

<b>Title:</b>	<b>Case Study: Appropriate use of multi-beam and AGDS</b>
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# 1. Introduction

## 1.1. Goals of Mapping

Envision Mapping Ltd was contracted to undertake a survey of the Moray Firth cSAC within the 30m contour. The qualifying marine feature of the cSAC is the annex 1 habitat: sandbanks which are slightly covered by sea water all the time (down to 20m below chart datum). The aim was to map all biotopes, but with the emphasis on the main sediment features and biota, using acoustic remote sensing techniques combined with grab and video sampling. A RoxAnn™ acoustic ground discrimination system was used in conjunction with a GeoSwath™ interferometric swath bathymetric system.

## 1.2. Pilot Sites

The area of the survey is shown in Figure 1. The survey did not extend beyond the 30m contour and some areas were selected as priority areas for more comprehensive survey, based on sediment distributions from published sources, such as the BGS and Metoc data.

Habitat data that could be useful for ground truthing were provided by SNH. Two sources contained sublittoral data: ROV records (but all out of the survey area) and a few sublittoral records from the Marine Recorder database (Cromarty Firth area only). There were a disappointing number of records. Most of the data are restricted to broad habitat (sediment) types (gravely sands, muddy sand and mixed sediment), but *Modiolus* biotopes have been found at the entrance to the Cromarty Firth and brittlestar beds off the Black Isle. In addition, results from 10 grab samples were available. Though these records were few, and could not be used for ground truthing purposes, they did serve to corroborate the sediments and biotopes found in this survey.

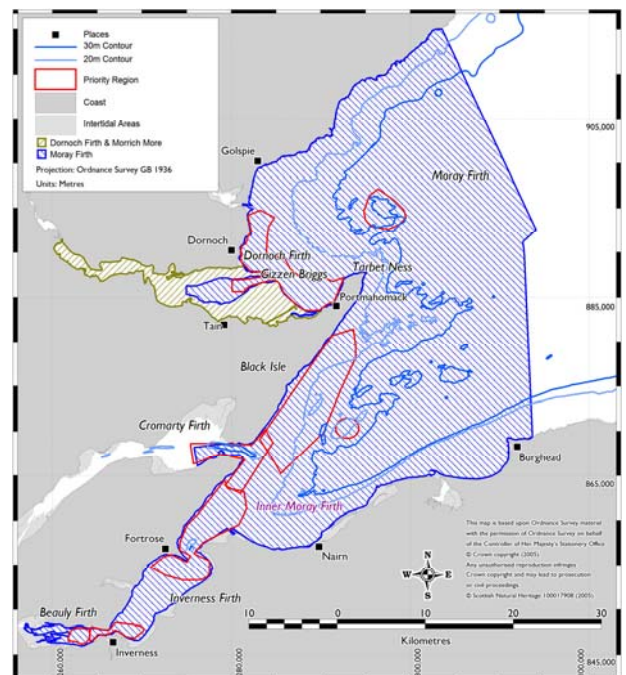


Figure 1: The geography of the Moray Firth cSAC.

## 1.3. Methods Summary

The Moray Firth cSAC is a large area with a perimeter of 382km and covers an area of 1510km<sup>2</sup>. In order to survey the whole area as requested in the tender, the strategy adopted was to use a track spacing of 350m for the priority areas to give a full coverage combined with very broad track spacing of 1000m for the areas outwith the priority areas. This approach was considered optimal given the areas to be covered and a realistic time scale. Two acoustic systems were used to survey the area: a RoxAnn AGDS system and a GeoSwath swath bathymetric system. This proved to be an efficient use of vessel time in that AGDS and GeoSwath data (side scan, swath bathymetry and backscatter) were collected simultaneously. The high resolution of the swath system gives information on bedform features as well as general bathymetry and major seabed sediment categories. Accurate motion-sensing allows correction for motion and tide. Although AGDS gives poor resolution, it supplements swath data by giving greater discrimination between different sediment types. The two systems can be

operated at a vessel speed of around 10-12kmhr<sup>-1</sup>, which enabled areas to be covered relatively rapidly. A drop down video and grab were used for ground truthing.

### 1.3.1. RoxAnn AGDS System

Envision used a *RoxAnn*<sup>TM</sup> GroundMaster AGDS operating at 50kHz. Acoustic ground discrimination systems (AGDS) are based on single beam echo sounders and, apart from determining depth, are designed to detect different substrata by their acoustic reflectance properties: hard surfaces produce strong echoes whilst soft surfaces results in a weak signal. Additionally, rough surfaces will produce an echo that decays slowly (a property termed 'backscatter') whilst flat surfaces result in a rapid decay of the signal. These properties can be used to discriminate broad categories of sea floor habitats (Foster-Smith *et al.* 2000, Foster-Smith *et al.* 2001 and Foster-Smith & Sotheran, 2003). The acoustic data, together with GPS data, are logged onto a laptop and the systems are portable and self-contained.

Although the data can be displayed in real time, Envision analyse the data using image processing and GIS (Sotheran *et al.* 1997).

### 1.3.2. Swath bathymetry/side scan sonar

GeoAcoustics' GeoSwath meets IHO SP44 Special Order specifications. It is an interferometric system operating at 250kHz that uses the phase content of the signal to measure the angle of the wave front of the returning echo. The depth of the seabed reflecting surface is calculated from this angle and elapsed time. The system also measures signal amplitude and sidescan images are derived from this information. The system offers a good resolution from which accurate and detailed bathymetric models can be produced.

### 1.3.3. Ground truth sampling survey

A drop-down video camera was deployed to collect information on the biology and main sediment characteristics of the seafloor. Video sample sites were selected on the basis of the different acoustic ground types identified from the on-site display of RoxAnn data. The duration of the videos was kept to between 1 and 2 minutes to reduce GPS positional errors.

Grab sample sites were selected from the video sample sites. All grabs were taken with Van Veen 0.1m<sup>2</sup> grab and sediment samples were retained from all grabs taken.

## 2. The characteristics of the habitat type

The qualifying marine feature of the cSAC is the Annex 1 habitat: sandbanks which are slightly covered by sea water all the time (down to 20m below chart datum). Topography, depth, gross sediment type and biotope all need to be considered together in applying the current definition of sandbanks to particular situations.

1. Topography: Broadly, a sandbank is described as rising from the general level of the surrounding seafloor. This would include sandy mounds, sand bars and barriers. Sandbanks may also include mounds that are too deep to be much affected by present day hydrodynamic processes – relict banks. Sediments also rise from deeper, offshore

sediment plains towards the shore. These sand features fringing the shoreline might also be considered.

2. Depth: Banks slightly covered by water all the time down to a depth of 20m would qualify, but the lower depth limit might be extended down to 30m where this is considered necessary to preserve the integrity of a reef.
3. Sediment: Sediments described in Annex I can range from gravely sand to muddy sand. Thus, gravels (mixed with finer sediments), might qualify but cobbles do not. However, mixtures of very different sediments, such as bedrock, boulder and sand, are often encountered and boundaries between rocky and sandy habitats may be very 'fuzzy', e.g. it is difficult to assign a cut-off between muddy sands and sandy muds that could be justified for mapping purposes.
4. Biotope: Some specific communities are listed in the definition of sandbanks; eelgrass *Zostera marina* beds and maerl beds. All other biotopes associated with the range of qualifying sediment types will need to be considered, e.g. sandy shallow bivalve, worm, crustacean and echinoderm communities; mobile fauna; sandeels and; epifaunal communities where coarse material such as small stones and shell are present. Brittlestar beds (*Ophiothrix fragilis* and *Ophiocoma nigra*) which are often associated with these mixed coarse sediments are also specifically mentioned in Annex 1 guidance.

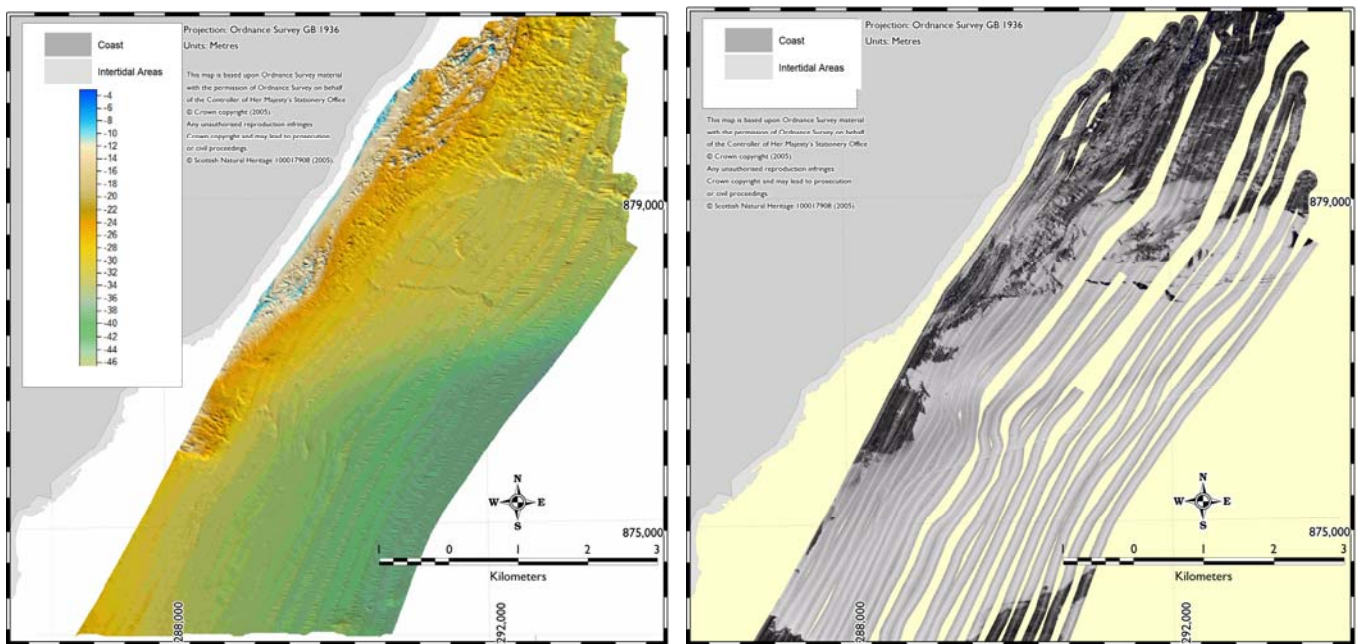
The areas that potentially qualify as sandbanks were extensive within the firth and covered a wide range of topographic types and sediments. The biota of the different sandbank types were substantially different: sparsely populated macrotidal sandbanks associated with deep scoured channels; deeper, offshore epifaunal relict sandbanks and; rich sediment slopes extending from the shore into deep water whose biotopes largely centred around *Amphiura filiformis*.

The morphological description of sandbanks within the survey area overlaps with other feature types, such as shallow inlets and bays. At the other extreme, sandy mud habitats lie at or below the 20m contour and overlap with the deeper mud habitats that lie without the sandbank definition or other Annex I habitat.

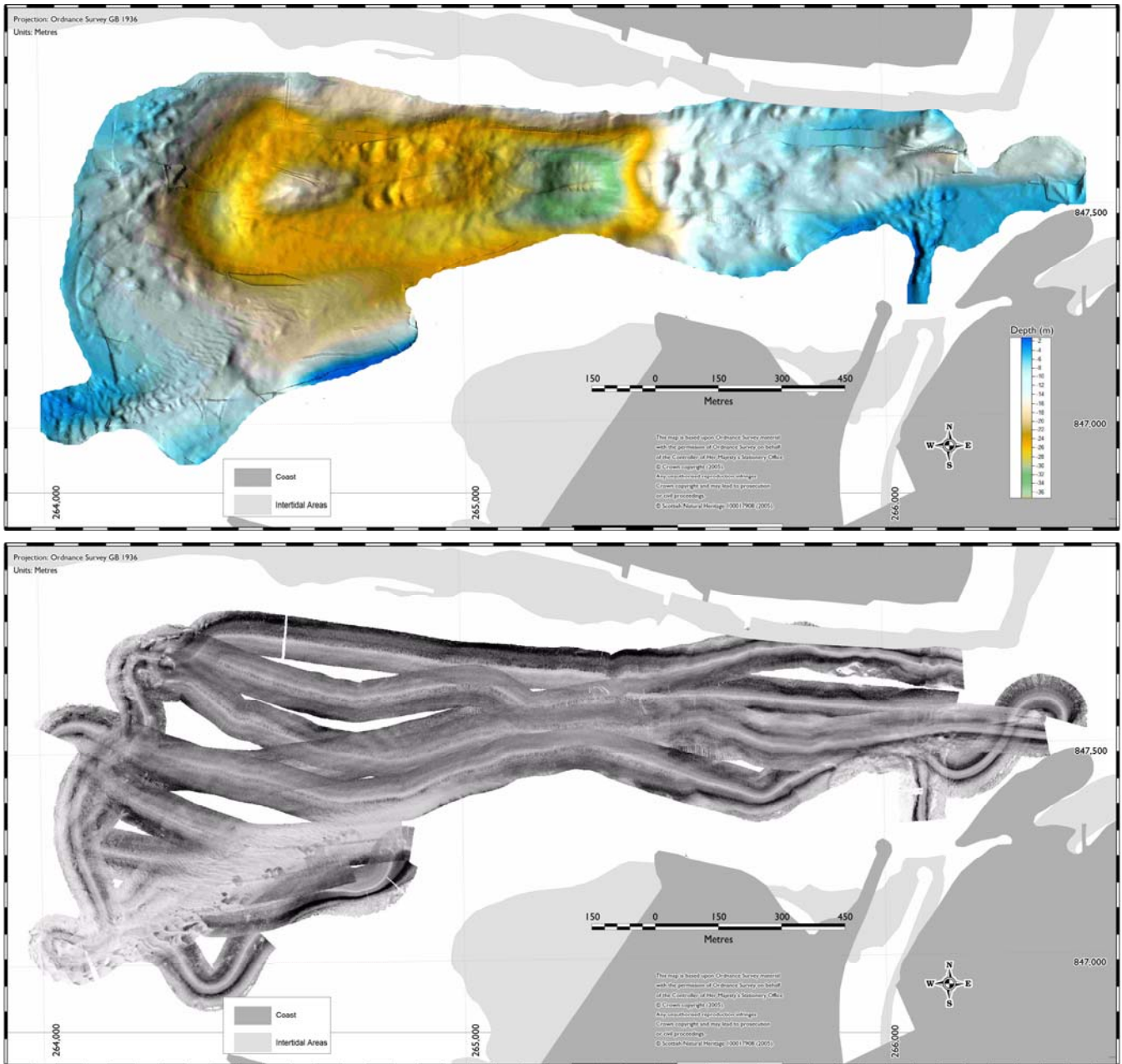
It was believed appropriate to take the widest view of the interpretation of the definition of sandbanks, to ensure the inclusion of a wide representation of a diverse range of biotopes that also encompasses different parts of the marine ecosystem. Another justification for the widest interpretation is the regional context of the sediments in the Moray Firth: Although the area occupied by sandy sediments shallower than 20m is large within the Moray Firth, sandy habitats shallower than 20m are scattered and generally much smaller elsewhere within Scotland as a whole. Only three other SACs (Arisaig on the west coast, Loch Maddy in the Outer Hebrides and Sanday, in Orkney) have sandbanks listed amongst their features of interest, and there is some confusion with large shallow inlets in the case of two of these sites, so direct comparison is not strictly appropriate for topographic reasons. The sandbanks of the Sound of Arisaig are largely of maerl and are not representative of the Scottish east coast. Thus, the sandbanks of the Moray Firth make a substantial contribution to both the diversity and ecology of the eastern coast of Scotland.

### 2.1.1. Summary of bedforms derived from swath and side scan

Although the swath bathymetry and side scan (backscatter) data are both derived from the same physical measurements of the Geoswath system, the nature of the information that can be obtained from the images derived from these two datasets is different. The bathymetric images reveal topographic features ranging upwards from moderately sized sand waves (the limit is approximately 0.2m height, 2m wave length). Rocky reefs and large sand waves are easily discerned. The side scan backscatter data show changes in reflectivity of the sea floor as well as features rising from the sea bed that throw distinct acoustic shadows. Distinct patches of ground with different reflectivity can be seen with a resolution of about 1m. Rocky areas with a distinct profile can be observed. Gradual changes in reflectivity can also be seen, although delineating boundaries along gradations is very subjective. The two sets of images are complementary since the swath bathymetric data cannot distinguish between hard and soft ground unless associated with changes in topography whilst the side scan images very often cannot pick up large sand waves or distinguish topographically complex areas (bedrock) from level but hard and rough areas (boulders). Side scan can differentiate pockets of softer sediment mixed in with harder ground, however.



**Figure 2. Left: Enlargement sun illuminated bathymetric image of the northern section of the of the Black Isle (Cromarty Harbour Seals; Priority area 2). Right: Side scan mosaic image of the northern section of the of the Black Isle (Cromarty Harbour Seals; Priority area 2). (Source: Swath System)**



**Figure 3. Upper: Sun illuminated bathymetric image of the subtidal Beaulieu Firth (priority area 4) (Source: Swath System). Lower: Side scan mosaic image of the subtidal Beaulieu Firth (priority area 4) (Source: Swath System)**

The process used to classify the swath images was firstly to digitise polygons around features and regions of distinct acoustic reflectivity discernable from the side scan (backscatter) images. Regions of different reflectivity with a more gradual change were delineated, albeit subjectively. The sediment ground truth data were used to inform this process. Coded digitised polygons were then overlain on the sun illuminated swath images and edited to incorporate information on topographic features. This involved reclassification of the original polygons, redrawing boundaries and introducing new polygons (splitting original polygons and erasing overlap

areas). Interpolated polygons were produced, for areas covered by wider swath spacing outside the priority areas. These are shown with a dotted outline to make clear that their status is uncertain (see Figure 4, for an example).

Together, the two systems have been used to distinguish the following categories. Reflectivity can be used to distinguish the habitat categories listed in Table 1.

**Table 1. List and description of features distinguished by the side scan and swath bathymetry.**

Bedform or sediment character	Description
Bedrock & boulder	Hard rough ground with bedrock features
Gravelly ribbons	Thin elongated ribbons of harder ground with no obvious associated relief
Hard ground	Uniform texture with strong backscatter
Hard rough ground	Uneven texture with strong backscatter but weak or no broader scale features
Large sand waves, hard ground	Sand waves with wavelength greater than 50m (often much greater), weak backscatter
Large sand waves, soft ground	Sand waves with wavelength greater than 50m, strong backscatter
Moderately hard ground	Uniform texture with moderately strong backscatter
Moderately soft ground	Uniform texture with moderately weak backscatter
Patchy	Patchy (100m scale) soft and hard ground
Patchy rock & sand	Patches of ground with rocky features and softer, uniform ground in approximately equal proportions
Ridge, soft ground	Unique ridge north of the entrance to Cromarty Firth
Rocky	Hard ground with small but discernable rocky features
Sand & scattered rocks	Scattered rocks in sand, sand greatly predominating
Sand & linear features	Soft to moderately hard ground with thin elongated raised features
Sand waves, hard ground	Sand waves with wavelength less than 50m, weak backscatter
Sand waves, soft ground	Sand waves with wavelength less than 50m, strong backscatter
Soft ground	Uniform texture with weak backscatter
Tidal features	Soft or moderately soft ground with numerous small thin elongated features

The sides scan images were interpreted independently of the data from AGDS to facilitate comparison of the two approaches.

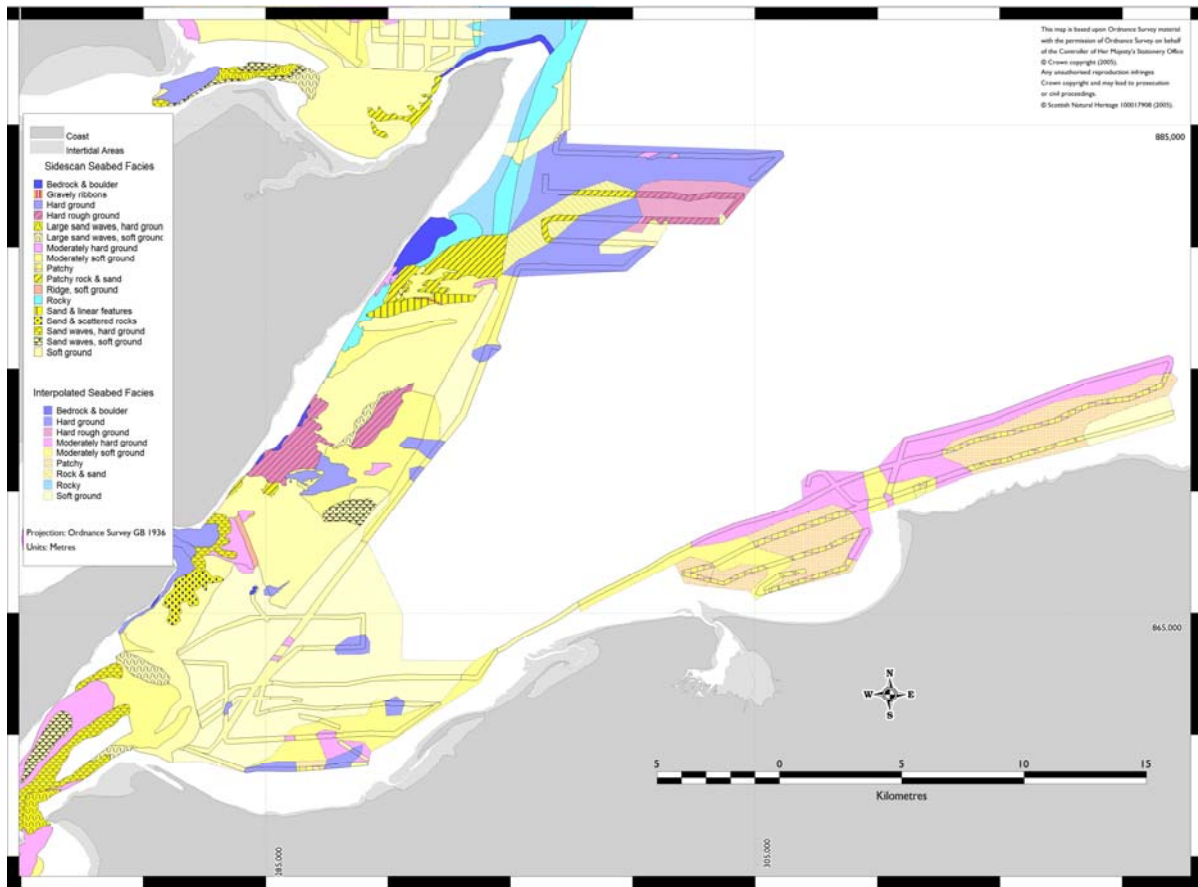


Figure 4. Sea bed feature classes digitised from the side scan and swath images. The slightly lighter hues outlined with a dotted line show areas interpolated by eye between tracks

### 3. Analysis and classification of the acoustic and ground truth data

Classification of remotely sensed data, such as AGDS, is based on the derivation of acoustic signatures for the different categories (classes) of sediment or biotopes. The number of possible biotope mapping units was reduced from 28 to 12. Then prior probability classification (see [ENV CS09 Prior Probability Classification](#) case study) was applied to the biotope and sediment data and the resulting maps are shown in Figure 5. The south coast was poorly sampled, due to adverse weather. Thus, the predicted sediment and biotope distributions are very tentative in this region.

The distribution of sandy biotope groups as predicted from the interpretation of the acoustic data using the samples for ground truthing, can then be mapped. These biotopes may be regarded as constituents of sandbanks, but the interpretation has been deliberately kept broad and other interpretations of the definition of sandbanks may exclude some of these biotopes (Figure 6).

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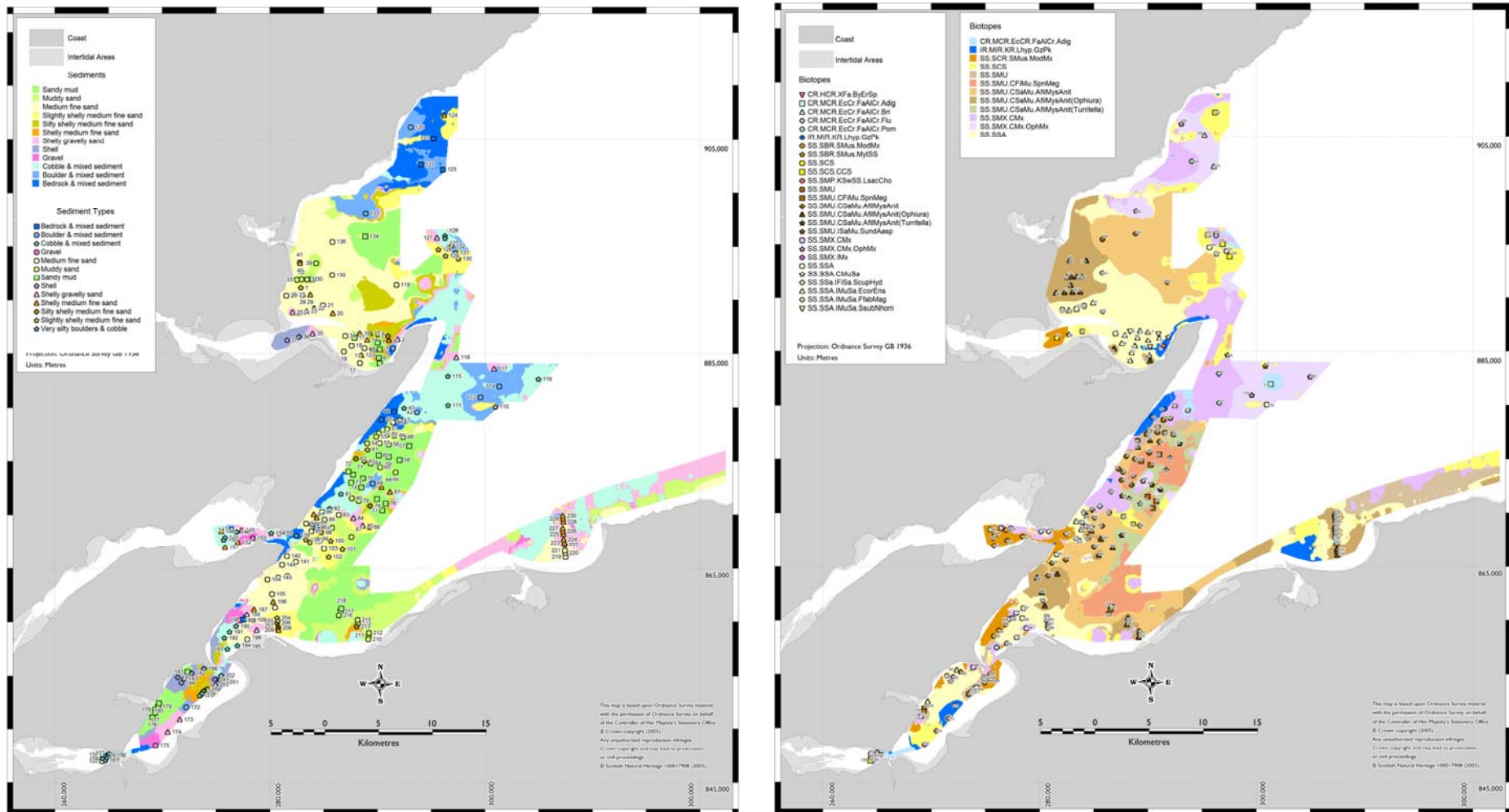
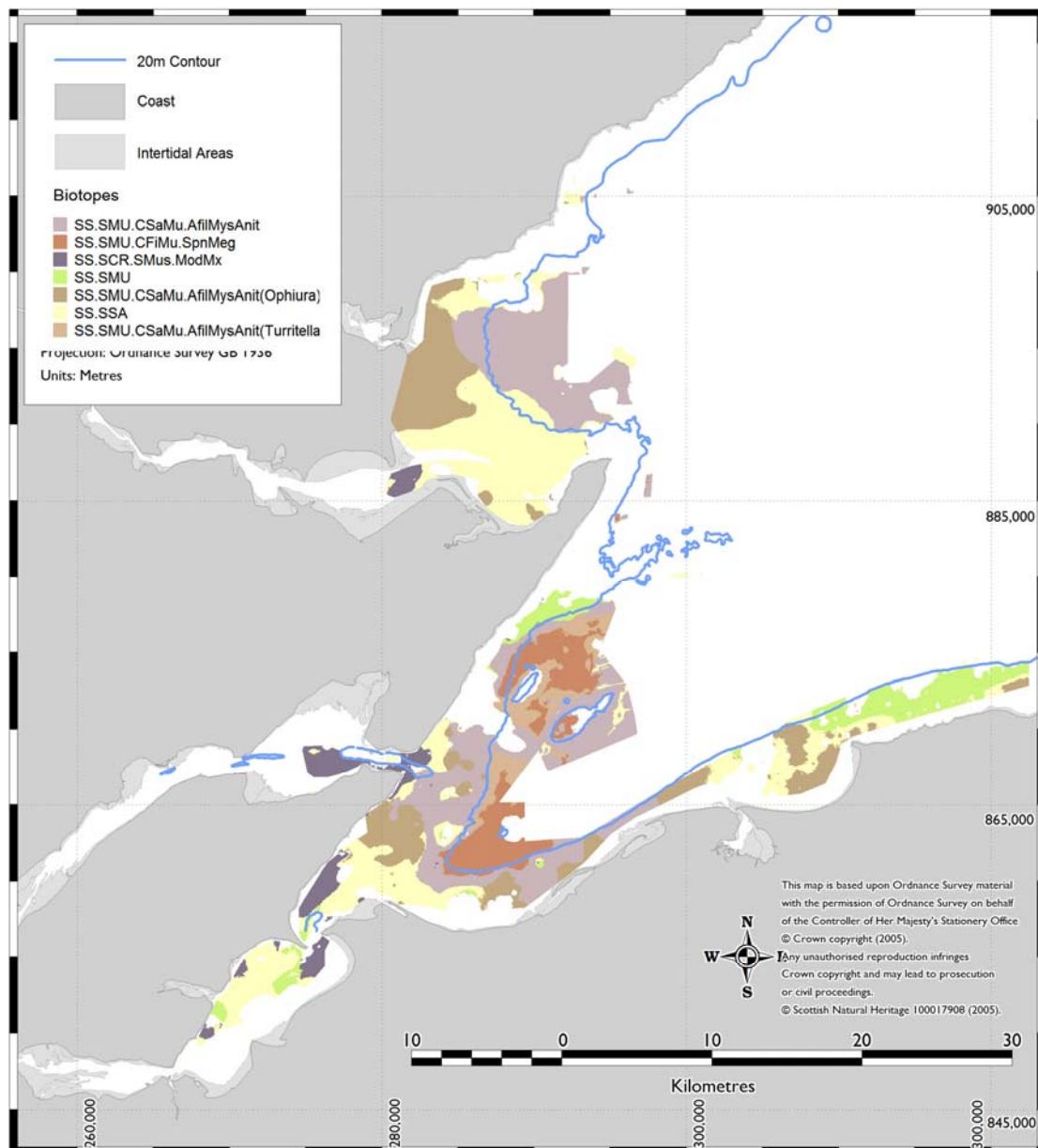


Figure 5. Distribution of the sediments (Left) and biotope groups (Right) as predicted from the interpretation of the acoustic data using the samples for ground truthing. (Source: AGDS).

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**Figure 6. Distribution of the sandy biotope groups as predicted from the interpretation of the acoustic data using the samples for ground truthing. (Source: AGDS). These biotoypes may be regarded as constituents of sandbanks, but the interpretation has been deliberately kept broad and other interpretations of the definition of sandbanks may exclude some of these biotoypes.**

#### 4. Summary, discussion and comparison of techniques

Knowledge of sea floor habitats in the area has directly come from grabs and video. Topography (derived from high resolution bathymetry) and side scan images of sea floor features are also directly interpretable where there are sufficient indisputable features that can be readily identified. This work has shown that broad topographic features and finer scale features from side scan images can be classified together. However, much of the sea floor is of uniform texture with variations in general backscatter strengths. This is more difficult to interpret, especially over such a large area where there is a need to process blocks of tracks separately from other blocks due to the very large amounts of data involved. It appears that the display

outputs of backscatter (the images) may not be standardised as to overall image intensity. Thus, these uniform backscatter areas can only be assigned to categories of their relative intensity (hard to soft ground).

#### 4.1.1. AGDS

AGDS give track values of acoustic variables approximately related to roughness (E1) and hardness (E2). However, the data are not directly interpretable in the sense of images of features (except at the very broad scale). Interpretation is mediated through knowledge of the sea floor obtained from other sampling techniques. However, training the AGDS through supervised classification has its limitations: the classification requires quite extensive and geographically comprehensive sampling to work successfully. Although the number of samples taken in this survey was large, the area was also very large and the density of samples was consequently sparse over much of the survey area. Thus, there are many discrete areas of particular AGDS acoustic ground type that are unsupported by ground truth data.

The less direct approach to classification of AGDS data (which might appear almost ‘black box’ to those not directly involved in analysis) adds to the sense of uncertainty of the maps. This may be justified: there are instances where the training data (samples used to train classification) do not match the predicted distribution and places where complex patterns of habitat distribution are predicted without any supporting ground truth data. This is an inevitable feature of classification and particularly where there are large numbers of samples. This might seem counter-intuitive, but the greater the number of samples may mean that the acoustic signatures for each class will spread to include a wider range of acoustic values. The combination of positional inaccuracies of the acoustic and ground truth systems, inherent variability in acoustic systems, limits to discriminatory powers, misclassification of samples and (in large surveys) geographic differences in habitat/biotope characteristics make this inevitable. It must be expected that matches between samples and predicted habitat distribution will not be perfect.

#### 4.1.2. Swath Bathymetry and Side scan images

It might be expected that, since interpretation of high resolution side scan and topographic images has the advantage of direct link to sea bed features, that confidence in the maps will be high. However, classification is still open to debate where the ground is heterogeneous and/or shows gradations of backscatter accompanied by low levels of texture information. Polygon boundaries will be chosen subjectively and there may be a level of arbitrariness about the classes assigned to the polygons (one of the causes of misclassification).

Providing 100% coverage of large areas using swath systems is time consuming, logistically complex, expensive in terms of processing time and involves extremely large datasets with all the inherent problems of handling very large files. It is tempting to slightly increase track spacing to reduce overlap risks, but having blank areas between adjacent tracks and mosaicing will involve some interpolation to fill gaps and reduce the effect of poor quality data. As soon as gaps become too large and frequent, then they need to be filled using classification of the swaths followed by interpolation of these classes between tracks. This has been done ‘by eye’ in this study. Immediately this transition between 100% coverage and spaced tracks takes place, the nature of the mapping exercise changes from fine scale, detailed, direct mapping to broad scale generalisation: It does not make sense to have a map with very fine detail

interspersed with the cartographer's best guess as to what happens between tracks. Inevitably, the power of the map will be determined by the lowest resolution. One need only look at the map of side scan/swath to see this transition. Clearly, the uncertainty increases considerably as track spacing increases.

#### 4.1.3. Uncertainty

Uncertainty in a system can only be judged against information which is more accurate (closer to the real situation on the sea bed). It would be tempting to assume that direct sampling of the sea floor provides this unequivocal information. However, each sampling technique 'sees' the sea floor in different ways (different scales, resolutions and features). The video provided good evidence of habitat features, epifauna and flora together with conspicuous infauna over 10-100m. Grabs were used to sample sediment for PSA analysis and infaunal composition, but at a fine scale (0.1m) not representative of the broader scale. Which properties affect the acoustic data is not known. There is also the issue of positional uncertainty of the samples and this is particularly severe when locating the grab sample on a video transect where the ground is heterogeneous. The task of trying to synthesise the sample data into a single ground truth data set is not trivial and a potential source of error and uncertainty.

## 5. Conclusions

Viewing maps requires awareness of these limitations, and users should not have unrealistic expectations about map detail (spatial and number of classes discriminated) and consistency between the various lines of evidence presented. There has been the opportunity in this study to compare information from a number of remote systems (AGDS, sides scan and swath bathymetry) and sampling techniques (video, infaunal analysis of grabs, on-board inspection of grabs and PSA). At present, there is no clear procedure for synthesising much of the data from these different sources because of differences in scale, resolution, approaches to analysis and features identified. However, surveys can be designed in which the complementary nature of the systems is capitalised upon (see [ENV CS13 Complementary acoustic survey techniques.doc](#)).

## 6. Acknowledgements

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