Mapping seabed habitats in UK waters

Practical Acoustic Ground Discrimination Workshop
6-11th September 2003

Workshop Report

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Contents

Executive Summary

In recent years the application of acoustic mapping methodologies, in particular the use of acoustic ground discrimination systems (AGDS) used in conjunction with ground-truth sampling, has become common practice in monitoring and mapping seabed habitats at a number of Special Areas of Conservation (SACs) around the UK coastline. Whilst this approach offers advantages over more traditional style benthic grab surveys, the accuracy of the spatial distribution maps produced from such surveys has on occasions been questionable.

Previous investigations into the application of AGDS have gone some way to assess the benefits and limitations of such systems for continuous coverage seabed mapping. The findings from many of these previous studies were used to develop procedural guidelines for conducting AGDS surveys which are presented as part of the Joint Nature Conservation Committee (JNCC) Marine Monitoring Handbook. However, as the number of research/contract groups undertaking broad-scale seabed mapping activities at various sites around the UK coastline increases it is essential to improve communication between these groups and to further refine guidelines and recommendations on best practice for the production of full-coverage seabed biotope maps using AGDS. To address these issues a UK National Acoustic Ground Discrimination Workshop was hosted by the Scottish Association for Marine Science at Dunstaffnage Marine Laboratory from 6-11th September 2003.

The workshop brought together a number of UK research/contract groups who use the AGDS, RoxAnn, for the production of biotope maps. The main aim was to critically evaluate this acoustic system for use in mapping seabed biotopes. A small test site on the west coast of Scotland, within the Firth of Lorn candidate SAC, encompassing a wide range of benthic habitats was chosen as the study site. Prior to the workshop, the area was surveyed using sidescan sonar to accurately map seabed features and two contingency RoxAnn data sets were collected. Ground-truthing using a drop-down video system was also carried out at various sites across the area for the purposes of external validation of the final habitat maps. The first two days of the workshop were held at sea and participants were invited to apply their own mapping methodology over this study area using at least 2 separate RoxAnn systems. Issues such as survey design, system set up and data quality assessment were addressed. A common ground-truthing data set (underwater video data) was also collected from within the test site during this time, and issues relating to the selection of ground-truthing stations were discussed.

The common ground-truthing data set was then used during the processing of the RoxAnn data sets back at the laboratory during a 2-day data-processing workshop. Workshop sessions were run covering various aspects of data handling, quality assessment and data processing to review methods of best practice. Spatial coverage maps were produced from each of the RoxAnn data sets and the accuracy and predictive capability of each map was then tested against the external ground-truthing data set collected prior to the workshop. A total of four different RoxAnn data sets were collected and processed during the workshop to assess aspects such as between-system variability, survey design and data quality.

The final session of the workshop was open to all interested parties within the UK; the primary focus of this session was to present the findings of the workshop to non-specialist environmental managers/advisors involved in the implementation and end use of biotope maps. Issues relating to accuracy, predictive capability and system limitations were discussed to provide a better understanding of this type of mapping approach to non-specialists who regularly use the out-puts from such surveys.

Comparisons between the four maximum likelihood classification maps produced from the four RoxAnn datasets collected was done using internal and external accuracy assessment techniques based on the video ground-truth data sets. These results revealed a moderate level of agreement in terms of the spatial distribution of the six habitat classes (life-forms) identified within the study area between the four data sets. The ability of the RoxAnn system to identify discrete seabed features mapped using sidescan sonar was also tested. RoxAnn consistently overestimated the percentage of rocky reef habitat and underestimated the percentage of mud habitat within the area compared to that measured by sidescan sonar. A number of recommendations relating to the use of AGDS for the production of continuous coverage maps and relating to the JNCC Marine Monitoring Handbook guidelines are proposed.

1. Background

Maps which show the distribution of habitats and biota, together with accompanying data and statistics, are central to many aspects of environmental appraisal, in particular for use in the assessment of the natural heritage (conservation) and the impacts of human activities on biological resources of the seabed. Recent developments in seabed mapping techniques, driven by continuous improvements in acoustic systems (e.g. side-scan sonar, multibeam sonar, acoustic ground discrimination systems), offer the potential to radically alter approaches to monitoring and mapping this component of the marine ecosystem. In recent years the application of acoustic mapping methodology (in particular the use of acoustic ground discrimination systems – AGDS), used in conjunction with ground-truth sampling, has become common practice in monitoring and mapping seabed habitats at a number of Special Areas of Conservation (SACs) around the UK coastline (e.g. Davies 1999; Foster-Smith and Sotheran, 1999; Foster-Smith et al 1999, 2000; Service 1998; Service and Magorrian 1997). Whilst this approach offers advantages over more traditional style benthic grab surveys, the accuracy of the spatial distribution maps produced from such surveys has on occasion been questioned.

There have been a number of previous investigations into the application of AGDS which have gone some way to assess the benefits and limitations of such systems for continuous coverage seabed mapping (Anon 2000; Foster-Smith and Sotheran 2003; Foster-Smith et al. 1999; Greenstreet et al. 1997; Hamilton et al. 1999; Hull and Nunny, 1998; Magorrian et al. 1995; Pinn and Robertson, 1998 and 2003; Wilding et al. 2003). Many of the issues addressed during the current workshop (e.g. effects of vessel speed, variability between systems, line spacing etc) have been investigated in detail in a number of the studies listed above, and many of these findings were used to develop procedural guidelines for conducting AGDS surveys which are presented as part of the Joint Nature Conservation Committee (JNCC) Marine Monitoring Handbook (Foster-Smith et al, 2001a). However, as the number of research/contract groups undertaking broad-scale seabed mapping activities at various sites around the UK coastline increases it is essential to improve communication between the groups and to further refine guidelines and recommendations on best practice for the production of full-coverage seabed biotope maps using AGDS. This would help to further evaluate the utility of such acoustic systems for the production of seabed habitat maps.

This workshop aimed to address some of these points by bringing together UK research/contract groups who use the AGDS, RoxAnn, for the production of biotope maps. The workshop aimed to compare and contrast mapping methodology and ultimately biotope maps produced by each group over the same area of seabed using the same research vessel. Existing guidelines (Foster-Smith et al, 2001a) were used as the basis for the workshop and discussions were held to address the various aspects of AGDS survey from data collection through to the production of habitat maps.

Details regarding how AGDS work and information relating to the various post-processing methods are covered in detail elsewhere (Foster-Smith et al., 2001a and b; Foster-Smith and Sotheran, 2003) and will not be covered in this report. This report will focus on presenting discussion points raised during the various stages of the workshop from data collection through to final map production, and will compare and evaluate the habitat maps produced during the course of the workshop.

2. Structure of the Workshop

The workshop aimed to critically evaluate the use of the Acoustic Ground Discrimination System, RoxAnn, for use in mapping seabed biotopes. A small test site on the west coast of Scotland within the Firth of Lorn candidate SAC encompassing a wide range of benthic habitats was chosen as the study site (Figure 1). Prior to the workshop, the area was surveyed using sidescan sonar to accurately map seabed features and two contingency RoxAnn data sets were collected. Ground-truthing using a drop-down video system was also carried out at various sites across the area for the purposes of external validation of the final habitat maps.

A number of research/survey teams working with the AGDS RoxAnn were invited to participate in the workshop. Participants were asked to apply their own mapping methodology over this study area using at least 2 separate RoxAnn systems during a 2 day data collection workshop at sea. Issues such as survey design, system set up and data quality assessment were addressed. A common ground-truthing data set (underwater video data) was also collected from within the test site during this time, and issues relating to the selection of ground-truthing stations were discussed.

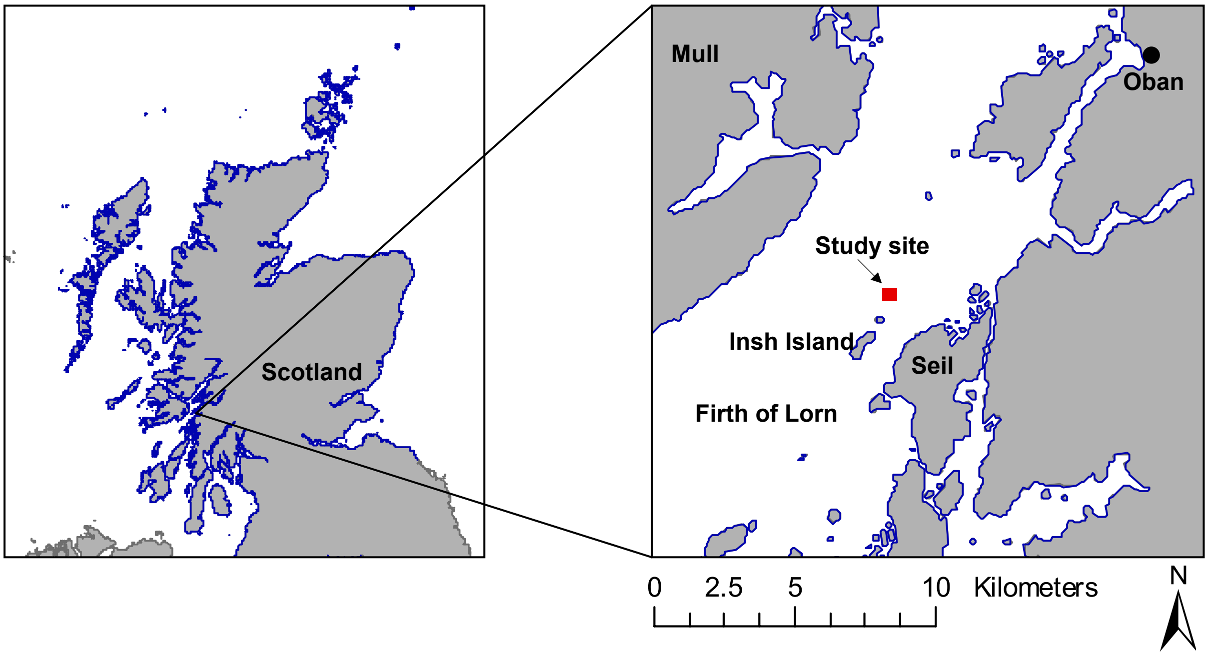

Figure 1. Location of the study area, Firth of Lorn, Scotland

The common ground-truthing data set was then used to process the RoxAnn data sets back at the laboratory during a 2-day data-processing workshop. Workshop sessions were run covering various aspects of data handling, quality assessment and data processing to review methods of best practice. Spatial coverage maps were produced from each of the RoxAnn data sets and the accuracy and predictive capability of each map was then tested against the external ground-truthing data set collected prior to the workshop. A total of four different RoxAnn data sets were collected and processed during the workshop to assess aspects such as between-system variability, survey design and data quality.

The final session of the workshop was opened up to all interested parties within the UK; the primary focus of this session was to present the findings of the workshop to non-specialist environmental managers/advisors involved in the implementation and end use of biotope maps. Issues relating to accuracy, predictive capability and system limitations were discussed to provide a better understanding of this mapping approach to non-specialists who regularly use the outputs from such surveys.

Workshop objectives:

- To compare the reliability of the AGDS RoxAnn, for the production of full spatial coverage maps of seabed habitats and biotopes, through comparison of the outputs from a number of different RoxAnn systems over the same area of seabed.

- To compare and evaluate different approaches to seabed mapping between different research teams within the UK, with the aim of identifying and standardising best practice.

- To assess the predictive capability of biotope maps produced using RoxAnn through the collection and application of an external ground-truthing data set.

- To report on the significance of the findings for the management and monitoring of SACs.

- To provide a better understanding to non-specialist environmental managers/advisors of the techniques and data processing methodologies involved in the production of full-spatial coverage biotope maps produced using the AGDS RoxAnn, and to highlight potential benefits/limitations of biotope maps produced in this way.

Research groups:

Representatives from six research teams/organisations attended the workshop, namely: Scottish Association for Marine Science (SAMS); Department for Agriculture and Rural Development, Northern Ireland (DARD); Queens University, Belfast; Fisheries Research Services, Aberdeen (FRS); Centre for Environment, Fisheries and Aquaculture Science (CEFAS); Joint Nature Conservation Committee (JNCC). Unfortunately, two key research teams were unable to attend the workshop and as a result a number of data processing issues were not discussed to the degree anticipated. However, the workshop allowed comparison between the data sets collected allowing valuable evaluation of survey designs proposed by each research team.

This report incorporates points raised during the open-session on the final day of the workshop.

3. Workshop findings/discussion issues

The following sections present the methodology adopted and the discussion points covered by the workshop participants (WP) during the course of the workshop, and the structure of the report broadly follows that used in the JNCC Marine Monitoring Handbook (Foster-Smith et al, 2001a). Conclusions from each of the discussion issues are listed at the end of each section.

3.1 Equipment and set up

Two vessels were used during the course of the workshop. The RV Seol Mara was used to collect data prior to the workshop, and the RV Calanus was used during the two day data collection exercise as part of the workshop (Figure 2). Both vessels provide an adequate platform for conducting AGDS surveys as specified in the JNCC Marine Monitoring Handbook (Foster-Smith et al, 2001a).

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Figure 2. RV Calanus and RV Seol Mara

Two RoxAnn systems were used during the workshop, both operated at 200kHz which was agreed by all WP to be the most suitable frequency for the water depths encountered at the survey site (15-60m). Both systems came complete with transducer and RoxAnn signal processor. The data logging software *RoxMap* was used to log the data throughout the course of the workshop, and an agreed power setting and save rate was used during all data collection to eliminate the effects of these parameters on the final habitat maps (Figure 3).

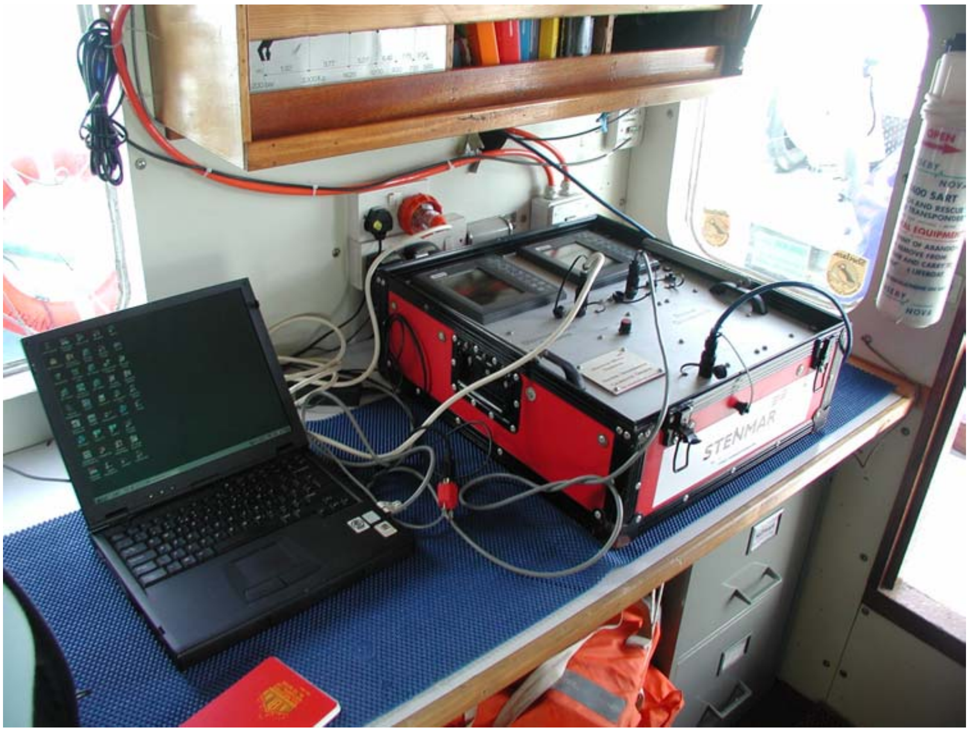


Figure 3. RoxAnn signal processing unit linked to a laptop recording the data using the data logging software RoxMap.

On both vessels an over-the-side mount was used to deploy the transducer(s) (Figure 4). This is the commonest method of deployment for portable RoxAnn systems, especially from smaller vessels, and there was agreement amongst the WP that this is an adequate method of deployment as long as the mounting pole is stable at working speed, that there are no signs of aeration beneath the transducer, and that the transducer protrudes below the hull of the vessel to avoid multipath interference. A number of WP also raised the issue of permanent hull-mounted transducers, which are often used when conducting surveys from larger vessels. Such system configurations offer a very stable mounting for the transducer, although fouling of the transducer face could affect data quality and the gradual build-up of material on the transducer over time could affect survey repeatability. This is an unavoidable consequence of permanent hull-mounted systems and regular cleaning of the transducer by diver or dry-docking is the only way to limit problems arising from the build-up of bio-fouling.

Differential GPS was used on both RV Seol Mara and RV Calanus. In both cases the GPS antennae was positioned directly above the transducer to minimise heading error. This was agreed by all WP to be the preferable set up, although it should be noted that this configuration may not always be possible, particularly when the vessels own GPS system is used.

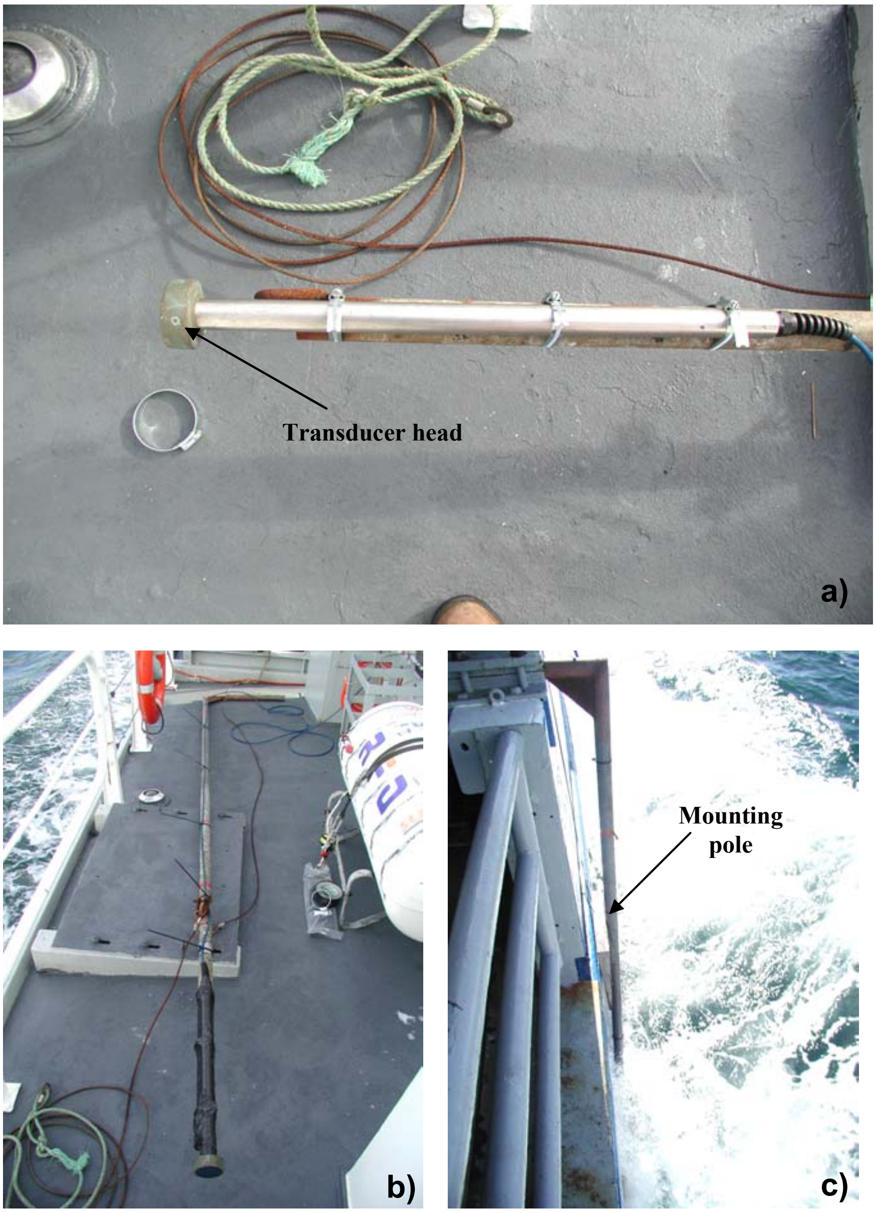


Figure 4. a) RoxAnn transducer attached securely to the over-the-side mounting pole; b) Mounting pole from RV Calanus prior to deployment; c) Mounting pole on RV Calanus following deployment.

There are a wide range of ground-truthing options open to surveyors of which the pros and cons have been discussed at length in previous studies (see Foster-Smith et al. 1999, 2001 a and b; Brown et al. 2001). By far the most popular technique for ground-truthing AGDS data sets is underwater video as this provides a rapid means of collecting a large number of field samples which is crucial for the production of biotope/habitats maps using AGDS. Video also permits the observation of conspicuous sea floor characteristics at a scale appropriate to the echo-sounder footprint. It is also an appropriate method for collecting data over a range of seabed types in contrast to other techniques which may be limited in their application to specific seabed characteristics (e.g. grab sampling is limited to regions of softer sediments and can not be used effectively on rocky or consolidated substrates). However, it should be noted that in regions of poor visibility, or where strong currents prevail, the application of video ground-truthing may not be suitable and in such locations it may be necessary to employ other ground-truthing techniques.

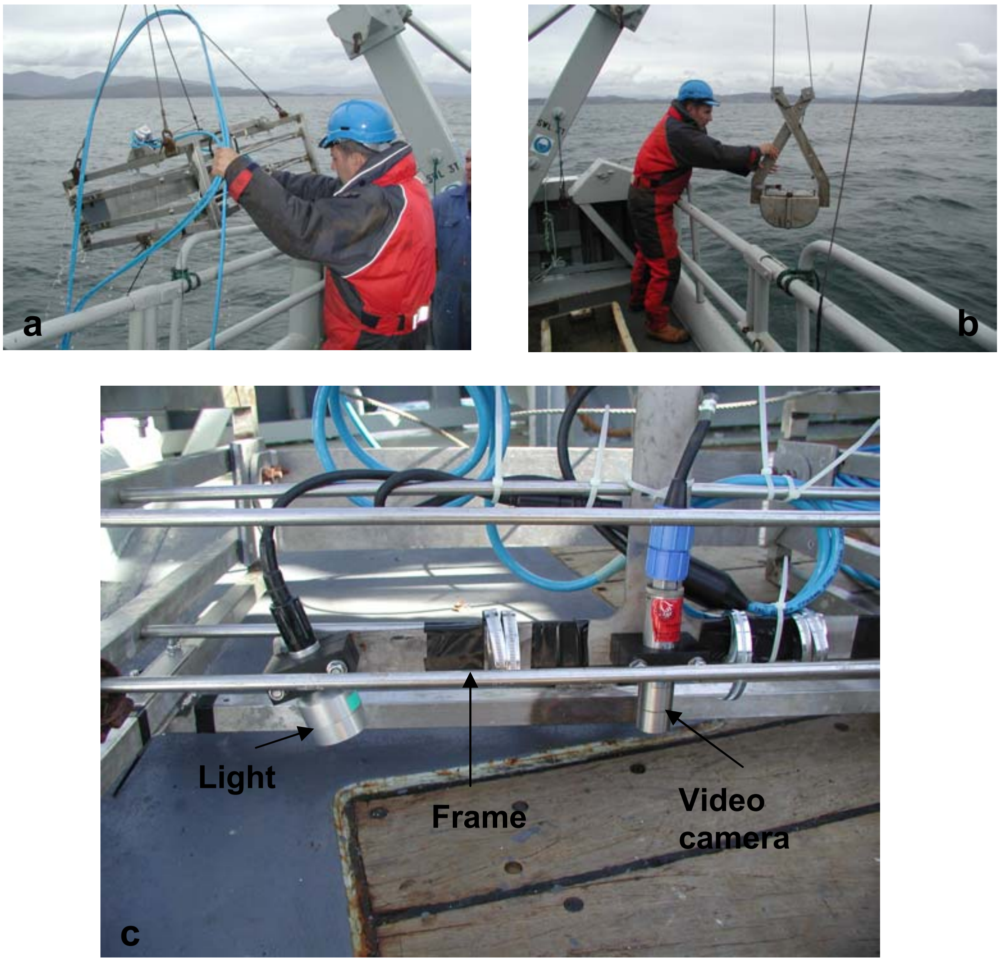


Figure 5. a) Deployment of drop camera frame from RV Calanus; b) Deployment of Van veen grab from stern of RV Calanus; c) Video camera and lights attached to the drop frame.

It was universally accepted amongst the WP that video was the most appropriate technique for use at the survey site, and therefore a drop-down video system was used (Figure 5). The system was deployed from the stern of the research vessel and was suspended approximately 1-2m above the seabed to obtain images of surficial sediments, seabed features and conspicuous epifauna. WP also discussed the benefits of using more than one ground-truthing method to assist in defining biotopes from the video footage. It was agreed that this would be a beneficial approach and a limited number of grab samples using a Van-veen grab (Figure 5) were collected at selected sampling locations.

Conclusions:

- WP felt that the recommendation laid down in the JNCC Marine Monitoring Handbook (Foster-Smith et al. 2001a) relating to equipment set up and data collection procedures were, on the whole, comprehensive and sufficiently detailed.

- Survey sites and survey requirements can vary widely and WP agreed that a degree of flexibility needs to be retained in the guidelines to allow informed decision by the surveyor regarding the choice of AGDS system, system configuration, and selection of ground-truthing techniques on a survey-by-survey basis. The guidelines as they stand are sufficiently flexible to meet this requirement.

3.2 Survey design and data collection

Survey design:

Four RoxAnn data sets were collected during and prior to the workshop which were consequently used in the data processing exercises (see later). Each participating research group was given the opportunity to design a survey which they deemed appropriate for the study area. The aim of this was to examine the difference between biotope maps produced from surveys conducted by different research teams using different survey strategies (e.g. line spacing, track orientation etc.). Two of these survey strategies were adopted for use during the workshop: A north-south survey line design with track spacing of approximately 100m; and an east-west survey line design with track spacing of approximately 70m (Figure 9). Track spacing was chosen based on the time available for the survey, information taken from hydrographic charts, and prior knowledge relating to the heterogeneity of the seabed in the region from earlier studies in the vicinity of the Firth of Lorn (Davies, 1999). The decision regarding track orientation was based on weather constraints and personal preference. Track plots are shown in black in Figure 9.

The JNCC Marine Monitoring Handbook (Foster-Smith et al. 2001a) lists recommendations regarding survey design which are sufficiently flexible to accommodate the wide variety of seabed characteristics likely to be encountered during surveys, and to accommodate decisions relating to survey design which may arise as a result of weather constraints, operational restrictions or a lack of knowledge about the site. The WP felt that the guidelines regarding this issue were sufficiently detailed as they currently stand. In the current exercise the variability in design between survey teams would allow the effect of survey design on final map production to be assessed.

Working speeds of 7-8 knots for AGDS surveys are quoted in the JNCC Marine Monitoring Handbook (Foster-Smith et al. 2001a). In theory vessel speed, within reason, should have little if no effect on data quality and should only affect the intensity of data points on the seabed. The decision as to what speed a survey should be conducted will depend on factors such as the nature of the survey vessel being used, the stability of the transducer mounting and the sea state. Many of these parameters will vary between surveys and the final decision as to what speed the survey vessel should be run will come down to the surveyor on the day of the survey. During the current workshop three survey speeds were adopted; one of the survey grids was run at 4 knots, two of the survey grids were run at 6 knots, and the remaining survey grid was run at 8 knots. These were agreed by the WP to be a representative range of survey speeds commonly used when collecting AGDS data and would allow the effect of vessel speed on the final habitat map to be assessed.

Quality assurance issues relating to data collection and the maintenance of data quality during the field survey were discussed by the WP. Measures which should be adopted to ensure data quality are covered in the JNCC Marine Monitoring Handbook (Foster-Smith et al. 2001a) and the WP felt that these were sufficiently detailed and comprehensive. During the workshop these guidelines were adhered to. Data collected during the workshop was logged using the software *RoxMap*.

The following table summarises the various parameters relating to the four RoxAnn data sets that were collected:

	Research vessel	Track orientation	Vessel speed	RoxAnn system	Track spacing
Data set 1	RV Calanus	North-south	4 knots	200kHz system (SAMS)	100m
Data set 2	RV Calanus	North-south	8 knots	200kHz system (SAMS)	100m
Data set 3	RV Seol Mara	East-west	6 knots	200kHz system (SAMS)	70m
Data set 4	RV Seol Mara	East-west	6 knots	200kHz system (Stenmar)	70m

Table 1: Summary of the survey parameters associated with the four RoxAnn data sets.

A sidescan sonar survey was also conducted at the site from RV Seol Mara prior to the workshop. An Edgetech 272 sidescan sonar fish, operating at the 100kHz frequency setting, was used to image the seafloor at the study site, with data logged using an Octopus^{TM} 460 data acquisition system. Sidescan sonar fish approximate layback was logged manually from the length of cable deployed and water depth, and an average layback applied to the data prior to data processing. A mosaic of the sidescan sonar data was produced using CodaOctopus^{TM} mosaicing and editing software in order to produce a spatial image of the seabed features within the study area (e.g. rocky reefs, regions of soft mud) (Figure 6).

The sidescan sonar mosaic could be divided into three acoustically distinct regions with confidence. Rocky reefs were clearly discernable and were characterised by a strong acoustic reflectance and regions of acoustic shadow. These features could be mapped to a relatively high level of accuracy (Figure 7). Regions of low acoustic reflectance (probably relating to regions of soft mud and muddy sand) could also be identified and delineated, although this habitat did not always have distinct boundaries and there was therefore a degree of subjectivity as to where the boundary was placed. For the purpose of the workshop these two acoustic regions were classified with life-form categories used in the RoxAnn classification, namely MCR/MIR for the rocky reefs and CMU for the low reflective regions (see section 3.3). The region between these two classes had an intermediate acoustic reflectance and could not be classified with any confidence into any of the life-form classes used for the RoxAnn classification. It is likely that this intermediate region contained a number of different life-forms. However, identifying two acoustic regions from the sidescan sonar data which could be loosely linked to discrete life-form classes offered another means against which to test the predictive capability of the RoxAnn maximum likelihood maps (see section 3.3), although the aim of this exercise was not to make comparisons between AGDS and sidescan sonar as tools for mapping seabed habitats.

It should be recognized that there is a degree of positional error associated with the sidescan mosaic as a result of the layback between the sidescan sonar fish and the dGPS receiver on the research vessel, and that comparisons between the AGDS maps and the interpretation of the sidescan sonar mosaic are relative with respect to these positional errors.

The selection of appropriate ground-truthing sites is crucial for the production of good-quality habitat maps. The JNCC Marine Monitoring Handbook (Foster-Smith et al. 2001a) offers a comprehensive list of recommendations for the selection of sites which the WP felt were adequate for ground-truthing AGDS data. Nonetheless, the selection of ground-truthing stations can still be problematic, particularly in regions where the sea floor is heterogeneous in nature.

During the workshop 16 drop-down video stations were sampled for the purposes of signature development, and 10 drop-down video stations were sampled for the purpose of accuracy assessment (Figure 8). The JNCC guidelines were adhered to as closely as possible. The WP felt it was also necessary to use a second ground-truthing technique to confirm the nature of several types of sediments recorded during the video dips. A Van-veen grab was therefore deployed at seven stations to collect sediment samples. These were examined on deck to confirm sediment characteristics from the video data.

The logging of positional information relating to the ground-truthing data was an issue that the WP discussed at length, and this topic is poorly covered in the JNCC Marine Monitoring Handbook (Foster-Smith et al. 2001a). There are several ways by which this can be done and the selected approach will have a significant effect on accuracy. The simplest method when using video and probably the most commonly used approach (and the approach used during the current workshop), is to log the vessels position and relate its location to the video data by time. This approach is adequate when working in shallow waters when the video system is likely to be directly below the vessel. This approach can be improved by incorporating an overlay onto the video screen displaying vessel position, vessel heading, station number and time. However, in deeper waters, or when using towed camera systems there is undoubtedly a layback between the vessel and the location of the camera on the seabed. In such situations a positional error is inevitable. In regions of homogeneous substrata this may not cause any major concerns, but in regions where the seabed has a degree of heterogeneity the difference in position between the vessel and the camera can reduce the accuracy of the final habitat map. In such situations it is advisable to use an underwater positioning system/beacon attached to the underwater camera.

Conclusions:

- WP felt that survey design and data collection recommendations laid down in the JNCC Marine Monitoring Handbook (Foster-Smith et al. 2001a) were, on the whole, comprehensive and sufficiently detailed.

- Positional accuracy was flagged up as one of the most crucial requirements for both AGDS and ground-truth data collection. Positioning the GPS antenna above the transducer reduces positional error when logging the RoxAnn data. On vessels where the GPS antennae is not directly above the transducer it should be noted that there will be a positional offset between the logged position of each acoustic return and the actual ensonified area of seabed.

- It was agreed that the recommendations for ground-truthing AGDS data sets as laid down in the JNCC Marine Monitoring Handbook were appropriate and sufficiently flexible to allow the surveyor to make informed decisions regarding the type of sampling gear and method of deployment. However, it was felt that quality issues relating to video data and positional accuracy of data should be raised. This is referred to in the JNCC guidelines but its importance needs to be strengthened, particularly when using towed or drop down video systems in relatively deep water. Lay back issues can affect the quality and accuracy of the final habitat maps, especially where there is disparity between the accuracy of the AGDS data and ground-truthing data (see later). Ideally a underwater positioning system should be employed to accurately locate the camera system on the seabed. However, where cost or operational restraints prevent this every effort should be made to log the position of the ground-truth data as accurately as possible.

- The quantity of ground-truthing data was also raised by WP as an issue of concern. Ground-truth data is used in subsequent data analysis and accuracy assessments and should be of sufficient quantity to serve both purposes. Foster-Smith et al. (1999) discuss this issue at length, and whilst it is not possible to be prescriptive as to the minimum number of ground-truthing data points as this is greatly affected by the degree of homogeneity of the seabed, it should be strongly pointed out that increasing the number of ground-truthing stations will strengthen accuracy of the final habitat map and improve the ability to assess the accuracy of such maps.

Figure 6. Sidescan sonar mosaic of the Firth of Lorn study site. Grey-scale: Dark regions are reflective/hard**.**

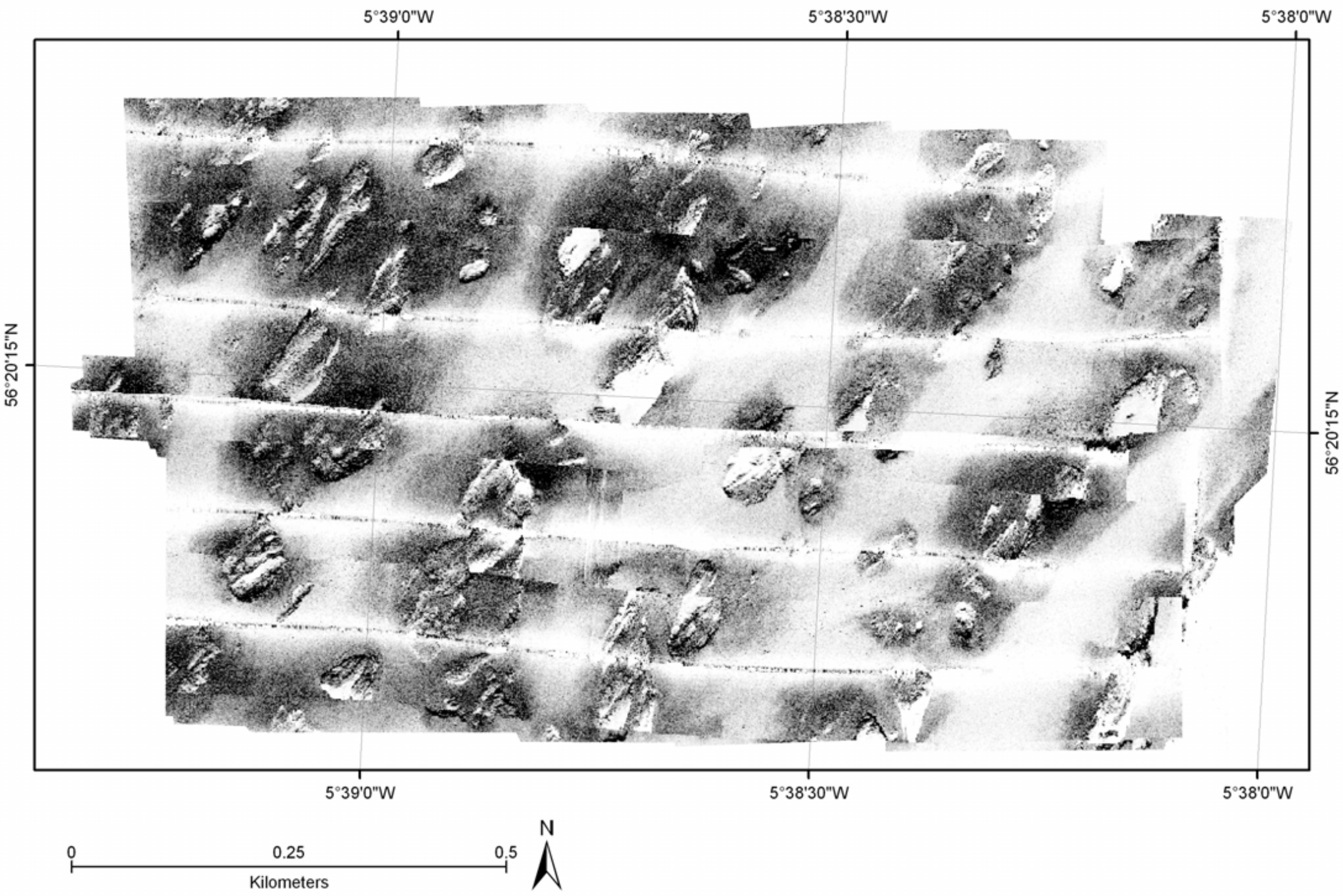


Figure 7. Sidescan sonar interpretation: Strong acoustic return and regions of shadow - Rocky reefs (MCR/MIR); Low acoustic return - Circalittoral mud (CMU); Intermediate acoustic return – unclassified region between rocky-reefs and regions of mud.

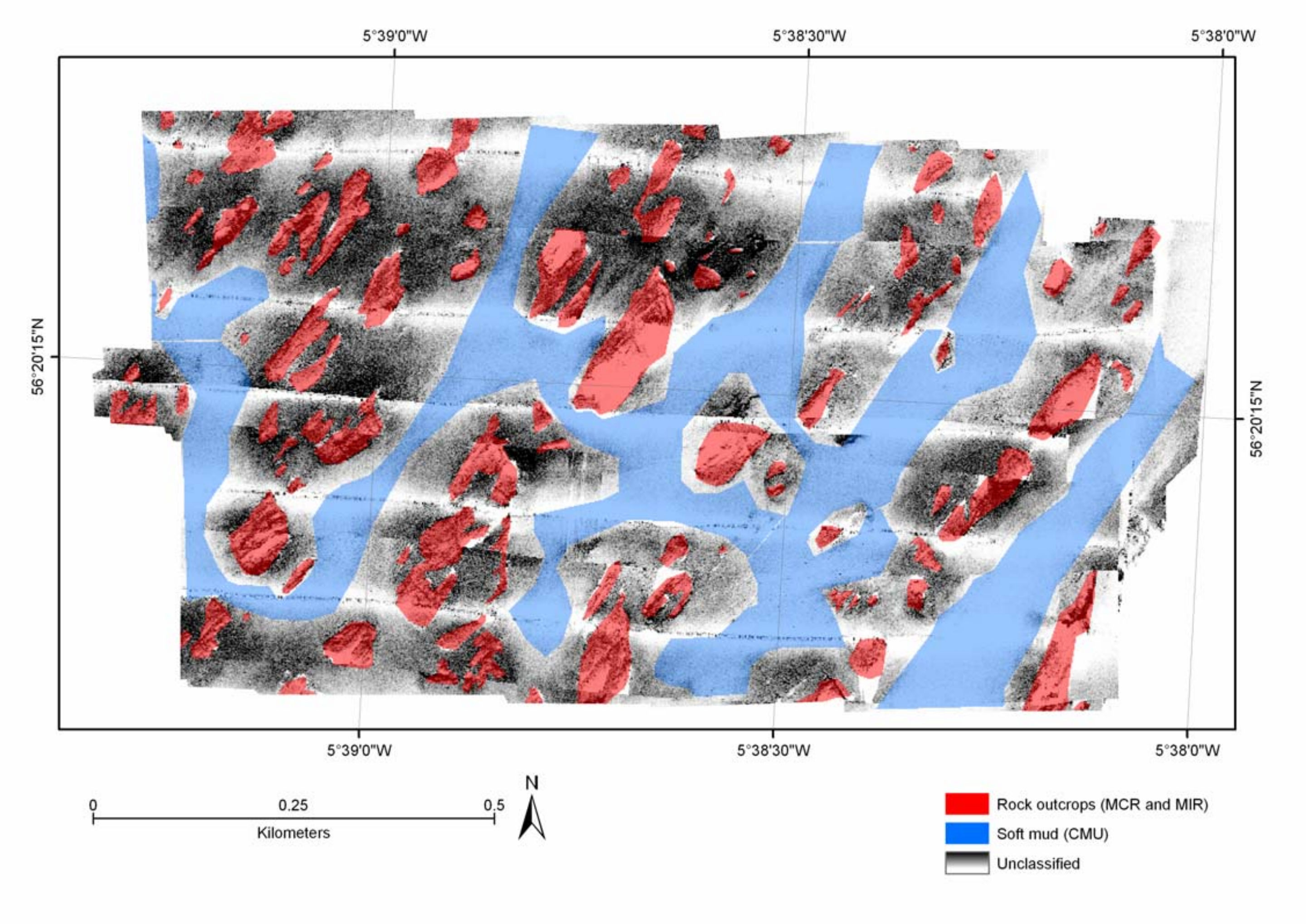
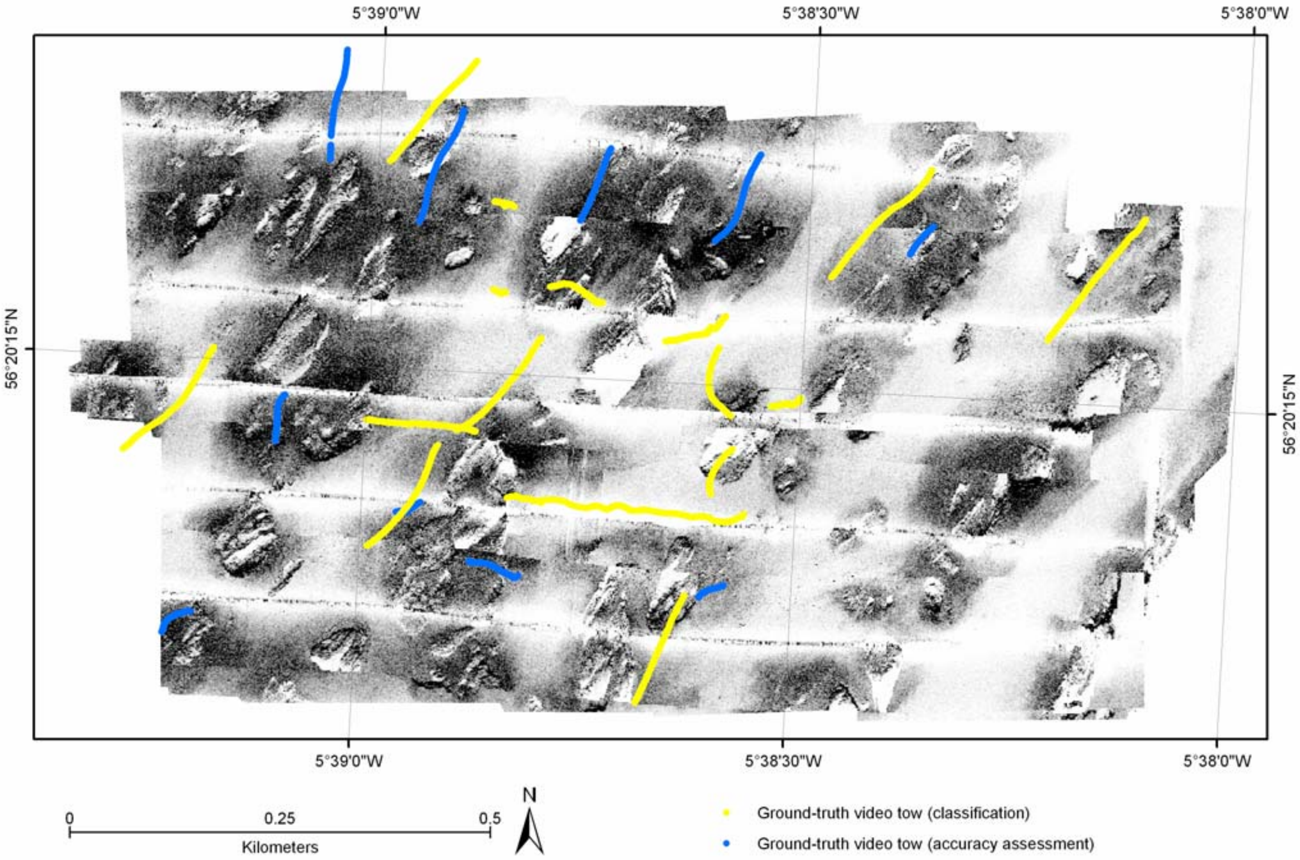


Figure 8. Video ground-truthing deployments overlaid on the sidescan sonar mosaic.



3.3 Data Processing

All data was processed using the same methodology, following the approach described by Foster-Smith and Sotheran (2003), Foster-Smith et al. (2001b) and referred to in the JNCC Marine Monitoring Handbook (Foster-Smith et al. 2001a). This approach is widely, although not universally, adopted in the UK to process AGDS data. Whilst it is recognised that other research groups in the UK, who were unable to attend the workshop, may adopt different approaches, it was felt that based on the expertise available amongst the WP it would be beneficial to use a single standardised data processing approach. This would eliminate the influence of data processing procedures on the final habitat maps, and allow comparisons to be made based on factors such as survey design, vessel speed, vessel type and system to be assessed. Unfortunately however, the limited experience in alternative data processing approaches amongst the WP meant that these guidelines and procedures could not be further refined during the course of the workshop. The following therefore describes the data processing methodology adopted for analysis of the four AGDS data sets collected as part of the workshop:

Preliminary data treatment:

Each RoxAnn data set was subjected to data filtering and exploration procedures. A spreadsheet macro was applied to each data set which highlighted spurious data points based on sequential depth changes of more than 1.5 meters. These data points were then examined in a GIS using a non-Earth plot (e.g. Datapoint ID as x axis and depth as y axis) and removed when the change was unlikely to be 'real' (i.e. There was not a steep slope that would account for such 1.5m changes in depth). The macro also produced an acoustic variability index value for each data point. This was generated by square-rooting the absolute value of the next data point minus the current data point for each of E1 and E2, then adding these together. This provides a measure of along-track data variability for E1 and E2, which was used in later analysis. Scatter plots of E1, E2 and depth were also produced to check for dependencies between variables, and checks were made for navigation jumps using the GIS package, *ArcGIS 8.3.* No tidal corrections were applied to the data as surveys took less than 1 hour and it was felt unnecessary for the purposes of the workshop, although this would be recommended as general practice.

Variograms were produced using the software package *Surfer* surface mapping system in order to establish the degree of spatial correlation within each of the data sets and to establish the maximum distance over which interpolation was deemed to be appropriate. The reader is referred to Foster-Smith and Sotheran (2003) for a detailed discussion on preliminary data treatment procedures.

Interpolation:

As many of the seabed maps produced for marine SACs in the UK are continuous coverage maps, and in order to conduct supervised classification procedures on the data sets, it was necessary to conduct interpolation procedures on each of the data sets. Interpolation parameters were established from the variogram analysis and the same parameters (search radius size, interpolation technique etc.) were applied to each data set:

Pixel size:	$10m^2$ (determined from acoustic footprint combined with size of survey area)
Interpolation technique:	Inverse Distance Weighting to a Power of 2
Search radius:	150m (to correspond to the smallest sill distance from the four data set variograms)

For each or the four RoxAnn data sets E1, E2, acoustic variability (see above) and depth were interpolated using *Surfer* to give full coverage of the survey area. The survey area dimensions were kept the same for each data set, however, it should be noted that some of the RoxAnn survey tracks were quite far from the edge of the survey area in some of the data sets and therefore ‘edge effects’ occur in the interpolated grids. The interpolated data grids were used in subsequent classification procedures. The reader is referred to Burroughs and McDonnell (1998) and Foster-Smith and Sotheran (2003) for a detailed discussion on interpolation procedures.

Classification:

All classification procedures were carried out using the software package *Idrisi*. Interpolated data grids from each of the four RoxAnn data sets were imported into *Idrisi* to be saved as raster images. These images were stretched such that each pixel in the image was assigned a value of between 0 and 256, based on the magnitude of the original data value. The raster images for each of E1, E2, acoustic variability and depth were combined in a collection for each of the data sets, which were used for supervised classification.

Supervised classification is a three-stage procedure and the following steps were followed:

a) ‘Training sites’ were determined for use in acoustic signature development (see stage b). This was done based on ground-truthing data, which was in this case 16 of the drop down video stations. From the video footage six distinct seabed classes (Life-forms) were identified based on the National Marine Habitat Classification for Britain and Ireland Version 03.02 (internet version – Connor et al 2003). These were:

1) Circalittoral gravel and sands (CGS)
2) Circalittoral gravel and sands with boulders (CGS.B)
3) Circalittoral muddy sand (CMS)
4) Circalittoral mud (CMU)
5) Moderately exposed circalittoral rock (MCR)
6) Moderately exposed infralittoral rock (MIR)

Training sites were digitised in a GIS around areas of each video tow where each life-form was recorded. A small buffer zone was included to ensure sufficient data was included within each life-form class.

b) The training sites were used to develop acoustic signatures for each RoxAnn data set within *Idrisi*, which calculates the mean and range for each of E1, E2, acoustic variability and depth for each seabed class. This was done within the software by overlaying of the training sites onto the appropriate raster images and recording the mean and range of pixel values beneath each training site and storing this data as signature files.

c) A pixel classification method was then applied to the collection of raster images for each data set. Maximum likelihood classification was chosen as the classification method as it is universally acclaimed as the most satisfactory method (Baily and Gatrell 1995, Wilkie and Finn 1996, Eastman 1999). The Maximum Likelihood classification is based on the probability density function associated with a particular training site signature (Clark Labs, 2002). The acoustic signatures are used to calculate the likelihood of pixel membership to each seabed category. For each of the four RoxAnn data sets this was done using the above training sites and using interpolated E1, E2, acoustic variability and depth data, resulting in each pixel being assigned to the category to which it most likely belonged. This was the final stage in map production for each of the four RoxAnn data sets and resulted in four seabed maps classified in to the six life-forms.

The final maps in *Idrisi* were converted to vector files which could be exported as ESRI shape files for incorporation into ArcMap 8.3 GIS.

Conclusions:

- The WP agreed that AGDS data analysis is a vast subject and many routes can be taken through the process of data interpretation. It was recognised that different research/survey teams within the UK adopt different approaches but unfortunately it was felt that there was insufficient breadth of experience amongst the research teams who attended the workshop to compare and contrast a range of approaches. It was agreed though that guidelines on this subject need to be flexible to accommodate the end needs of the biotope maps. The JNCC Marine Monitoring Handbook (Foster-Smith et al. 2001a) provides a ‘loose’ guide to this subject area, and in light of developing methodologies and ideas within this field it was felt by the WP that the guidelines as they stand are sufficiently detailed and allow a degree of flexibility.

- Whilst it was recognised by the WP that only one data processing approach was adopted, it was felt that under the limited time available during the workshop that adopting a single approach would be beneficial. It should be noted however that different data processing approaches will undoubtedly produce slightly different seabed habitat maps.

4. Comparison of biotope maps

Accuracy assessment:

On the whole the spatial pattern of the six life-forms presented in the four maximum likelihood maps (Figure 9) appear broadly similar, particularly the spatial patterns of the two rock life-forms (MCR and MIR) and the occurrence of the mud life-form (CMU). All four maps pick out the main regions of rocky reefs in similar areas of the survey site, and all indicate a roughly south-west to north-east orientation of features, particularly regions of muddy substrate.

Internal accuracy assessments were used to measure the match between ground validation data and the classified pixels (Table 2). This method shows a matrix of seabed classes (in this case life-forms) as identified at the ground-truth sample locations against the life-forms predicted from the AGDS data from the same location. This process was carried out using *Idrisi*, and the pixels within each ground-truthing buffer were compared with the same pixels from the classified maps. The highlighted diagonal cells within each matrix in Table 2 indicate an exact match between ground-truthing and map pixels. Comparing the exact match value with the row total provides an estimate of how accurately each life-form class was predicted, and which life-form classes were commonly confused (known as errors of commission). Similarly, comparing the exact match with the column total shows how many ground-truth pixels within each class fell within another mapped life-form class (known as errors of commission). The overall internal accuracy is calculated as the proportion of the sum of the diagonal values (exact match) against the total number of pixels (sum of column or row totals).

Internal accuracy assessments for the four RoxAnn data sets reveal a moderately high level of accuracy (Table 2). The map produced from the RoxAnn data set collected at 8 knots aboard RV Calanus showed the lowest overall internal accuracy (57%) which may be a consequence of fewer data points collected during the survey due to the higher survey speed. Overall internal accuracy values for the other three data sets were fairly consistent (68-69%). For all the data sets the circalittoral rock (MCR) and circalittoral mud (CMU) life-forms showed the highest internal accuracies. The infralittoral rock life-form (MIR) was regularly confused with the circalittoral rock (MCR) life-form, which is a likely consequence of similar acoustic properties between these two habitats. The remaining life-forms, which are likely to have acoustic signatures somewhere between the extremes of rock and mud and are likely to consist of varying proportions of soft and hard substrates, were regularly confused with each other. On the whole, the internal accuracy measures indicate that the classification process worked reasonably well.

Calanus N-S 4kts SAMS 100m

		Ground-truth data							
		CGS	CGS.B	CMS	CMU	MCR	MIR	Total	% Correct
Mapped units	CGS	48	18	7	5	4	0	82	59
	CGS.B	1	42	0	7	5	0	55	77
	CMS	11	19	67	46	1	0	144	47
	CMU	6	27	1	83	0	0	117	71
	MCR	3	14	0	1	108	0	126	86
	MIR	0	0	0	0	6	13	19	69
	Total	69	120	75	142	124	13	543	
	% Correct	70	35	90	59	87	100		**68%**

Calanus N-S 8kts SAMS 100m

		Ground-truth data							
		CGS	CGS.B	CMS	CMU	MCR	MIR	Total	% Correct
Mapped units	CGS	51	35	14	16	29	0	145	35
	CGS.B	3	26	0	11	11	0	51	51
	CMS	8	36	56	20	5	0	125	45
	CMU	2	6	0	95	2	0	105	91
	MCR	4	17	5	0	68	0	94	72
	MIR	1	0	0	0	9	13	23	57
	Total	69	120	75	142	124	13	543	
	% Correct	74	22	75	67	65	100		**57%**

Seol Mara E-W 6kts SAMS 70m

		Ground-truth data							
		CGS	CGS.B	CMS	CMU	MCR	MIR	Total	% Correct
Mapped units	CGS	35	21	5	20	1	0	82	43
	CGS.B	8	44	0	8	5	0	65	68
	CMS	18	31	66	11	0	0	126	52
	CMU	6	12	4	102	2	0	126	81
	MCR	2	12	0	1	111	0	126	88
	MIR	0	0	0	0	5	13	18	72
	Total	69	120	75	142	124	13	543	
	% Correct	51	37	88	72	90	100		**69%**

Seol Mara E-W 6kts STEN 70m

		Ground-truth data							
		CGS	CGS.B	CMS	CMU	MCR	MIR	Total	% Correct
Mapped units	CGS	26	9	6	5	1	0	47	65
	CGS.B	7	36	1	8	4	0	56	64
	CMS	24	26	57	7	1	0	115	50
	CMU	11	42	11	120	1	0	185	65
	MCR	1	7	0	2	116	0	126	92
	MIR	0	0	0	0	1	13	14	29
	Total	69	120	75	142	124	13	543	
	% Correct	38	30	76	85	35	100		**68%**

Table 2. Internal error matrices for the six life-forms for each of the four RoxAnn maximum likelihood maps.

In a similar way to the internal accuracy assessments, external accuracy assessments were also carried out on the four RoxAnn maps (Table 3). This method provides a more robust means of assessing accuracy. It uses similar comparisons as the internal accuracy assessment test but instead of using the ground-truth data used during the maximum likelihood classification process it compares the number of pixels of each life-form from a buffered external ground-truth data set (i.e. the ground-truth tows shown in blue in Figure 8 which were held back for the purpose of validation). As for the internal accuracy matrices the highlighted diagonal cells within each matrix in Table 3 indicate an exact match between ground-truthing and map pixels. Unfortunately the external ground-truthing video tows did not cover any of the infralittoral rock life-form (MIR) and therefore this class had to be removed from the analysis.

Overall accuracies were, not surprisingly, much lower than the internal accuracies. The poorest performance was from the data set collected aboard RV Calanus at 4 knots which showed an overall accuracy of just 20%. The other three maps performed slightly better with overall accuracies between 28-30% (Table 3). The circalittoral rock life-form (MCR) was often mistaken for the circalittoral gravely sand with boulders (CGS.B) life-form which can probably be explained as both these habitats consist of a relatively hard, acoustically reflective substrata which are likely to be confused during the classification process. The circalittoral mud life-form (CMU) was also commonly misclassified. It should be noted that the external ground-truthing data set was fairly modest in terms of coverage, and a fairer estimate of map accuracy would have been achieved if a larger external data set had been used. Nonetheless, the results highlight some of the problems associated with misclassification of similar biotopes.

The sidescan sonar data could only be divided with confidence into three acoustic classes (Figure 7: high reflectivity – classified as MCR/MIR; low reflectivity – classified as CMU; and intermediate backscatter values – left uncoloured in the figure). It is therefore not possible to map beyond the resolution of these three classes using this data, unless other parameters such as depth are also used to help refine the classification. External accuracy assessments on the interpretation of the sidescan sonar data set for the mud (CMU) and rock (MCR/MIR) life form classes revealed an overall accuracy measure of 55% (Table 4). This value is higher than the overall external accuracies for the RoxAnn maximum likelihood maps, but is still relatively low. It should be noted, however, that the sidescan interpretation is based

Calanus N-S 4kts SAMS 100m

		Ground-truth data						
		CGS	CGS.B	CMS	CMU	MCR	Total	% Correct
Mapped units	CGS	1	6	5	0	2	14	8%
	CGS.B	0	0	4	0	1	5	0%
	CMS	2	2	4	0	0	8	50%
	CMU	0	0	0	2	0	2	100%
	MCR	3	16	4	0	4	27	15%
	Total	6	24	17	2	7	56	
	% Correct	17%	0%	24%	100%	68%		**20%**

Calanus N-S 8kts SAMS 100m

		Ground-truth data						
		CGS	CGS.B	CMS	CMU	MCR	Total	% Correct
Mapped units	CGS	2	3	4	0	1	10	20%
	CGS.B	0	2	0	1	0	3	67%
	CMS	0	3	7	1	2	13	54%
	CMU	1	0	1	0	0	2	0%
	MCR	4	16	5	0	5	30	17%
	Total	7	24	17	2	8	58	
	% Correct	29%	8%	41%	0%			**28%**

Seol Mara E-W 6kts SAMS 70m

		Ground-truth data						
		CGS	CGS.B	CMS	CMU	MCR	Total	% Correct
Mapped units	CGS	2	7	6	0	2	17	12%
	CGS.B	3	6	4	0	0	13	46%
	CMS	0	0	5	2	2	9	66%
	CMU	0	0	1	0	0	1	0%
	MCR	2	11	1	0	4	18	22%
	Total	7	24	17	2	8	58	
	% Correct	29%	25%	30%	0%	50%		**30%**

Seol Mara E-W 6kts STEN 70m

		Ground-truth data						
		CGS	CGS.B	CMS	CMU	MCR	Total	% Correct
Mapped units	CGS	0	2	0	0	1	3	0%
	CGS.B	0	3	5	0	2	10	30%
	CMS	2	3	8	1	1	15	53%
	CMU	1	0	0	1	0	2	50%
	MCR	4	16	4	0	4	28	15%
	Total	7	24	17	2	8	59	
	% Correct	0%	13%	47%	50%	50%		**28%**

Table 3. External error matrices for the six life-forms for each of the four RoxAnn maximum likelihood maps.

solely on the backscatter mosaic and that no ground-truthing data was used to assist the interpretation. The production of seabed habitat maps based on sidescan sonar data would normally be produced through an iterative process using both backscatter and ground-truth information. It should also be noted that the mosaic was produced using an average layback value between the sidescan sonar fish and the vessel. This would introduce positional errors which would reduce external accuracy assessment. This could easily be rectified if a higher accuracy map were required by using the exact layback values along each sidescan sonar line, or by attaching a position fixing device to the fish. Nonetheless, this test does highlight the benefits of using swathe acoustic systems over single-beam systems, particularly for use in mapping discrete features (i.e. rock reefs) on the seabed.

	CMU	MCR/MIR	Total	% Correct
CMU	26	33	59	44
MCR	7	23	30	77
Total	33	56	89	
% Correct	79	41		**55%**

Table 4. External error matrix for the sidescan sonar interpreted habitat map (Figure 7) of the MCR and CMU life-form classes against all the video ground-truthing data (classification and external ground-truth video data sets).

The maps produced using maximum likelihood classification are predictive maps and a degree of confusion between classes which are likely to have similar acoustic properties should be expected. This raises the question as to whether it is possible to discriminate between the six life-forms acoustically, or whether classes should be merged into broader, acoustically distinctive groups for the purpose of mapping? This issue has been debated at length (Brown et al. 2002; Foster-Smith et al. 2001b; Foster-Smith and Sotheran 2003), and was discussed by the WP during the course of the workshop.

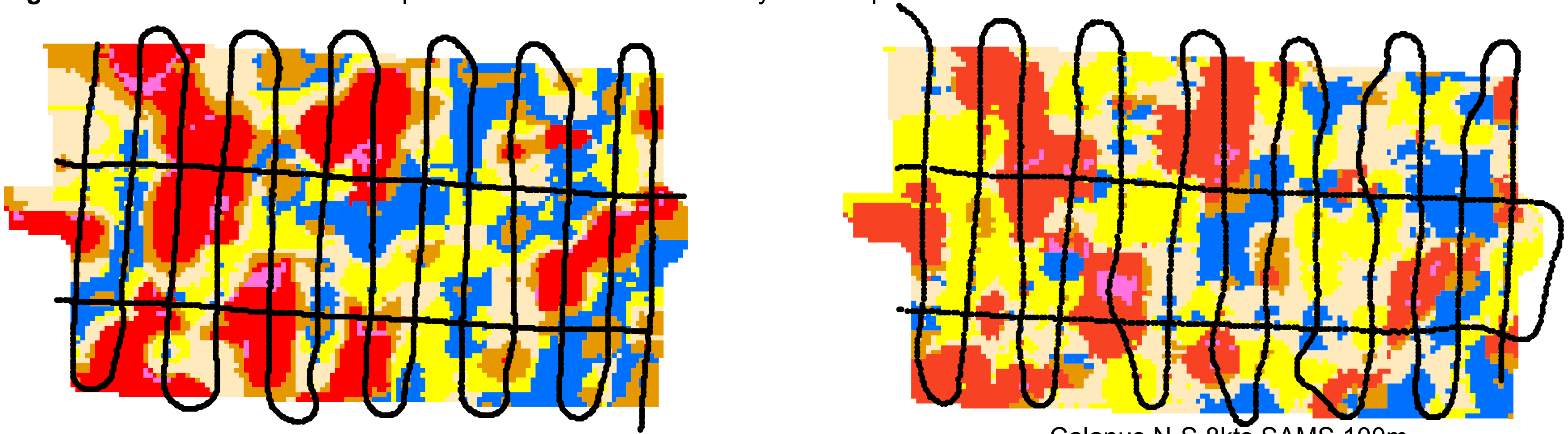
It would have been possible to sub-divide the ground-truthing video data into a larger number of visibly identifiable classes (the six life-forms could have been further divided into more detailed classes (i.e. biotopes) based on the National Marine Habitat Classification for Britain and Ireland Version 03.02, internet version – Connor et al 2003), and many maps produced for SACs attempt to do this. However, it is likely that this would have led to a greater degree of confusion and error between categories on the final habitat map. Within the six life-form classes in the current study there was confusion between a number of classes which probably had similar acoustic properties (e.g. MCR, MIR and CGS.B are all acoustically reflective habitats; CMU and CMS are likely to have similar, relatively low acoustic reflectance). The WP agreed that the process of classifying the ground-truth data was a crucial stage in the production of a seabed map, and it should be strongly noted that not every class identified from video data can be mapped using acoustic techniques. It should also be noted that the maximum likelihood classification technique requires a minimum number of pixels to be covered by training sites for each class in order to develop an adequate set of signatures, therefore if an identified ground-truthing class is too small in extent it cannot be mapped using this procedure.

It is paramount that there is a clear linkage between the classification units and the acoustic technique being used. It is highly likely that a number of visibly identifiable ‘units’ (whether they be life-forms, biotope complexes or biotopes) recorded using visual survey techniques will fall within a single acoustic map region, and that it will not be possible to map every visibly identifiable ‘unit’ using acoustic methods. Further research is needed to determine which habitats or communities can be mapped with a high degree of certainty when using an acoustic system (which may be largely hierarchy-independent). An appropriate classification scheme should then be developed for such broadscale mapping that can then be referred to the appropriate units in the National Marine Habitat Classification for Britain and Ireland.

Spatial comparison of habitat maps:

Comparisons were made on the frequency of occurrence of each life-form from each of the RoxAnn maximum likelihood maps, and of the CMU and MCR/MIR life-forms from the sidescan sonar interpretation (Figure 10). The percentage cover of each life-form was generally similar between the four RoxAnn maximum likelihood maps (usually between 5-10% of each other). Noticeable differences were a much lower occurrence of the CGS life-form on the RoxAnn map produced from the data collected aboard RV Seol Mara using the Stenmar-hired RoxAnn system, and the CGS.B life-form from the data set collected aboard RV Calanus running at 8 knots. Comparison of the sidescan sonar and RoxAnn maps revealed that the RoxAnn data sets consistently had lower occurrences of the muddy habitat CMU and higher occurrences of the rocky reef habitats MCR and MIR than interpreted from the sidescan sonar data.

Figure 9. Maximum Likelihood maps from the four RoxAnn surveys. Track plots are overlaid in black.



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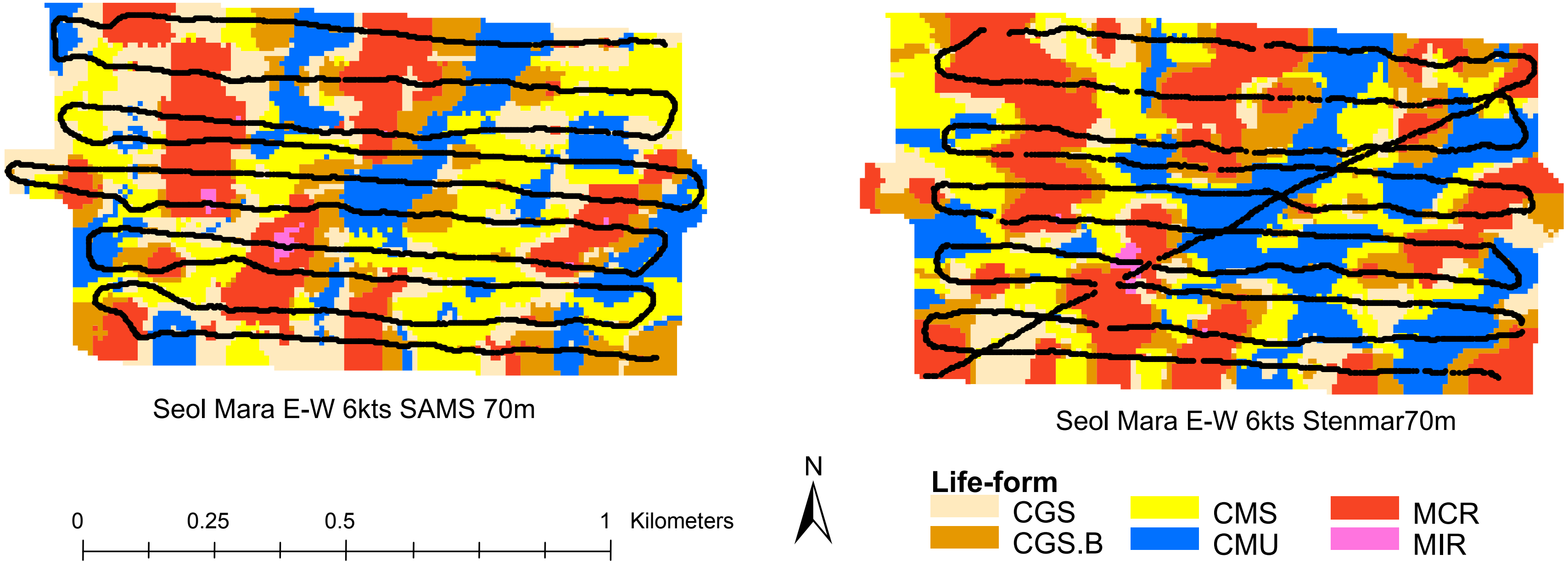


Seol Mara E-W 6kts SAMS 70m

Seol Mara E-W 6kts Stenmar70m

In addition, the spatial distribution of the six life-forms were compared between each of the RoxAnn maximum likelihood maps. A pixel-by-pixel comparison was conducted using cross-tabulation methods in *Idrisi*. Pair-wise comparisons of each of the maps were performed and then an overall comparison was made between all four maps (Figure 11). Agreement between pair-wise comparisons ranged from 39-43%. A number of regions of rock (MCR) and mud (CMU) appeared to be consistently mapped between surveys. The overall comparison between the four maps revealed 16% agreement. Despite such low values the general pattern of distribution of life-forms was similar, and it should be noted pixel-by-pixel comparisons often hide general spatial trends which can be detected by eye. Additionally, as mentioned in section 3.3, due to the different survey track extents between data sets the edge of the interpolated area was in some instances quite far from any ‘real’ datapoints, which increases their likelihood of misclassification.

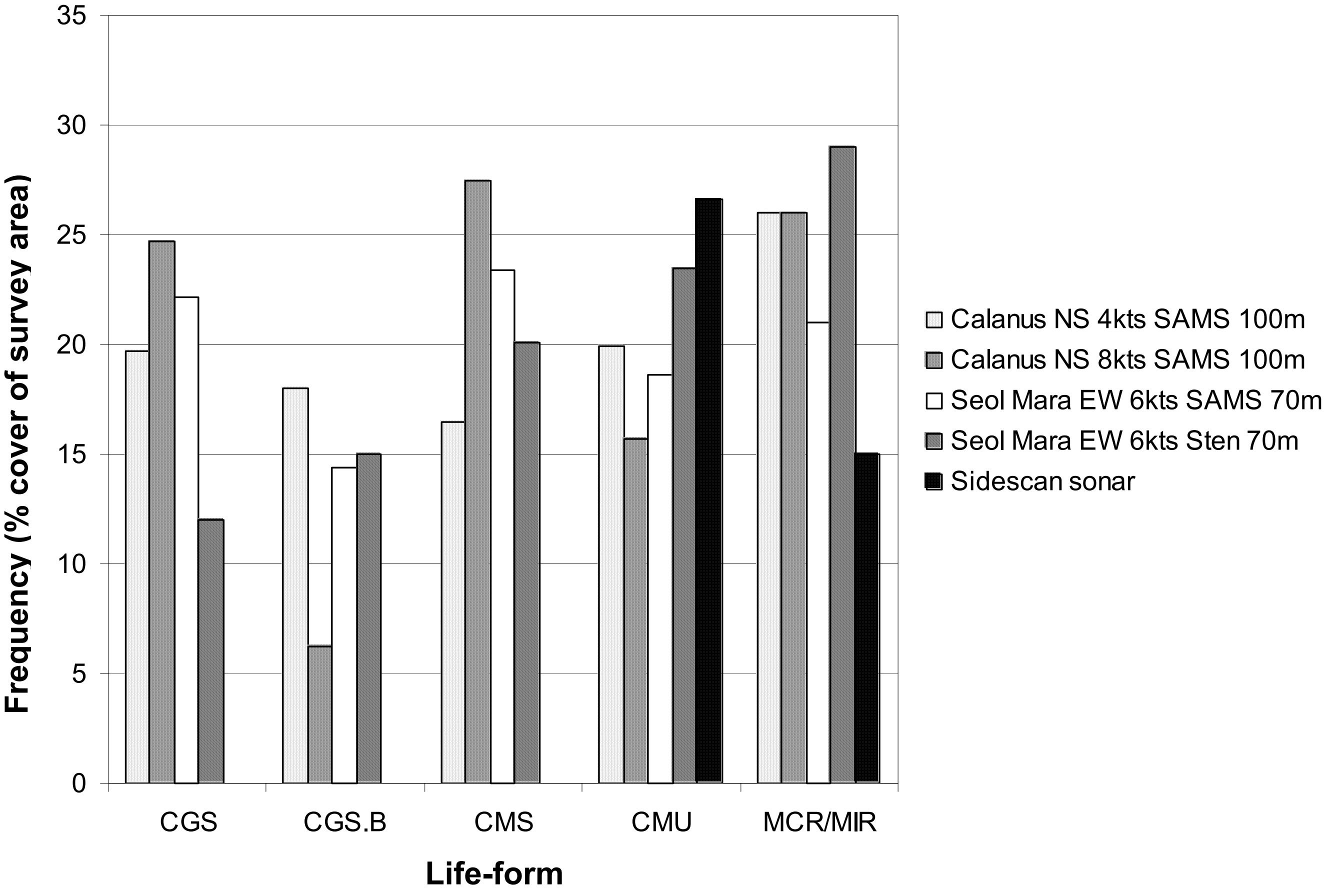


Figure 10. Frequency of each life-form on the four RoxAnn maximum likelihood maps and on the sidescan sonar interpretation.

A final test was also carried out to compare the mud (CMU) and rocky reef (MCR/MIR) life-forms between the sidescan sonar interpreted map and the four RoxAnn maps. As above, a pixel-by-pixel comparison was conducted using cross-tabulation methods in *Idrisi*, and each of the RoxAnn maps was compared to the sidescan sonar interpretation (Figure 12). White regions represent life-forms other than the CMU or MCR/MIR classes in the case of the RoxAnn maps, or unclassified intermediate backscatter values in the case of the sidescan sonar interpretation. Black areas show regions of disagreement between the sidescan sonar interpretation and each RoxAnn maps for the mud (CMU) and rocky reef (MCR/MIR) life-form areas. Levels of agreement between MCR/MIR and CMU regions on the sidescan sonar map with those same regions on each of the RoxAnn maps ranged from 28-43%. The RoxAnn map produced from the data collected aboard RV Seol Mara using the Stenmar hired RoxAnn system showed the highest agreement with the sidescan sonar interpretation (43%). The RoxAnn maps consistently predicted higher frequency of the MCR/MIR file-forms and lower frequencies of the CMU life form compared to the sidescan sonar map.

Figure 11. Comparison of RoxAnn maximum likelihood maps showing regions classified the same between data sets.

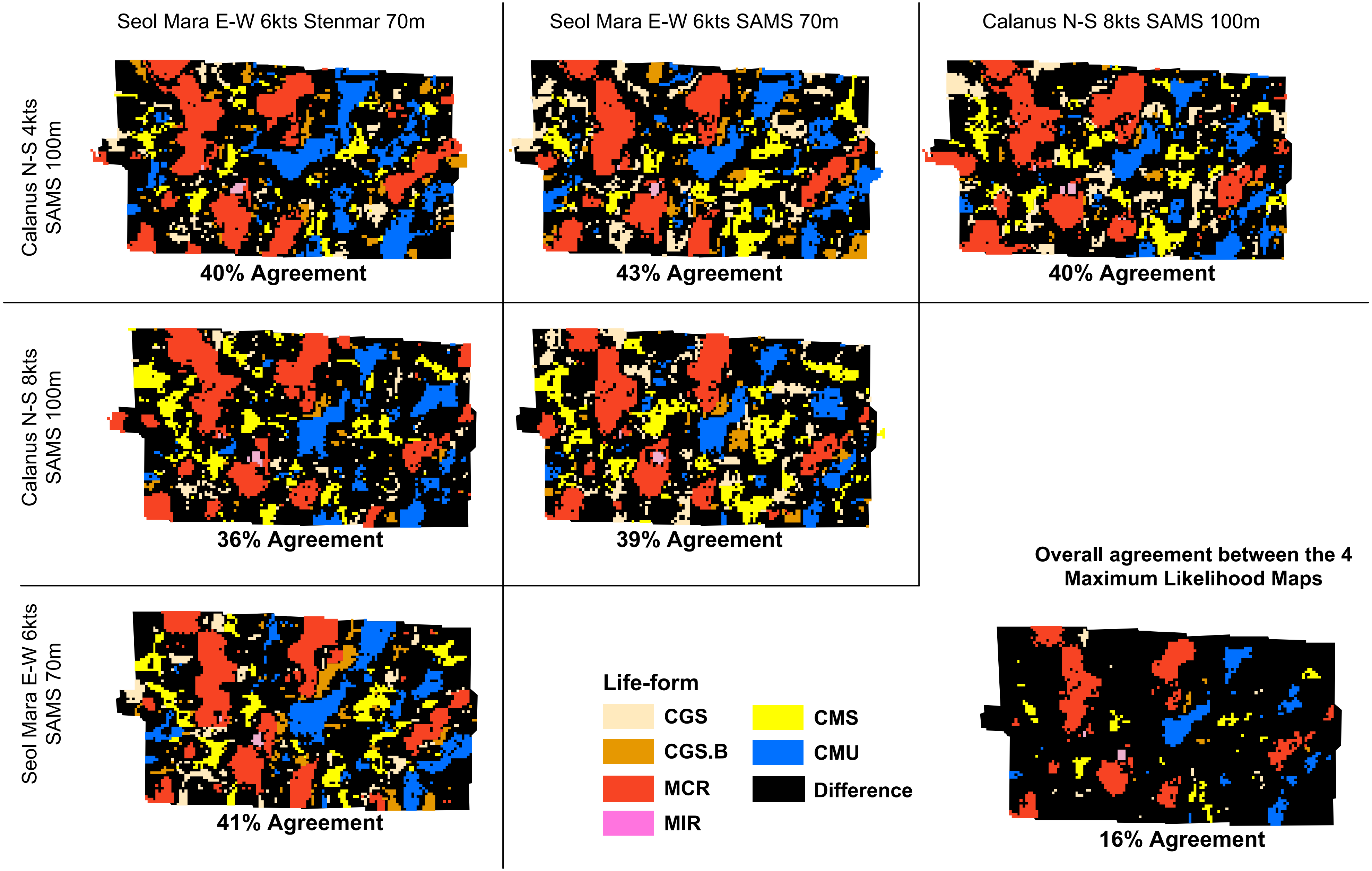
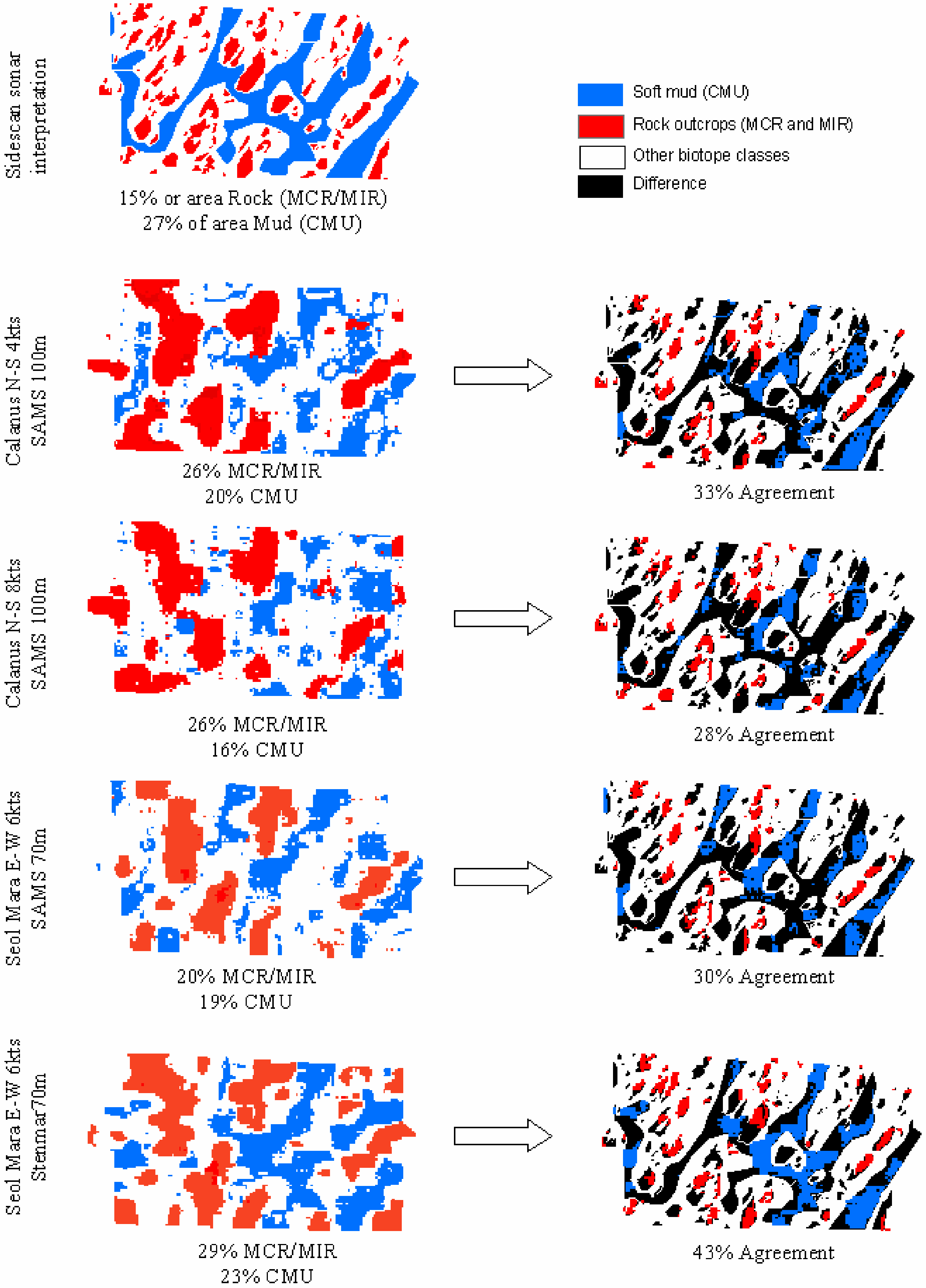


Figure 12. Comparison of RoxAnn maximum likelihood rock (MCR and MIR) and mud (CMU) classes against the sidescan sonar interpretation.



15% or area Rock (MCR/MIR)
27% of area Mud (CMU)

26% MCR/MIR
20% CMU

33% Agreement

26% MCR/MIR
16% CMU

28% Agreement

20% MCR/MIR
19% CMU

30% Agreement

29% MCR/MIR
23% CMU

43% Agreement

5. Discussion and Conclusions

Surveys of marine areas of conservation or scientific interest using AGDS systems provide a method for broad-scale predictive assessment of seabed characteristics and habitats. The very nature of AGDS systems, using single beam technology, will always mean that interpolation methods will be necessary if continuous coverage maps are required. This will undoubtedly lead to poor discrimination of small-scale features and a degree of miss-classification for the following reasons:

- Values in the un-surveyed regions between survey lines are estimates based on the real data within each survey line. It should be noted that survey track spacing should be adjusted relative to the scale of heterogeneity in the survey area, such that there is less weight upon interpolated data when acoustic signatures are developed.

- There will be a degree of averaging across the echo-sounder footprint, and this itself will lead to poor discrimination where very heterogeneous seabeds are encountered. Additionally, as depth increases so too does the area of the echo-sounder footprint, such that it may span more than one habitat and thus be unable to discriminate between them.

- In regions where there is a large depth range, it is difficult to decide upon the appropriate transducer frequency and beam angle. This can result in problems of depth dependency in the acoustic data which can prove problematic for acoustic signature development where life-forms occur throughout a range of depths.

However, habitat maps produced solely by AGDS provide valuable information relating to broad-scale predictive distributions of habitats and relative abundances of each habitat class within an area. It is crucial that environmental managers using the final habitat maps understand the limitations of the survey techniques, and that they have information relating to how the surveys were conducted (e.g. line-spacing, number of ground-truthing stations etc.) and the processes by which the maps were produced (e.g. interpolation parameters, classification techniques etc.) if the maps are to be used in a responsible and appropriate manner.

The current study compared four maps produced using data from four separate surveys. Survey parameters varied slightly between each of the data sets (e.g. survey vessel, RoxAnn system, survey speed, survey design). Nonetheless the final habitat maps were all broadly similar. Predicted percentage cover of each of the six life-form classes identified in the survey area showed similar levels of each life-form between the four maps (Figure 10). This measure is useful when assessing how common or rare a particular map unit (i.e. habitat/life-form/biotope) is within a region, and can be a useful measure when making decisions regarding conservation issues relating to particular habitats. Predicted spatial patterns of habitats were broadly similar when comparing each map with each other (approximately 40% agreement), although overall agreement between all four maps was low (16%) (Figure 11). If accurate discrimination of boundaries between habitats is not a crucial requirement of a continuous coverage map then the four maximum likelihood maps produced in this study are probably adequate for management purposes. However, if the end use of the habitat map demands a high degree of accuracy in relation to habitat boundaries and discrete seabed features then AGDS is probably not an appropriate tool for map production and other techniques (i.e. swathe acoustic systems) should be used instead.

Concerns were raised during the open-session of the workshop that the study area was too small and too heterogeneous to make a fair assessment of the ability of AGDS to map seabed habitats. Signature development involves the incorporation of a small buffer around the ground-truth sample positions that are used to extract acoustic data which are assumed to be associated with the habitat class identified from the field record. The resulting acoustic signature may include data that are unlikely to be associated with a particular habitat class and will inevitably lead to signature overlap between habitat classes. This is particularly problematic in regions where the seafloor is very heterogeneous, where different habitat classes lie close together (e.g. either side of a biotope boundary), where large buffers are used, or where ground-truthing samples are not located near any real acoustic data. In the current study buffers were kept as small as possible and ground-truthing samples were targeted on top of AGDS survey lines. Care was also taken when creating the buffers so that as little overlap as possible occurred near the boundaries between life-form classes.

Foster-Smith et al (2000) estimates the footprint size of a standard AGDS system to be in the region of 13 m wide by 20 m long for a vessel working in 10 m of water at a speed of 10 km/h with a dGPS error of 10 m and a beam angle of the AGDS transducer of 15^o. All of these survey parameters are similar to those used in the workshop study, and therefore a similar foot print size can be assumed for each of the four RoxAnn surveys, although it should be noted that footprint size will increase as water depths become greater. The distinctive seabed features identified by the sidescan sonar survey (i.e. rocky reefs, regions of soft mud) were usually no less than around 100 m in dimension. Therefore, whilst the seabed within the study area was relatively heterogeneous, the degree of heterogeneity was greater than the footprint size and equal to or greater than the survey track spacing and was thus within the ability of the AGDS to discriminate. Variogram analysis also indicated that interpolation at this scale, assessed using along track variability which also gives an indication of seabed heterogeneity, was possible as stated in the JNCC Marine Monitoring Handbook (Foster-Smith et al. 2001a). Whilst the study site is undoubtedly a challenging area to map, it was felt that the trials were a fair test of the system, and that the area was representative of the high degree of seabed heterogeneity often associated with marine SACs.

Although the aim of the workshop was not to compare the ability of AGDS and sidescan sonar for mapping seabed habitats, comparison of the maps produced using these two systems did prove interesting. The sidescan sonar data was interpreted by eye, and whilst there are developing software packages designed to automate this process, this is by far the most common and accurate method of interpretation at this moment in time. Using this approach three acoustically distinct regions could be confidently identified (Figure 7). In contrast the AGDS data was classified using the video ground-truthing data which was categorised into six life-forms. This ground-truthing data was used to guide the classification process and resulted in the four maximum likelihood maps that contained a degree of disagreement between each other with respect to the spatial distribution of the six life-forms. This raises the question as to the resolution to which benthic habitats can be accurately mapped based on acoustic data.

The decision to use six life-form categories was based on the information derived from the video data. However, whilst six life forms could be distinguished visually this may not have been the case acoustically. In the current study only three acoustically distinct habitats could be mapped when using the sidescan sonar. Within some of these regions there were likely to be several different life-forms (and probably a larger number of biotopes) which could be identified using visual techniques. It is important to realise that it not possible to map every visually identifiable class and that continuous coverage maps can only be produced based on the classes, or combination of classes, which can be acoustically distinguished. It would therefore seem better to map at a coarser resolution with a greater degree of spatial accuracy whilst recognising that within each acoustic region there are a number of higher resolution (visually identifiable) classes or ground-types. To monitor and assess abundances and spatial extent of these higher resolution classes' techniques other than acoustics (e.g. video, diver or grab sampling) should be used.

Several advantages of swathe systems compared to AGDS, when continuous coverage maps are required, are clearly demonstrated from the outputs of the workshop. The very nature of AGDS and the many routes through which the data can be processed means that continuous coverage maps produced using different processing methodology and survey approaches will differ slightly from each other. Swathe systems are also not without their limitations and problems. Although not tested during the current workshop, sidescan sonar interpretation of the same area conducted independently by two or more skilled individuals will likely result in slightly different habitat maps as the positioning or habitat boundaries is based on subjective analysis by eye. However, unlike AGDS, carefully designed swathe surveys will give data for every area of the survey site which will remove some of the uncertainty encountered when using AGDS. Features which may be of conservation importance, such as reefs, can easily be missed during the interpolation process when using AGDS if they lie between the tracks. When using swathe acoustic techniques this risk is minimized. The ability of AGDS to discriminate at a higher resolution than swathe systems should not be underestimated though. A number of research and survey teams are now moving towards the complementary use of AGDS and swathe systems when producing continuous coverage maps. With this approach the AGDS data is not interpolated, but instead the track data is classified and overlain on the swathe mosaic to assist interpretation of the backscatter. This is a much more robust approach which utilises the strengths of each system by using the two techniques in a complementary manner.

It should also be acknowledged that maps produced by AGDS are very often subject to more critical appraisal than output generated from more traditional methods such as diver and other spot sampling techniques. Whilst there are limitations and drawbacks to using AGDS for continuous coverage mapping, this approach still offers advantages for this application over the use of conventional methods used alone.

6. Recommendations

- The JNCC Marine Monitoring Handbook (Foster-Smith et al. 2001a) is, on the whole, comprehensive and sufficiently detailed for the purpose of AGDS surveys in marine SACs or other regions of conservation interest. A degree of flexibility needs to be retained to allow for informed decision making by the surveyor as conditions and requirements are often very different between survey sites.

- The need to ensure high levels of positional accuracy when collecting both AGDS data and ground-truthing data should be strengthened within the JNCC Marine Monitoring Handbook guidelines, particularly when using towed or drop down video systems in relatively deep water.

- Whilst it is not possible to be prescriptive as to the minimum number of ground-truthing data points collected during a survey as this is greatly affected by the degree of homogeneity of the seabed and can vary dramatically from one survey area to the next, it should be highlighted within the JNCC Marine Monitoring Handbook guidelines that increasing the number of ground-truthing stations will strengthen accuracy of the final habitat map and improve the ability to assess the accuracy of such maps.

- AGDS data analysis is a vast subject and many routes can be taken through the process of data interpretation. Different research/survey teams within the UK adopt different approaches and there was insufficient breadth of experience amongst the research teams who participated in the current workshop to compare and contrast a range of approaches. The JNCC Marine Monitoring Handbook (Foster-Smith et al. 2001a) provides a outline to this subject area, and in light of developing methodologies and ideas within this field the guidelines as they stand are sufficiently detailed and allow for a degree of flexibility.

- AGDS systems should not be the only system used when accurate mapping of seabed features is required. Swathe systems are recommended for such applications when a high degree of precision is required for mapping distinct seabed features or boundaries between different acoustically distinct habitats. In such situations AGDS can be used as a complementary system, and can usually be operated along side swathe systems to provide valuable additional data which can often help when interpreting the swathe acoustic data.

- When mapping seabed habitats using acoustic techniques it is crucial that the resolution of the map is linked to what can be discriminated acoustically.

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