MESH MAPPING EUROPEAN SEABED HABITATS

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Title:	**Case Study: Use of complementary techniques for habitat mapping**
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Workgroup:	
MESH action:	Action 5.2: Case histories on the applications of habitat mapping
Version:	0.1 DRAFT
Date published:	23/02/2007
File name:	ENV CS13 Complementary acoustic survey techniques.doc
Language:	English
Number of pages:	15
Summary:	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. This case study explores how the information derived from each of these systems may be used in a complementary way, to derive maps in which higher confidence may be placed.
Reference/citation:	ISBN or full reference.
Keywords:	Acoustic techniques, acoustic ground discrimination, AGDS, swath bathymetry, side-scan, classification, biotope mapping.

This project has received European Regional Development Funding through the INTERREG III B Community Initiative

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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. This case study explores how the information derived from each of these systems may be used in a complementary way, to derive maps in which higher confidence may be placed.

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.

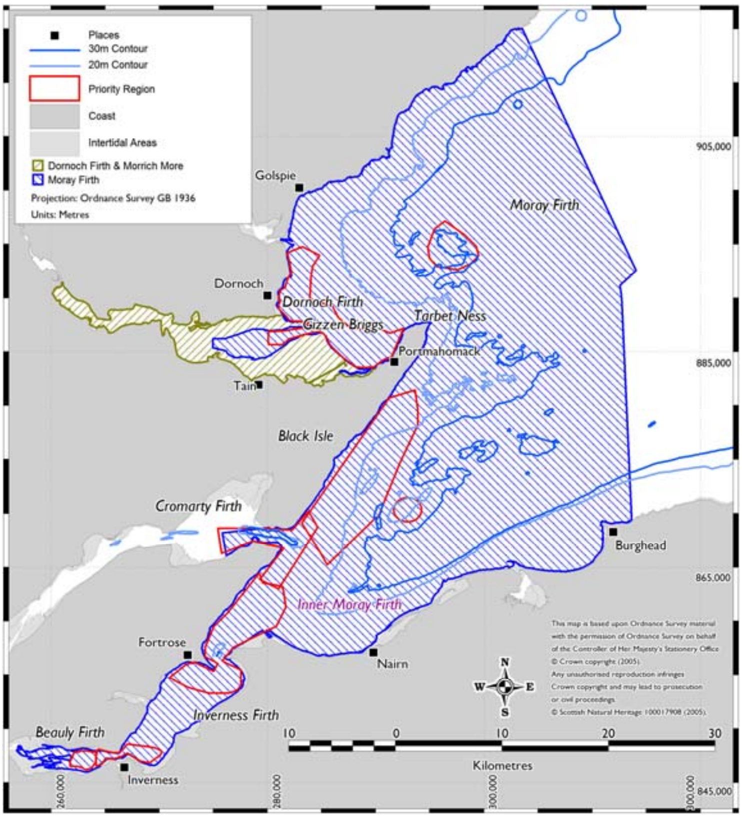

Figure 1: The geography of the Moray Firth cSAC.

1.3. Methods Summary

The Moray Firth cSAC is a large area with a perimeter of 382km and covers an area of 1510km^2. 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^{-1}, 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™ GroundMaster AGDS operating at 50kHz. The RoxAnn system uses analogue signal processing hardware to select two elements from the echo and measure signal strength integrated over the time. The first selected segment of the echo is the decaying echo after the initial peak and is taken to be a measure of roughness of the ground (or ‘E1’). The second segment is the whole of the first multiple echo and is interpreted as a measure of ground hardness (or ‘E2’). AGDS are relatively inexpensive systems linked to standard echo-sounders. They can be deployed from a variety of vessels of opportunity and relatively large areas can be surveyed (although at low resolution) quite rapidly. They do not however give a complete coverage of the sea floor since the data are essentially discrete points centred on the acoustic footprint directly under the vessel as it tracks over the survey area. Furthermore, the echo-sounder wide beam width results in large acoustic footprints in deep water. These two issues mean that the resolution of AGDS is less than is possible with swath or sidescan type systems. The properties E1 and E2 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

Recently bathymetric sidescan equipment has seen significant developments where a combination of decreasing electronic costs and increasing power of personal computing has made the technique become a reality for lower budget, high resolution near shore surveying. A bathymetric sidescan system is one that is used to measure the depth to sea floor and amplitude of sonar return from the sea floor along a line extending outwards from the sonar transducer at right angles to the direction of motion of the sonar (Geen et al., 1993). As the sonar platform moves forwards, a profile of sweeps is defined as a ribbon-shaped surface of depth measurements known as a swath in a similar manner to a sidescan image of the seafloor. The final deliverables from a bathymetric sidescan system are a very high resolution, 3D bathymetric map of the sea floor and a co-located amplitude map similar to a mosaic sidescan record. A typical far range limit is about 7.5 times the water depth giving a total swath width of approximately 15 times the water depth.

Envision used the GeoAcoustics' GeoSwath. 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 data

A survey was conducted using a drop-down video camera, 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^2 grab and sediment samples were retained from all grabs taken.

In addition, some habitat data for ground truthing was 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.

1.4. Analysis of complementary multi-source information

Traditional biological sampling has relied on point samples recorded directly (by divers) or remotely using cameras or sampling devices (grab, dredge). Interpreting these observations in a spatial context has proved difficult due to a lack of information on the topographical structure of the adjacent seabed. Topographical information is necessary both for understanding the context of the location of the sample – e.g. whether it is on a slope, or in a basin, and for understanding the seabed between sample locations. Acoustic techniques offer the opportunity to construct topographic models of the seabed within an area. Such models have the twin benefit of improving our understanding of marine protected areas, and helping the public dissemination of information.

Recent developments in desktop geographic information systems (GIS) have further enhanced our capability of visualising complex spatial data. In particular, overlaying biological interpretations on three-dimensional models of the seafloor can significantly enhance our understanding of marine ecosystems and, hopefully, make a significant contribution to the management of marine protected areas.

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. The derivation of a working definition of this habitat is described fully in a separate case study ENV CS12 Appropriate use of multi-beam vs AGDS.doc, but 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 widest view of the interpretation of the definition of sandbanks was taken to ensure the inclusion of a wide representation of a diverse range of biotopes that also encompasses different parts of the marine ecosystem. As such, the sandbanks of the Moray Firth make a substantial contribution to both the diversity and ecology of the eastern coast of Scotland.

The objectives of the survey permitted the evaluation of both acoustic systems for visualising the important seabed features to support the monitoring and management of the site. Furthermore, the project tested these techniques against other high resolution ground validation methods such as remote video. The information from these systems was used to produce depth charts and bottom type classification maps at resolutions previously un-obtainable. Moreover, the survey demonstrated the rapid data acquisition possible with these techniques. Complex visualisations were generated in a desktop geographical information system (GIS), to help link the biological and acoustic data to create classified maps of the seabed. The methods adopted during this survey provide a protocol for future survey work on marine SACs together with an evaluation of the acoustic techniques for ground discrimination. It also demonstrated the complementary nature of the techniques, and the contribution that combining the data collected can make, to increasing both the accuracy and user confidence in the maps created.

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.

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.

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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 2, for an example).

Together, the two systems have been used to distinguish the following categories. Reflectivity can be used to distinguish the following: bedrock & boulder; gravelly ribbons; hard ground; hard rough ground; large sand waves, hard ground; large sand waves, soft ground; moderately hard ground; moderately soft ground; patchy; patchy rock & sand; ridge, soft ground; rocky; sand & scattered rocks; sand & linear features; sand waves; hard ground; sand waves, soft ground; soft ground; tidal features.

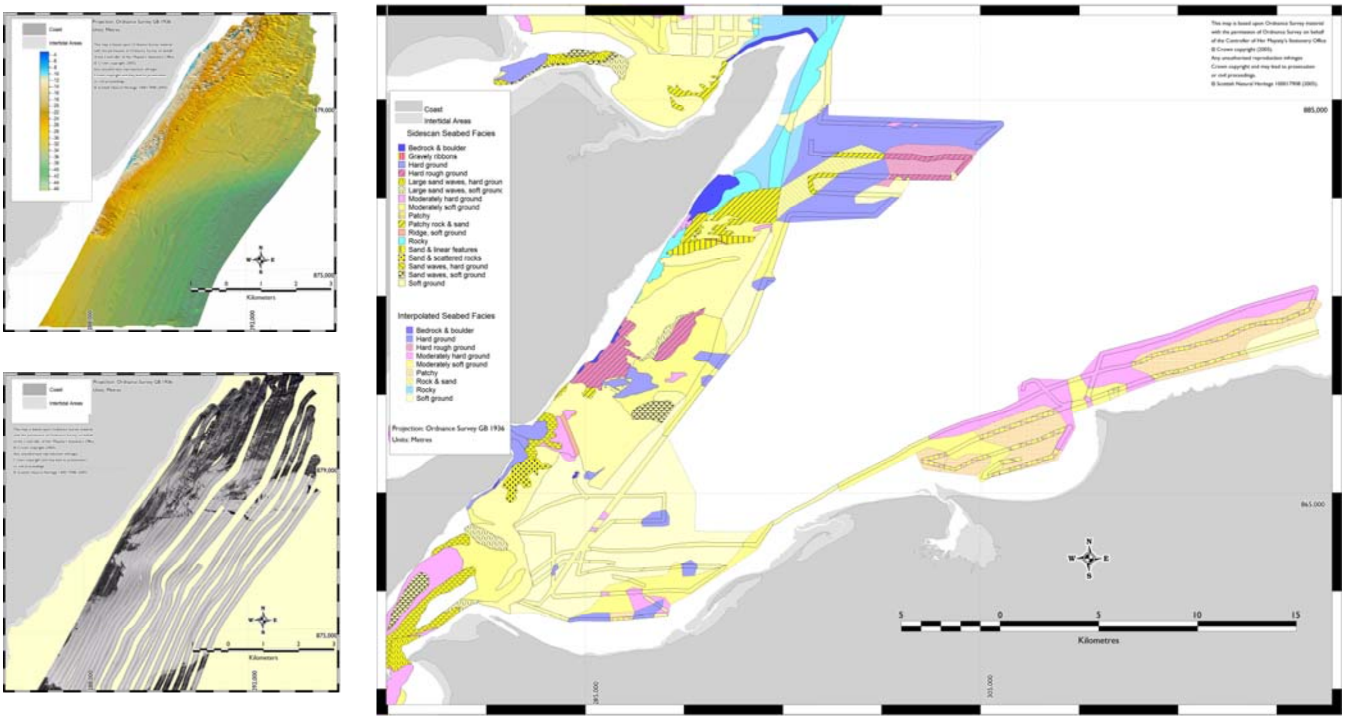

Figure 2. Sea bed feature classes (right) digitised from the side scan (bottom left) and swath images (top left). The slightly lighter hues outlined with a dotted line show areas interpolated by eye between tracks.

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

3. Summary: comparison of techniques

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 E1 and E2 values can however be used independently of any attempt at classification: areas characterised by particular values can be displayed over other data, such as the side scan images (or their interpretation). Three examples where RoxAnn E1 and E2 values have been overlain on side scan/swath interpretations are examined below. These allow us to compare the results obtained using the Geoswath system.

There is broad agreement between the distribution and position of boundaries indicated by side scan, the AGDS track data (Figure 3, Figure 4 and Figure 5). However, there are also some notable differences between the information the techniques produce. Some examples are discussed below.

1. Figure 3 is a complex area of rocky reefs and sediment features off the Black Isle. There is agreement in the disposition of the rocky reefs, even at quite a fine scale. However, interpolation (and subsequent classification) has blurred some of the finer detail through the averaging involved (referred to in the discussion above). Thus, sandy embayments and patches in the rocky reef of about 150m have been 'lost' in the analysis between the track data and classification. Likewise, fingers of rock of about the same width projecting out into sediment have been lost. This level of detail in the boundary between two very distinct habitats may or may not be a significant limitation to the use of habitat maps.

2. In the same figure, the extensive rocky area at the top of the map has been split into three categories in the interpretation of the side scan/swath images: bedrock & boulder, rocky (probably boulder) and patchy rock & sand. The same area is categorised as either bedrock & boulder or cobble & mixed sediment with the AGDS classification and the uninterpreted track data would not appear to have picked up the boundary between rocky and patchy rock & sand. It is likely that small patchy features are not well detected by AGDS.

3. The difference between silty fine sand and (silty) medium fine sand discriminated by AGDS was not discriminated by obvious differences in backscatter of the side scan. Although there may have been a difference, it is certainly the case that differences in backscatter strengths are easier to quantify in AGDS.

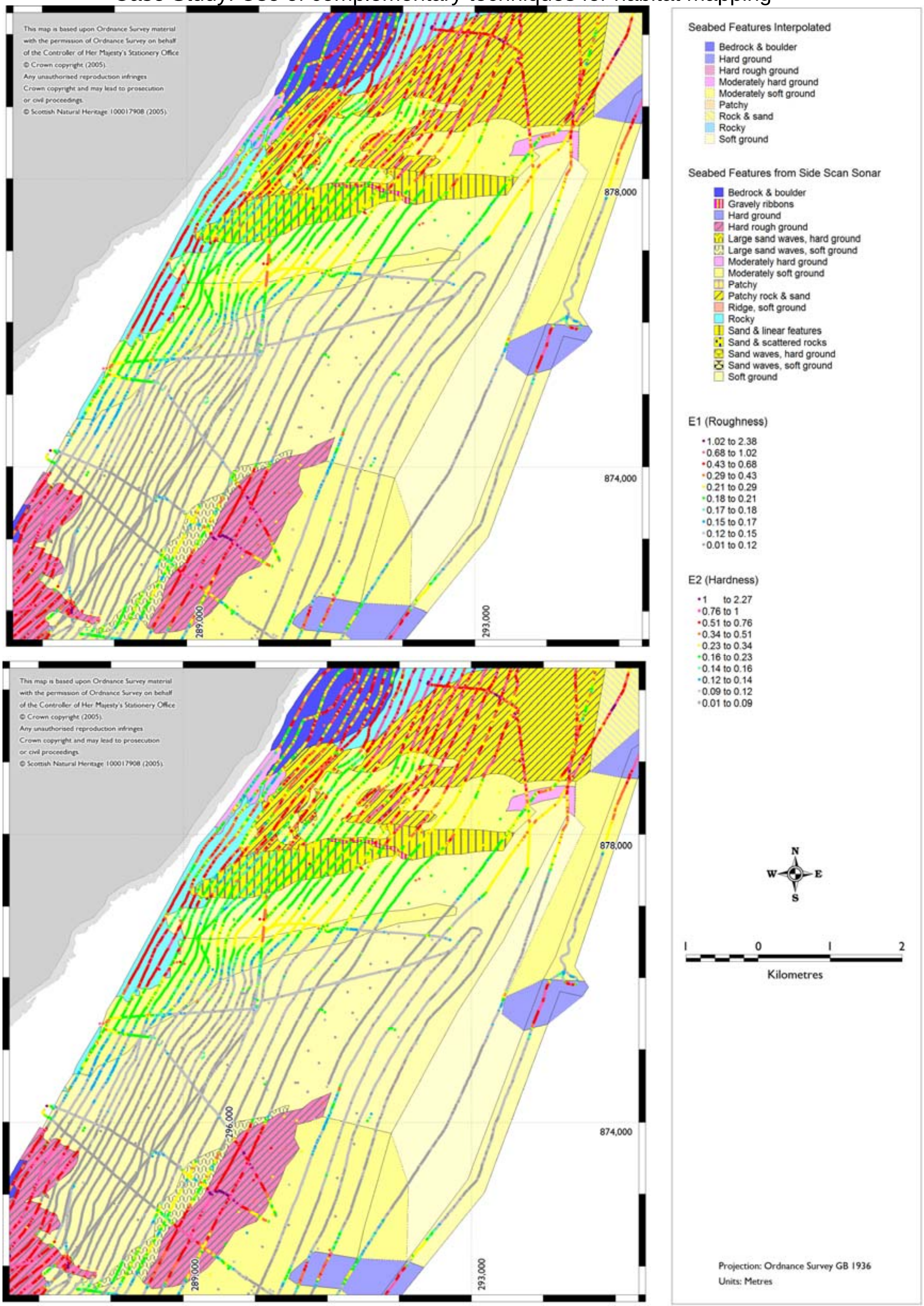

Figure 3. E1 and E2 track data superimposed on the digitised classes from the side scan and swath images for the northern Black Isle area

4. Figure 4, of the southern section of the Dornoch Firth again shows that there is good agreement in the distribution of the rocky habitats. E1 (roughness) also shows changes in values coincident with observed changes between moderately hard ground and softer ground in the side scan images. E1 also returns lower values in the centre of the bay off Portmahomack extending northeast towards the seal bank. These differences in E1 values (not, interestingly, also seen in E2) have been interpreted as spanning the range of sediments from silty fine sand, medium fine sand and silty shelly medium fine sand. This might suggest that AGDS has greater powers of discrimination between sediment types.

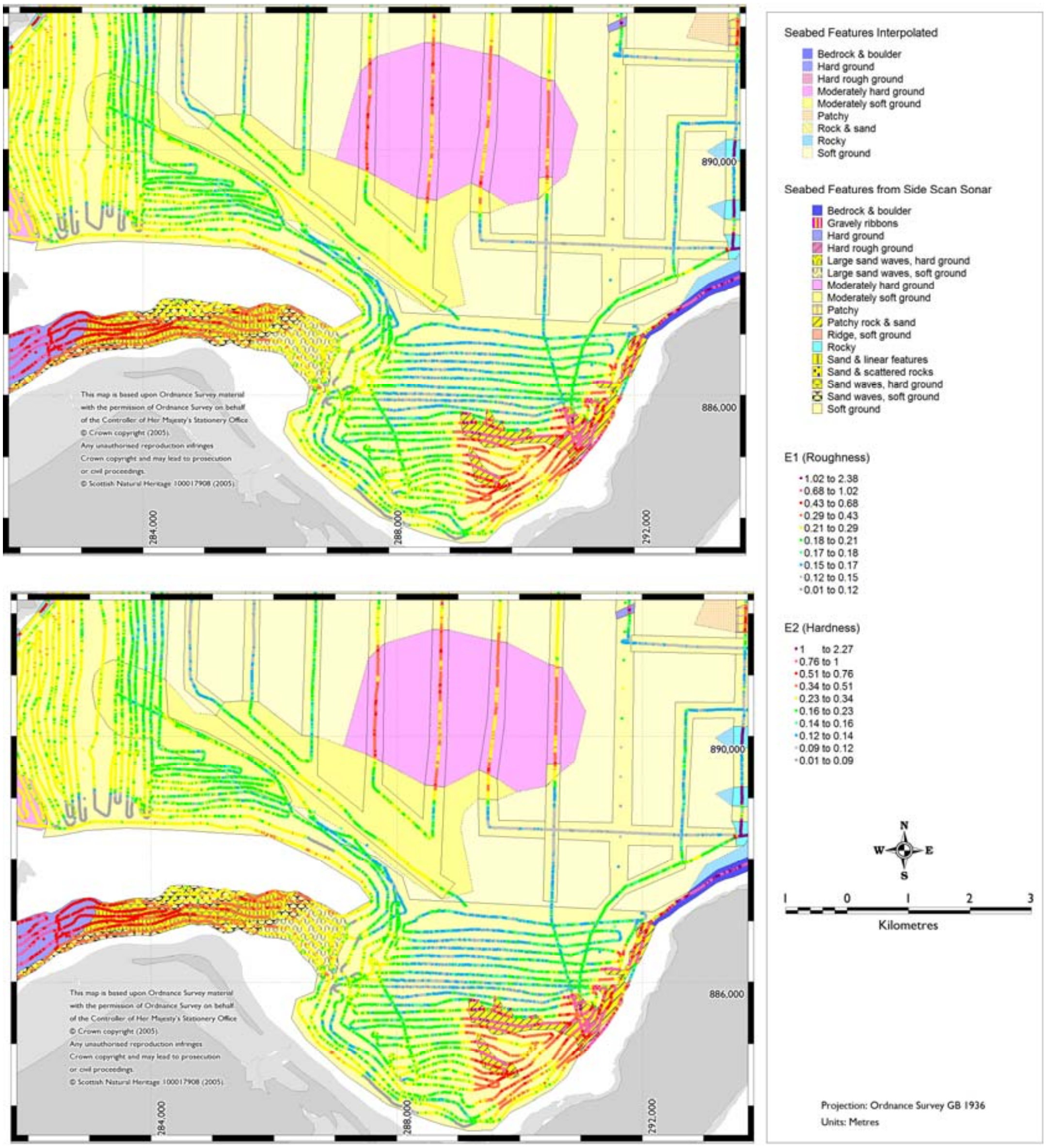

Figure 4. E1 and E2 track data superimposed on the digitised classes from the side scan and swath images for the southern Dornoch Firth.

5. In Figure 5, a detailed map of seal bank in the outer Dornoch Firth, many of the issues outlined above can be seen more graphically, perhaps because of the finer scale of the maps. Thus, the sidescan has been used to delineate detailed boundaries in the cobbley habitats that are about 25m in width. Changes in AGDS track data coincide with many of these boundaries. However, the interpolated and classified AGDS has smoothed out most of this fine detail. Only a sandy patch about 350m has survived the process to appear in the sediment map. However, AGDS has given very different E1 values for the sediment to the west of the harder ground than the sediment patches found within the hard ground. Interpretation of the side scan/swath images have not made this distinction.

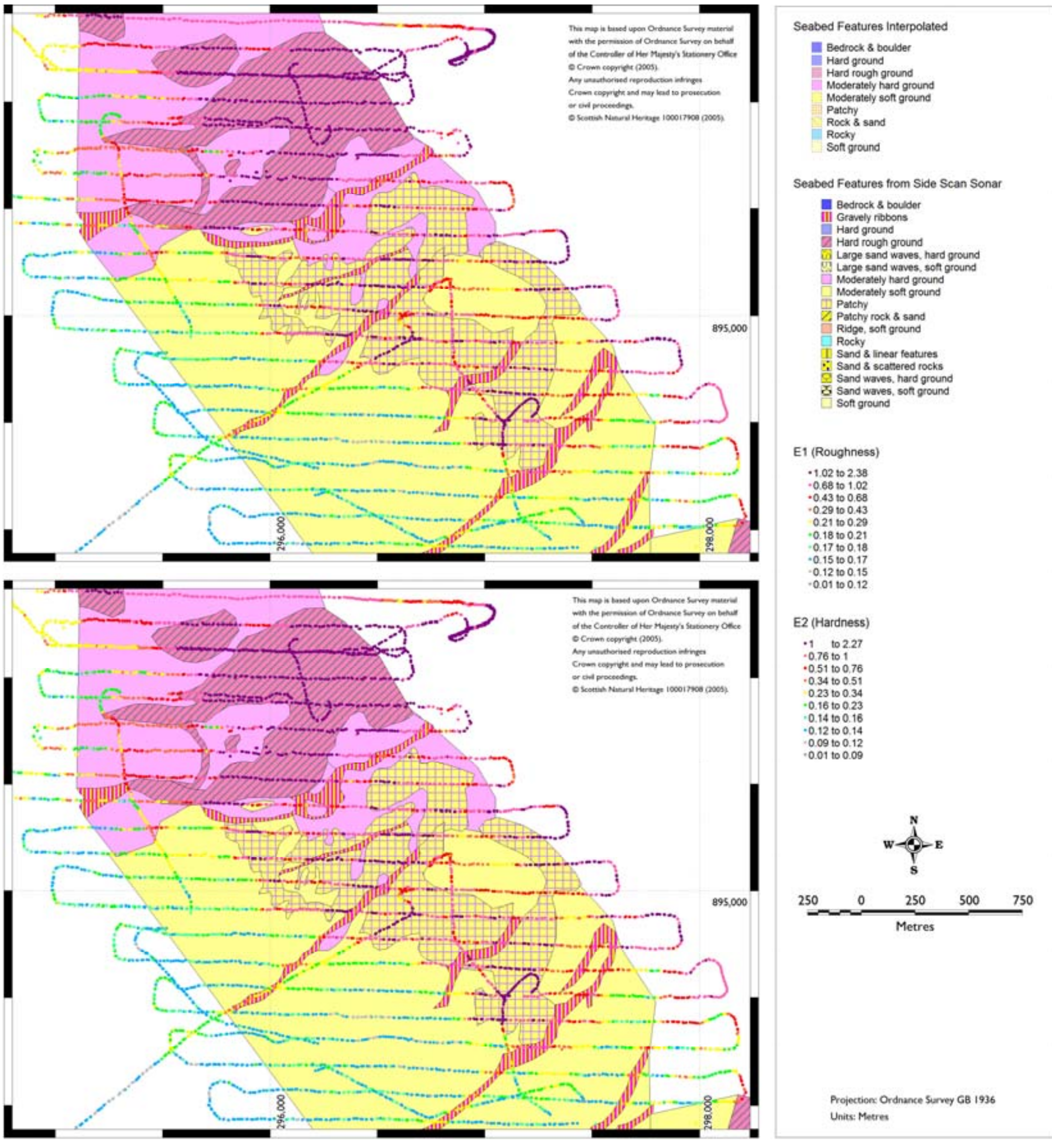

Figure 5. E1 and E2 track data superimposed on the digitised classes from the side scan and swath images for seal bank, Dornoch Firth

Whether these variations in AGDS values are significant in terms of sediment characteristics is open to question. It may be that any variation of E1 (and possibly E2) within homogeneous polygons drawn from side scan images would not justify subdivision or alteration of the habitat or biotope class assigned to the polygon. It might, however, stimulate further more detailed study to establish the nature of the differences in sediment type and their biological significance (if any).

4. Conclusions

The combination of positional inaccuracies of the acoustic and ground truth systems, inherent variability in acoustic systems, limits to the discriminatory powers, misclassification of samples and (in large surveys) geographic differences in habitat/biotope characteristics make uncertainty in the maps inevitable. It must be expected that matches between samples and predicted habitat distribution will not be perfect.

It may also be apparent that the maps based on AGDS lack fine spatial detail, certainly compared to the resolution of some of the side scan images. One of the effects of interpolation using a distance weighted average is to smooth the data. This removes some of the finer detail that can be seen along the tracks. However, it could be argued that the acoustic data are inherently variable in a way that is not necessarily related to ground conditions. Together with the combined spatial imprecision of the sampling and acoustic systems, this could mean that a strict adherence to the fine scale variability would result in analysis showing spurious levels of detail. This is the view adopted by the authors. The maps from the AGDS data are relatively low resolution, broad scale and generalised. They are designed to be viewed at a scale of about 1:25,000 or greater.

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, and it is tempting to broaden track spacing. Slightly increasing track spacing to reduce overlap risks 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.

People viewing maps should be aware of these limitations to mapping and 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, it is possible to overlay data to assess the extent to which information from one source might be used to complement that from another.

The following general conclusions may be drawn from the above discussion and comparison of techniques:-

1. ADGS can be used to delineate boundary conditions along tracks to within a few track points (approximately to within 50m) but interpolation will reduce resolution to features of about 150-350m in extent (although this would depend upon methods and parameters used for interpolation to some extent).

2. AGDS probably have greater powers of sediment discrimination than side scan backscatter. However, the realisation of this power is dependant upon the design of the ground truth sampling program. Supervised classification will only predict the distribution of the classes identified and insufficient sampling would reduce class representation in the ground truth data.

3. Side scan and swath together can be used to detect a wide range of small and large topographic features and the outputs from each are complementary.

4. The fine resolution of side scan and swath images can be used to assess patchiness of features ranging from a few metres upwards. AGDS has limited ability to measure point-to-point variability and very broad scale topographic features.

5. It is impractical to map features as digitised vector polygons at a very fine scale (e.g., less than 25m, as in the case of seal bank) and larger polygons with characteristics summarising fine scale patchiness might provide the best compromise between detail and manageability.

6. There is an abrupt change in detail, resolution and uncertainty as a survey departs from 100% coverage. This is approximately at about 200m track spacing (but is depth-dependant). This is near to the minimum recommended track spacing of 250m for AGDS (Foster-Smith *et al.* 2001).

These conclusions have implications for the commissioning and design of habitat mapping surveys. Firstly, the use of a combination of complementary techniques that can be run concurrently is probably the most efficient use of resources. The extra running costs are small in comparison with other survey and reporting costs. Swath systems that can be run at reasonable cruising speeds collect fine scale data from which bedform features can be determined. AGDS are relatively cheap and easy to deploy together with swath systems.

Secondly, the survey of large areas present many logistical problems (apart from the increased likelihood that bad weather will be encountered): It is probably better to split the survey into a number of geographic sections. The acoustic tracking would be completed in each section before starting the next. This could add to survey time because of logistical constraints, but would ensure that all the data for each section would be consistent, which would benefit the analysis of the data. In the present survey, areas were juggled to fit in with weather and time constraints and some areas were completed piecemeal when the vessel was on passage between Inverness and the main survey site for the day. In some cases, mosaicing tracks separated by many days has created problems not only in the processing, but also record-keeping.

Thirdly, ground truthing/sampling design must take account of the various requirements of the rest of the survey. (1) Fine scale side scan/swath images can be directly interpretable independently of any other ground truthing technique. However, they will only provide information on bedforms, which may not provide sufficient information on sediments and certainly not for biotopes. (2) A distinction needs to be made between sampling to ground truth the acoustic data and sampling to provide additional and detailed information. Techniques that give different scale views of the sea floor and sample different components will not provide comparable information. Ground truth data must be consistent in order to be used for classification and, if a mixture of techniques are used and deployed at different locations, this classification will be set at a level of detail determined by the lowest common denominator between the techniques. Thus, if many locations were sampled incompletely (e.g., just video and no grab), then the whole ground truth data sets will limited to the level of detail of the video. However, a comprehensive sampling design could be adopted but could only be used for ground truthing with confidence where effort has been taken to ensure the gear was deployed at the same location. Trying to meld together data from many different techniques into a single set of classes (necessary for ground truthing) is beset with difficulties. However, the use of detailed sampling at selected locations can be used to increase the knowledge of the broadly defined ground truth classes.

Fourthly, the requirement for detail (resolution and accuracy) needs to be justified and built into the survey design. Is it important to know exactly where fingers of rocky reef or patches of sand occur? If the answer is yes, then 100% coverage is required. For broader scale information, it may be sufficient to characterise tracks and interpolate between them to draw boundaries between ground types that might, in themselves, be quite heterogeneous. Broader scale surveys may only be required to indicate approximate positions of these ground types, but the problems of interpolation will severely impact on the confidence of the map. Very broad scale survey is justifiable if it is used (1) as a precursor to more detailed survey or (2) to provide broad scale context for nested detailed survey (as is the case in this survey). However, those using the information must be aware of the purpose of the surveys and the limitations to confidence.

It is possible that, in future, techniques will improve the quality of the remotely sensed data and reduce uncertainty. More stable acoustic systems, greater processing power and techniques for supervised classification of swath images will be developed that will reduce the need to make many of the compromises involved with survey design discussed above. It is hoped that the data used in this survey will continue to be used to further advances in survey design through the MESH project.

5. Acknowledgements

- These surveys were completed by Envision Mapping Ltd. for Scottish Natural Heritage.

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