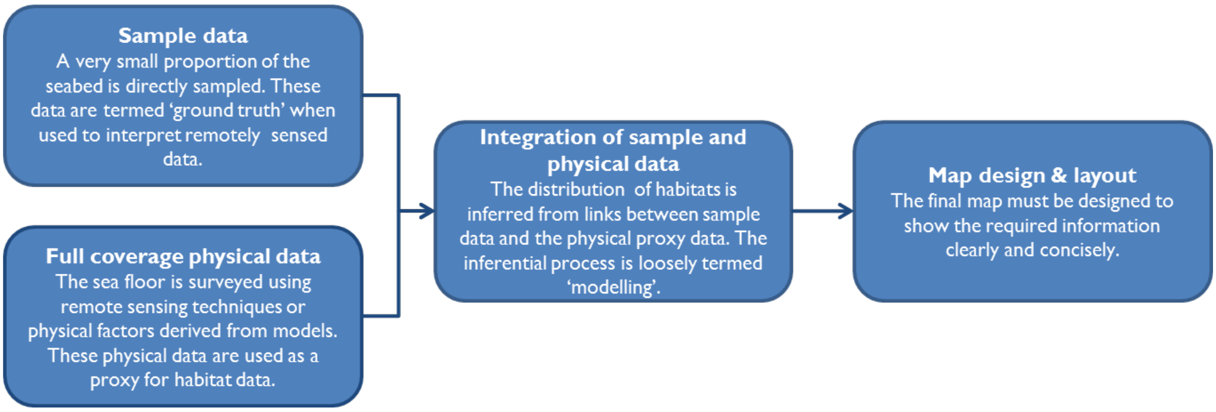

Figure 1: A flow chart of the main stages in making a habitat map by integrating sample data and full coverage physical data (MESH)

The progress of the analysis of the data has been described in some detail in the progress reports and this report summarises the analyses that underpin the final interpretation. The data provided for analysis were geophysical (multibeam and sidescan) and the results of the sampling campaign (grab infauna, PSA, video and trawl). The geophysical data were provided as XYZ data from the processed multibeam data and mosaicked sidescan images. The infaunal sample data were provided as a site/species spreadsheet and as a report of the video data.

Special consideration must be given to the number of samples supporting each class and their spatial distribution in order to ensure a satisfactory habitat class structure suitable for ground truthing. The class structure often needs refining after inspection of the preliminary results of integration with the geophysical data to reduce 'confusion' between classes. Since derivation of habitat classes is pivotal for habitat mapping, Envision undertook the statistical analysis and interpretation of the sample data.

Although the primary output was a description and distribution map of the biological habitat classes, a separate output was a distribution map of the sediment classes (modified Folk classes). Note that the habitat classes are derived from the statistical analysis of the site records. The biological habitat classes derived from this analysis have been cross referenced with the descriptions to the Marine Habitat Classification for Britain & Ireland (v04.05) (http://jncc.defra.gov.uk/page-1584). However, it is considered that the locally relevant statistical habitat classes best describe the areas of interest since the matching process is often somewhat arbitrary and unsatisfactory for that reason.

D. Methods for analysis

D1. Ground truth data

The sample data were accompanied by a separate file of position data and a master *Excel* spreadsheet was prepared collating grab samples, video, PSA and trawl (video-trawl). The infaunal data were in a standard site/species format with counts of individuals for most species, but presence/absence for colonial epifaunal species. The video data were provided as a pdf of the video report. This was translated into an *Excel* spreadsheet with fields for position, depth, sediment and seabed features, assigned biotope and conspicuous fauna. IECS provided the benthic infaunal data for the phase 1 and ECR with GEMS supplying the phase 1 geophysical data and Osiris Surveys providing the geophysical data for the ECR.

The video records were often not coincident with the grab sample data and this meant that combining grab and video records into a unified description of a sample point was not always possible. It was decided that the habitat class structure would be determined primarily by the grab sample data and that these classes would be augmented by video data.

The primary tool for the statistical analysis of the infaunal data was the *PRIMER* software package. The species without abundance data were extracted and set aside for assessing epifaunal diversity (species counts). The site records of the remaining species were imported into *PRIMER* and a resemblance matrix calculated. CLUSTER and MDS plots were used to show relationships between records and the SIMPROF routine used to determine statistically significance clusters and the average species compositions of the clusters. The resulting clusters were modified by absorbing those with only a small number of records into larger groups (which formed the basis of habitat classes) on the basis of species similarity where this was justified. The infaunal species compositions formed the basis of the descriptions of the habitat classes.

The PSA data for both the phase 1 and export cable route were processed by IECS and their Folk classification used for examining the relationship between the biological habitat classes and sediment. The Folks classes for each of the sample points were also used to classify the geophysical data in a separate and parallel integration analysis as well as being the sediment classes used for constructing the sediment distribution maps.

In addition, the PSA data for the samples within each biological habitat class were processed using *GRADSTATS* software to provide a visual display of the sediment characteristics for each habitat class on the triangular modified Folks graph. These plots showed the spread of sediment within each habitat class more completely than simply the Folks class. These are included in the summary descriptions of the biota classes.

D2. Geophysical data input

The Phase 1 geophysical data was provided at the start of the contract and at a later date for the ECR as it became available. The complete grab sample data were provided at the start of the contract. Primarily for this reason the sample data were analysed together for both the Phase 1 and the ECR but the integration with the geophysical data was undertaken for the Phase 1 area and the ECR separately. However, the biological characteristics of the two areas were fairly distinct and the geophysical data sets differed so that separate integration probably assisted the interpretation process. The maps from the two areas were easily combined post processing.

D2.1. Multibeam bathymetry data

The multibeam bathymetry data (XYZ) were smoothed using spatial averaging to a 10m grid resolution (from the 1m resolution provided). This was considered necessary to reduce the noise in the data (although meeting IHO Order 1 standards) and to reduce file sizes for analysis. The 10m resolution was adopted for all subsequent processing. The properties of the multibeam data sets are given in Table 1.

Table 1: Properties of the input data of the multibeam bathymetry images for the Phase 1 and ECR areas and these properties were adopted for other input data

	Phase 1	ECR
Min X (eastings)	550000	517630
Max X (eastings)	595000	555450
Min Y (northings)	6260000	6259780
Max Y (northings)	6285000	6274180
Resolution	10m	10m
Ref. system	UTM-30N	UTM-30N
Unit distance	Metres	Metres

D2.2. Slope

Bathymetry can be used to derive other parameters such as slope and variance. The latter is suitable for showing finer scale features (<5m^2) such as small sand waves. However, although the data for the Phase 1 areas were adequate for detection of broad scale features (>5m^2) such as mega-ripples and sand banks through an analysis of slope, fine scale features were obscured by the noise in the data. Hence, slope was the only derived layer used that was derived from the bathymetry for Phase 1. The ECR data, by contrast, could be processed to show fine scale variability and this thematic layer was used as one of the inputs into the integration analysis for this area.

D2.3. Multibeam backscatter

The multibeam backscatter was processed by the surveyors using *QTC* classification to derive acoustic classes (a form of Automatic Ground Discrimination – AGDS). However, this did not appear to be very successful and the classes reflected different stages in the survey by date. The raw backscatter values were requested and inspected, but exploratory analysis of sample tracks suggested that the data were too noisy to extract any useful information on the acoustic reflectance properties of the sea floor. As a consequence, no equivalence to AGDS was available from the multibeam data.

In order to compensate for lack of AGDS data, the derivatives from the multibeam bathymetry were used within the classification and Bayesian statistics with probabilities of habitat distribution were employed to strengthen the mapping classification process.

D2.4. Sidescan

Geophysical analysis of sidescan data is usually undertaken on the individual track data (or even raw sidescan waterfall images) prior to mosaicking and features are identified by expert interpretation and digitised by hand. However, the procedure Envision adopt for biological interpretation works best using images that can be input into statistical image processing. This usually involves further processing of the sidescan mosaic to produce a suitable image. However, the mosaicking process reduces the resolution of the raw data and also standardises the dynamic range of the backscatter.

The sidescan data were provided as mosaics for the Phase I and ECR separately. These images showed pronounced stripes of dark and light bands due to differences in reflectance across the swaths of each track. Preliminary image analysis indicated that these stripes would dominate any integration analysis and attempts were made to filter out the most severe striping. The technique adopted for both the Phase I and the ECR sidescan mosaics was to set the minimum backscatter values above the actual minimum followed by filtering and smoothing the data. This appeared to be moderately successful and the result was probably equivalent to a basic AGDS data set. These images were used as inputs into the integration process.

D3. Integration

The prepared geophysical data were as follows: - The Phase I survey area had three input layers (bathymetry, slope and sidescan backscatter) whilst the ECR survey area had four layers (as for Phase I with "variability in depth" as the fourth layer).

The ground truth point data were buffered to create a training area of 100m radius around each point and these areas associated with the appropriate habitat class and Folks sediment class (for the parallel sediment map).

The integration analysis was performed in the GIS and image processing software *Idrisi Taiga*. The training areas were used to extract values from each of the geophysical layers that could be associated with the biological habitat classes (or Folks classes). These values were used to create a statistical 'signature' for each class.

These signatures were then applied to the whole geophysical data set. An uncomplex and commonly used method of classifying images is using maximum likelihood whereby each grid cell is assigned to the class to which the grid cell has the highest probability of membership. This works well where the data in the images provide sufficient discrimination. This was the case for the ECR and the habitat and sediment maps have been derived using maximum likelihood. However, the results for the Phase I indicated a lack of discriminatory power that resulted in a high level of confusion between classes.

A second approach to integrated analysis overcame this tendency for confusion: The point sample data were used to derive probability images of occurrence that reflect spatial trends in biota across the Phase I site. These images were then incorporated into a Maximum Likelihood model as prior probability images that moderated the integration process based on an interpretation of the geophysical data alone. A schematic diagram illustrating the main stages in the analytical process is shown in Figure 2.

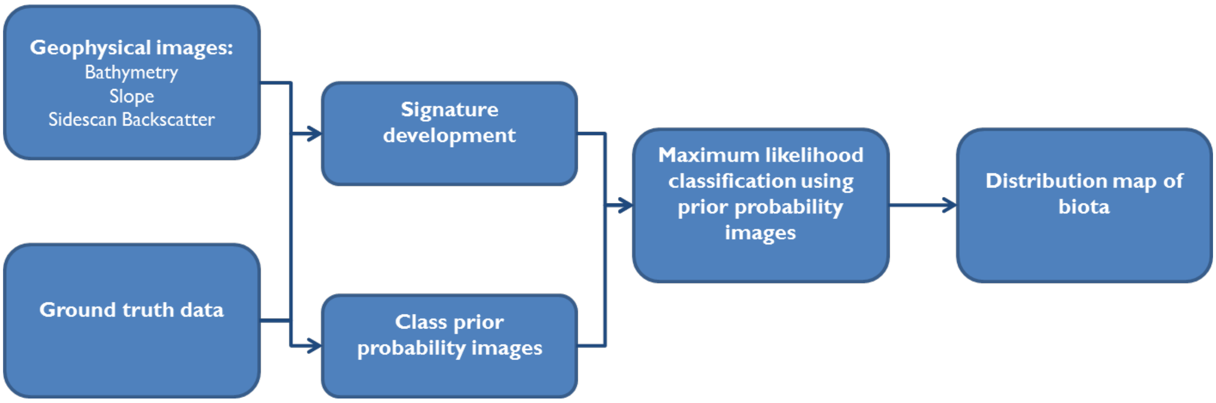

Figure 2: Schematic diagram outlining the main stages in the modelling of the distribution of biotas classes

E. Results

E1. Geophysical images

Images from the geophysical data that were used as inputs for integrated analysis are shown in summary in Figure 3 for the Phase 1 site and Figure 4 for the ECR.

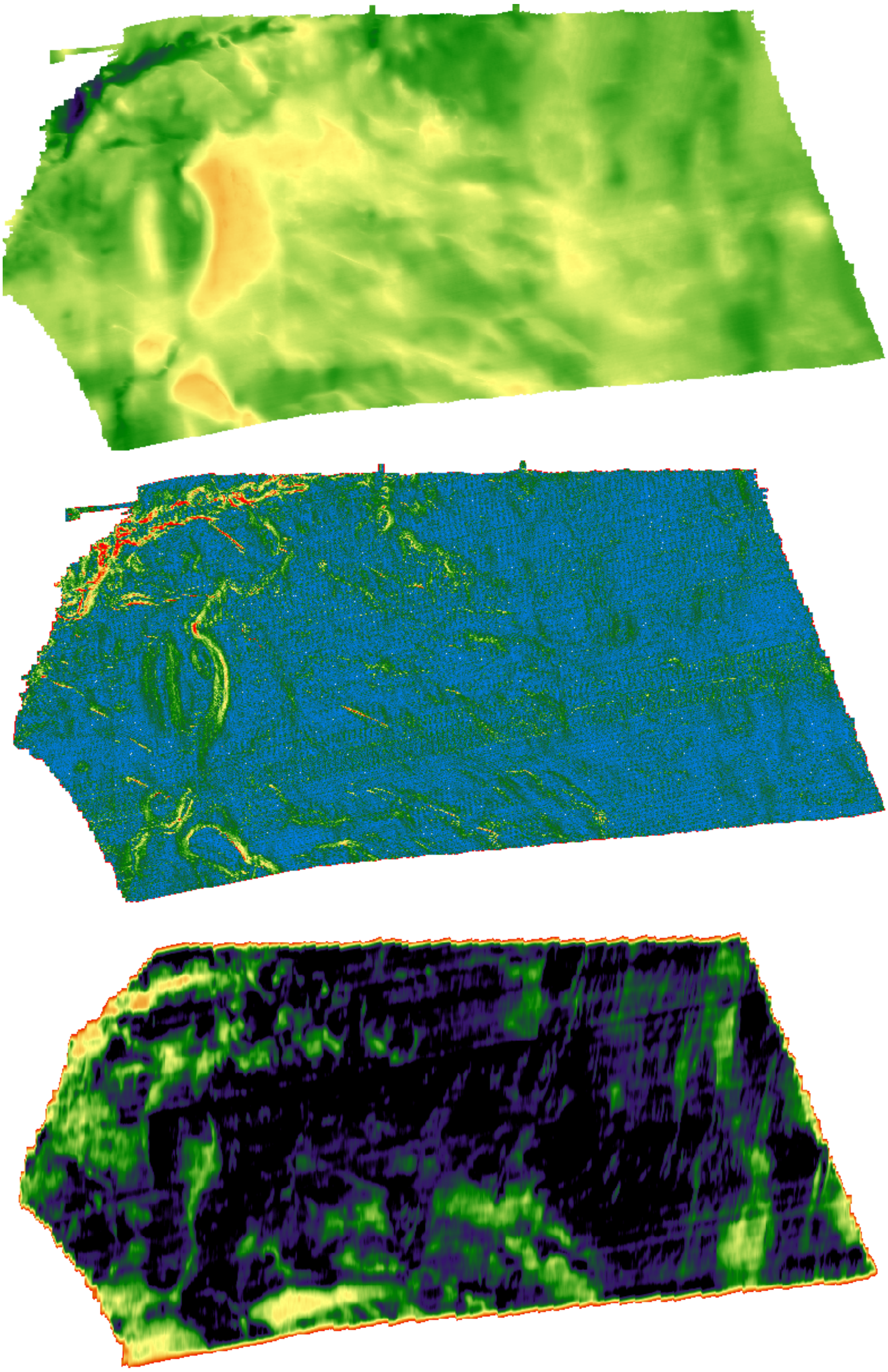

Figure 3: Images used in the integrated analysis for the Phase 1 area: From top to bottom: - Bathymetry; Slope; Side scan backscatter

Figure 4: Images used in the integrated analysis for the ECR: From top to bottom: - Bathymetry; Slope; depth variability; Side scan backscatter

Figure 3 and Figure 4 show the various datasets used within the analyses and illustrate the different features which can be detected by each data set, The bathymetry shows the general topographical features within the Phase I and ECR survey areas with the derived slope highlighting the more distinct prominent features and also the edges of the topographic features with the sidescan backscatter revealing the surface textures and patterns which may not be detected or be obvious within the other data sets. For the ECR depth variability was used in addition to the datasets common to the Phase I area, this variability enhanced the detection of the rugged ground types.

E2. Sediment

E2.1. PSA data from grab samples

Most of the sediments were gravelly sands or sandy gravels with some samples having significant mud content, especially in the ECR and the inner Phase I area (Figure 5).

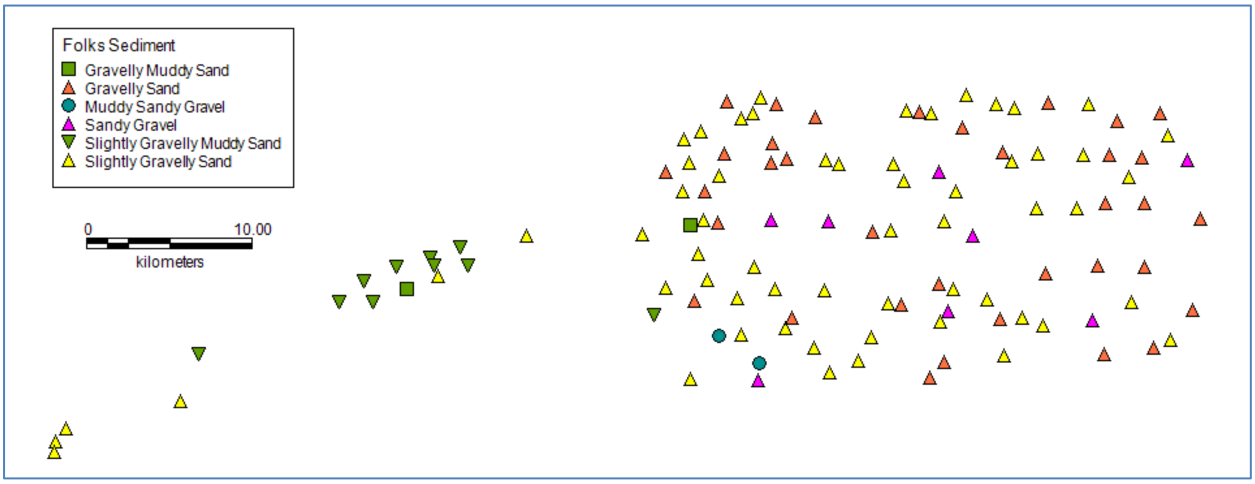

Figure 5: Distribution of the PSA data (modified Folks) as classified by GEMS

E2.2. Sediment characteristics from video samples

The majority of the sediments were shelly or gravelly sand, often rippled or with larger megaripples. It is likely, therefore, that the sediments in the area and the fauna they support are subject to some level of disturbance. Cobbles were recorded as occasional at many sites and there were six sites where the predominant sediment was cobbles. The gravel and cobble would also be expected to support epifauna.

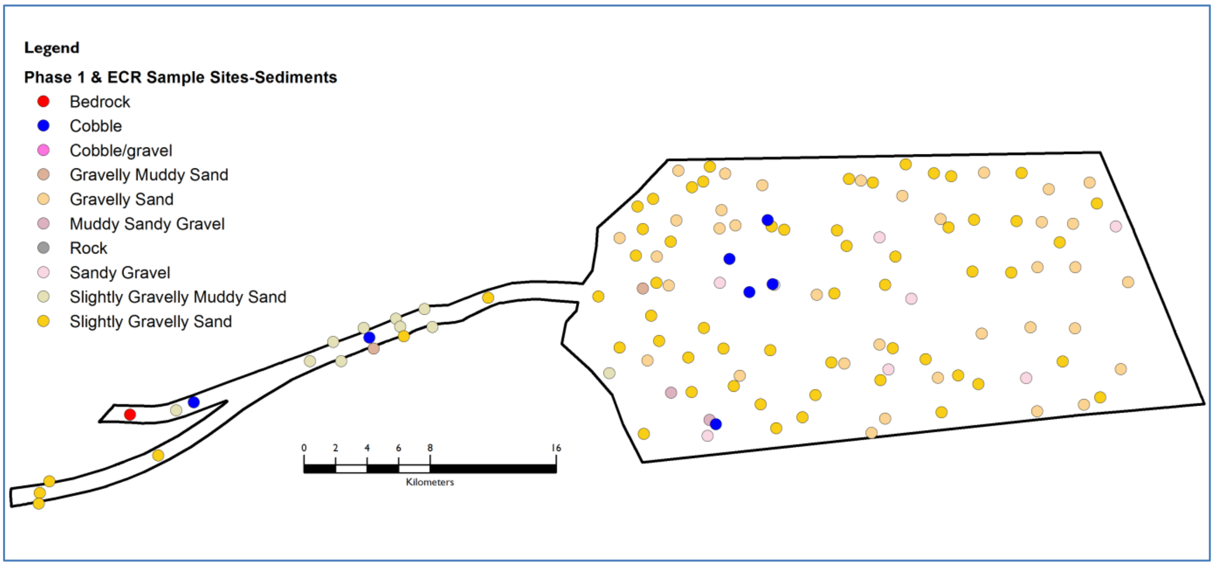

Figure 6: Distribution of the sediment types (visual classification by surveyors) within the Phase 1 and ECR survey areas

Combining the evidence from the PSA and the video data into a single dataset that can be used for integration with the geophysical data may not be satisfactory because of the uncertain visual classification of gravelly sands. There were enough PSA samples for satisfactory interpretation without using the video directly. However, cobble and bedrock are not satisfactorily sampled by grabs and the video samples for cobble and bedrock were included in the ground truthing sediment sample set (Figure 6).

E2.3. Sediment relationships with the biota assemblages

The PSA data for each of the habitat classes were processed using GRADSTATS to provide a visual display of the sediment characteristics for each group according to the modified Folks classification. The triangular graphs of the PSA data are included in the summary habitat descriptions in Appendix 3.

E3. Biota

E3.1. Analysis of infauna from grab samples

The infaunal data from the Phase 1 and ECR sampling have been combined and analysed using the CLUSTER and SIMPROF routines in PRIMER. No transformation was used: This was to accentuate the differences in abundance of the species since a large proportion of the samples had low overall species abundance.

Figure 7 shows the dendrogram from the CLUSTER analysis with the most significant branches coloured black and the less significant branches in red. The letters refer to the significant clusters (see Appendix 1). The species composition and average abundance is summarised in Appendix 2 for the significant clusters. Note that epifauna and encrusting fauna recorded by presence/absence has been treated separately and the average epifaunal counts have been included in the first row for comparison with the infaunal analysis.

The plot of the similarity between samples, using the MDS routine in Primer, is shown in Figure 8a with the samples labelled according to the cluster to which they belong. Figure 8b shows the same MDS plot with the points labelled with the habitat classes.

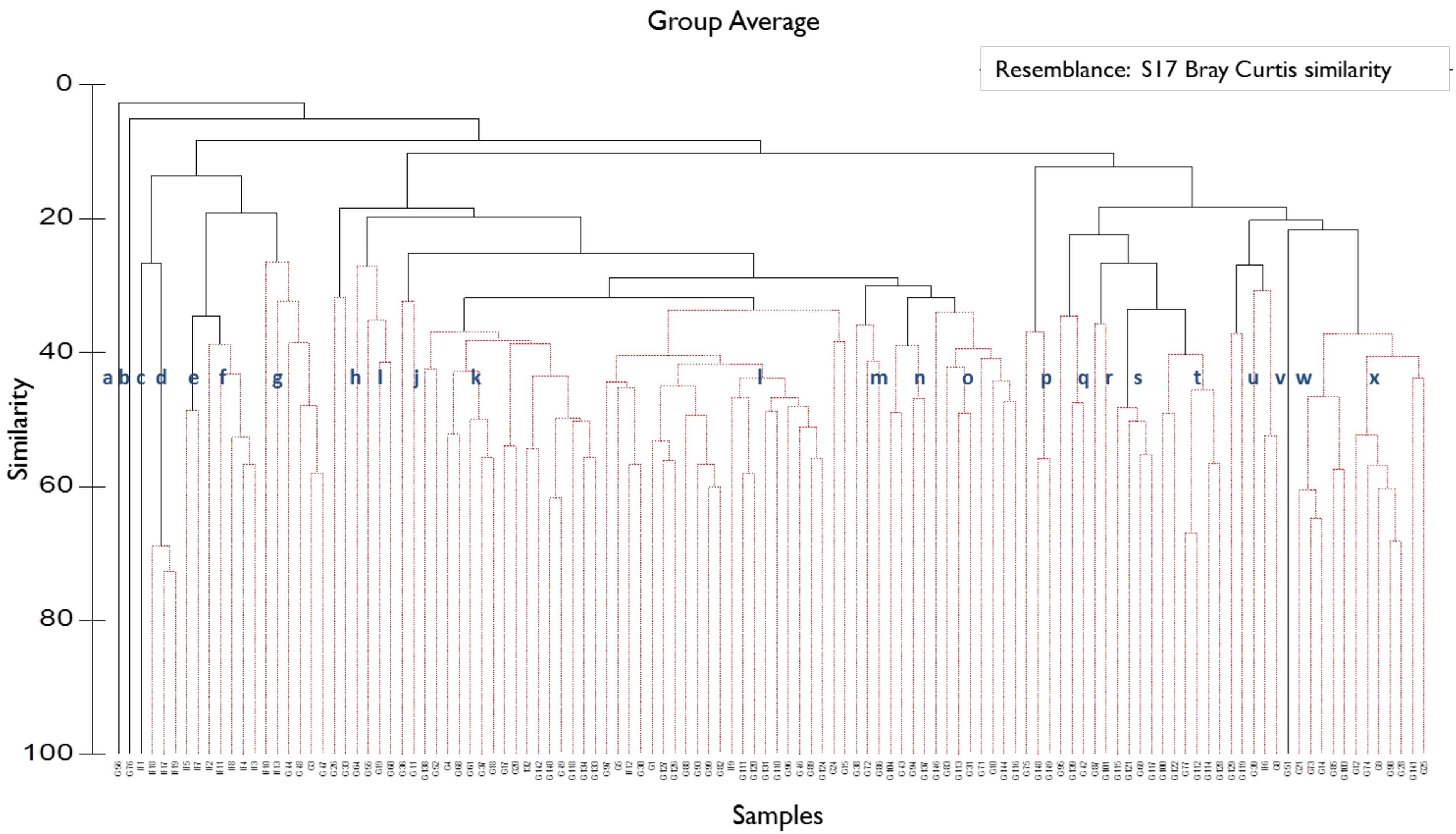

Figure 7: The dendrogram output from the CLUSTER analysis (PRIMER) of the infauna. The branches with solid black lines are statistically significant. The blue letters superimposed on the dendrogram refer to the significant clusters (see Appendix 1)

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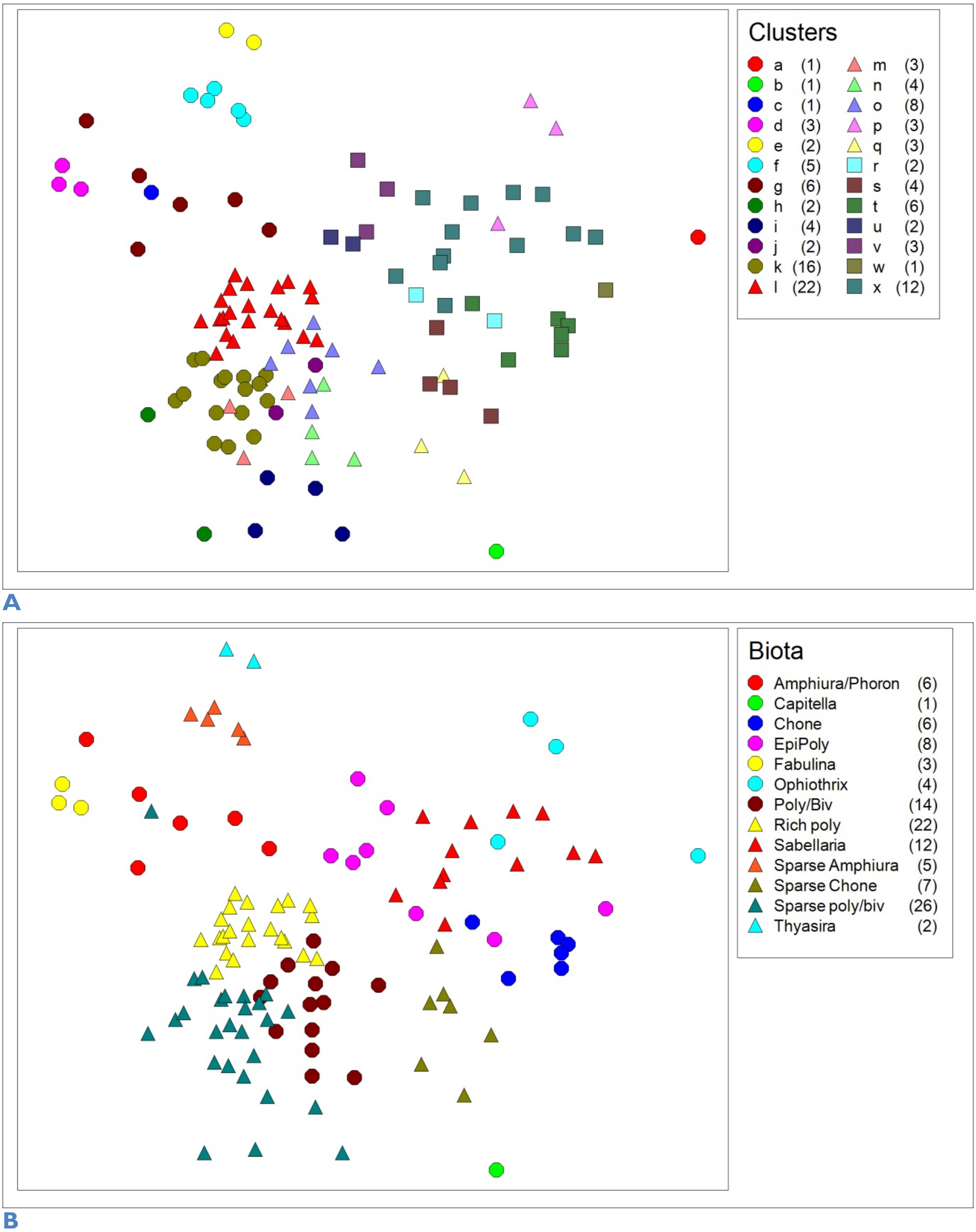


Figure 8: MDS plot of similarity between samples indicating the relationship between the faunal clusters identified by the CLUSTER analysis. 8b is the same plot with records labelled with the habitat classes used for analysis

The number of statistically distinct clusters (a-w; 24 clusters) was considered too large for successful integration analysis, especially considering that 4 contain only 1 example, and 5 contain only two samples each whilst 3 clusters contain 12, 16 and 22 samples. The number of clusters has been reduced by amalgamation based on species composition.

Table 2 is the revised list of clusters which have been given a title summarising their biological characteristics.

Table 2 Rearrangement of the clusters into habitat classes

Biota	Clusters	Number	Comments
Capitella	b	1	Unique: not used in the analysis
Fabulina	d	3	Small but discrete cluster
Thyasira	e	2	Small but discrete cluster
Sparse Amphiura	f	5	Discrete cluster
Dense Amphiura/Phoronis	g	6	Discrete cluster
Sparse polychaete/bivalve	kmihc	26	Overlapping clusters of sparse polychaetes
Rich polychaete	l	22	Large discrete cluster
Polychaete/Bivalve	noj	14	Very similar
Ophiothrix	pa	4	Ophiothrix unites these samples
Epifauna/Polychaete	ruvw	8	Sparse polychaetes, but rich epifauna
Sparse Chone	sq	7	Overlapping clusters with sparse Chone
Dense Chone	t	6	Discrete cluster
Sabellaria	x	12	Discrete cluster

Cluster b remains a single sample characterised by abundant *Capitella* and was not used in the integrated analysis. Instead, it has been displayed on the map as a point. Clusters e and d have only two or three samples but were also distinct and geographically clustered in the ECR and have been retained for integrated analysis. These refined clusters have been tagged with the predominant biota and are termed 'habitat classes'. These classes correspond loosely to MNCR biotope classes and are included in Appendix 1.

The distribution of these clusters (Figure 9) shows few obvious trends. It is possible that *Chone* (a tube-living Sabellid) was more prevalent in the east and south east section of the Phase 1 site. It may also be the case that there was a swath of sparse infauna running north east to south west dividing the richer polychaete assemblages (which were more numerous in the north western and south eastern sections of the Phase 1 area).

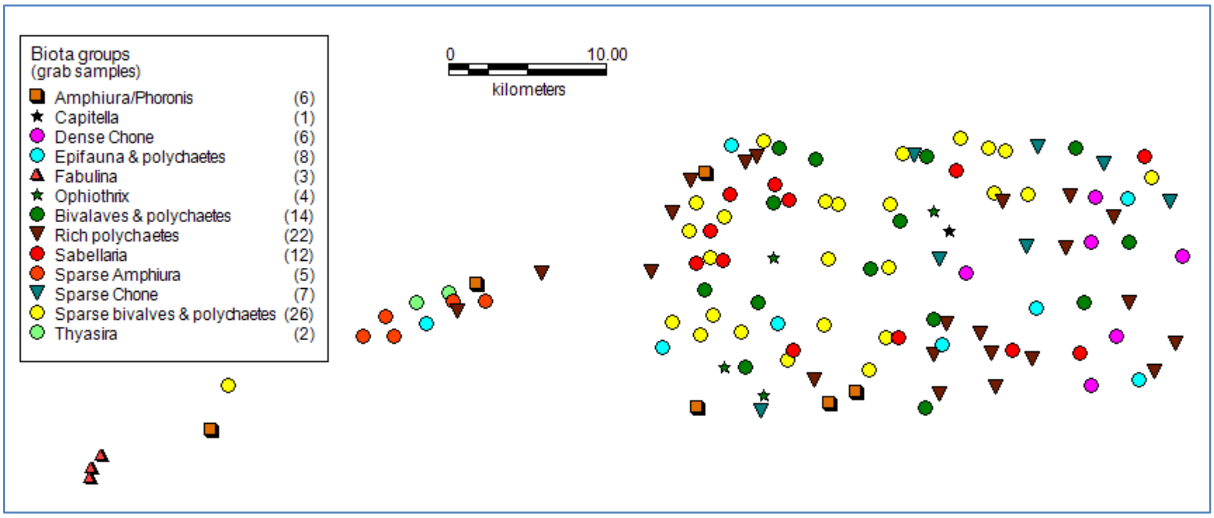


Figure 9: Distribution of the habitat classes derived from analysis of the grab data

E3.2. Epifauna

The species recorded by presence/absence (approximately corresponding to epifauna and encrusting fauna) were common wherever the sediment contained gravel; shell or cobble for attachment and the distribution of epifauna is related to sediment (PSA):Sandy gravels and gravelly sands as a generality supported rich epifauna whilst slightly gravelly sands were low in epifauna (Table 3).

Table 3: Distribution of epifauna across the range of sediments recorded from the grab samples

Sediment (Folks)	No samples	Average number of species
Muddy Sandy Gravel	2	14.5
Sandy Gravel	8	14.0
Gravelly Sand	35	11.1
Gravelly Muddy Sand	2	10.5
Slightly Gravelly Sand	59	4.2
Slightly Gravelly Muddy Sand	10	0.9

E3.3. Epifaunal characteristics from video samples

Most of the species recorded were probably opportunistic. For example, the majority of these suitable sites supported bryozoan/hydroid turf (especially *Flustra foliacea*) and the tube worm *Hydroides norvegica*. However, the purple urchin *Echinocyamus pusillus* and the sea squirt *Ascidiella scabra* were characteristic of only some samples. In order to simplify the habitat class structure that will be used for integrated analysis, the dominant epifaunal assemblages (or lack of epifauna) have been correlated with the infaunal groups (Table 4).

Table 4: Relationship between epifauna and infaunal groups (=habitat class)

Infaunal group (habitat class)	% samples with epifauna	Characterising epifauna
Sabellaria	100	Bryozoan/hydroid turf; faunal crusts
Ophiothrix	100	Bryozoan/hydroid turf; faunal crusts
Dense Chone	100	Bryozoan/hydroid turf; faunal crusts; Ascidiella
Sparse Chone	86	Bryozoan/hydroid turf; faunal crusts; Echinocyamus
Epifauna & Polychaetes	75	Bryozoan/hydroid turf; faunal crusts; Ascidiella
Polychaetes/ bivalves	57	Echinocyamus; Ascidiella
Rich polychaetes	45	Echinocyamus; Ascidiella
Dense Amphiura/Phoronis	17	Echinocyamus
Sparse polychaetes/ bivalves	8	Echinocyamus
Sparse Amphiura	0	0
Fabulina	0	0
Thyasira	0	0
Capitella	0	0

There appeared to be a close correspondence between infauna and epifauna and the epifaunal component was integrated with the infauna to create a simplified system of habitat classification that was used as the ground truth datasets for integrated analysis (rather than map the infauna and epifauna separately).

Epifauna (particularly the bryozoan *Flustra foliacea*) were observed in the majority of video samples, although data on relative abundance was not provided. The evidence from the video samples was difficult to incorporate into the habitat class descriptions because most of the video samples were not co-located with the grab samples. This reinforced the decision to use the grab samples as the basis of the habitat classes, with the exception of the cobble sites which were not sampled by the grab.

The distribution of the richness of epifauna (number of species per sample) shows no clear spatial trends over the Phase 1 site, but epifaunal richness was low in the ECR (Figure 10).

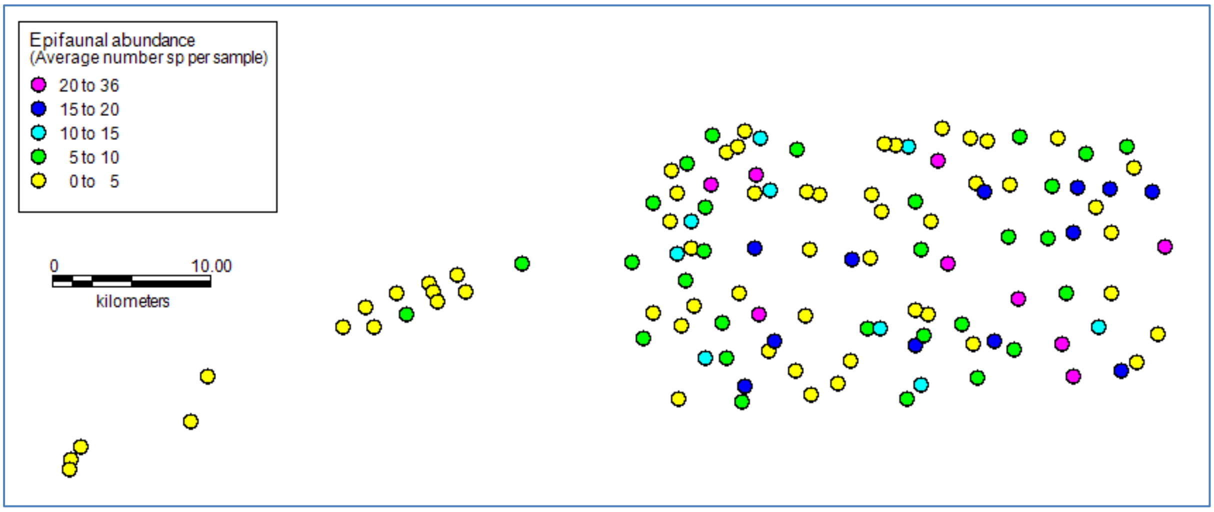


Figure 10: Distribution of epifaunal abundance as assessed from number of species recorded per sample

In summary, the grab sample data provided a firm basis for a habitat classification that can be used for analysis of the geophysical data. Epifauna were distributed across the habitat classes according to sediment type and the opportunity the shell, gravel and cobble provided for attachment. The epifaunal species were generally common across most of the samples. Because of this, it was decided to add epifaunal characteristics (largely abundance) to the habitat classes in order to provide an integrated classification suitable for mapping.

The video data have provided additional sample sites covering cobble sediment not sampled by grab. Otherwise, the information from the video will not be used for the ground truth directly, but will be used to help validate any interpretation by overlaying the data onto interpreted maps to assess map confidence.

Table 5 shows the biota classes used for mapping and references this local classification system to the national JNCC biotope classification, The Marine Habitat Classification for Britain & Ireland (v04.05). Sediments dominated by *Chone spp*. are not accounted for within the classification with the closest match being 'Offshore circalittoral mixed sediment' (SS.SMx.OMx) which has been used with the addition of a modifier '.(Chone)'.

Table 5: Biota classes used for habitat mapping cross referenced to the Marine Habitat Classification for Britain & Ireland (v04.05

Biota Class	JNCC Biotope Code	JNCC Biotope Name
Amphiura/Phoronis	SMu.CSaMu.AfilMysAnit	*Amphiura filiformis*, *Mysella bidentata* and *Abra nitida* in circalittoral sandy mud
Chone (dense)	SS.SMx.OMx.(Chone)	Offshore circalittoral mixed sediment (with *Chone spp.*)
Epifauna & Polychaetes	SS.SMx.OMx.PoVen	Polychaete-rich deep Venus community in offshore mixed sediments
Fabulina	SSa.IMuSa.FfabMag	*Fabulina fabula* and *Magelona mirabilis* with venerid bivalves and amphipods in infralittoral compacted fine muddy sand
Faunal turf	SMX.CMx.FluHyd	*Flustra foliacea* and *Hydrallmania falcata* on tide-swept circalittoral mixed sediment
Ophiothrix	SMx.CMx.OphMx	*Ophiothrix fragilis* and/or *Ophiocomina nigra* brittlestar beds on sublittoral mixed sediment
Polychaetes/ bivalves	SS.SMx.OMx.PoVen	Polychaete-rich deep Venus community in offshore mixed sediments
Rich polychaetes	SS.SMx.OMx.PoVen	Polychaete-rich deep Venus community in offshore mixed sediments
Sabellaria	SBR.PoR.SspiMx	*Sabellaria spinulosa* and *Polydora spp.* on stable circalittoral mixed sediment
Sparse Amphiura	SMx.CMx.MysThyMx	*Mysella bidentata* and *Thyasira spp.* in circalittoral muddy mixed sediment
Sparse Chone	SS.SMx.OMx.(Chone)	Offshore circalittoral mixed sediment (with *Chone spp.*)
Sparse poly/biv	SCS.ICS.MoeVen	*Moerella spp.* with venerid bivalves in infralittoral gravelly sand
Thyasira	SCS.CMx	Circalittoral mixed sediment
Capitella	SS.SMu.ISaMu.Cap	*Capitella capitata* in enriched sublittoral muddy sediments

F. Integrated analysis

The distribution maps of habitat classes and sediment follow in the Map Section. The standard methods for assessing agreement between the ground truth data and the interpreted habitat class and sediment distributions (the Kappa agreement index that calculates the proportion of correct predictions over and above chance) do not give a true indication of predictive power of the maps, especially for the Phase 1 map where prior probability images constrain the predicted distribution of the classes to be spatially faithful to the ground truth data. This exaggerates the apparent agreement and is not a good measure of accuracy.

A better assessment is to use an independent sample data set to validate the maps. The only data set is the video (which was only used peripherally for classifying the ground truth data). However, the habitat code (Marine Habitat Classification for Britain & Ireland) assigned by the surveyors based on video information are largely determined by the sediment type and must be regarded as tentative. The codes are probably best compared to the sediment map rather than the habitat classes. The distribution of the video records (Figure 11) largely supports the sediment map with predominantly gravelly habitats to the east and finer sands in the west and a ridge of harder ground with epifauna and brittle stars running north/south.

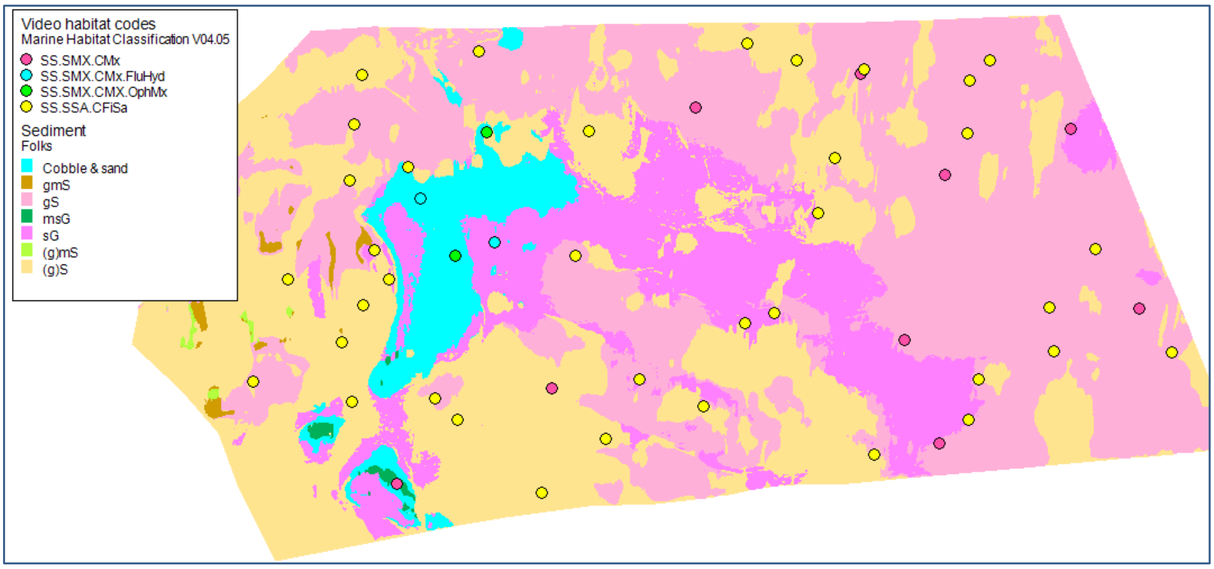


Figure 11: Video records labelled with Marine Habitat codes (Marine Habitat Classification for Britain & Ireland v04.05) superimposed on the predicted sediment distribution

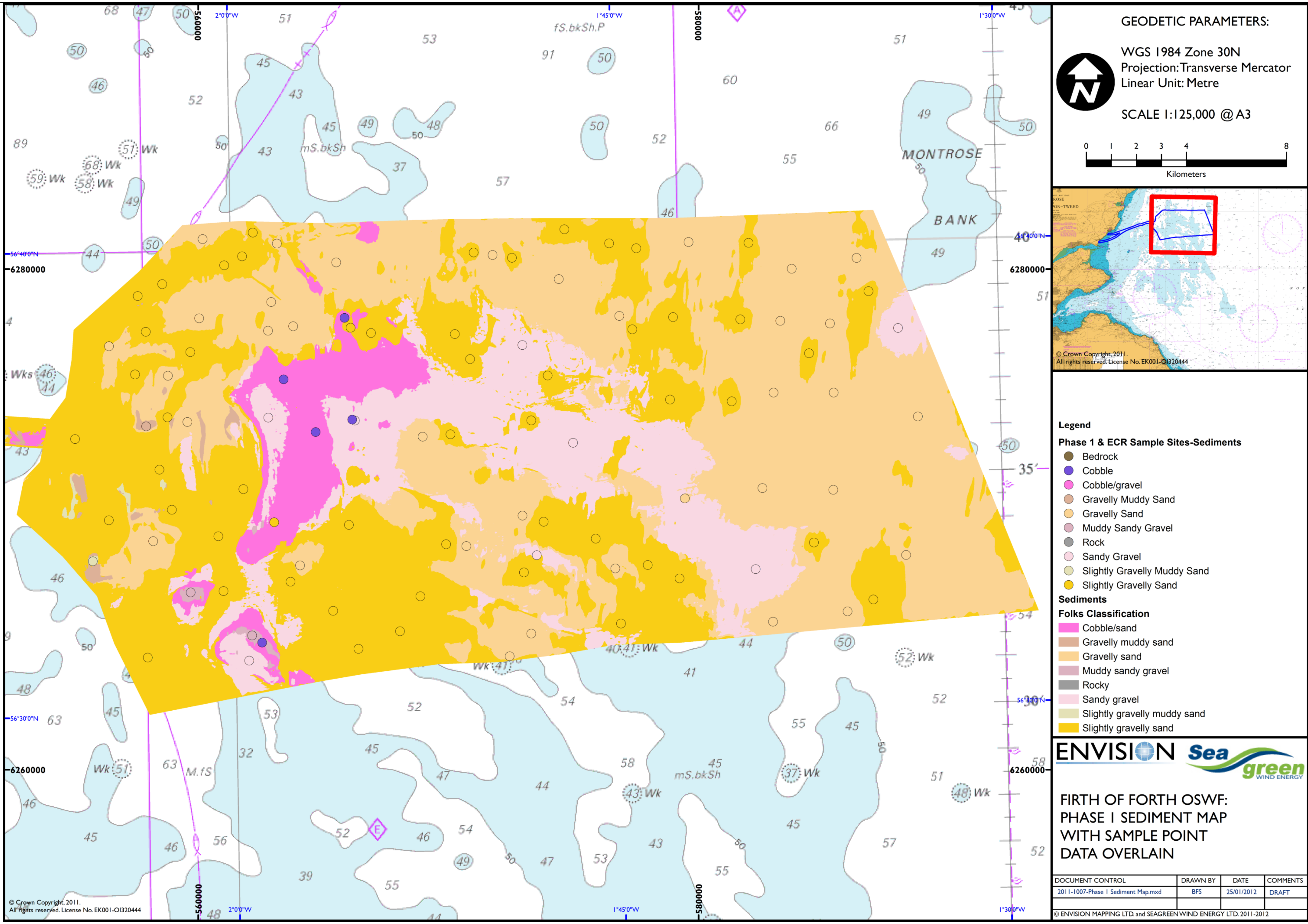
However, the success of the map is best seen in the trends in the obvious correspondence between distribution of the biota and the geophysical features and bathymetry (Figure 3 & Figure 4). The following are some of the most significant trends that can be identified from the distribution map:-

1. There is a broad raised ridge of cobble and coarse sediment running north/south that is characterised by epifauna and *Ophiothrix*.
2. The majority of the Phase 1 area is level or undulating with occasional linear sediment waves. The area can be divided into western and eastern halves. The western half is dominated by two classes: *Sabellaria* and sparse polychaetes and bivalves. The eastern half is dominated by *Chone* and rich polychaete classes. There appears to be a transition between

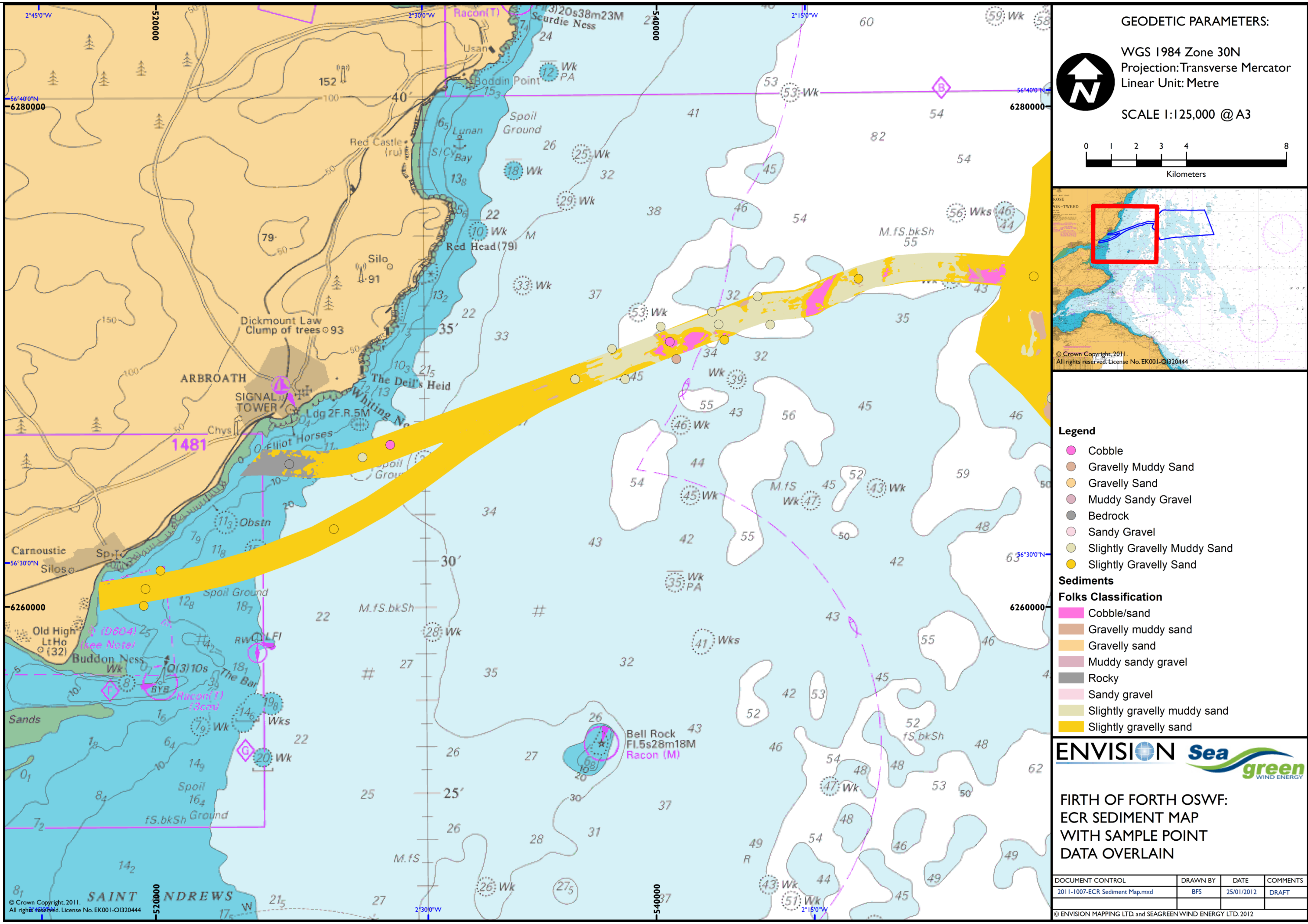
the two halves with moderately rich polychaetes and bivalves and sparse *Chone* in the northern and central section of the site. These would appear to be quite marked trends in the communities across the Phase 1 site.

3. It is noteworthy that the *Sabellaria* classes are generally diverse and this contrasts with the sparse polychaete communities. It is possible that the colonisation of suitable areas by *Sabellaria* increase the diversity of habitats that would otherwise be somewhat sparse. There is no evidence from the video that these worms form extensive or well-developed reefs. However, the draft list of Priority Marine Features in Scottish Territorial Waters (http://www.snh.gov.uk/docs/B874876.pdf) does not include this reef habitat (presumably because *Sabellaria spinulosa* reefs have not been recorded in Scottish waters).
4. There are deeper water habitats on the north western and south western margins of the Phase 1 site that support the statistically distinct *Amphiura/Phoronis* classes.
5. The grounds at the margins of the deeper water habitats support rich polychaete biota.
6. The ECR is more uniform in its sediment being largely slightly gravelly sands or slightly gravelly muddy sands with a bedrock platform on the western shallow water extremity of the northern route. There are also hard ground ridges crossing the ECR at the eastern end (presumed to be cobble and sand, although no ground truth data were available).
7. The sands support the bivalve *Thyasira* and *Fabulina* habitat classes that were not found in the Phase 1 area. Other communities were characterised by *Amphiura*.

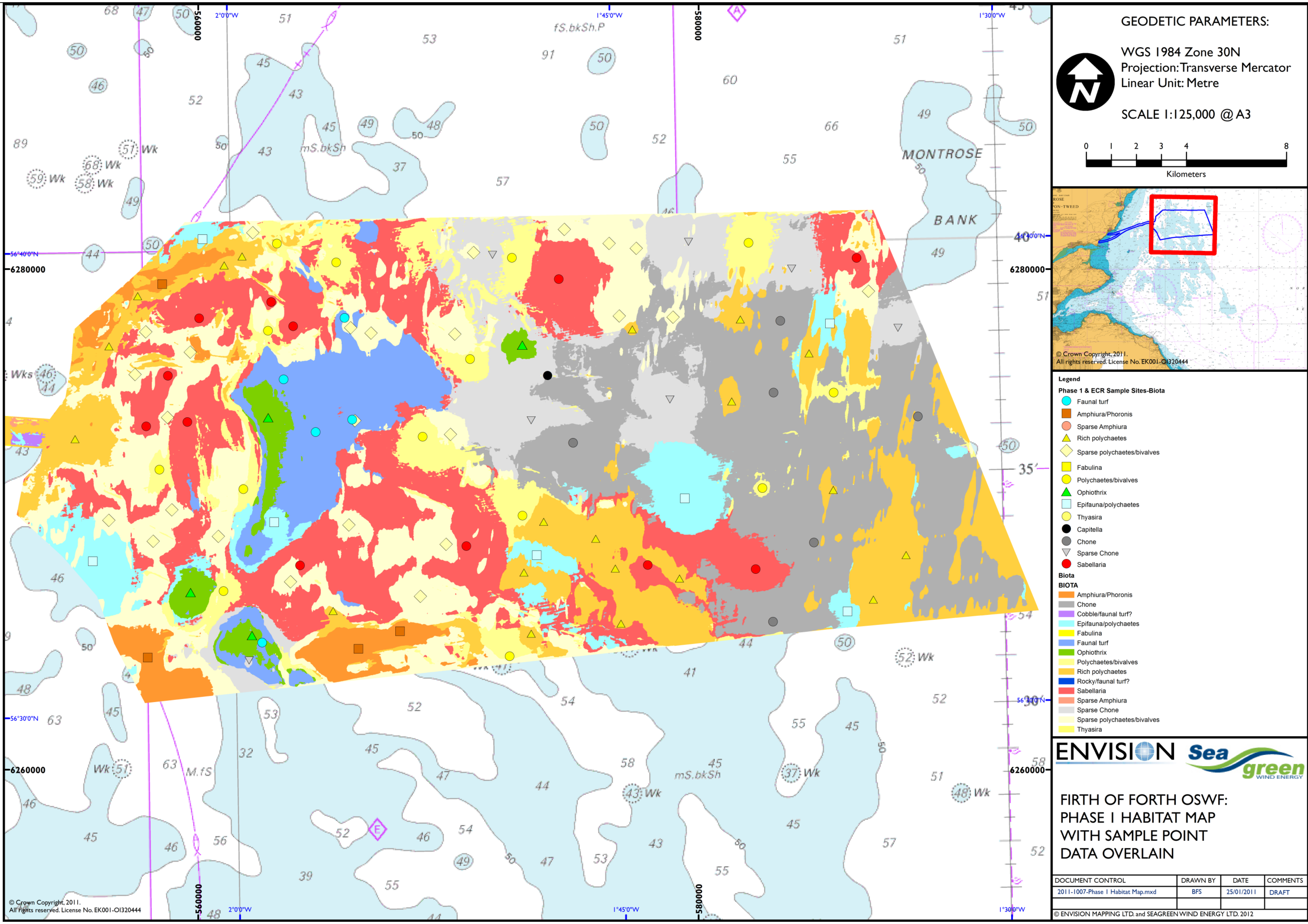
G. Map Section



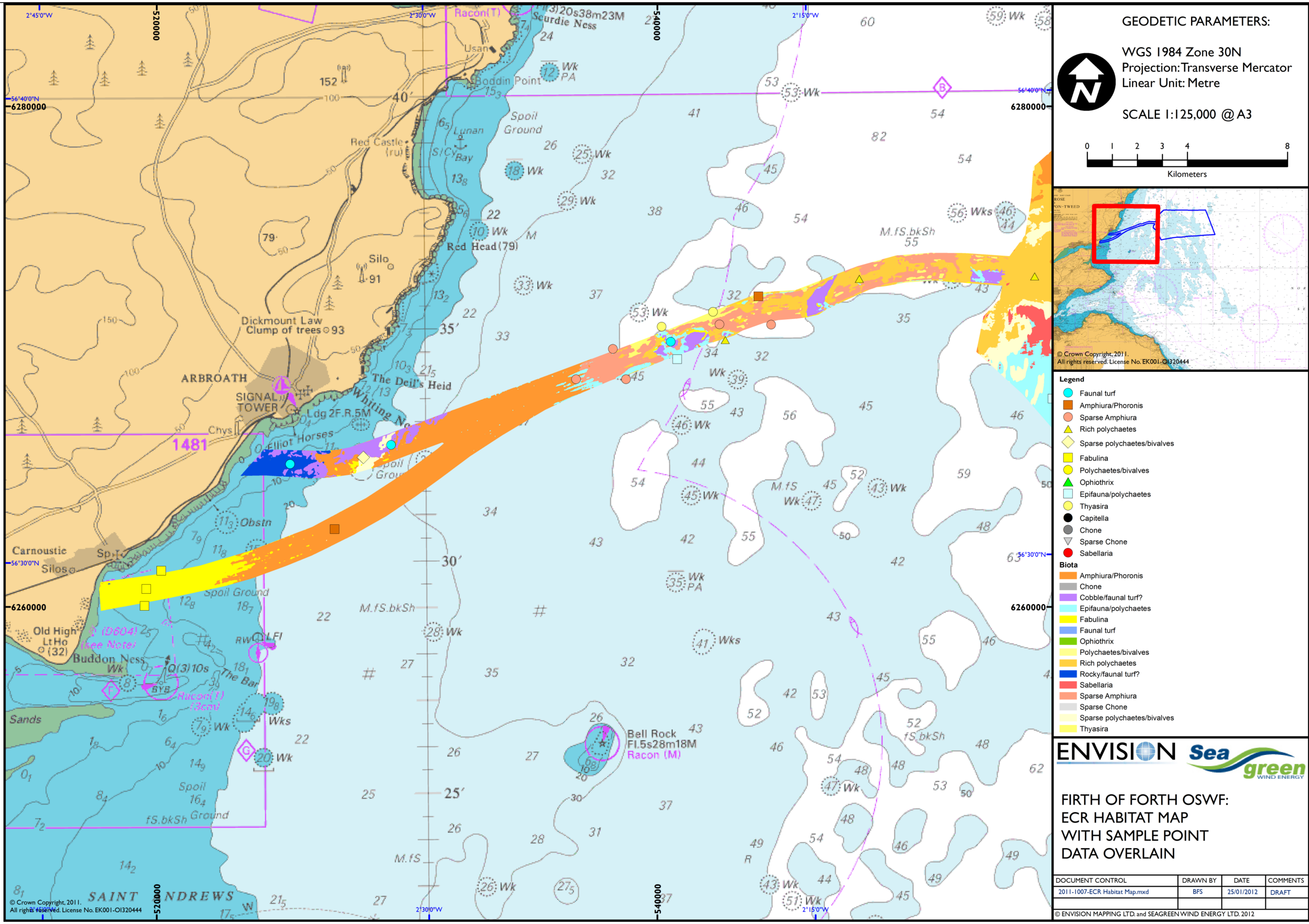
Map 1: Firth of Forth OSWF Area, Phase 1 predictive sediment map overlain with sample site locations coloured by sediment type



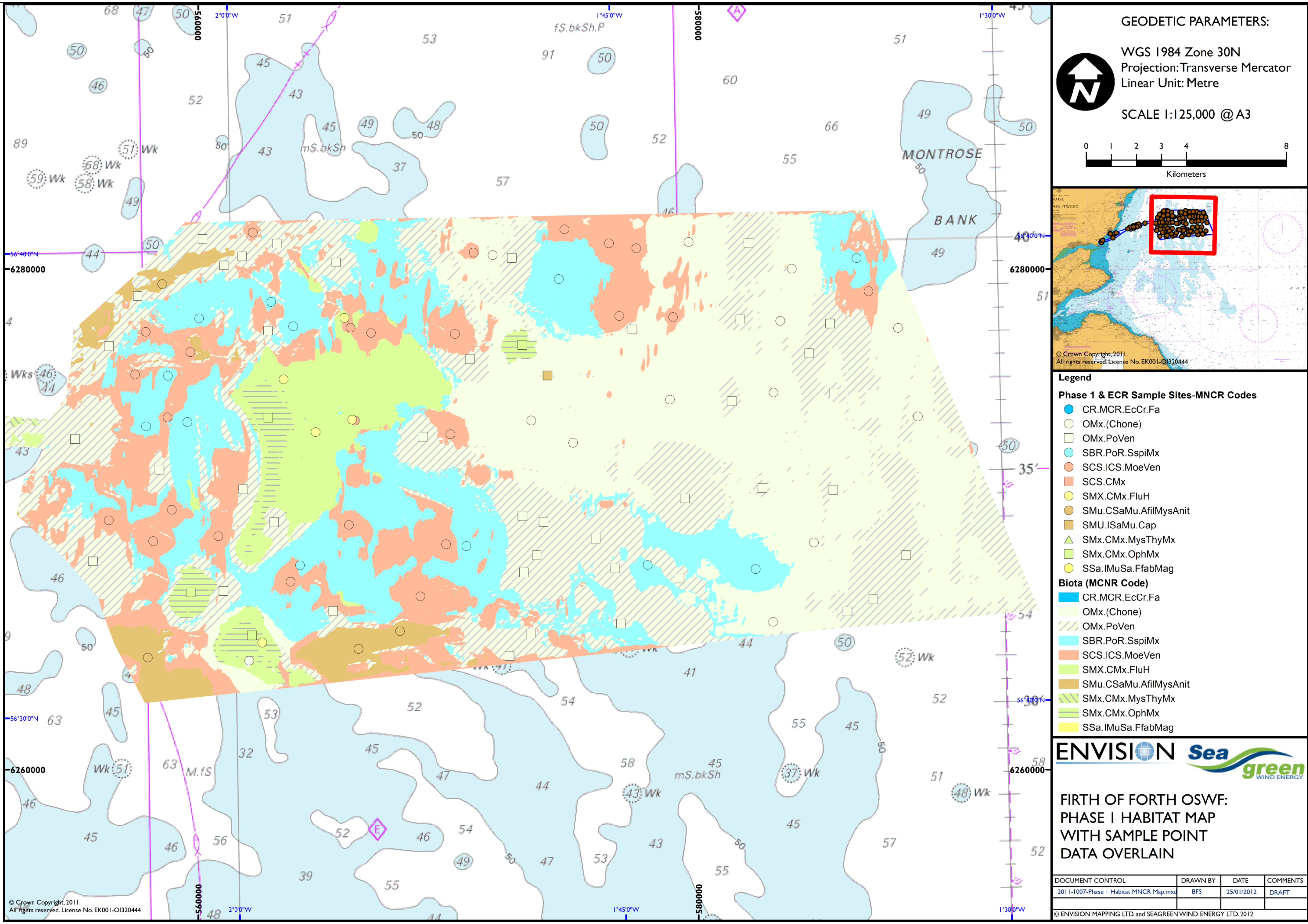
Map 2: Firth of Forth OSWF Area, Export Cable Route predictive sediment map overlain with sample site locations coloured by sediment type.



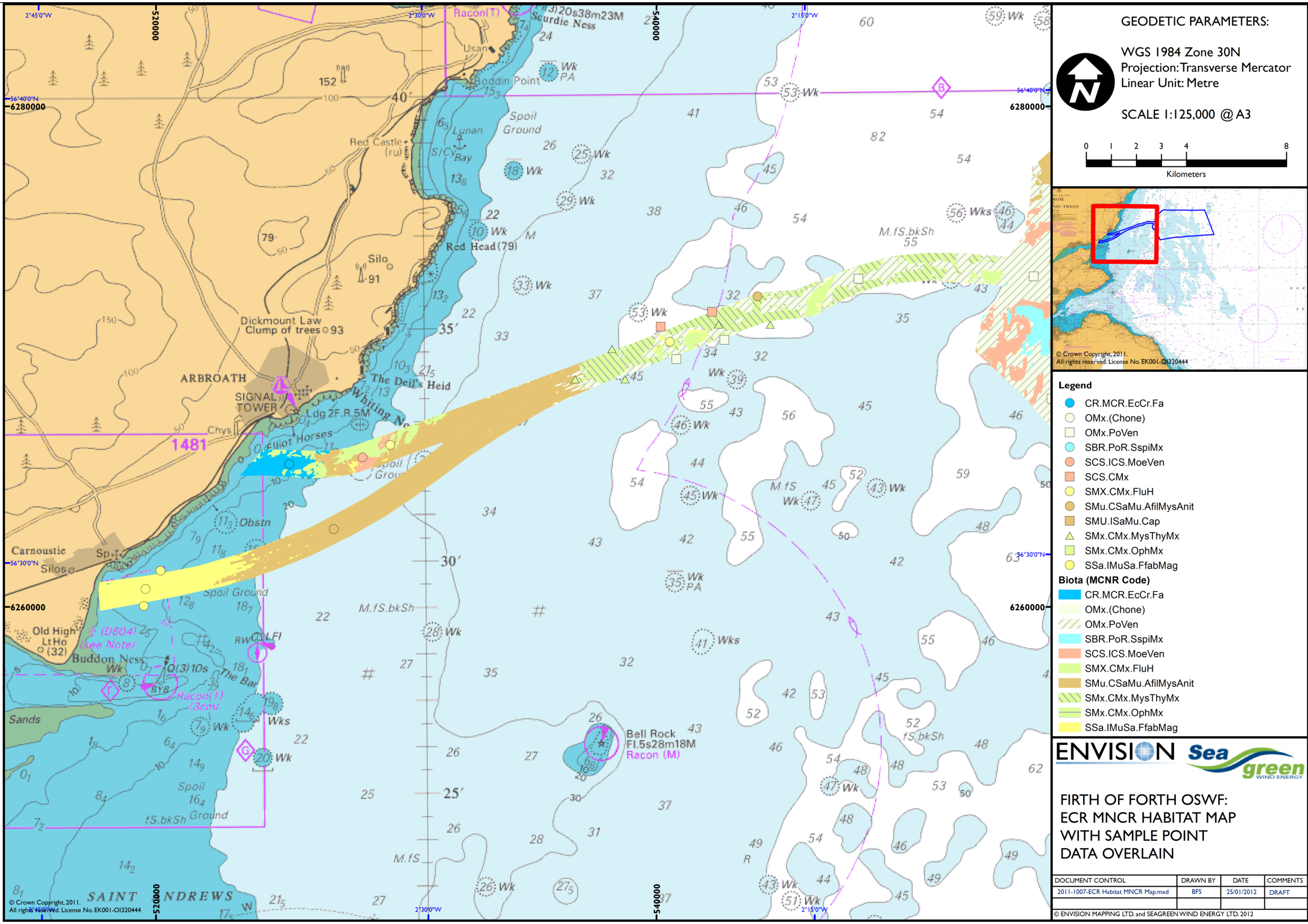
Map 3: Firth of Forth OSWF Area, Phase I predictive habitat map overlain with sample site locations coloured by habitat type



Map 4: Firth of Forth OSWF Area, Export Cable Route predictive habitat map overlain with sample site locations coloured by habitat type



Map 5: Firth of Forth OSWF Area, Phase 1 predictive habitat (EUNIS/MNCR) map overlain with sample site locations coloured by habitat type (MNCR Colour Scheme)



Map 6: Firth of Forth OSWF Area, Export Cable Route predictive habitat (EUNIS/MNCR) map overlain with sample site locations coloured by habitat type (MNCR Colour Scheme)

H. Appendix I – Ground truth data habitat classes

Sample	Cluster	Cluster Group	Habitat Class	Marine Habitat Classification Code
G56	a	p	Ophiothrix	SMx.CMx.OphMx
G76	b	b	Capitella	SMU.ISaMu.Cap
IF1	c	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
IF18	d	d	Fabulina	SSa.IMuSa.FfabMag
IF17	d	d	Fabulina	SSa.IMuSa.FfabMag
IF19	d	d	Fabulina	SSa.IMuSa.FfabMag
IF5	e	e	Thyasira	SCS.CMx
IF7	e	e	Thyasira	SCS.CMx
IF4	f	f	Sparse Amphiura	SMx.CMx.MysThyMx
IF11	f	f	Sparse Amphiura	SMx.CMx.MysThyMx
IF3	f	f	Sparse Amphiura	SMx.CMx.MysThyMx
IF8	f	f	Sparse Amphiura	SMx.CMx.MysThyMx
IF2	f	f	Sparse Amphiura	SMx.CMx.MysThyMx
IF13	g	g	Amphiura/Phoron	SMu.CSaMu.AfilMysAnit
G44	g	g	Amphiura/Phoron	SMu.CSaMu.AfilMysAnit
G3	g	g	Amphiura/Phoron	SMu.CSaMu.AfilMysAnit
G47	g	g	Amphiura/Phoron	SMu.CSaMu.AfilMysAnit
G48	g	g	Amphiura/Phoron	SMu.CSaMu.AfilMysAnit
IF10	g	g	Amphiura/Phoron	SMu.CSaMu.AfilMysAnit
G26	h	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G33	h	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G64	i	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G19	i	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G55	i	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G60	i	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G36	j	noj	Poly/Biv	SS.SMx.OMx.PoVen
G11	j	noj	Poly/Biv	SS.SMx.OMx.PoVen
G138	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G134	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G133	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G52	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G140	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G4	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G132	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G49	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G17	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G68	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G142	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G20	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G37	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G118	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G18	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G61	k	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G96	l	l	Rich poly	SS.SMx.OMx.PoVen
G89	l	l	Rich poly	SS.SMx.OMx.PoVen
G131	l	l	Rich poly	SS.SMx.OMx.PoVen
G46	l	l	Rich poly	SS.SMx.OMx.PoVen
G124	l	l	Rich poly	SS.SMx.OMx.PoVen
G110	l	l	Rich poly	SS.SMx.OMx.PoVen
G88	l	l	Rich poly	SS.SMx.OMx.PoVen
G127	l	l	Rich poly	SS.SMx.OMx.PoVen
G24	l	l	Rich poly	SS.SMx.OMx.PoVen

Sample	Cluster	Cluster Group	Habitat Class	Marine Habitat Classification Code
G99	l	l	Rich poly	SS.SMx.OMx.PoVen
G82	l	l	Rich poly	SS.SMx.OMx.PoVen
G93	l	l	Rich poly	SS.SMx.OMx.PoVen
G5	l	l	Rich poly	SS.SMx.OMx.PoVen
IF12	l	l	Rich poly	SS.SMx.OMx.PoVen
IF9	l	l	Rich poly	SS.SMx.OMx.PoVen
G111	l	l	Rich poly	SS.SMx.OMx.PoVen
G30	l	l	Rich poly	SS.SMx.OMx.PoVen
G15	l	l	Rich poly	SS.SMx.OMx.PoVen
G120	l	l	Rich poly	SS.SMx.OMx.PoVen
G126	l	l	Rich poly	SS.SMx.OMx.PoVen
G1	l	l	Rich poly	SS.SMx.OMx.PoVen
G97	l	l	Rich poly	SS.SMx.OMx.PoVen
G72	m	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G86	m	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G38	m	kmihc	Sparse poly/biv	SCS.ICS.MoeVen
G94	n	noj	Poly/Biv	SS.SMx.OMx.PoVen
G104	n	noj	Poly/Biv	SS.SMx.OMx.PoVen
G43	n	noj	Poly/Biv	SS.SMx.OMx.PoVen
G137	n	noj	Poly/Biv	SS.SMx.OMx.PoVen
G146	o	noj	Poly/Biv	SS.SMx.OMx.PoVen
G71	o	noj	Poly/Biv	SS.SMx.OMx.PoVen
G113	o	noj	Poly/Biv	SS.SMx.OMx.PoVen
G31	o	noj	Poly/Biv	SS.SMx.OMx.PoVen
G144	o	noj	Poly/Biv	SS.SMx.OMx.PoVen
G116	o	noj	Poly/Biv	SS.SMx.OMx.PoVen
G10	o	noj	Poly/Biv	SS.SMx.OMx.PoVen
G83	o	noj	Poly/Biv	SS.SMx.OMx.PoVen
G148	p	p	Ophiothrix	SMx.CMx.OphMx
G149	p	p	Ophiothrix	SMx.CMx.OphMx
G75	p	p	Ophiothrix	SMx.CMx.OphMx
G139	q	sq	Sparse Chone	SS.SMx.OMx.(Chone)
G42	q	sq	Sparse Chone	SS.SMx.OMx.(Chone)
G95	q	sq	Sparse Chone	SS.SMx.OMx.(Chone)
G87	r	ruvw	EpiPoly	SS.SMx.OMx.PoVen
G101	r	ruvw	EpiPoly	SS.SMx.OMx.PoVen
G115	s	sq	Sparse Chone	SS.SMx.OMx.(Chone)
G121	s	sq	Sparse Chone	SS.SMx.OMx.(Chone)
G69	s	sq	Sparse Chone	SS.SMx.OMx.(Chone)
G117	s	sq	Sparse Chone	SS.SMx.OMx.(Chone)
G77	t	t	Chone	SS.SMx.OMx.(Chone)
G100	t	t	Chone	SS.SMx.OMx.(Chone)
G112	t	t	Chone	SS.SMx.OMx.(Chone)
G114	t	t	Chone	SS.SMx.OMx.(Chone)
G122	t	t	Chone	SS.SMx.OMx.(Chone)
G128	t	t	Chone	SS.SMx.OMx.(Chone)
G129	u	ruvw	EpiPoly	SS.SMx.OMx.PoVen
G119	u	ruvw	EpiPoly	SS.SMx.OMx.PoVen
G39	v	ruvw	EpiPoly	SS.SMx.OMx.PoVen
IF6	v	ruvw	EpiPoly	SS.SMx.OMx.PoVen
G0	v	ruvw	EpiPoly	SS.SMx.OMx.PoVen
G51	w	ruvw	EpiPoly	SS.SMx.OMx.PoVen
G21	x	x	Sabellaria	SBR.PoR.SspiMx
G85	x	x	Sabellaria	SBR.PoR.SspiMx
G73	x	x	Sabellaria	SBR.PoR.SspiMx
G14	x	x	Sabellaria	SBR.PoR.SspiMx

Sample	Cluster	Cluster Group	Habitat Class	Marine Habitat Classification Code
G103	x	x	Sabellaria	SBR.PoR.SspiMx
G12	x	x	Sabellaria	SBR.PoR.SspiMx
G9	x	x	Sabellaria	SBR.PoR.SspiMx
G98	x	x	Sabellaria	SBR.PoR.SspiMx
G141	x	x	Sabellaria	SBR.PoR.SspiMx
G28	x	x	Sabellaria	SBR.PoR.SspiMx
G74	x	x	Sabellaria	SBR.PoR.SspiMx
G25	x	x	Sabellaria	SBR.PoR.SspiMx
V3	C	cob	Faunal turf	SMX.CMx.FluHyd
V6	C	cob	Faunal turf	SMX.CMx.FluHyd
V14	C	cob	Faunal turf	SMX.CMx.FluHyd
V23	C	cob	Faunal turf	SMX.CMx.FluHyd
V24	C	cob	Faunal turf	SMX.CMx.FluHyd
V1ECR	R	Rock	Faunal turf	CR.MCR.EcCr
V2ECR	C	cob	Faunal turf	SMX.CMx.FluHyd
V5ECR	C	cob	Faunal turf	SMX.CMx.FluHyd

I. Appendix 2 – Cluster analysis results and sample data

Results of the CLUSTER/SIMPROF analysis (PRIMER) of the infauna of the Phase 1 & ECR samples with columns showing the clusters ranked according to overall abundance (left to right = high to low abundance) and overall species abundance (top to bottom). The cells have been formatted by colour to highlight abundances. The numbers for the clusters with single samples (a, b, c & w) are not averages (columns shaded purple). Only the most abundant species have been included.

Cluster	t	x	p	s	q	r	d	u	g	l	f	j	n	o	v	k	m	e	i	h	a	b	c	w
Epifauna (Average sp. count)	21	18	11	8	8	16	1	16	3	5	0	4	5	7	7	1	3	0	2	1	15	4	0	22
Sample Frequency	6	12	3	4	3	2	3	2	6	22	5	2	4	8	3	16	3	2	4	2	1	1	1	1
Clusters grouped	t	x	pa	sq	sq	ruvwc	d	ruvwc	g	l	f	noj	noj	noj	ruvwc	kmih	kmihc	e	kmih	kmihc	pa	b	ruvwc	ruvwc
Habitat class	**Chone**	**Sabellaria**	**Ophiothrix**	**Sparse Chone**	**Sparse Chone**	**Epifauna/Poly**	**Fabulina**	**Epifauna/Poly**	**Amphiura/Phoronis**	**Rich poly**	**Sparse Amphiura**	**Poly/Bivalves**	**Poly/Bivalves**	**Poly/Bivalves**	**Epifauna/Poly**	**Sparse poly/bivalves**	**Sparse poly/bivalves**	**Thyasira**	**Sparse poly/bivalves**	**Sparse poly/bivalves**	**Ophiothrix**	**Capitella**	**Sparse poly/bivalves**	**Epifauna/Poly**
Total abundance score	517	345	271	158	145	123	114	113	105	75	74	66	62	61	60	45	24	24	16	8	95	734	620	92
Species (ranked by abundance)																								
Chone	149			90	5																1		12	
Ophiothrix fragilis			201																		7			
Sabellaria spinulosa	24	159		2		1		9															8	
Hydroides norvegica	36	20	5			53		5													12	2	43	
Ascidiella scabra	53	31				20		8							2								21	
NEMATODA	36			5	49	5																4		
NEMERTEA	12	16	10	6	7	8		5	2	4	3	1	3	2	7	1	1	1		1		5	14	2
Spiophanes bombyx		2					20	16	12	7		17	1	2		1		1						10
Glycera lapidum	11	4		11	14	8				1		3	7	5		1	2		4			25	5	
Lumbrineris cingulata	6	13	12			5		7		2					15								1	
Pomatoceros triqueter	32	19						1													39		302	
Capitella													6									592		
Ophelia borealis				3	4					12		3	6	8		6	5		2			2		
Fabulina fabula							37																	3
Moerella pygmaea												2	17	3		7	4		4			5		
Amphiura filiformis									23	1	9													5
Phoronis		2						2	28		1													
Notomastus	10	2		3	2	3				2		2		3	4			1			2	1	3	
Chamelia striatula							7		8	1	13													2
Thyasira (Thyasira) flexuosa											15							14						1

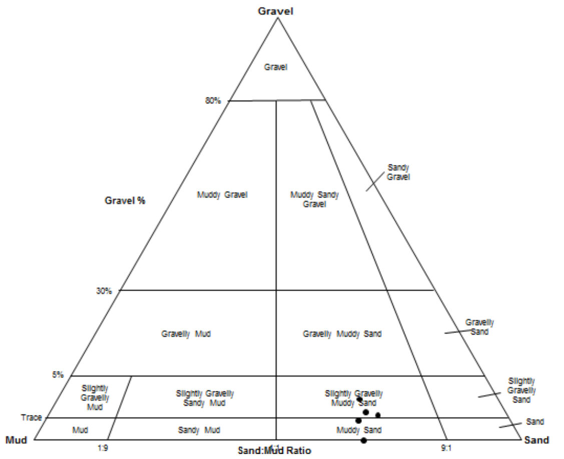
Cluster	t	x	p	s	q	r	d	u	g	l	f	j	n	o	v	k	m	e	i	h	a	b	c	w
Cochlodesma praetenue								4	6	8		2		2		4	2		1					2
Spio armata	5	3								5				2		6	2			5			10	
Grania	6			4	16																	3		
Magelona johnstoni							23																	
Atylus vedlomensis	9			12								2										1		
Aonides paucibranchiata	6			4	5			1					4	1					1		5	4		
Leptochiton asellus	11	6	4																		7		6	
Pholoe inornata	3	6			7			3							1								6	
Ammodytes												14				1	5					5		
Goniadella gracilis	7				6							2	2	2		1						10		
Galathowenia oculata		2						8	2	2	1			1	3									
Urothoe marina				2	8							3	3	3								2		
Ophiura albida		5	6			3						2			2								15	2
Galathea intermedia	8	5				4															2		39	
Pholoe baltica	8	2		2		1		2	2						2									
Mediomastus fragilis		3	13																					
Phisidia aurea	3	3		3		4									2									
Edwarsiidae								2	3	1			7	1	1				1			26		
Thelepus cincinnatus								15																
Timoclea ovata	4					3		3		2			2			1						1		
Eumida sanguinea	3	6						2						1	3								7	
Polycirrus latidens/medusa	3					4				1		2		3		1			1			2	1	
Abra prismatica									4	6				1		2								4
Aurospio banyulensis	5	6				2															2	1	7	
Owenia fusiformis								4		2	1			2		2	2							28
Cirratulus cirratus	7	4				2																	15	
Echinocyamus pusillus					4					1		3		1		2						5		
Laonice bahusiensis	9			2																			16	
Subadyte pellucida			10																		4			
Hiatella arctica	7	3																			8		2	
Spisula elliptica/solida										1			6	1		2						2		
Dosinia (Asa) exoleta						1		3		3				1		2						1		

J. Appendix 3 – Habitat classes

Descriptions of the habitat classes used for the integrated analysis and displayed on the habitat class distribution map.

1. Sparse Amphiura

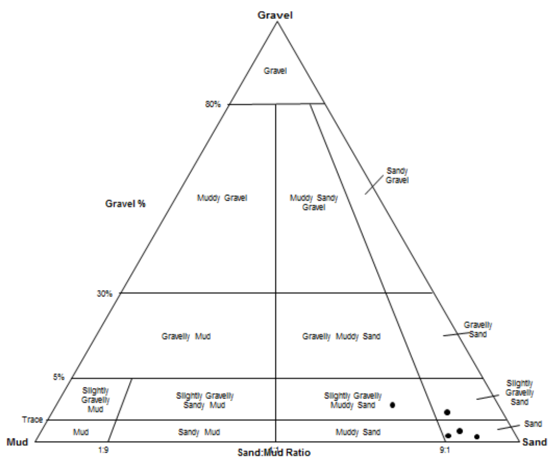
Species	Average abundance
Thyasira (Thyasira) flexuosa	15.2
Chamelia striatula	13
Amphiura filiformis	9.4
Mysella bidentata	6
Diplocirrus glaucus	3.8
Harpinia antennaria	3.4
NEMERTEA	3
Chaetoderma nitidulum	2.4
Ampelisca tenuicornis	2.2
Abra nitida	1.8
Trichobranchus roseus	1.8
Turritella communis	1.8
Galathowenia oculata	1.4
Owenia fusiformis	1.4
Nephtys hombergii	1.4
Peresiella clymenoides	1.4
Amphictene auricoma	1.2
Magelona alleni	1.2
Malmgrenia darbouxi	1.2
Phoronis	0.8



5 sites. Dominated by bivalves, but characterised by low numbers of *Amphiura.* Epifauna sparse or absent. Sediment slightly gravelly muddy sand.

2. Dense Amphiura/Phoronis

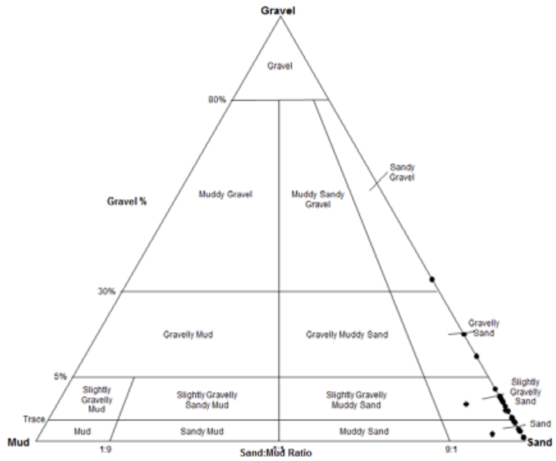
Species	Average abundance
Phoronis	28
Amphiura filiformis	22.67
Spiophanes bombyx	11.5
Chamelia striatula	7.5
Cochlodesma praetenue	5.67
Abra prismatica	4.17
Harpinia antennaria	3.5
Mysella bidentata	3.33
Edwarsiidae	2.67
Lucinoma borealis	2.33
Phaxas pellucidus	2.17
Bathyporeia tenuipes	2
NEMERTEA	1.67
Diplocirrus glaucus	1.67
Galathowenia oculata	1.5
Pholoe baltica	1.5
Scoloplos armiger	1.33
Gari (Psammobia) fervensis	0.83
Bathyporeia elegans	0.67



6 sites. *Amphiura/Phoronis* dominated, but also with a range of bivalves. Epifauna sparse and characterised by *Echinocyamus pusillus*. Sediment sandy or slightly gravelly sand.

3. Sparse poly/bivalves

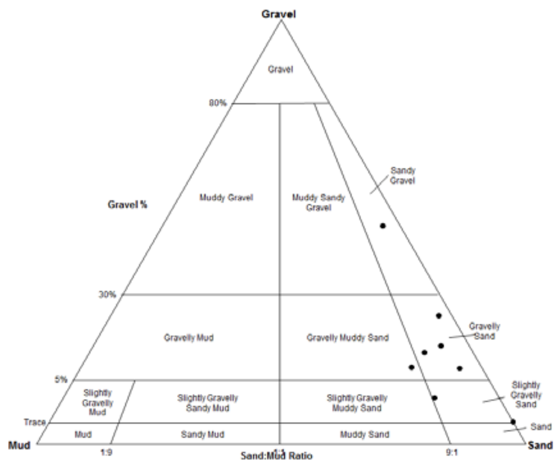
Species	Average abundance
Moerella pygmaea	5.12
Spio armata	4.50
Ophelia borealis	4.42
Cochlodesma praetenue	2.62
Glycera lapidum	1.58
Nephtys cirrosa	1.54
Dosinia (Asa) exoleta	1.35
Ammodytes	1.23
Spisula elliptica/solida	1.23
Abra prismatica	1.19
Owenia fusiformis	1.15
Echinocyamus pusillus	0.96
Timoclea ovata	0.89
NEMERTEA	0.85
Chaetozone christiei	0.81
Nothria hyperborea	0.77
Eteone flava/ longa	0.62
Spiophanes bombyx	0.58
Polycirrus latidens/medusa	0.50
Goniadella gracilis	0.39
Pisione remota	0.27
Edwarsiidae	0.19
Aonides paucibranchiata	0.15
Branchiostoma lanceolatum	0.15
Exogone hebes	0.15
Nephtys caeca	0.15
Aglaophamus rubella	0.12



26 sites. *Amphiura/Phoronis* dominated, but also with a range of bivalves. Epifauna sparse and characterised by *Echinocyamus pusillus*. Sediment sandy or slightly gravelly sand.

4. Epifauna/Polychaetes

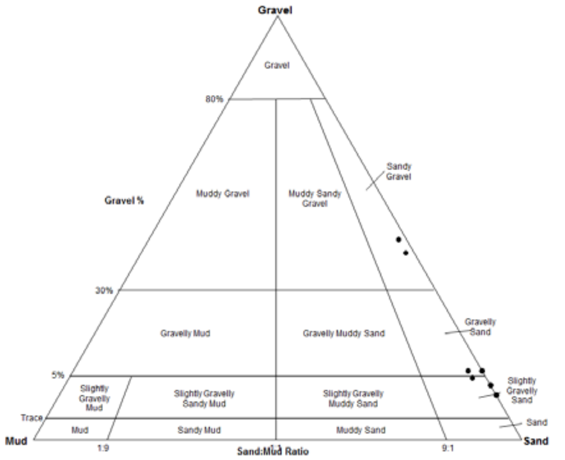
Species	Average abundance
Pomatoceros triqueter	38.00
Hydroides norvegica	19.88
Ascidiella scabra	10.13
Lumbrineris cingulata	8.50
NEMERTEA	7.38
Spiophanes bombyx	3.88
Thelepus cincinnatus	3.75
Sabellaria spinulosa	3.50
Galathowenia oculata	3.00
Notomastus	2.25
Glycera lapidum	2.00
Phisidia aurea	1.87
Eusyllis blomstrandi	1.75
Eumida sanguinea	1.50
Pholoe baltica	1.50
Anobothrus gracilis	1.38
Ophiura albida	1.38
Timoclea ovata	1.38
Spio armata	1.25
Polycirrus denticulatus	1.13
NEMATODA	1.13
Pholoe inornata	1.12
Cochlodesma praetenue	1.00
Edwarsiidae	1.00



8 sites. Characterised by rich epifauna including *Ascidiella* and tube-building polychaetes. Infaunal polychaetes also rich. Gravelly sands and sandy gravels.

5. Sparse Chone

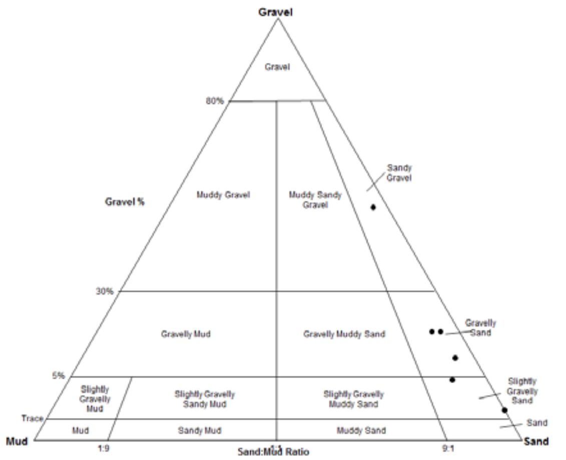
Species	Average abundance
Chone	53.43
NEMATODA	24.14
Glycera lapidum	11.86
Grania	9.14
Atylus vedlomensis	6.86
NEMERTEA	6.43
Aonides paucibranchiata	4.43
Urothoe marina	4.14
Polygordius appendiculatus	3.57
Ophelia borealis	3.43
Pholoe inornata	3.00
Syllis cornuta	2.71
Goniadella gracilis	2.57
Sphaerosyllis hystrix/taylori	2.57
Notomastus	2.29
Phisidia aurea	1.86
Echinocyamus pusillus	1.71
Pisione remota	1.57
Laonice bahusiensis	1.00
Sabellaria spinulosa	0.86
Pholoe baltica	0.86



7 sites. Characterised by moderate or low numbers of *Chone*. Moderate epifauna including *Echinocyamus pusillus*. Slightly gravelly sand, gravelly sand and sandy gravel.

6. Dense Chone

Species	Average abundance
Chone	149.33
Ascidiella scabra	53
Hydroides norvegica	36.33
NEMATODA	36.17
Pomatoceros triqueter	32.33
Sabellaria spinulosa	23.83
NEMERTEA	12.17
Glycera lapidum	11.33
Leptochiton asellus	10.83
Notomastus	9.5
Atylus vedlomensis	8.83
Laonice bahusiensis	8.83
Galathea intermedia	8.33
Pholoe baltica	7.5
Hiatella arctica	6.83
Goniadella gracilis	6.67
Cirratulus cirratus	6.5
Sphaerosyllis bulbosa	6.5
Aonides paucibranchiata	5.83
Lumbrineris cingulata	5.67
Grania	5.67
Amphipholis squamata	5.67
Spio armata	5.17
Aurospio banyulensis	5.17
Gammaropsis maculata	4.17
Pisione remota	4
Parvicardium ovale	4
Cheirocratus	3.83
Glycymeris glycymeris	3.83
Modiolula phaseolina	3.67
Timoclea ovata	3.5
Eteone flava/ longa	3.5
Phisidia aurea	3.33
Harmothoe	3.33



6 sites. Characterised by high numbers of *Chone* and moderate numbers of *Sabellaria* together with a large range of other polychaete species. Rich epifauna including bryozoan hydroid turf, tube worms and *Ascidiella*. Sediment mostly gravelly sands.

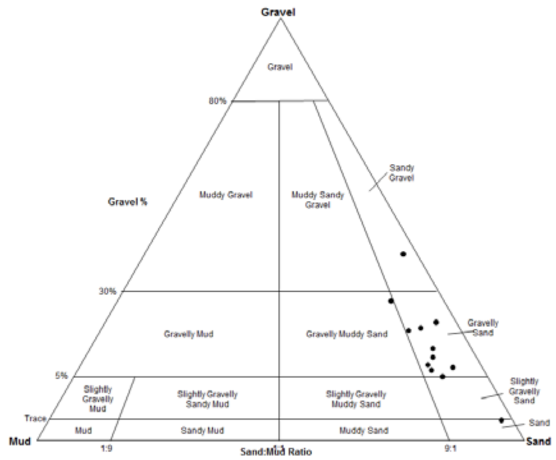
7. Ophiothrix

Species	Average abundance
Ophiothrix fragilis	152.75
Mediomastus fragilis	10.00
Pomatoceros triqueter	9.75
Lumbrineris cingulata	9.00
NEMERTEA	7.75
Subadyte pellucida	7.75
Hydroides norvegica	7.00
Ophiura albida	4.75
Leptochiton asellus	3.00
Minuspio cirrifera	2.75
Chone	0.25

4 sites. Characterised by rich epifauna of bryozoans and hydroids and *Ophithrix fragilis*. Infauna sparse. Coarse sediment of sandy gravels.

8. Sabellaria spinulosa

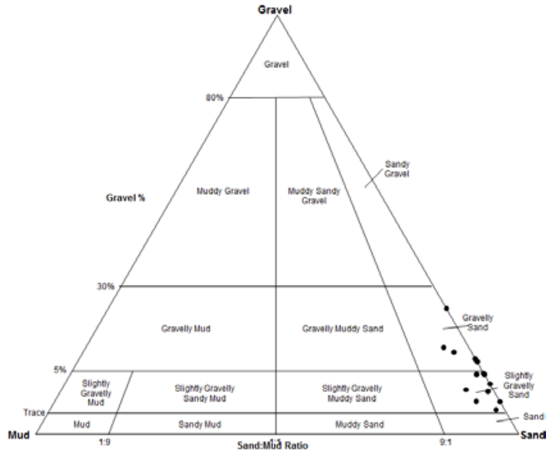
Species	Average abundance
Sabellaria spinulosa	159.08
Ascidiella scabra	31.17
Hydroides norvegica	20.08
Pomatoceros triqueter	18.58
NEMERTEA	16
Lumbrineris cingulata	12.5
Pholoe inornata	6.33
Urothoe elegans	6.25
Eumida sanguinea	5.67
Leptochiton asellus	5.58
Aurospio banyulensis	5.5
Galathea intermedia	5.33
Ophiura albida	5
Cirratulus cirratus	4
Glycera lapidum	3.92
Phisidia aurea	3.33
Mediomastus fragilis	3.08
Hiatella arctica	3.08
Parvicardium ovale	2.67
Spio armata	2.5
Spiophanes bombyx	2.42
Notomastus	2.33
Galathowenia oculata	2.33
Polycirrus denticulatus	2.25
Minuspio cirrifera	2.17
Ophiopholis aculeata	2
Cheirocratus	1.92
Dipolydora caeca	1.75
Paradoneis lyra	1.75
Harmothoe	1.67
Pholoe baltica	1.58
Chaetozone zetlandica	1.58
Phoronis	1.5



12 sites. Characterised by dense *Sabellaria spinulosa* and rich epifauna of bryozoans and hydroids, *Ascidiella* and faunal crusts. Infauna rich. Coarse sediment of gravelly sand.

9. Polychaetes and bivalves

Species	Average abundance
Ophelia borealis	6.65
Moerella pygmaea	6.57
Glycera lapidum	5.14
Spiophanes bombyx	4.07
Urothoe marina	3.14
Edwarsiidae	2.36
NEMERTEA	2.21
Spisula elliptica/solida	2.15
Goniadella gracilis	2.15
Notomastus	2.07
Polycirrus latidens/medusa	2.00
Ammodytes	2.00
Syllis cornuta	1.86
Aonides paucibranchiata	1.79
Exogone hebes	1.43
Nothria hyperborea	1.36
Cochlodesma praetenue	1.29
Polycirrus denticulatus	1.07
Clymenura johnstoni	1.07
Spio armata	1.00
Echinocyamus pusillus	1.00
Owenia fusiformis	0.93
Dosinia (Asa) exoleta	0.79
Polycirrus	0.79
Abra prismatica	0.65



14 sites. Characterised by moderately rich polychaetes and sparse bivalves. Moderately rich epifauna. Similar to the "sparse polychaete" group but with richer polychaete fauna and fewer bivalves. Gravelly sand and slightly gravelly sand.

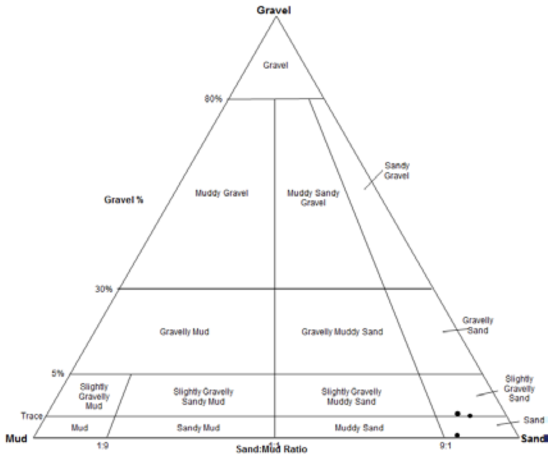
10. Rich polychaetes (Ophelia)

Species	Average abundance
Ophelia borealis	11.86
Cochlodesma praetenue	8.05
Spiophanes bombyx	6.68
Abra prismatica	5.64
Spio armata	4.5
NEMERTEA	4
Nothria hyperborea	2.95
Dosinia (Asa) exoleta	2.64
Owenia fusiformis	2.36
Clymenura johnstoni	2.05
Timoclea ovata	2
Chaetozone christiei	1.86
Notomastus	1.73
Galathowenia oculata	1.55
Polycarpa fibrosa	1.55
Lumbrineris cingulata	1.5
Nephtys cirrosa	1.5
Amphiura filiformis	1.45
Edwarsiidae	1.41
Echinocyamus pusillus	1.32
Chamelia striatula	1.27
Scoloplos armiger	1.27
Spisula elliptica/solida	1.18
Glycera lapidum	1.09
Polycirrus latidens/medusa	1.05

22 sites. Characterised by rich polychaete infauna, (particularly *Ophelia* and *Spiophanes*) and bivalves. Moderately sparse epifauna. Similar to the "polychaetes and bivalves" group but with a greater dominance of *Ophelia*. Gravelly sand, slightly gravelly sand and sand.

11. Fabulina

Species	Average abundance
Fabulina fabula	36.67
Magelona johnstoni	22.67
Spiophanes bombyx	20
Thracia phaseolina	9.67
Chamelia striatula	7
Nucula (Nucula) nitidosa	6
Spio decorata	4.67
Chaetozone christiei	4.33
Phaxas pellucidus	3



3 sites. Characterised by the bivalve *Fabulina* and other bivalves together with the polychaetes *Magelonia* and *Spiophanes*. Epifauna absent. Slightly gravelly sand or sand.

12. Thyasira

Species	Average abundance
Thyasira (Thyasira) flexuosa	13.5
Abra nitida	4.5
Trichobranchus roseus	2.5
NEMERTEA	1
Spiophanes bombyx	1
Notomastus	1

2 sites. Characterised by the bivalves *Thyasira* and *Abra nitida* together with low numbers of a small range of polychaetes. Epifauna absent. Slightly gravelly muddy sand or muddy sand.

13. Capitella

1 site. Characterised by large numbers of the polychaete *Capitella* and low numbers of a small range of other polychaetes. Found on slightly gravelly sand.

14. Epifauna on cobble

6 sites. Identified from video: Cobbles with epifauna of bryozoan and hydroid turf.

K. Appendix 4 - Confidence and certainty

K1. Background to certainty measurement

The classification procedure calculates the probability of the occurrence of each class for each pixel as a class probability image. The map of the biota shows the class with the maximum probability for each pixel, although other classes could be assigned to the pixel, but with lower probability values. Certainty measurements compare the competing probabilities for all the classes and classification certainty is taken to mean the likelihood of the maximally predicted class being present as compared to other classes.

Ten classes were identified within the Phase 1 area and this would mean that a class with a probability of 0.1 (for a given pixel) would represent an assignment no better than chance. The greater the probability above 0.1, the more certain that the class should be assigned to the pixel as compared to classes with lower probability values. (Since the cable route was analysed separately, the equivalent chance value is approximately 0.14.) Maximum pixel values greater than 0.1 but less than 0.5 could mean that, although the assigned class is more likely than chance, other classes 'compete' for the maximum position: There will be a moderate level of uncertainty attached to the map at these locations. The scope for competing classes reduces the higher the maximum probability value.

However, the measurement does not give the predictive accuracy of the map (how well the map predicts the location of a class if a second validation survey were to be conducted). Instead, it measures how consistent the interpretation is with the survey data. The interpretation of these measures as a level of confidence in the map is more subjective, although based on calculated certainty values. In this analysis the uncertainty values have been re-classed into a small number of confidence categories (Table 6).

Table 6: The translation of maximum probability values into descriptive categories of certainty

Probability	Certainty
Chance (e.g., 0.1) to 0.35	Low, maximum probability close to chance (very likely that at least one other class could be assigned to the pixel with probability close to the maximum)
>0.35 to 0.5	Moderate, maximum probability above chance (still likely that one other class might have similar probability)
>0.5 to 0.8	High, maximum probability much higher than chance (no other class will have probability equal to maximum)
>0.8 to 1.0	Very high, maximum probability approaches 1 (very unlikely that any other class could be assigned)

K2. Correlation matrix

How serious is the issue of uncertain classification to the validity of the map? One way of viewing this is to ask which classes are most likely to be confused. A simple way to calculate this is to compare the maximal class (1st choice) with the next-most likely (2nd choice) and construct a correlation matrix between these two images. If the classes that produce similar probability distributions are also similar to each other biologically, then the confusion between them is unlikely to seriously detract from the overall confidence of the map. If the classes are very different, then this undermines the usefulness of the map to a greater extent.

K3. Results of certainty measurement

The reclassified maximum probability images resulting from the classification is given in Figure 12 & Figure 13 which show the four categories of certainty. There are small areas of the Phase 1 area that should be considered as being of low certainty and approximately half the area is of high or very high certainty.

The confusion in the Phase 1 area classification (see the correlation matrix in Table 7) is usually between similar classes. Thus, confusion often occurs between; (1) faunal turf and *Ophiothrix*, (2) sparse polychaetes/bivalves and polychaetes/ bivalves, (3) *Amphiura/Phoronis* and rich polychaetes, (4) sparse *Chone* and abundant *Chone* and, (5) epifauna/polychaetes and *Sabellaria*.

Table 7: Correlation matrix between 1st choice class (maximal probability) and 2nd choice. The values represent the percentage of pixels of the combined classes that overlap, irrespective of the actual values of the probabilities of the 2nd choice (i.e., 2nd choice values may or may not be close to 1st choice values)

	Faunal turf	Amphiura/Phoronis	Sparse polychaetes/bivalves	Rich polychaetes/bivalves	Polychaetes/bivalves	Ophiothrix	Epifauna/polychaetes	Sparse Chone	Chone
Amphiura/Phoronis	0								
Sparse polychaetes/bivalves	5	26							
Rich polychaetes/bivalves	0	29	17						
Polychaetes/bivalves	0	20	46	22					
Ophiothrix	67	0	0	0	2				
Epifauna/polychaetes	5	5	3	18	2	3			
Sparse Chone	3	1	9	1	17	5	9		
Chone	0	0	0	7	8	0	12	39	
Sabellaria	14	0	17	10	16	0	32	13	16

It is possible to amalgamate the probability images of the five classes as above and produce a simplified biota maps along with higher levels of certainties (Figure 14 to Figure 17).

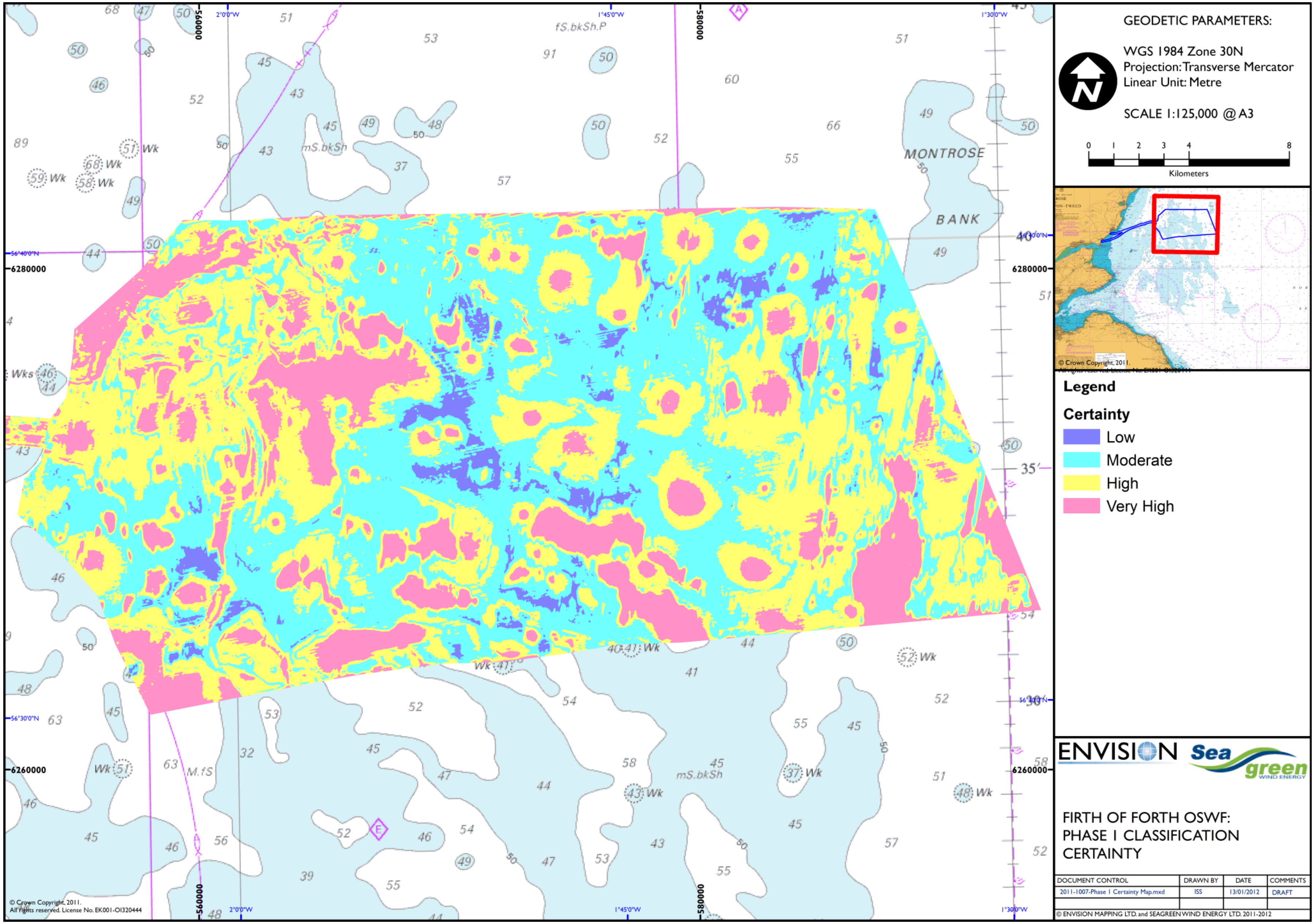


Figure 12: Certainty map of the biota classification of the phase 1 area

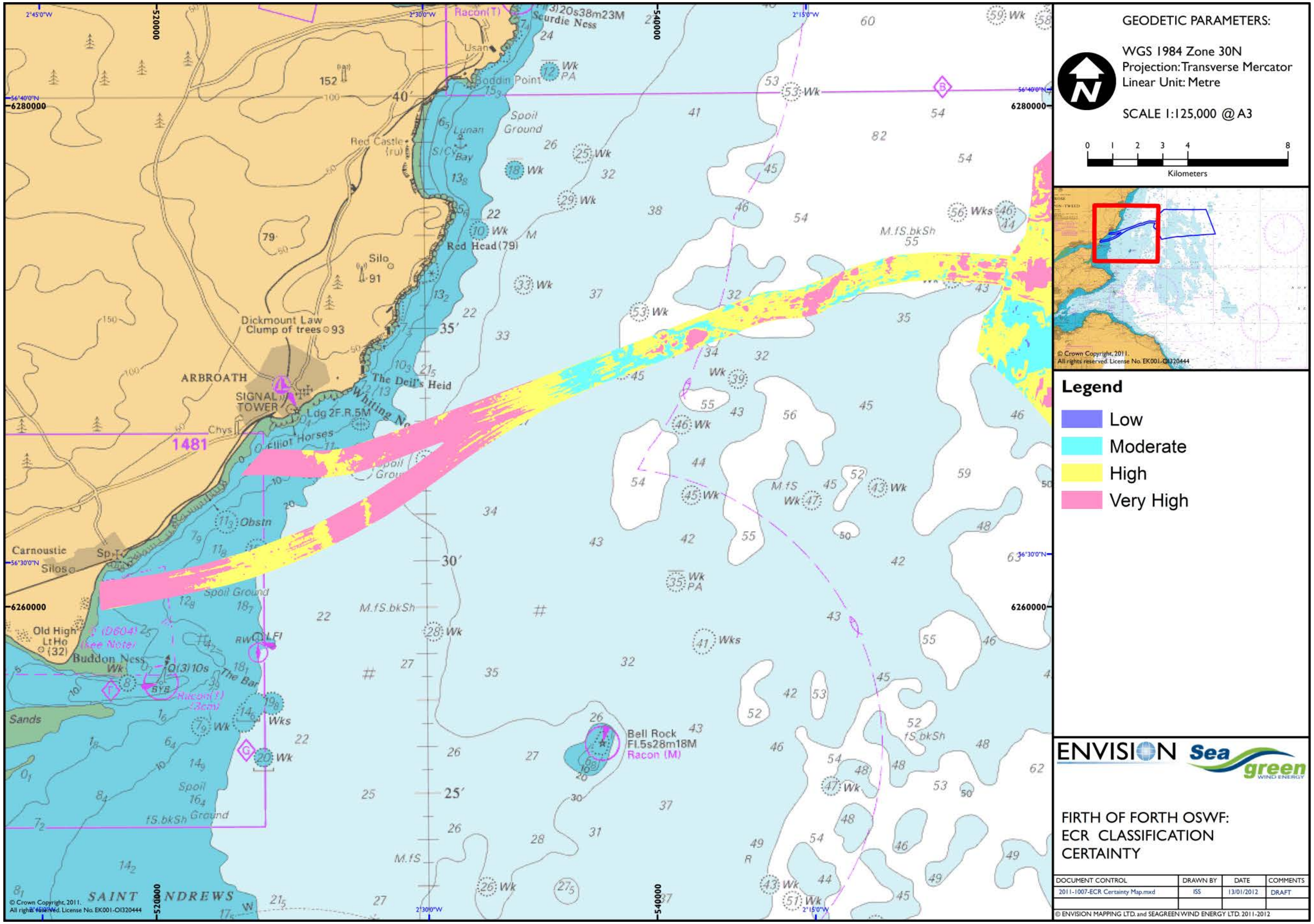


Figure 13: Certainty map of the biota classification of the ECR area

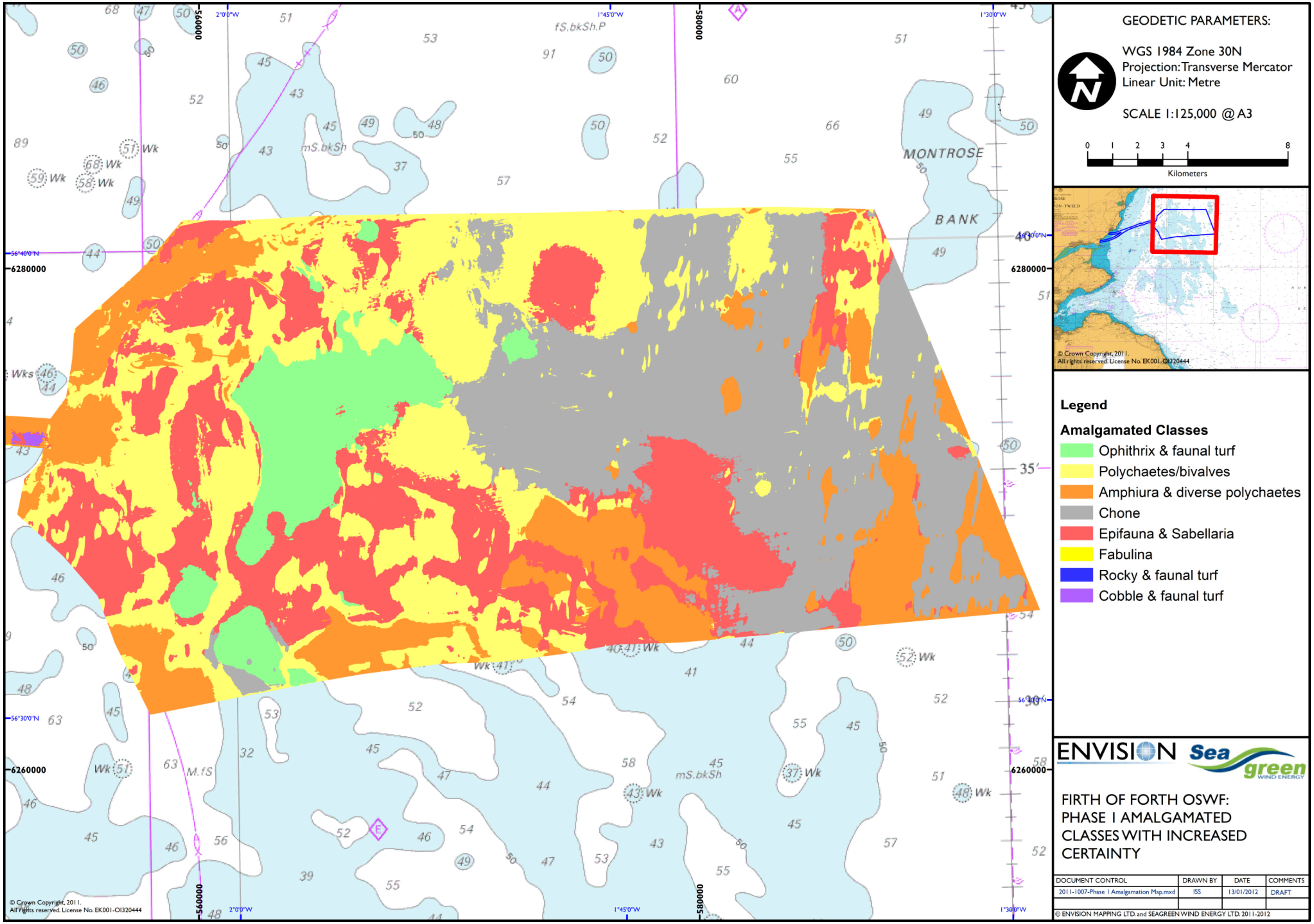


Figure 14: Map of amalgamated biological classes for the Phase 1 area

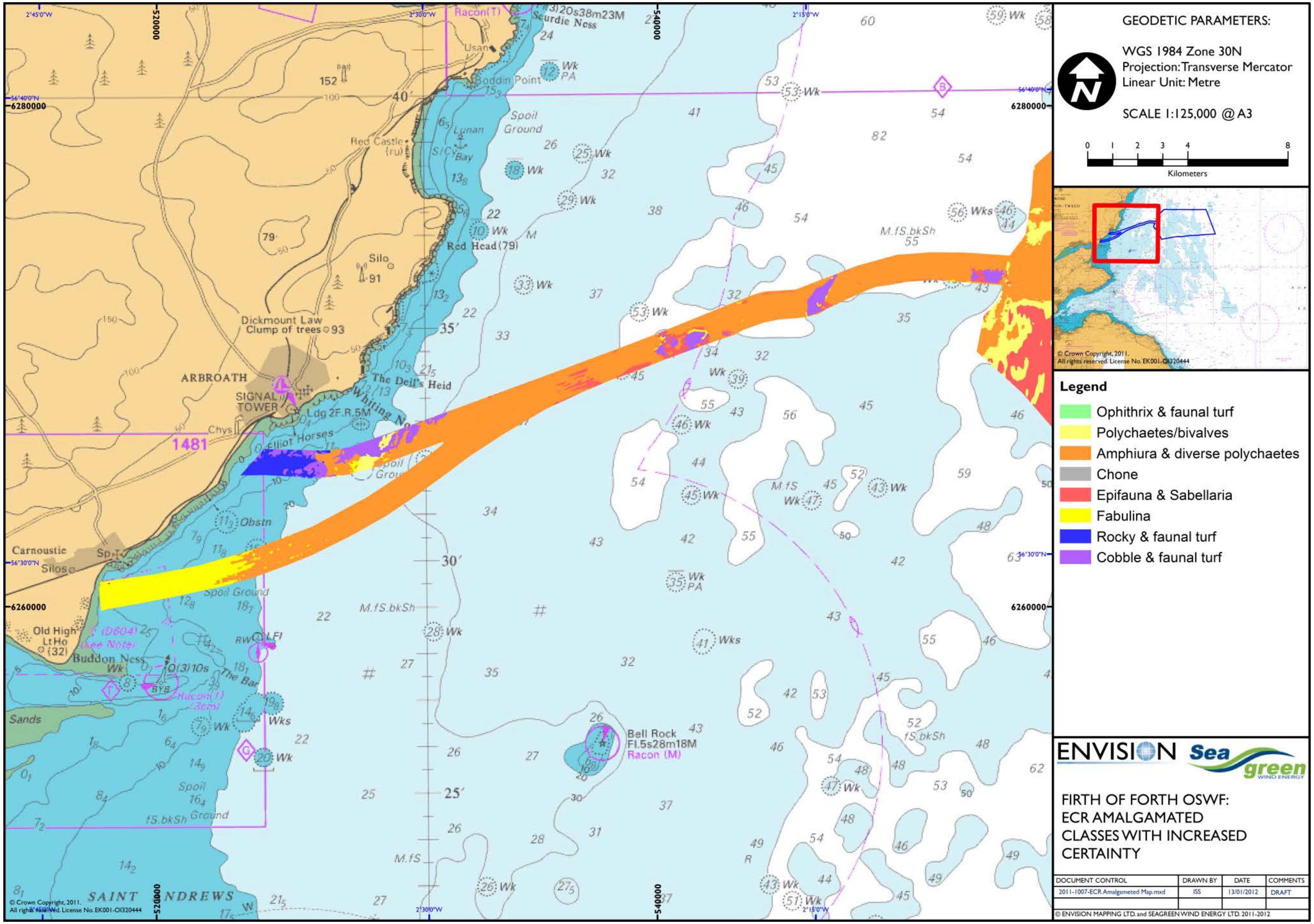


Figure 15: Map of amalgamated biological classes for the ECR area

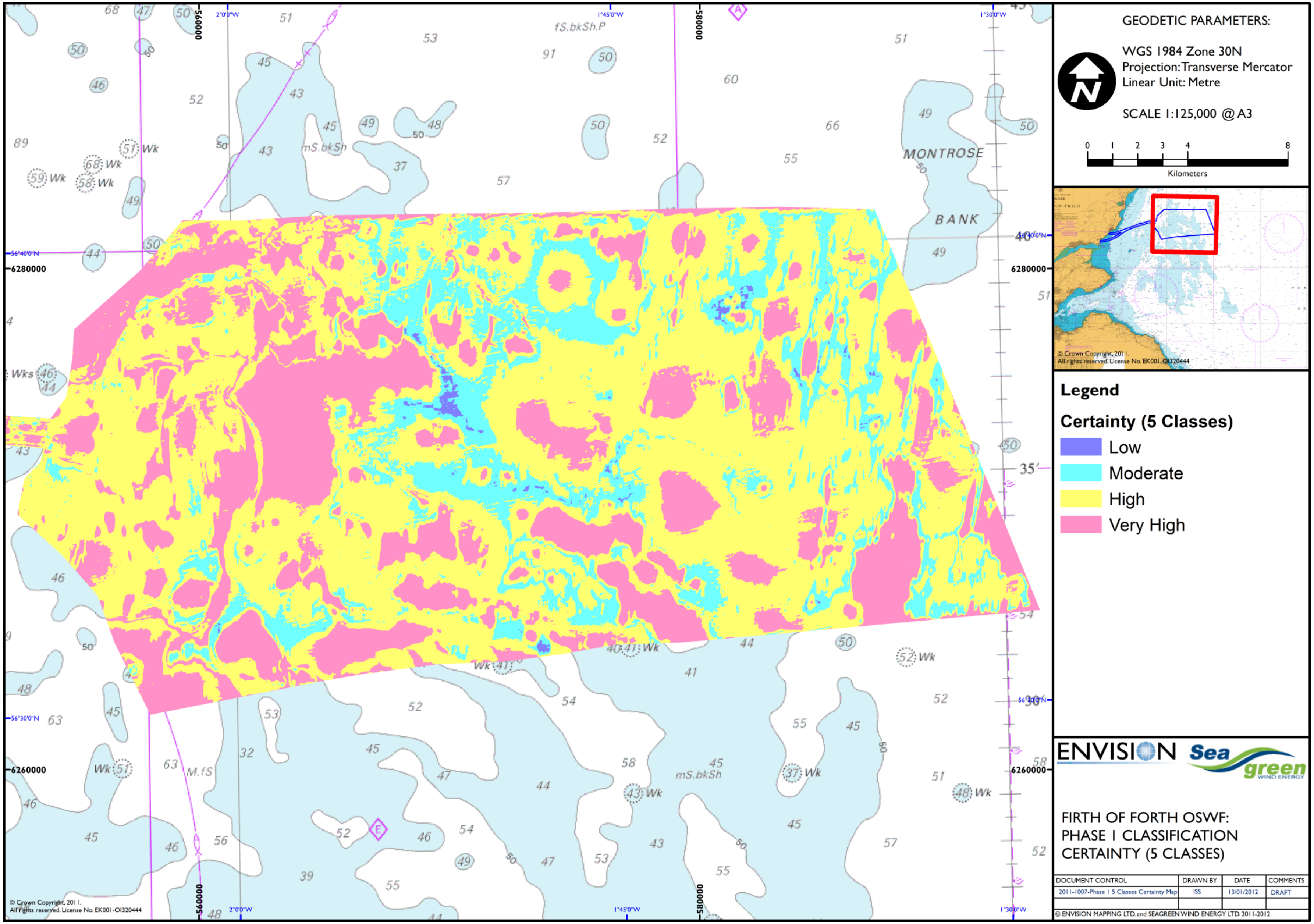


Figure 16: Certainty map of the biota classification using the five amalgamated classes given in the text and Figure 14

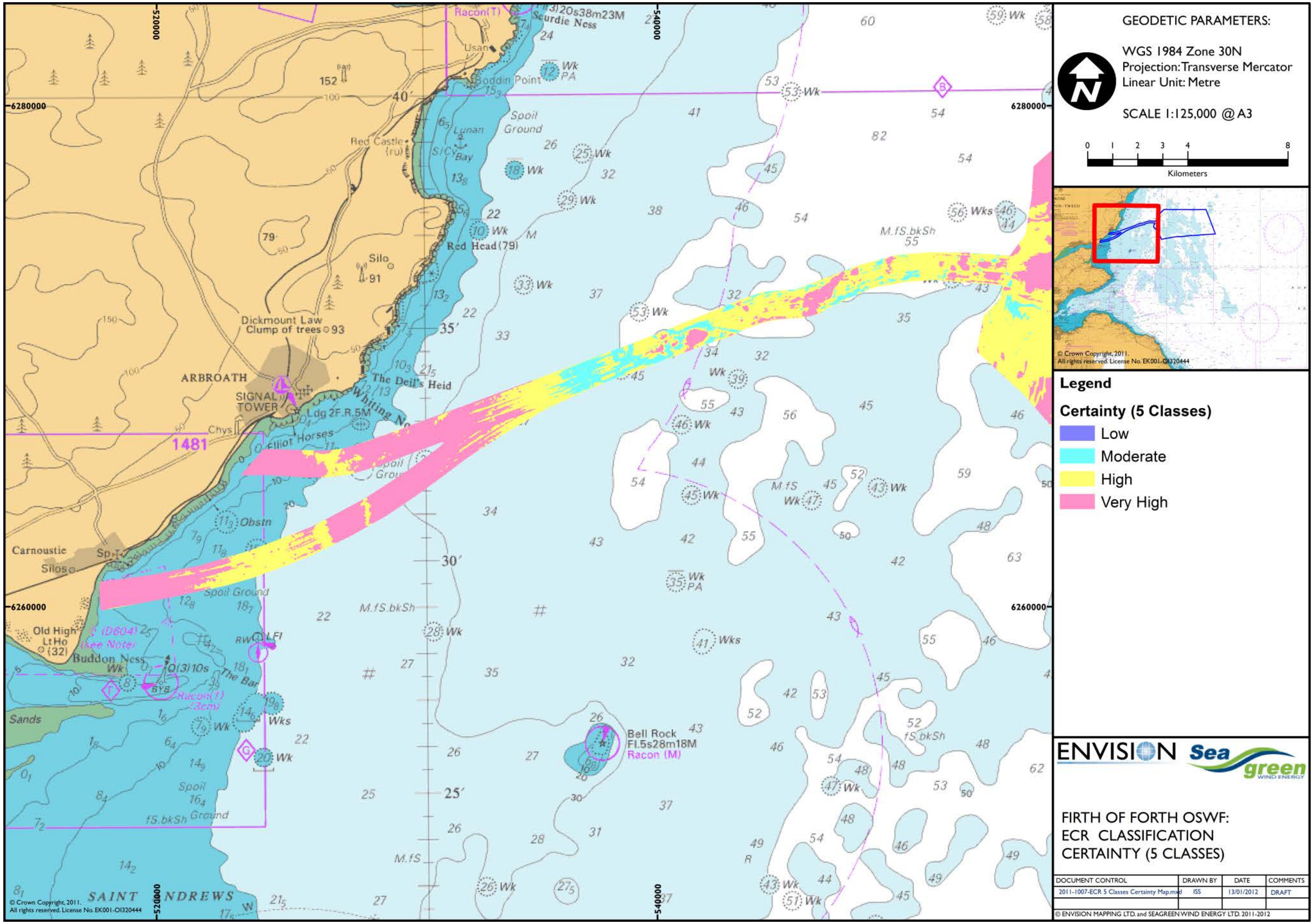


Figure 17: Certainty map of the biota classification using the five amalgamated classes given in the text and Figure 15

K4. Summary

Measures of certainty for the original classes, determined primarily through the statistical analysis of the infauna and supplemented by video data, support a reasonable level of confidence in the success of the classification process. The classes that were classified least successfully were those that were likely to be confused with other similar classes. Amalgamation of the similar classes reduces the total number of classes mapped, but increases the confidence level of the distribution map: As with all amalgamations, there is a trade-off between information content and confidence. However, if the map user is aware that the uncertainty involves similar biological classes, this reduced certainty may be acceptable in order to preserve the biological information.

L. Appendix 5 - Sandeel Preference Map Production

Map of sandeel preference were produced using sidescan sonar mosaics and particle size analysis (PSA) data from grab samples.

L1. Classification of grab samples to sandeel preference

The PSA data from each grab were grouped to produce the percentage content of 'coarse sands' and 'sands and fine sands' as per Greenstreet *et al.* 2010. The sand and silt fractions from the PSA data were merged to produce the 'sands and fine sands' category with the two coarser sand fractions combined to produce the 'coarse sands' category. These data were then plotted on an xy axis and overlain onto the categories from Greenstreet *et al.* 2010 (Figure 18)

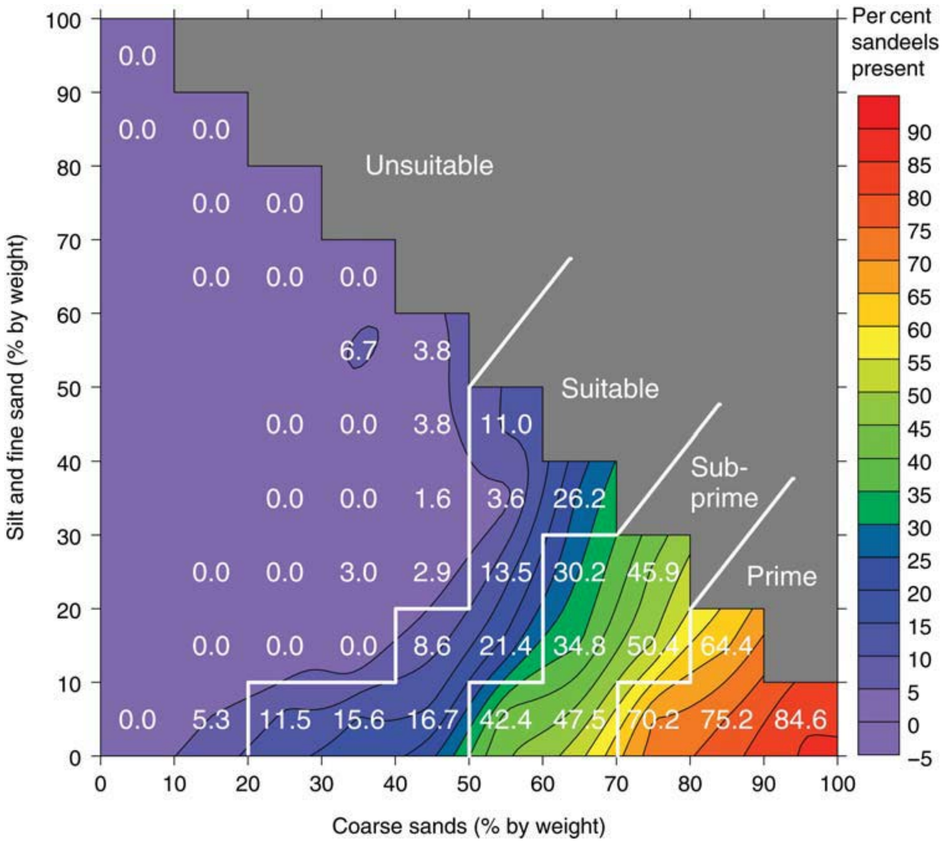


Figure 18: Categorization of the seabed sediment into four sandeel sediment preference categories, depending on the relationship between the percentages of silt and fine sand and of coarse sand in the sediment and the proportion of samples with sandeels recorded present. (From Greenstreet *et al.* 2010)

This resultant plot (Figure 19) enabled each grab sample to be allocated to one of four categories, Prime, Subprime, Suitable or Unsuitable, depending upon the ratio of silt and fine sand to coarse sand in each sample.

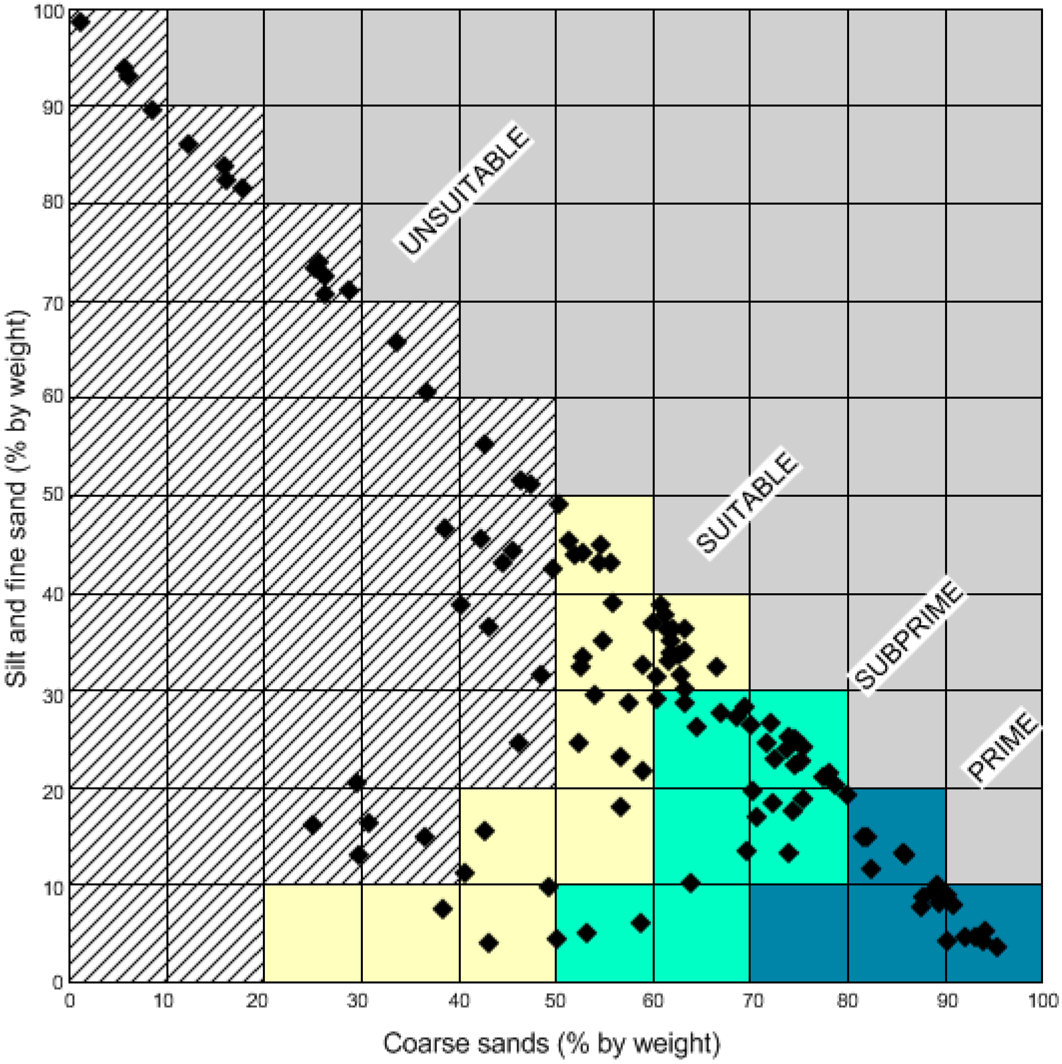


Figure 19: Plot of sample sites from Phase 1 area plotted over sandeel suitability

L2. Classification of Phase1 and ECR areas

Once the sample points were allocated to a sandeel preference category the sidescan data and the sample points were intersected with each other to determine the sidescan backscatter strength associated with each sandeel preference category. This process of signature development produces statistics for each category (mean, variance and covariance) which can then be applied to the whole of the sidescan data using a maximum likelihood classification[1]. The result is a full coverage map representing the most likely category of sandeel preference associated with the sidescan backscatter.

[1] *Maximum Likelihood classification is based on statistics (mean; variance/covariance), a Bayesian Probability Function is calculated from the inputs for classes established from training sites. Each pixel is then judged as to the class to which it most probably belong*

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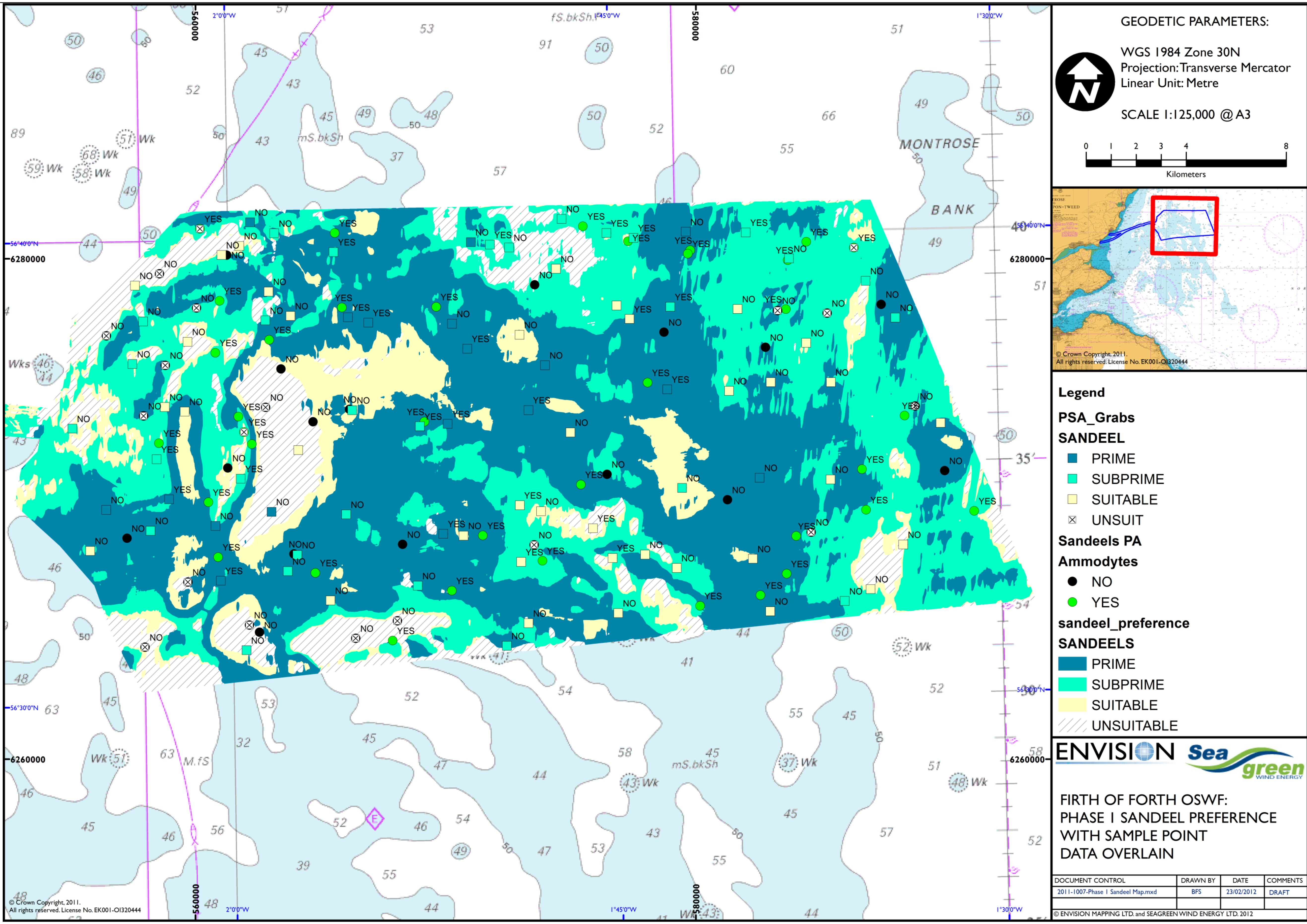

Figure 20: Map showing sandeel habitat preference for Firth of Forth OSWF Phase 1 Area, sample points used within the analysis are shown with preference and other sites show the presence or absence s of sandeels within the sample

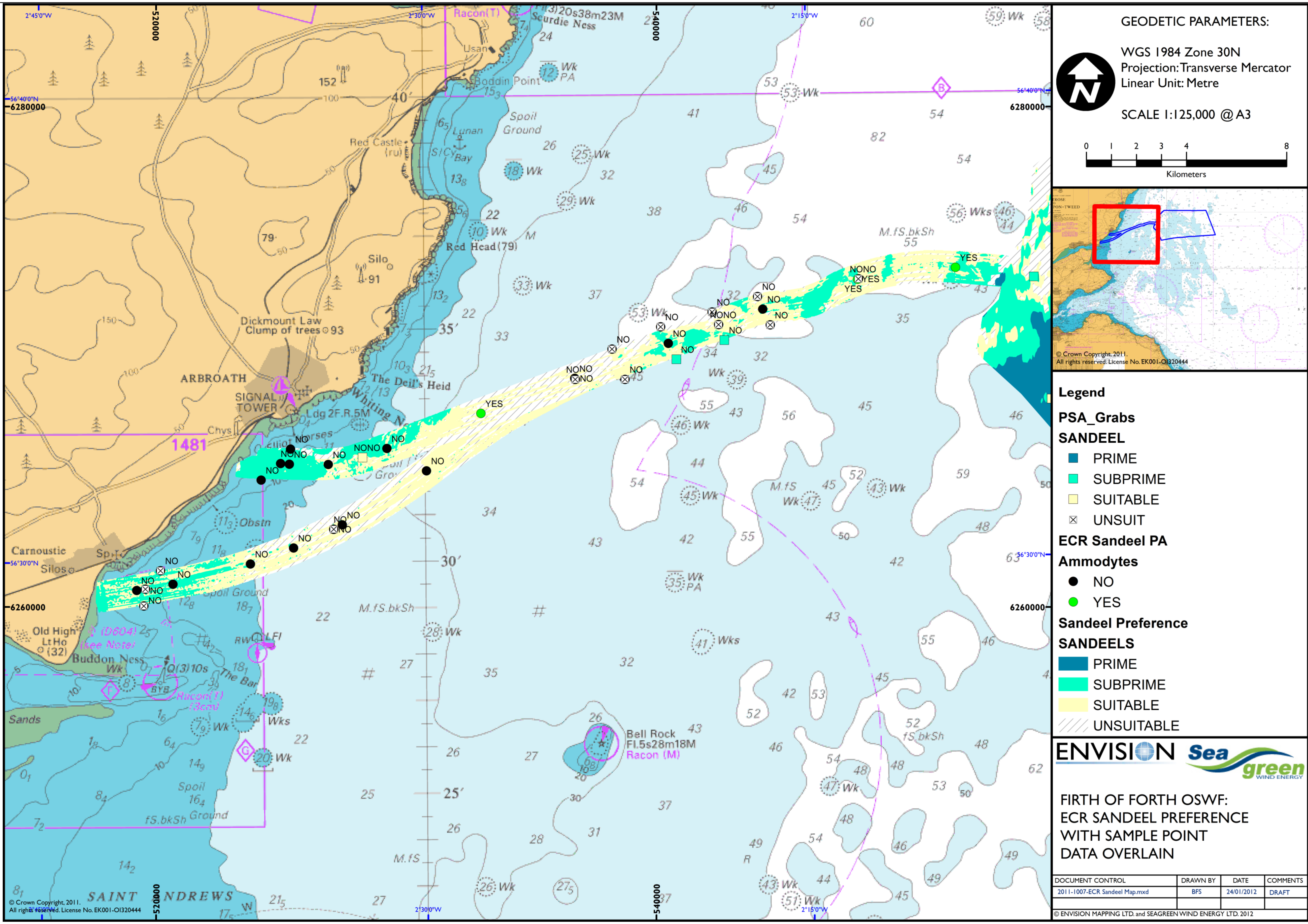

Figure 21: Map showing sandeel habitat preference for Firth of Forth OSWF Export Cable Route Area, sample points used within the analysis are shown with preference and other sites show the presence or absence s of sandeels within the sample