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Acoustic seabed survey techniques for monitoring Marine SACs: a trial of three systems

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Acoustic seabed survey techniques for monitoring marine SACs: a trial of three systems

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Summary

Three acoustic seabed mapping systems were trialed in Plymouth Sound to determine their effectiveness in identifying and spatially discriminating marine benthic biotopes. The three systems were, i. a dual frequency sidescan sonar (*EG&G 272*), ii. a swath-sounding interferometer (*Submetrix 2000*) and, iii. a normal beam acoustic ground discrimination system (AGDS, *RoxAnn*).

The study established a calibration area that was surveyed by each system on more than one occasion. In comparing the data sets:

- it may be concluded that no single system tested offers the ability to reliably map the full range of biotope complexes with the accuracy or resolution required for monitoring purposes;
- the classified bathymetric data was the most spatially ‘consistent’ data obtained, but the data does not easily lend itself to habitat complex classification;
- the AGDS was able to discriminate and identify the greatest number of habitat and biotope complexes, but their spatial extent was subject to significant variation between surveys;
- the sidescan sonar provided the highest resolution data of seabed features, but the sonograph required careful interpretation in order to produce a classified map of habitat complexes;
- of the systems trialed the most appropriate (cost/effective) method for broad-scale seabed habitat mapping is a combination of the sidescan sonar (providing information on habitat complexes) and swath-sounding interferometer (providing quantitative bathymetric data);
- within habitat complex features defined by the swath systems the application of AGDS would appear to offer the most effective means of mapping more subtle variations associated with biotope complexes.

The principal recommendation of the study is that in order to establish the true cost-effectiveness of each system (or any combination of systems) in monitoring marine biotopes (biodiversity), it is essential that an area of seabed is accurately mapped in terms of its habitat and associated biological community (epifauna and infauna). This may be achieved by selecting a 500 m by 500 m calibration box (as in the present study) and intensively ground truthing the area with underwater video cameras, SCUBA and grab sampling techniques. Whilst some ground truth sampling was undertaken in the present study it was insufficient to fully define the extent of biological variation within the calibration box. Ultimately there is a need to quantify the extent to which the acoustic mapping systems underestimate the biological variation within any acoustically recognisable habitat and that this should be the primary objective of any future study. The present study achieves the first step toward achieving this objective by quantifying the ability and repeatability of acoustic systems to detect habitat features.

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1. Introduction

The UK Marine SAC's project, funded under the EC LIFE programme, aims to develop demonstration schemes of management on 12 marine Special Areas of Conservation (SAC), one of which is the Plymouth Sound Estuaries cSAC. One task of the LIFE project is trialing different techniques for monitoring, and investigating their value in developing monitoring programmes to report on the condition of designated seabed habitat features.

1.1 Aims

The project aims are to:

evaluate the ability of different acoustic techniques to consistently discriminate between sublittoral habitats;

assess the repeatability of different acoustic mapping techniques;

estimate the cost/benefits of such techniques, and;

determine points of good practice and quality assurance to inform relevant procedural guidelines in the UK marine SAC's project monitoring handbook.

Of the many sonar devices that are currently available on the market for seabed mapping purposes it is possible to broadly classify them into one of four categories, namely; i. broad-acoustic beam (swath) systems such as sidescan sonars used for seabed mapping and geophysical surveys, ii. ground discriminating single beam echo-sounders (AGDS) such as RoxAnn and QTC-View, predominantly used for seabed sediment discrimination, iii. multiple narrow-beam swath bathymetric systems which have been used to generate high resolution topographical images of the seabed and, iv. multiple beam (interferometric) sidescan sonar systems.

1.2 Sidescan sonar

Sidescan sonar has been defined as an acoustic imaging device used to provide wide-area, high resolution pictures of the seabed. The system typically consists of an underwater transducer connected via a cable to a shipboard recording device. In basic operation, the side scan sonar recorder charges capacitors in the tow fish through the cable. On command from the recorder the stored power is discharged through the transducers which in turn emit the acoustic signal. The emitting lobe of sonar energy (narrow in azimuth) has a beam geometry that insonifies a wide swath of the seabed particularly when operated at relatively low frequencies e.g. < 100 kHz. Then over a very short period of time (from a few milliseconds up to one second) the returning echoes from the seafloor are received by the transducers, amplified on a time varied gain curve and then transmitted up to the recording unit. Most of the technological advances in side scan sonar relate to the control of the phase and amplitude of the emitting sonar signal and in the precise control of the time varied gain applied to the return signals. The recorder further processes these signals, in the case of a non-digital transducer it will convert the analogue signal in to digital format, calculates the proper position for each signal in the final record (pixel by pixel) and then prints these echoes on electro-sensitive or thermal paper one scan, or line at a time.

Modern high (dual) frequency digital sidescan sonar devices offer very high resolution images of the seabed that can detect objects in the order of tens of centimetres at a range of up to 100 m either side of the tow fish (total swath width 200 m), although the precise accuracy will depend on a number of factors. For example, the horizontal range between the transducer and the seabed is affected by the frequency of the signal and the grazing-angle of the signal to the bed which is itself determined by the altitude of the transducer above the sea floor. Some typical limits associated with sidescan sonar are as follows; operating at 117 kHz under optimal seabed conditions and altitude above the bed, a range of 300 m (600 m swath) can be obtained and typically 150 m at a frequency of 234 kHz. Accuracy, increases with decreasing range, for example, 0.1 m accuracy is typically obtained with a range of 50 m (100 m swath) where as ‘only’ 0.3 m accuracy is obtained at a range of 150 m.

A major advantage of sidescan sonar is that under optimal conditions it can generate an almost photo-realistic picture of the seabed. Once several swaths have been mosaiced, geological and sedimentological features are easily recognisable and their interpretation provides a valuable qualitative insight into the dynamics of the seabed. However, the quality (or amplitude) of the data is variable, for example the grey-scale (signal amplitude) between swaths covering the same area of seabed is often noticeably different. The variation in signal amplitude for the same area or type of seabed causes problems when trying to classify the sonograph, since ground truth samples (grabs and underwater cameras) may reveal the seabed to be the same but the sonograph indicates differences. Sidescan does not normally produce bathymetric data. However, sidescan sonar provides information on sediment texture, topography, bedforms and other discrete objects.

1.3 Swath-sounding interferometry

A swath-sounding system is one that is used to measure the depth to sea floor and amplitude of sonar return from the sea floor in a line extending outwards from the sonar transducer at right angles to the direction of motion of the sonar. As the sonar platform moves forwards, a profile of sweeps is defined as a ribbon-shaped surface of depth measurements known as a swath. The swath-sounding technique uses the phase content of the sonar signal to measure the angle of a wave front returned from the sonar target.

The term ‘interferometry’ is generally used to describe swath-sounding sonar techniques that use the phase content of the sonar signal to measure the angle of a wave front from a sonar target. This technique may be contrasted with the ‘multibeam’ set of sonars which generate a set of receive beams, and look for an amplitude peak on each beam in order to detect the sea-bed across the swath.

The sonar signal is narrow in azimuth (that is, viewed from above), and wide in elevation (viewed from the side) thus producing a small ensonified patch on the sea floor as the sound wave moves out from the transducers. The ensonified patch scatters sound energy in all directions. When this scattered sound is detected back at the transducers, the angle it makes with the transducer is measured. The range is calculated from the travel time there-and-back and the range and angle pair enable the location of the ensonified seabed patch to be known relative to the sonar transducer.

In addition to the location, the amplitude of the returned signal can be measured and compared with the source signal giving a measure of the loss in signal to the water column and the amount of scatter or reflectance from the sea floor. The amount of signal loss due to sea floor conditions has been used to discriminate different types of sea floor such as different sediment types and biological features.

The Submetrix System 2000 produces a swath width of approximately 15 times water depth in most conditions and measures thousands of depths every ping, across the swath. The result of this is a full coverage map of the sea floor with outputs including 3D bathymetric views and mosaic amplitude images similar to a sidescan sonar.

1.4 Acoustic ground discrimination systems

The operation of the AGDS system is described fully in other publications and reports (Foster-Smith *et al.*, 1997). However, normal incidence single beam echo-sounders may be used to obtain a variety of information about the reflective characteristics of the seabed. They send a pulse of sound at a particular frequency (usually between 30 kHz and 200 kHz) that reflects from the seabed and the echo is picked up by the transducer. RoxAnn is an AGDS that has been most frequently used for environmental studies round the UK. The system uses echo-integration methodology to derive values for an electronically gated tail part of the first return echo (E1) and the whole of the first multiple return echo (E2). While E2 is primarily a function of the gross reflectivity of the sediment and therefore hardness, E1 is influenced by the small to meso-scale backscatter from the seabed and is used to describe the roughness of the bottom. By plotting E1 against E2 various acoustically different seabed types can be discriminated. With appropriate ground truth calibration, acoustic discrimination systems can be remarkably effective at showing where changes in seabed characteristics occur. However, great caution should be exercised in trying to directly compare readings taken on different surveys as it is often very difficult to be sure that the sounder is delivering the same power level into the water column, especially when there may be intervals of months or years between the surveys.

Although AGDS is relatively simple to use, the output requires considerable interpolation in order to generate a broad scale map of the seabed with 100 % coverage. In addition the area insonified by the echo-sounder directly under the vessel depends on the beam angle and depth of the seabed. For example, an echo sounder with a beam angle of 15° with a depth under the boat of 30 m would insonify an area with a radius of about 7 m. This limits the ability of the system to discriminate small features accurately. For example, a 7 m swath of the seabed that is composed of sand with 1 or two cobbles would have a different E1/E2 value compared to an adjacent 7 m swath of sand with say 5 or 6 cobbles. However, the habitat in both cases would be the same, that is a sandy bottom with cobbles.

2. Survey methods and implementation

A seabed mapping survey was conducted in Plymouth Sound for English Nature using three acoustic systems, namely; i. a dual frequency sidescan sonar (EG&G 272) operated by Emu Environmental Ltd, ii. a swath-sounding sonar (Submetrix System 2000) operated by Sedimentary Systems Research Group, University of St Andrews and an engineer from

Submetrix Ltd and iii. a normal beam Acoustic Ground Discrimination System (AGDS, RoxAnn) operated by SeaMap Ltd., University of Newcastle. The field survey was conducted between 18 and 26 January 2000, aboard the survey vessel 'Mariner' owned and operated by Emu Environmental, and a full set of survey log-sheets is provided in Appendix A.

In order to meet the project aims, two areas were identified for mapping, namely; i. a relatively large area (measuring about 19 km^2) of seabed taking the shape of a T as shown in Figure 1, and ii. a much smaller area measuring about 500 m 500 m which was designated as the survey calibration box (Figure 1). The objective of establishing survey area i. was to allow the individual systems to be compared in terms of their relative ability to discriminate or classify benthic biotopes and this is reported in Section 3.2, whereas the objective of ii. was to allow the repeatability of each system to be compared and this is reported in Section 3.3.

At the beginning and end of each day (conditions permitting) a calibration box was surveyed on a 25 m line spacing running east - west and then north - south, to provide a snap-shot in time of the seabed features within the calibration box. A summary table of the total area and calibration box survey activities are presented in Tables 1 and 2. Each (snap-shot) survey of the calibration box were analysed and interpreted separately. The entire area was surveyed by each of the systems over a number of days and all the results for each system were mosaiced to generate one map which were then analysed.

2.1 Position fixing and navigation

The Navigation System used was a Leica 530 real time Kinematic Global Positioning System (RTK GPS) comprising of:

- reference station consisting of GPS processor and radio transmitter;
- mobile unit consisting of GPS processor and radio receiver.

The operating principle of the system is to provide enhanced accuracy GPS positions. Raw position from a GPS, at the time of the survey, can only be guaranteed to an accuracy of between 50 m and 100 m. This can be significantly improved by providing a correction to the satellite signals based on errors observed at a point of known position. The errors that are observed are calculated on a correction of the phase of the satellite signal containing the positioning message to force the position solution to that of the known position of the reference station. The corrections can then be broadcast via a radio link to a mobile unit, which will incorporate these corrections into its position calculation.

In the case of RTK GPS the phase corrections that are broadcast give a reported operational accuracy of 0.02 m in the horizontal plane and 0.04 m in the vertical plane.

2.1.1 Survey Datums

The mapping reference frame for the survey was the UK National Grid (OSGB36). The RTK GPS works on the World Geodetic System (WGS84) ellipsoid and transformation parameters from WGS84 to OSGB36 have to be established or standard parameters used in order to fix the position in correct space.

A control survey was conducted to establish a reference station position at a location with radio visibility throughout the survey area.

The point selected was at Fort Bovisand Underwater Centre (SX4850) as this provided both logistical advantages and met the requirements for radio transmission.

The co-ordinates of the reference station were established by calculating baseline lengths between the point and Ordnance Survey trigonometric pillars. The raw GPS satellite data was logged simultaneously at each ‘trig pillar’ and the reference station. From this data baseline lengths were calculated with an accuracy of ± 0.02 m. By adjusting the baseline network and referring it to the ‘trig pillar’ OSGB36 co-ordinates the co-ordinates for each survey point in OSGB36 were derived. In the network adjustment the transformation parameters from WGS84 to OSGB36 were calculated. They were then applied in the navigation package for online survey operations.

A vertical reference plane was established for the processing of the Submetrix and RoxAnn systems which measured bathymetry. All heights for the survey were referred to Ordnance Datum Newlyn (ODN). A water level gauge was deployed in the vicinity of the breakwater fort in Plymouth Sound at location E 247 221; N 050 467.

Tide data was also acquired from the Admiralty tide gauge located at No.1 jetty Devonport dockyard.

The data from the admiralty was issued in Chart Datum. A standard shift of –3.22 m was applied to give tide heights corrected to ODN.

2.2.2 On-board positioning

Horizontal positions were derived on the vessel through the mobile unit of the RTK GPS receiving correction data from the reference station (described above).

The unit was interfaced into the navigation computer where the WGS84 co-ordinates where transformed and the vessel position displayed to give track guidance and logged for survey planning and processing.

The unit was also interfaced to each acoustic system, where it was logged for geo-referencing of the acquired survey data.

The system performed well providing centimetre accuracy both in plan and height for the duration of the survey. There were times, however, when there was limited satellite coverage resulting in a reduction of the system accuracy to the nearest decimetre. This particularly affected the height positioning.

2.2 Swath-sounding interferometry

This component of the survey was undertaken on the 18 and 19 January 2000 by the Sedimentary Systems Research Group (SSRG) of the University of St Andrews and an engineer from Submetrix Ltd. The primary objective of the survey was to produce a data set of bathymetry and sea-bottom amplitude for comparison with other remotely sensed geophysical data and ground truth data from video and grab sampling (Section 3.2.2). The final deliverables included a bathymetric chart for the harbour together with amplitude data over key areas of bottom calibration.

The Submetrix 2000 series sonar was operated at 234 kHz with an optimal spreading limit set at 100 m slant range providing a vertical (bathymetric elevation) accuracy of 0.1 m.

2.2.1 Data logging and processing

The processing steps for the 2000 series data are:

- gather raw sonar amplitude and bathymetric data swath by swath;
- correct data for ancillary measurements (i.e. speed of sound) swath by swath;
- filter data to find 'good' bottom points (i.e. those at which coincidental amplitude and bathymetric values occur) swath by swath;
- define grid area and bin size (resolution) based upon the filtered data specification;
- grid (mosaic) data by combining swaths;
- filter gridded data by smoothing where necessary.

Critical to processing swath-sounding sonar is an exact measure of the transducer position and orientation. In order to achieve this it is important that full differential navigation is maintained throughout the survey and that a motion reference unit and heading compass are deployed with the sonar. Because the sonar is mounted on a fixed platform on the bow of the boat, it is possible to know at all times not only where the sonar is but also its attitude from the sensors. These instruments give an exact location and orientation of the transducer elements which are input to the acquisition computer in real time. For this survey a Trimble RTK differential signal was provided and maintained throughout the survey by Emu Environmental.

The transducers were deployed in a bow mount location (Plate 1) with the transducer heads 90 cm below the water line. A DMS 205 motion reference unit was used to give transducer orientation corrections. The equipment was mobilised onto the boat in three hours with the acquisition hardware set-up (the topside-dry unit) in a relatively small space within the wheel house (Plate 2 shows a typical topside-dry set-up). Prior to the survey a number of calibrations were conducted:

- circular magnetic heading calibration – this was conducted just outside the main harbour at the beginning of the survey and at the beginning of the second day for calibrating the magnetic compass;
- patch sonar transducer calibration – a 9 swath wide survey patch was chosen where the sea floor was relatively flat in the main calibration area in order to correct and adjust the transducer staves.

Navigation was provided by Emu Environmental through a Trimble RTK system. Tide data was also provided post survey based on model tides as discrepancies were noted in the RTK height information during the survey. Sound velocity measurements were made by SSRG at the start and during the survey to calibrate the transducers. This measurement is critical to correctly positioning both the bathymetric and sidescan data for the survey.

A calibration survey area was defined at the centre of the site for tracking errors in the survey systems and for tracking drift both during each day of surveying and also to track any drift between days of surveying. Within this survey area lines were acquired separately in two perpendicular directions (approximately north-south and east-west) and at two different orientations for the full calibration lines. These data were supplied separately to ABP Research for comparison and a comparison was also made separately by SSRG of the data.

The weather was fine with a low sea state and small swell during the survey at Plymouth with the Submetrix system. During the survey the Trimbel RTK GPS showed some significant portions of the survey when the differential correction was compromised for height. However, because the swath-sounding system was deployed to give 100% overlap between swaths, corrections could be applied with the modelled tidal data to the Submetrix data to compensate for this. Using this technique, the position errors were reduced to less than 1m over the entire survey and in places less than 0.4m. Height information was obtained to errors of less than 1m for all the area with less than 0.2m for 40% of the area.

2.3 Side Scan Sonar

This component of the survey was undertaken on the 21, 22 and 26 January 2000 by Emu Environmental Ltd. with the primary objective to provide a data set of sea-bottom amplitude data for comparison with other remotely sensed geophysical data and ground truth data from video and grab sampling (Section 2.5). The final deliverables included a high resolution seabed textural map and an interpreted map of biotopes based upon ground truth data (Section 3).

An EG&G 272 side scan sonar fish with an EG&G 260 thermal recorder were interfaced to a Triton Elics digital acquisition and processing system to produce a digital acoustic image of the seabed. The Triton system was interfaced with the positioning system to give a real time geo-referenced digital image (sonograph) of the seabed.

The system was operated, in general, at a frequency of 500 kHz and a range setting of 100 m per channel.

The survey line schedule was set at a parallel line spacing of 50 m, thereby providing approximately 50 % overlap of swaths.

2.3.1 Data logging and processing

The sidescan digital data was combined with the positioning information and logged in the Triton Elics system in the Triton Elics propriety *xtf* file protocol. The position was recorded every second and tagged to the sidescan data with a recording interval proportional to the pulse repetition rate and digitising capabilities of the system.

The digitally acquired data was processed in the Triton system within the Isis sonar software and exported to 'DelphMap' software where the data was mosaiced and the resultant image classified by texture. The processed data was exported to DelphMap in an interpolated format in a data bin size of 0.2 m.

Classification was performed using the Triton Elics classification utility in DelphMap. This program works on the basis of identifying regions with similar textural qualities. The system is 'trained' to find textural types that have been selected and defined by the user. Texture can be defined as taking a central pixel value of a region and computing the neighbourhood relationship of the pixels within the region. The program will take this value, obtained through training, and look for regions with the same value. The derivation of the region value is made with associated algorithms using an array of parameters. Six classifications were identified on the north-south side scan lines in the control box. These corresponded to the following seabed features:

- flat substrata (sands and muds);
- rippled substrata (sands and coarse sands);
- cobbles;
- broken reef/boulder;
- coherent boulder;
- distorted data.

Confirmation of the classification was undertaken by using the same classes to examine the east-west lines from the same area. Similar areas of substrata distribution were noted, although clear distortion of the data has occurred along the centre of each of the side scan lines.

The analytical capacity of the Triton system is presently limited, such that only small sections of an overall area can be processed at any one time. The limits of the system were encountered during the processing of the data from the processing system. Both the full east-west lines and the north-south lines could not be processed using the software in its current stage of development. Triton Elics are however in the process of addressing the deficiencies of the software to increase its ability to cope with larger areas of analysis.

Mosaics of the data were exported as Geo-referenced *Tiff* images and the classified boundaries as *dxf* files for export into other programs for further analysis or plotting. Paper plots were made for a visual analysis of the area for a basis on which to compare the other sets of data.

2.4 Acoustic ground discrimination system

The operation of the AGDS system is described fully in other publications and reports, notably; Foster-Smith *et al.*, 1997.

The AGDS used was a single frequency RoxAnn system operating at 200 kHz with a Koden CVS-8112 echo sounder. The RoxAnn survey was undertaken on the 18 and 19 January 2000. The track spacing was set at 50 m intervals, provided by Emu.

A test area was used for calibration during both days.

2.4.1 Data logging and processing

The RoxAnn and DGPS outputs were logged using Microplot. Microplot saved data every two seconds, and an average value for E1, E2 and depth were calculated over the two second interval and logged together with the ships' position at the moment when the values are saved.

The data have been exported from the above logging software as ASCII text files and imported into *Excel*. Data resulting from other analyses (e.g., accuracy assessment) was also imported into *Excel* for statistical analysis.

MapInfo Professional is the geographic information system (GIS) in which most of the spatial display (including map design), the creation of vector layers (such as coastlines), spatial editing, spatial query and the creation of vector buffers is performed. Data can be imported from or exported to *Excel, Idrisi* and other programmes.

The data were imported into *Surfer for Windows* for interpolation of the track point data. This route was used where any quantitative analysis was performed on gridded values or where they were exported to the image processing and classification procedures.

Classification was performed using *Idrisi for Windows*. Other operations were also performed in *Idrisi*, such as image enhancement.

RoxAnn is designed to discriminate between sediment classes on the basis of two variables (E1 and E2). Indeed, it is promoted as a prospecting tool whereby values of E1 and E2 that lie between certain upper and lower limits are taken to indicate particular ground types. However, such rectangular 'boxes' (termed parallelepipeds) are a very crude way of representing acoustic characteristics of a sediment since it is likely that many ground types will have indistinct acoustic signatures and with varying degrees of overlap with others. Certainly, no signature will fit conveniently into an exclusive rectangular box in such situations. It is more realistic to expect a more irregular arrangement of points clustered around 'nodes' in the scatterplot of E1 against E2 that correspond to different biotopes. These clusters might be quite distinct if there are only a few biotopes. However, the more biotopes that are included in a survey and the more intermediates between types are found, the less distinct the nodes will become.

An approach to analysis that is more in keeping with this expected distribution of the data than the use of parallelepipeds is the estimation of the likelihood (probability) that a set of values corresponds with a given sediment type.

The purpose of editing the acoustic data is to eliminate doubtful records and to prepare the data for analysis. Before the acoustic data can be analysed in detail, the recorded depths must be corrected to chart datum, and the acoustic data need to be scrutinised carefully and edited to eliminate spurious data points. Although this editing can be done within the data logging software (Microplot) it is recommended that all data are saved and editing carried out after the data have been exported into a spreadsheet. Additionally, further treatment of the data may be required depending upon the type of analysis anticipated, including standardisation of E1 and E2. The following sections highlight the operations, which are routinely used by SeaMap, which are performed on the data.

2.4.2 Correcting to chart datum

Depths were corrected to chart datum by applying corrections from Devonport tidal gauge. The corrections were applied at the minimum time interval of 10 minutes to reduce the size of the steps in the corrected depth records between intervals.

2.4.3 Editing track data on the basis of positional uncertainty or boat speed

All editing was performed on a copy of the original data and no records were irretrievably lost through the editing process.

Acoustic data need inspection to eliminate dubious points related either to large skips in position caused by GPS error or to spurious depth, E1 and E2 values. Positional errors will occur even when using DGPS since the differential signal may be lost on occasions. Small positional errors are difficult to identify but larger skips (of up to 500 m) are usually transitory and cause obvious spikes on the track. Additionally, values of E1 and E2 can increase when the speed of the vessel is very low or when the vessel comes to a stop, although this effect is more apparent on some vessels than others. Track associated with low vessel speed, (below 2 knots) were therefore deleted.

An automatic procedure was applied to the positions associated with the track data to highlight sections of track where there were large skips in position and where there was little change in the position of the survey vessel. This entailed calculating the distance between two consecutive points, and highlighting those where the jump in distance was either much greater than expected from the speed of the vessel, or where the change in position indicated that the vessel had slowed to a speed below the acceptable minimum (about 1 m per second) or come to a stop. It should be noted that these points were highlighted for inspection and possible deletion, but not automatically deleted. Note that if a record was selected for deletion, then the whole record, including depth, E1 and E2, was deleted.

2.4.4 Editing track data on the basis of erratic changes in depth

All depths <1.5 m (the minimum response depth set for the *RoxAnn* unit) and >40 m (above the maximum known depth in the survey area) were removed. An automatic procedure was applied to the depth data to highlight those sections of track where changes in depth were erratic. A record was compared to the average value of the two previous track points together with the two following points. Track points where a large difference (>5m) was calculated were highlighted and inspected. If a point appeared to be out of step with its neighbours, then it was deleted. Note that the whole record, including E1 and E2, was also deleted.

2.4.5 Editing track data on the basis of erratic changes in E1 and E2 values

Spurious changes in E1 and E2 are harder to detect than for position and depth and their causes are numerous. For example, values for E1 and E2 can change when the vessel alters course. Certain sea states might affect the values differently depending upon the ship's course. The apparatus has also been know to return lower values than expected on some tracks, often after many hours of recording acoustic data. There is no automatic way of highlighting erratic E1 and E2 values on their own. Careful inspection of the track during field recording, with reference to the echo sounder screen for reassurance, is recommended. This will alert the operator to any potential problems so that measures can be taken to rectify the situation. No obviously erratic tracks were detected visually during the present study.

Further editing may not be desirable and should only be performed with caution. Plotting E1 against E2 may reveal clusters of potentially dubious data that lie outside the expected distribution of the data. These points can be labelled and then displayed geographically to see if their distribution might reveal the causative factor. For example, a cluster might be associated with changes in the ship's course or any other of the potential factors listed above. Although scattergrams were prepared for E1 against E2, no obviously anomalous points were detected in this way in this study.

2.4.6 Standardisation of E1 and E2

Standardisation is recommended when data from surveys of the same area obtained on separate dates and/or using different vessels are to be combined for processing or compared. E1 and E2 cannot be standardised using the maximum value since every data set has a small number of high values that would unduly influence the standardisation. Instead, the data can be standardised by dividing all the records by the 95th percentile value (allowing for a wide scatter of values in the upper 5% band). This value is found by sorting the records for E1 (the process being repeated for E2) in descending order of magnitude and finding the record that separates the first 5% of the records from the subsequent 95%. The value for E1 for this record is used for standardisation. This has been found to produce a good match between surveys and works best when tracks over the same area can be used. These standardised values can be used in place of the original values. The data from this survey and the previous 1996 survey were standardised in this way.

The data from one survey (i.e., identical set up on consecutive days) were amalgamated prior to standardisation, having first ascertained using a scatter plot that there is no obvious day-to-day variability.

2.4.7 Interpolation of the Track Data

Whilst it is possible to interpret track point data and display the results on a map, it is far easier to see spatial patterns in data if these are displayed as a continuous picture. This is particularly true for broad scale survey where a user-friendly, general account of the distribution of habitats and biotopes is required. It must be stressed that producing a continuous coverage from point data does not improve the accuracy of the data. The track data cannot be improved upon in this way. This may seem an obvious point, but one that can cause confusion. Indeed it should be appreciated that much of the estimated data introduced through point-to-area transformation may be of dubious validity whilst important but small features seen on the track data may be lost.

The interpolation procedure was as follows:

interpolation package	*Surfer* version 7
Algorithm	Inverse distance squared
grid size	5 m
maximum number of points per interpolated values	25
search distance	250 m

2.5 Ground truthing

Two techniques for verifying seabed habitats and biotopes were employed during the survey on the 23 and 24 January 2000. These were benthic grabbing and remote video. Initial selection of sites for ground truth data was made after completion of the AGDS survey[5]. Subsequent sites were then selected after the initial sidescan sonar results had been produced[6]. The final selection of sites was refined after comparison of the sites and apparent differences between the AGDS and sidescan sonar requirements. Several sites were common to the two techniques, whereas others were specific to only one. Using the sidescan sonograph data it was possible to estimate the best type of sampling method for the type of seabed prior to ground truthing, this was not possible using the AGDS data, i.e. the AGDS method simply asked for ground truthing at a site without any advice on the nature of the ground, whereas sidescan was able to determine whether video or grabbing was the most likely option. The Submetrix survey team were happy with the AGDS sites and requested no further information or ground truthing to be undertaken.

The first method to be deployed was the underwater video camera which took place on 23 January 2000. The grabbing survey was undertaken predominately on 24 January 2000. Any sites where grabbing was not possible were resurveyed using a drop-down underwater video camera.

2.5.1 Grabbing

Areas of predominantly soft sediment identified from the side scan sonar survey data, and sites requested by the AGDS team, were sampled using a Day grab with a surface area of 0.1 m^2 (Plate 3). Sediment samples were collected to a depth of approximately 15 cm. Field methodologies were based on the JNCC procedural guidelines "Quantitative sampling of sublittoral sediment biotopes and species using remote-operated grabs" (Thomas, 1998). Given the primary objectives of the survey it was agreed that a fully quantitative baseline biotope evaluation was not appropriate or necessary. Therefore a modified version of the method was employed which is described below.

Upon collection of the sample a description of the sediment character was made, as well as notes on the quantity and quality of the sample collected. All information was recorded in the survey log. Single samples only were collected from each site unless the quantity of sediment retained was insufficient for the determination of the biotope. Where samples

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[5] Ground truth sample locations prefixed with ROX on Figure 1 refer to stations assigned immediately after the RoxAnn survey by SeaMap.

[6] Upon initial review of sidescan output additional ground truth stations were assigned and these are prefixed with the letters SSS (sidescan grabs) and TV (underwater video tows) in Figure 1.

could not be retained due to the nature of the seabed (cobbles/coarse gravel) then the site was resurveyed using a drop-down underwater video camera (Plate 4). The conspicuous species were identified on site, with an assessment made of their relative abundance. The samples were then retained and returned to the laboratory for examination of any species that it was not possible to identify on site. Identification of these species was conducted at Emu Environmental's laboratories. The samples were not quantitatively evaluated, with only dominant and/or conspicuous species being identified for the purposes of ascribing biotopes at each site sampled.

2.5.2 Underwater video camera

Video survey was employed to ground truth the conspicuous epifaunal and floral species assemblages together with the physical nature of the seabed across the survey area. A number of habitat features during the sidescan survey were identified as 'targets' for the video survey and care was taken to ensure that the appropriate areas were covered. In particular, the boundaries between seabed features were surveyed such as moving from sedimentary bedforms to rocky outcrops. Two techniques were used during the survey. The first employed a towed sledge and video camera to run survey lines where the sediment type was predominantly flat. The second approach employed a drop-down system, where the camera was fitted within a pyramid frame with a fixed quadrat base. This latter technique was used to provide detailed close up information on specific areas as well as allowing drift surveys to be conducted over regions where the substratum was rocky or too rough for the towed system to be deployed. Detailed logs of the video camera position and run time were recorded, with appropriate lay back from the vessel antenna position. The positional data were also collected digitally and provided accurate positional data for the video camera after return to the laboratory. While on site initial review of the data was conducted such that features of note on the video were recorded in the log, including conspicuous species and physical features. These were then used as verification of elapsed time and position on review of the video records.

2.5.3 Biotope description

Biotopes as defined in the MNCR Marine Biotopes Classification for Britain and Northern Ireland were described at different levels of definition for the data generated from the ground-truth grabbing and video surveys. An initial description of the biotopes was undertaken in order to match each sample with the highest level of definition possible. However, a subsequent analysis was undertaken to further refine the biotope classification using existing data from English Nature and the JNCC. The following levels of definition were therefore considered most appropriate:

- MNCR habitat complex level;
- MNCR biotope complex level;
- MNCR biotope level.

Additional descriptive notes for each site were provided in the tabulated data, along with site positions. Where video data are presented, the biotopes are defined within boundaries, i.e. start and finish locations.

In many cases description of biotopes at the fine biotope level was not possible, due either to a lack of detail in the ground truth data or a poor fit to biotopes as defined in Connor, *et al.*, 1997.

3. Results

3.1 Ground truthing

The results of Emu collected ground truth data are provided in Table 3(a-c) and Appendix B (video footage descriptions). English Nature and JNCC-provided biotope descriptions from previous surveys are given in Tables 4 and 5.

A total of 22 principal substrata types were identified during the present survey. The AGDS ground truth grab sites accounted for 10 of the identified substrata types, with the additional sidescan grab sites adding a further two types. The remaining 10 types were all identified from underwater video footage. Of the latter, the main differences were due to variations within the physical structure of bedrock outcrops.

With respect to the habitat complex level classification the AGDS grab sites accounted for seven complexes while an additional one complex was added following the sidescan grabbing, with a further two added following underwater video sampling. At the biotope complex level, eight different types were identified from the AGDS samples, with a further three added following additional grabbing to ground truth the sidescan sonar data. A remaining four biotope complexes were identified from the underwater video footage.

Substrata and habitat complex definition was possible for all grab and video collected data. At the biotope complex level approximately 90% of the data could be fitted to an existing description, however, at the biotope level only 50% of the data could be fitted with any degree of confidence to an existing biotope.

3.2 Total area maps

In order to highlight differences and/or similarities between the systems in terms of their broad-scale mapping capability, each system generated a set of broad-scale habitat complex maps and these are described below:

3.2.1 Sidescan sonar

A mosaic of all the individual sidescan swath data is presented in Figure 2a, which highlights the spatial extent of the survey and some variation in seabed type. It is noteworthy that sections of the survey immediately to the north and west of the calibration area appear as lighter shades of grey compared to the rest of the survey data. This tends to indicate that the seabed in these areas is composed of less reflective soft sediment, such as mud or muddy sands. The data was saved as a *geotif* on a grid of 0.2 m before being imported into *ArcView* for annotating and interpretation and although the resolution of the image presented in Figure 2a is limited by the scale of the plot and resolution of the printer (in this case a colour laser-jet TEK 740 at 1200 dpi), the original *geotif*, however, contains the high resolution data. This is clearly demonstrated by an expanded section of the mosaic as shown in Appendix C, which clearly reveals areas of mobile sediment and rocky outcrops without the need for extensive ground truthing.

An interpretation of the entire sidescan data in conjunction with the ground truth data (provided in Tables 3(a-c) to 5) is presented in Figure 2b. The interpretation is based upon a review of the sonograph by ‘eye’ in which certain bedform features typical of sand waves, ripples, and bed-rock can be recognised, as well as textural features typical of sediment mixtures such as sands and gravels. By cross-referencing the initial interpretation with ground-truth data in the vicinity of each identifiable feature a habitat complex classification was achieved. Although this process is subjective, the underlying sonograph data is always available to ensure that the interpretation can be quality assured and re-interpreted at any time.

A total of four principal habitat complexes were identifiable and mapped using the sidescan sonar, these are: i. a combination of MCR (moderately exposed circalittoral rock), MIR (moderately exposed infralittoral rock), ECR (exposed circalitoral rock) and EIR (exposed infralittoral rock), ii. IMX (infralittoral mixed sediments) and CMX (circalitoral mixed sediments), iii. CGS (circalittoral clean gravels and sands) and IGS (infralittoral gravels and clean sands), and finally, iv. IMU (infralittoral muds) and IMS (infralittoral muddy sands). The principal distinguishing feature between the IMX/CMX and IGS/CGS is that the IGS/CGS has bedforms associated with it such as sand waves.

3.2.2 Swath-sounding interferometry

A mosaic of all the individual amplitude swath data is presented in Figure 3a, which highlights the spatial extent of the swath survey and some variation in seabed type. It is noteworthy that sections of the survey immediately to the west of the calibration area appear to have a more rough texture compared to the rest of the survey data. This tends to indicate that the seabed in this area is composed of irregular patches of hard sediment or has an irregular topography. The amplitude data was saved as ASCII text on a grid of 1 m before being imported into *Erdas* and then *ArcView* for annotating and interpreting. Again, the resolution of the image presented in Figure 3a is limited by the scale of the plot and resolution of the printer. The original *geotif*, however, contains the 1 m resolution data. Appendix D shows an expanded section of the swath amplitude data for the same areas highlighted in Appendix C for the sidescan sonar data. It is important to note that the image handling and printer settings for both sets of data were exactly the same so the differences observed between Appendix C and D is entirely due to differences in the quality of the raw data.

A mosaic of all the individual bathymetric soundings is presented in Figure 3b, which highlights a considerable degree of variation in seabed topography. The amplitude data was saved as ASCII text on a grid of 1 m before being imported into *Erdas* and then *ArcView* for annotating and interpreting. Unlike the amplitude data, the bathymetric data is absolute and fully quantitative, it is therefore readily classified. In the present case this was achieved by simply binning the depths into 1 m intervals, the result of which is presented in Figure 3b.

An interpretation of both sets of data has been undertaken to provide a classified map of seabed biotopes (Figure 3c). The acoustic classification (Figure 3c) therefore represents only acoustic signatures of bathymetry and amplitude with 67% weight for bathymetry and 33% weight for amplitude. At each training site a polygon was digitised around each of the sites with a minimum of 20 by 20 pixels in each polygon. The parallelepiped method was used to classify individual pixels with relation to the known signatures at the training sites. The classification scheme produced 4 predominant classes of bottom type, namely; i. bedrock outcrops (MIR, EIR), ii. a transitionary condition between i. and iii consisting largely of sand., iii. coarse sand, shell and/or gravel iv. muds and muddy sands (IMS, IMU).

3.2.3 Acoustic Ground Discrimination System

The AGDS was calibrated by collecting data over the same ground at different times to assess any possible variation that might demonstrate the need for caution when comparing data collected by the same system on different occasions. The subset of the acoustic track records that fell within the test area were extracted from the AGDS data sets and statistical analysis compared day to day for variability. The mean and standard deviation were calculated for all variables. The results are presented in Table 6 comparing the data for the single AGDS for hard and soft ground (Table 6).

Initially the RoxAnn (E1, E2) values were assigned to one of 20 classes given in Table 7. However, classification of the classes at the biotope complex level was not possible owing to insufficient ground truth data to separate the biotopes, therefore each class of E1 and E2 values were assigned at a higher level of classification, that is at the habitat complex level.

The interpolated classified map of habitat complexes is presented in Figure 4a. It is apparent that 10 habitat complexes were identified, namely; MCR (moderately exposed circalittoral rock), MIR (moderately exposed infralittoral rock), IMX (infralittoral mixed sediments), CGS (circalittoral clean gravels and sands), IGS (infralittoral gravels and clean sands), EIR (exposed infralittoral rock), IMU (infralittoral muds), IMS (infralittoral muddy sands), CMX (circalittoral mixed sediments), and ECR (exposed circalittoral rock). In addition, to facilitate the comparison of the AGDS data with the other systems the 10 habitat complexes identified were re-grouped into 4 categories representing, i. mixed sediments (predominantly IGS/CGS without bedforms), ii. sands and gravels (IGS/CGS), iii. rocky outcrops (EIR/MIR) and iv. muds and muddy sands (IMU/IMS), and these are shown in Figure 4b.

3.2.4 Comparison of total area maps

The classified maps of the seabed produced by each system have been described separately in the preceding sections. However, there are some notable differences and similarities between each of the maps (Figures 2b, 3c and 4b) which are highlighted below:

- all three systems identified an area immediately to the west of the calibration box that was predominantly composed of habitat complex IMU;

- all three systems identified an outcrop of rock (EIR) extending out from Bovisand Fort into the calibration box area;

- the sidescan sonar discriminated 4 habitat complexes, the AGDS 10 habitat complexes and the swath-bathy system 3 habitat complexes;

- both the sidescan and AGDS identified areas to the north and west of the calibration box that were predominantly muddy in character (IMU, IMS). However, the swath-bathy system identified the same area as mixed gravels and sands (IGS, CGS, IMX);

- both the sidescan and AGDS identified an area in the southern most section to be predominantly composed of hard ground (cobbles, rock, sands and gravel). However, the swath-bathy system identified much of the same area as being predominantly composed of muddy sediments (IMU, IMS).

In order to quantify the differences between the systems in terms of their habitat discrimination a systematic pair-wise comparison of the classified output was undertaken. The method involves creating each file (system classification image) on the same grid in order to allow the same area between images to be compared pixel by pixel. The differences between total area system maps can then be graphically compared. However, the comparison can only take place at the lowest common habitat complex level. For example, if one system identifies an area (pixel) as IGS/CGS/IMX but the other system identifies the same pixel as CGS then this would generate a no difference result. The lowest common factor in this case is IGS/CGS/IMX. Therefore to allow for clear visual interpretation of comparative output we have reclassified the RoxAnn image into four classes namely: i. rock habitat complexes (EIR/ECR/MIR/MCR), ii. sand and gravel habitat complexes (ISG/CSG), iii. muddy habitat complexes (IMU/IMS) and, iv. mixed habitat complexes (IMX/CMX), see Figure 4b.

It can be seen in Figure 5 that significant areas (as indicated in black) have been classified differently between the systems (even when using fairly generic categories of habitat complexes). However, it is noteworthy that there are some striking similarities particularly between the sidescan sonar and AGDS classification. For example, rocky outcrops in the southern part of the area have been similarly identified as have the predominantly muddy sediment habitats in the north and west of the area. The significant difference occurs when the AGDS classifies areas as IGS/CGS when in deep water (>30 m) but in fact it should be rock (see southern most section of the north/south tracks), and when in shallow water (<10 m) the AGDS classifies areas as rock when in fact (by ground truthing) they should be ISG/CSG (see sections of the calibration box). It would appear that both the AGDS and Submetrix classifications are grossly influenced by changes in depth, to the extent that rock becomes either sand, gravel or mud in deeper water (>30m). Indeed, it was indicated in Section 3.2.2 that a 67% weighting was given to bathymetric data in the Submetrix classification.

Table 9 quantifies the differences between the system habitat classifications which clearly shows the increased similarity of the sidescan and AGDS classifications compared to the sidescan and Submetrix systems. The AGDS and Submetrix systems when compared demonstrated the least similarity. Table 9 also provide a breakdown of which misclassifications were most significant between systems. For example, the largest differences in misclassification between the AGDS and sidescan occur between IMX/CMX and EIR/ECR/MIR/MCR (38%), and IGS/CGS and EIR/ECR/MIR/MCR (32%).

3.3 Calibration box comparisons

In order to compare the (temporal) repeatability of each system in discriminating the various habitat complexes a calibration box was surveyed on several occasions. The results of the calibration box surveys are described below:

3.3.1 Sidescan sonar

For the sidescan sonar system 4 separate surveys of the calibration box were undertaken over 3 days (see Table 2). One survey in a north-south orientation on the 21 January 2000, two surveys (one east-west and one north-south) on 22 January 2000 and the final survey in an east-west direction on the 26 January 2000.

The results of these surveys are presented in Figures 6 to 13 which have been grouped together and presented in a 'tabbed' section called 'sidescan' within the present report. For each survey 2 figures have been produced, for example Figure 6 shows the classified map of the sidescan survey undertaken on the 21 January running survey lines in a north-south orientation. The classified map is based upon the mosaiced sonograph data which is presented in Figure 7. The inclusion of the filtered/binned amplitude data is important since this effectively represents a quality assurance step between the raw data and the classified image. It is noteworthy that the sonograph image used to generate the classified map was at a higher resolution than that which is presented in the report (as Figure 7) allowing the user to zoom in and identify the sand rippled areas classified as rippled sediments (IGS/CGS).

Three habitat complexes were identifiable, namely mixed sediments consisting mainly of sands and gravels with some mud (IMX and CMX), rippled sands and gravels (IGS and CGS) and bedrock (MIR, EIR). By far the most predominant feature within the calibration box is a mixed sand and gravel habitat complex, however, there is also a prominent rocky outcrop habitat complex in the northern section of the calibration box.

Comparing Figures 6, 8, 10 and 12, reveals no two maps are exactly the same, with all of the habitat complex boundaries varying in space over time and this is highlighted in Figure 13b. However, some general consistencies are apparent across all four surveys, namely:

- a band of rock runs in north-west/south-east orientation within the northern part of the box (highlighted in grey);
- on the eastern edge of the calibration box there are intrusions of mobile mixed sands and gravels;
- a consistent area of mixed sand and gravel is observed in the southern section of the box.

Table 10 indicates that for sidescan sonar an average of 79% of the seabed is classified the same on repeated surveys with a standard deviation of ± 4% (0.27 Ha). The greatest errors occur in defining the boundary between the mixed sediments (IMX/CMX) and the rocky outcrops (EIR/MIR) which accounts for 77% of the 21% of seabed misclassified. It was considered that due to the mobility of sand and gravel in the area adjacent to the rocky outcrops that some of this variation may in fact be due to real differences, but this assertion can not be validated.

3.3.2 Swath-sounding interferometry

For the swath-bathymetry system 4 separate surveys of the calibration box were undertaken on the same day (see Table 2). Two surveys (one east-west and the other north-south) in the morning of 19 January 2000 and then two surveys (one east-west and the other north-south) in the afternoon of 19 January 2000. The swath system was the only one not compared between days.

The results of these surveys are presented in Figures 14 to 21 (for the amplitude data) and Figure 22 to 29 (for the bathymetric data). Figures 14 to 29 have been grouped together and presented in a tabbed section called ‘swath-bathy’ within the present report.

Considering the amplitude data first (Figures 14 to 21), for each survey 2 figures have been produced, for example, Figure 14 shows the classified map of the swath-bathy survey undertaken on the morning of 19 January 2000 running survey lines in an east-west orientation. The classified map is based upon the mosaiced amplitude data which is presented in Figure 15, again the presentation of the amplitude data is an important QA step. It is noteworthy that the sonograph image used to generate the classified map was at a slightly higher resolution than that which is presented in the report (as Figure 15).

Two habitat complexes were identifiable, namely mixed sands and gravels (IGS and CGS) and bedrock (MIR, EIR). By far the most predominant feature within the calibration box is a mixed sand and gravel habitat complex, however, there is also a prominent rocky outcrop habitat complex occupying the northern section of the calibration box.

Comparing Figures 14, 16, 18 and 20 reveals no two maps are exactly the same, with each of the habitat complex boundaries varying in space between each survey and this is highlighted in Figure 21b. However, some general consistencies are apparent across all four surveys, namely:

- a band of rock runs in a north-west/south-east orientation within the northern part of the box (highlighted in grey);
- a consistent area of mixed sand and gravel is observed in the southern section of the box.

Table 10 indicates that for the swath-bathy (amplitude data) an average of 89% of the seabed is classified the same on repeated surveys with a standard deviation of ± 2% (0.14 Ha). The greatest errors occur in defining the boundary between the sand and gravel habitat (CSG/ISG) and the rocky outcrops (EIR/MIR) which accounts for 100 % of the 11 % of seabed misclassified. It was considered that due to the mobility of sand and gravel in the area adjacent to the rocky outcrops that some of the variation in habitat may in fact be due to real differences, but this assertion can not be validated.

In considering the bathymetric data (Figures 22 to 29), for each survey 2 figures have been produced, for example Figure 22 shows the raw bathymetric mosaiced data for survey undertaken on the morning of 19 January 2000 with survey lines running in an east-west direction. This data was then classified by binning the soundings into 1 m intervals and the classified map is presented in Figure 23. It is noteworthy that no subjective interpretation of the bathy data is required to reach the classified output presented in Figure 22, therefore an overlaying transparency is neither appropriate nor required. Indeed this is a ‘key’ advantage of using the bathymetric data. However, the bathymetric data does not lend itself easily to a habitat complex classification. Nevertheless, it will be shown that changes in bathymetry do correlate reasonably well with identified (mapped) habitat complexes.

Comparing Figures 23, 25, 27 and 29 reveals no two maps are exactly the same (Figure 29b). However, given the spatial complexity of the bathymetry the classified images are remarkably similar as is demonstrated in Figure 29b which compares the (dis)similarities between pairs of images.

Table 10 indicates that for the swath-bathy (bathymetry data) an average of 76.48% of the seabed is classified at the same depth during repeated surveys with a standard deviation of ± 4% (0.26 Ha) in area depth variation.

3.3.3 Acoustic Ground Discrimination System

For the AGDS 6 separate surveys of the calibration box were undertaken over 2 days (see Table 2). Two surveys (one east-west and the other north-south) were undertaken on the 18 January 2000 and then for surveys (two east-west and two north-south) on the 19 January 2000.

The results of these surveys are presented in Figures 31 to 35 and these have been grouped together and presented in a tabbed section called ‘AGDS’ within the present report.

A maximum of five habitat complexes were identifiable within the calibration box, namely; CGS (circalittoral sands and gravels), EIR (exposed infralittoral rock), IGS (infralittoral gravel and clean sands), IMX (infralittoral mixed sediments) and MIR (moderately exposed infralittoral rock). By far the most predominant feature within the calibration box is a mixed sand and gravel habitat complex (IGS and CGS), however, there is also a prominent rocky outcrop habitat complex occupying the northern section of the calibration box (EIR).

Comparing Figures 30 to 35, reveals that no two maps are exactly the same, indeed significant differences are apparent between the extent of mapped rock (MIR) which is highlighted in Figure 35b. If Figure 33 were not included then some general consistencies are apparent across all remaining surveys, namely:

- a band of rock runs in a north-west/south-east orientation within the northern part of the box (highlighted in orange);

- a consistent area of mixed sand and gravel is observed in the southern section of the box.

Table 10 indicates that for the AGDS an average of 76% of the seabed is classified the same on repeated surveys, however, there is significant variation in the average similarity as evidenced by the relatively large standard deviation of ± 8% (0.63 Ha). The greatest errors occur in defining the boundary between the CSG/ISG and the rocky outcrops EIR/MIR and the boundary between CGS and IGS, both account for 49% of the misclassified habitat, respectively. It was considered that due to the mobility of sand and gravel in the area adjacent to the rocky outcrops that some of the variation in habitat may in fact be due to real differences, but this assertion can not be validated.

The results of the temporal comparison for each system clearly reveals that there is a trade-off between the sensitivity of each system to discriminate habitats and its ability to map the boundaries of each habitat in the same space on repeated surveys. This is perhaps to be expected as the logical extension to this argument is that a system which can not discriminate any habitat will be the most consistent (repeatable) system and this is reflected in the classification of Submetrix amplitude data.

4. System cost/effectiveness

The above section provides a means of ranking the systems in terms of their ability to consistently map the habitats during repeated surveys and on their effectiveness at discriminating different levels of habitat. In this section, the objective is to consider each system as a complete package, that is taking into account such factors as ease of installing and calibrating the system whilst on survey and post processing the data back in the office.

The various factors or, cost/effective parameters, documented are presented in Table 11. It should, however, be noted that financial costs have not been explicitly quantified for each system since these will vary from survey to survey and on the overall market demand for the technique etc. To overcome this limitation a category has been included which ranks their cost on a relative basis with some indicative price based upon our own experience of surveying 1 km^2 of seabed with 100% coverage and post processing the data through to map production. It assumes that the boat, ground truth data collection and mob. demob. costs would be the same for each system, however these are not included in the indicative cost estimates presented in Table 11.

It is apparent from this table that a number of significant differences and common problems are experienced using the different systems. For example, a common problem encountered in setting-up the systems was establishing communication between the navigation aid and the system data logging hardware. Specifically this relates to the format of the text string which all navigation systems output and the assigned navigation string format expected by the survey system. Usually this can be easily changed to ensure both systems are using the same format, but with their being no single format for the data as either output or input then it is inevitable that differences occur which inevitably causes delay to the survey mobilisation. The principal difference between the echosounder systems (AGDS and Submetrix) and the sidescan sonar is that the former require hull mounted transducers which, due to the acoustic beam geometry, require relatively intensive calibration to compensate for the variation in the speed of sound through the water. Accurate beam geometry correction is not critical for the sidescan sonar since its strengths are in object detection and not in accurate position fixing objects.

Another important difference between the systems in terms of post-processing is that the AGDS system of classification is clearly more efficient than the other two swath systems.

This is mainly due to the amount of data which the swath systems generate compared to the AGDS which is not surprising given the swath systems are covering a much large area of seabed in a given amount of time. But also the procedures for classifying the AGDS data are better established and have to a large extent become standardised, making the whole process much more time efficient.

The joint classification of bathymetric and amplitude (sidescan) data is in its infancy, particularly from a biotope classification perspective, and this has inevitably led to difficulties in post processing the sidescan and bathymetric data sets for joint analysis (Figure 3c) which inevitably resulted in time and costs implications.

The data provided in Tables 8, 9, 10 and the comments provided in Table 11 (with the quantitative estimates of performance presented in red) can be used to assign a relative measure of effectiveness for each of the measured criteria. This is shown in Table 12. From Table 12 it is apparent that the sidescan sonar has an overall higher rating than the other two systems, due mainly to its consistent moderate performance, whereas the other two systems exhibit greater variation in performance across the measured criteria.

5. Conclusions

In order to fully evaluate any system in terms of its accuracy in discriminating and mapping marine benthic biotopes an accurate baseline map of the actual seabed biology must be available. Clearly for large areas of seabed such as Plymouth Sound there will always remain areas of the seabed not sampled and therefore subject to uncertainty in terms of their biological status. The value of acoustic mapping techniques is that they provide a means of interpolating between areas of known habitat and therefore biological status. However, in undertaking a comparative study of systems it is necessary to have 100% actual baseline biotope data in order to conclude which is the more accurate mapping tool. Without this level of certainty it is not possible to determine which is the most accurate and therefore most cost effective system.

Nevertheless, in undertaking a relative comparison of the three systems (as in the present study), a number of useful questions can be answered; namely:

- Which, if any, of the systems is most consistent in spatially discriminating identifiable seabed features during repeated surveys of the same area of seabed?
- Which, if any, of the systems demonstrate a greater degree of similarity with each other in classifying broad-scale habitat complexes?
- Which of the systems is able to discriminate the greatest number of habitat complexes?

1. It is apparent from the calibration box surveys that there is a trade-off between the number of habitat complexes a system can identify and its ability to map them consistently in space during repeat surveys of the same area. For example, the swath-bathy amplitude data when classified revealed two habitat complexes which remained in the same space during repeat surveys, however, it was evident from the

sidescan data that more subtle features such as mobile bedforms were not being detected by the swath-bathy system. By contrast the AGDS was able to identify and discriminate a maximum of 5 habitat complexes (within the calibration box), however, the spatial boundaries of each habitat complex varied significantly between surveys. The sidescan system fell in between these two extremes (see Tables 8 and 10).

2. Given that significant areas of bedrock are unlikely to move or be buried (certainly within the duration of the survey) we may assume that the mapped differences are due mainly to system errors and not natural causes.

3. In the case of the AGDS, there is evidence that the E1 and E2 values remain consistent between surveys (see Section 3), but the mapped boundaries nevertheless exhibit significant change. This tends to suggest that the greatest errors (in terms of statistical assumptions) are introduced during the post processing of the E1 and E2 data, namely the assigning of E1/E2 classes to ground truth data and their interpolation to generate the habitat maps.

4. In the case of sidescan sonar there is currently no tried and tested automatic means of classifying the data, although we are aware that a number of organisations, notably; the Defence, Evaluation and Research Agency (DERA - Bincleaves) and Simrad-Marconi are addressing this problem. Although the sidescan system offers the ability to produce 100% mosaiced maps of seabed features at the highest resolution it is often the case that two separate swaths covering the same area of seabed have significantly different ranges in grey-scale. The result of this is that neither supervised or unsupervised classification is appropriate for sidescan data and each sonograph has to be expertly interpreted.

5. In the case of the swath-bathy system the redundancy in the amplitude data caused by the filtering procedures (which ensure that only amplitude data that is coincidental with bathymetric soundings are utilised) effectively reduces the resolution of the amplitude data (in the majority of cases to a 1 m grid). The swath-bathy system is designed, first and foremost, to provide quantitative bathymetric data with known tolerances. The positional accuracy of the system is therefore critical and this is a major influence on how the data is first obtained and then subsequently processed. The absolute positional accuracy of sonar pings is not a concern of sidescan sonar systems and therefore they are able to achieve a much higher resolution image of the seabed albeit at the expense of positional spatial accuracy. The ability of the swath-bathy system to produce quantitative bathymetric maps with 100% coverage of seabed is very useful from a monitoring point of view.

6. In the case of the multi- and single beam echosounder systems (RoxAnn and Submetrix) there was evidence from the comparative analysis of the total area maps and ground truth data that these systems are significantly influenced by changes in depth of water, for example rocky habitat was misclassified in deep water as sands and gravels by the RoxAnn system and mud in shallow water was misclassified as rock by the Submetrix system.

- it may be concluded that no single system tested offers the ability to reliably map the full range of biotope complexes with the accuracy or resolution required for monitoring purposes;

- the classified bathymetric data was the most spatially ‘consistent’ data obtained, but the data does not easily lend itself to habitat complex classification;

- the AGDS was able to discriminate and identify the greatest number of habitat and biotope complexes, but their spatial extent was subject to significant variation between surveys;

- the sidescan sonar provided the highest resolution data of seabed features, but the sonograph required careful interpretation in order to produce a classified map of habitat complexes;

- of the systems trialed the most appropriate (cost/effective) method for broad-scale seabed habitat mapping is a combination of the sidescan sonar (providing information on habitat complexes) and swath-sounding interferometer (providing quantitative bathymetric data);

- within habitat complex features defined by the swath systems the application of AGDS would appear to offer the most effective means of mapping more subtle variations associated with biotope complexes.

6. Recommendations

1. The bathymetric data is quantitative and is therefore easily classified into depth ranges which can be used for monitoring purposes, particularly where the site has a range of features such as rocky outcrops and large sand waves. Swath bathymetry allows the boundaries of certain habitat features to be accurately determined without interpolation. However, bathymetric data alone can not be used to define habitat complexes or biotopes since it provides no information on sediment textures and small scale topographical features such as ripples.

2. The broad-scale mapping of habitat complexes requires information on seabed textures and the ability to resolve small scale changes in topography over wide-areas. The sidescan sonar system offers the ability to cover large areas of seabed at high resolution without interpolation. However, sidescan data alone can not be used to define all habitat or biotopes complexes since it does not record bathymetry. A combination of bathymetric data overlaid with sidescan data would most likely provide the most accurate classification of seabed habitat complexes and this should be investigated further.

3. The identification and discrimination of biotopes requires AGDS which is able to detect subtle changes in the 'properties[7]' of the seabed and is therefore able to detect much more variation than either the sidescan sonar or swath-bathy systems. However, the spatial mapping of these properties and their definition (linking to ground truth data) is subject to significant error. Previous workers have aimed to reduce this error by increasing the intensity of ground truth sampling (CEFAS, per. comm.) and reducing the line spacing between surveys tracks (both of which at some point will obviously defeat the purpose of using AGDS in the first place).

4. We recommend that normal beam AGDS not be used for broad-scale mapping of habitat complexes, but rather it may have value in monitoring the total amount of biotope variation within mapped habitat complexes. To estimate the extent of biotope variation does not itself require accurate mapping of the spatial boundaries between the biotopes. However, this would require further evaluation before confidently recommending AGDS as a tool for monitoring biotope variation within habitat features since some of the variation may indeed not be attributable to seabed (or biotope) differences.

5. In order to be certain of the above assertions and establish the true cost-effectiveness of each system (or any other system), it is essential that an area of seabed is (without question or doubt) accurately mapped in terms of its habitat and associated biological community (epifauna and infauna). This may be achieved by selecting a 500 m by 500 m calibration box (as in the present study) and intensively ground truthing the area with underwater video cameras, SCUBA and grab sampling techniques. Ideally, this would take place on more than one occasion. A definitive biotope map could then be produced and compared to the output from each of the trialed systems. Such an approach would answer how much of the biological (biotope) variation can reliably be accounted for by each of the systems or combination of systems.

6. A significant complication in setting the equipment up was establishing communication between the navigation and survey systems. We recommend that the navigation string format be specified by the surveyor and for the surveyor to ensure that the navigation equipment outputs the required format prior to mobilising the survey.

7. DGPS is essential and we strongly recommend that a dedicated base-station be set-up for the duration of any survey such as a Leica 530 Kinematic Global Positioning System (RTK DGPS) providing *xyz* position fixing in most cases to within decimetre accuracy.

8. The mapping reference frame should be the UK National Grid (OSGB36). Most GPS systems work on the World Geodetic System (WGS84) and therefore transformation parameters from WGS84 to OSGB36 are required to fix objects in correct UK space.

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[7] Properties in this context is used in the broadest sense, namely both biotic and abiotic factors will influence the classes defined by the AGDS, but their varying influence on the systems performance may give rise to a significant source of inconsistancy.

9. Calibration of multi- and single-beam echosounder systems is essential prior to survey commencing and preferably also during the survey to check the effect of tidal currents etc. on the attenuation of the acoustic signal. This is not required for the low-grazing sidescan sonar.

10. AGDS data should be provided in ASCII text format for storage and post-processing. Swath data from MBES, interferometry and sidescan sonars should be converted to a *geotif* format, i.e. a *tif* image file with a world co-ordinate reference file. The *geotif* should be gridded at the highest resolution possible. The large size of the datasets (often gigabytes of data) requires the use of optical drive systems for archiving data and powerful PC's (or workstations) with large hard drives and dual processors for processing the data. Many swath systems store the raw data in a proprietary compressed format which is specific to the system being used. It is therefore important to check with the surveyor that the data can be exported in *geotif* format and either saved to CD-ROM, DVD or removable optical drive.

11. When presenting the classified output from sidescan or amplitude data it is important to include an image of the original data. This then allows the reader to compare directly the interpreted classification with the raw (unclassified) data.

7. References

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Tables

Table 1. Total area survey activities

Activity	18/01/00 AGDS Swath-bathy	19/01/00 AGDS Swath-bathy	21/01/00 Sidescan
Activity	22/01/00 Sidescan	23/01/00 Ground truth	24/01/00 Ground truth
Activity	26/01/00 Sidescan		

Table 2. Calibration box survey activities

Activity	18/01/00 AGDS – EW1 AGDS – NS1	19/01/00 AGDS – EW2 (am) AGDS – NS2 (am) AGDS – EW3 (pm) AGDS – NS3 (pm) Swath-bathy – EW1 (am) Swath-bathy – NS1 (am) Swath-bathy – EW2 (pm) Swath-bathy – NS2 (pm)	21/01/00 Sidescan – NS
Activity	22/01/00 Sidescan - NS Sidescan – EW	26/01/00 Sidescan – EW	

Table 3a. Emu collected ground truth samples January 2000 - AGDS grab and video sites

Site	Easting	Northing	Substrata	Habitat complex	Biotope complex	Biotope	Notes
Rox 1(vid)	247918	51015	Gravelly Sand	CMX	?	?	Possibly superficial sands over solid substrata, cobbles
Rox 2(grb)	248168	51008	Gravelly Sand	IGS	IGS.FaS	IGS.NcirBat	
Rox 3(grb)	248270	50963	Gravelly Sand	IGS	IGS.FaS	IGS.Mob	
Rox 4(grb)	248119	50759	Sandy Gravel	IGS	IGS.FaG	IGS.?Sell	
Rox 5(vid)	248260	50609	Gravelly Sand	CGS	?	?	Well defined sand waves, possibly over solid substrata
Rox 6(grb)	247639	50760	Mud	IMU	IMU.MarMu	?	Anoxic1cm
Rox 7(grb)	246768	50901	Sandy mud	IMU	IMU.MarMu	IMU.TubeAP	
Rox 8(grb)	246564	51033	Shell Gravel with Cobbles	IGS	IGS.FaG	?ECR.PomByC	Particulate based but with final biotope only described in ECR
Rox 9 (grb)	246353	50955	Shell Gravel with Cobbles	IGS	IGS.FaG	?ECR.PomByC	Particulate based but with final biotope only described in ECR
Rox10(grb)	248073	49905	Fine Sand	IGS	IGS.FaS	IGS.Mob	
Rox11(vid)	248112	49779	Bedrock	MIR	MIR.SedK	?MIR.XKSerR	Seasonally impoverished or alternatively may be EIR.CC
Rox12(vid)	248264	49275	Bedrock and Boulders	MIR	MIR.KR	MIR.Lhyp.PK	Adjacent CGS sand wave area.
Rox13(vid)	248209	48818	Bedrock and mixed sediment	MIR	MIR.KR	MIR.Lhyp.PK	Bedrock area mixed with boulder, cobble, sand patches
Rox14(vid)	248173	47569	Bedrock and boulders	MCR	MCR.Xfa	MCR.?ErSEun	Mobile sand patches between predominantly Bedrock areas
Rox15(grb)	248368	51440	Fine Sand	IGS	IGS.FaS	IGS.Mob	Mobile Sands possibly on Rock
Rox16(grb)	248160	52362	Sandy Mud	IMU	IMU.MarMu	?	
Rox17(grb)	248371	53023	Silty Sand	IMX	IMX.FaMX	?	Fauna suggests mixed sediments. i.e., encrusting species.
Rox18(grb)	248166	51695	Mud	IMU	IMU.MarMu	?	
Rox19(grb)	247760	50623	Mud	IMU	IMU.EstMu	IMU.MobMud	Anoxic 1cm. Liquid mud
Rox20(grb)	246822	50588	Mud	IMU	IMU.MarMu	?	Anoxic 1cm

Table 3b. Emu collected ground truth samples January 2000 - Sidescan grab sites

Site	Easting	Northing	Substrata	Habitat complex	Biotope complex	Biotope	Notes
SSS1	248128	52890	Silty Sand	IMS	IMS.FaMS	?	
SSS2	248092	51177	Sandy Gravel	IGS	IGS.FaG	?	Shell Gravel
SSS4	248398	51746	Silty Sand	IMS	IMS.FaS	?	
SSS6	248091	50670	Sandy Gravel	CGS	?	?	Fauna suggests ECR.PomByC
SSS9	248094	49941	Sand	IGS	IGS.FaS	IGS.Mob	
SSS13	248195	51959	Silty Sand	IMS	IMS.FaMS	?	
SSS14	248196	51785	Mud	IMU	IMU.MarMu	?	
SSS15	248343	50111	Mudstone	MCR	MCR.SfR	?	
SSS17	248359	51615	Silty Sand	IMS	IMS.FaMS	?	
SSS18	248397	51206	Fine Sand	IMS	IMS.FaMS	IMS?EcorEns	IMS based on fauna
SSS21	248245	52305	Silty Sand	IMS	IMS.FaMS	?	
DD = drop down, TV = Towed video SSS = replaced grab site with DD.							

Table 3c. Emu collected ground truth samples January 2000 - Sidescan video sites

Site	Easting	Northing	Substrata	Habitat complex	Biotope complex	Biotope	Notes
DD01(a)	248086 to 248079	51000 to 50992	Gravelly Sand	IGS	IGS.FaS	?	No sand waves.Shell amongst gravel
DD01(b)	248079 to 248072	50992 to 50957	Bedrock Ridges with boulders	EIR	EIR.KFar	EIR.FoR	
DD01©	248072 to 248051	50957 to 50830	Gravelly Sand	IGS	IGS.FaS	?	No sand waves
DD02	248368 to 249307	48667 to 48606	Bedrock Ridges and mixed sediments	MIR	MIR.GzK	MIR?Lhyp.GzPk	Mixed sediment areas comprise cobbles, and sandy gravel
DD03	248358 to 248301	49239 to 49177	Bedrock and mixed sediment	MIR	MIR.GzK	MIR.?Lhyp.GzPk	
SSS16	248344 to 248320	50378 to 50385	Sandy Gravelly Cobbles	ECR	ECR.EFa	ECR.PomByC	
TV01(a)	248120 to 248144	50963 to 50990	Gravel	IGS	IGS.FaS	?	At the end of this line biotope changed to rock.
TV01(b)	248144	50990	Bedrock and boulder	MIR	?	?	
TV02(a)	248134 to 248119	52922 to 52986	Silty Sand	IMS	IMS.FaMS	?	
TV02(b)	248119 to 248079	52986 to 53045	Cobbly Sand	IMX	IMX.FaMx	?	At the end of this line biotope changed to rock
TV02(c)	248079	53045	Bedrock Ridges	ECR	ECR.Alc	ECR.AlcMaS	
TV03(a)	248388 to 248421	51561 to 51931	Silty Sand	IMS	IMS.FaMS	?	Mixed with small patches of cobbly, gravelly sand. IMX
TV04(a)	248098 to 248104	49975 to 50033	Sand	IGS	IGS.FaS	?	Rippled Sand
TV04(b)	248104 to 248074	50033 to 50124	Small boulders with mixed sediments	MIR	MIR.SedK	MIR.EphR	Mixed sediments comprised sandy, gravelly cobbles.
TV04(c)	248074 to 248103	50124 to 50177	Bedrock Ridges	MIR	MIR.SedK	MIR.?EphR	Different substrata but apparently the same biotope as above.
TV04(d)	248093 to 248078	50208 to 50397	Boulder Ridges	MIR	MIR.SedK	MIR.?EphR	Patches of sand (waves) between ridges. IGS.FaS
TV05(a)	248101 to 248093	48997 to 49063	Bedrock and mixed sediment	MIR	MIR.KR	MIR.?LhypPk	Mixed with small boulder, cobbles and sand.
TV05(b)	248099 to 248107	49255 to 49327	Bedrock and mixed sediment	MIR	MIR.KR	MIR.?Lhyp.Pk	Mixed with small boulder, cobbles and sand.
TV05(c)	248099 to 248096	49562 to 49654	Bedrock and mixed sediment	MIR	MIT.KR	MIR.?Lhyp.Pk	Mixed with small boulder, cobbles and sand.
TV07	248339 to 248322	50748 to 51135	Coarse Sand	IGS	IGS.FaS	?	Sand in ripples, with occasional boulder outcrops (MIR.Lhyp.Pk)

Site	Easting	Northing	Substrata	Habitat complex	Biotope complex	Biotope	Notes
TV08(a)	248391 to 248390	49782 to 50092	Bedrock, boulders and mixed sediment	MIR	MIR.SedK		Mixed cobbles and sand between boulder sand bedrock. Biotope bordering on MCR.Xfa
TV08(b)	248390 to 248373	50092 to 50194	Sandy Gravel	CGS	?	?	Sediment in distinct waves.
TV10(a)	248386 to 248492	50514 to 50510	Gravelly, Cobbly Sand	IMX	?	?	Sand waves
TV10(b)	248492 to 248505	50510 to 50513	Gravelly, Sand	IGS	IGS.FaS	?	Sand waves
TV10(c)	248505 to 248572	50512 to 50513	Bedrock Ridges and mixed sediments	MIR	MIR.KR	MIR.?LhypPk	cobbles and sand between ridges
TV10(d)	248572 to 248607	50513 to 50514	Gravelly, Cobbly Sand	IGS	IGS.FaS	?	Sand waves
TV11(a)	248209 to 248175	49822 to 49881	Gravelly, Cobbly Sand	IMX	IMX.FaMx	?	Sand waves
TV11(b)	248175 to 248199	49881 to 50072	Gravelly, Sand	IGS	IGS.FaS	?	Sand waves
TV11(c)	248199 to 248198	50072 to 50110	Sand	IGS	IGS.FaS	?	Sand ripples

Notes. Substrata descriptions are based on triangular analysis methods in Holme and McIntyre (1984).

Table 4. English Nature provided data collected in 1996 (see Figure 1)

Location	Site_No	Lat.	Lon.	OS Grid	Depth	Time (GMT)	Date	Method	Biotope
Breakwater	20	50.3356	-4.151	SX 469 506	11.7	12.41	09/12/98	Grab	IMU.MarMU
Breakwater	15	50.33748	-4.151183	SX 469 508	14.2	12.37	09/12/98	Grab	IMU.MarMU
Breakwater	9	50.33877	-4.151233	SX 469 510	13.9	12.34	09/12/98	Grab	IMU.MarMU
Breakwater	10	50.33897	-4.148967	SX 470 510	13.9	12.56	09/12/98	Grab	IMU.MarMU
Breakwater	16	50.33675	-4.148733	SX 471 508	13.9	12.47	09/12/98	Grab	IMU.MarMU
Breakwater	8	50.33932	-4.14675	SX 472 510	14.3	12.25	09/12/98	Grab	IMU.MarMU
Breakwater	6	50.34028	-4.1436	SX 474 511	13.5	10.27	09/12/98	Grab	IMU.MarMU
Breakwater	11	50.3392	-4.1435	SX 474 510	14.4	12.2	09/12/98	Grab	IMU.MarMU
Breakwater	17	50.33603	-4.143483	SX 474 507	12.4	14.15	09/12/98	Grab	IMU.MarMU
Breakwater	18	50.33557	-4.140533	SX 476 506	12.5	14.1	09/12/98	Grab	IMU.MarMU
Breakwater	19	50.33575	-4.14345	SX 474 506	12.4	14.2	09/12/98	Grab	IMU.MarMU
Breakwater	14	50.338	-4.145567	SX 473 509	13.7	14.26	09/12/98	Grab	IMU.MarMU
Breakwater	12	50.33813	-4.1395	SX 477 509	14.2	12.15	09/12/98	Grab	IMU.MarMU
Breakwater	13	50.33793	-4.1408	SX 476 509	14.4	11.06	09/12/98	Grab	IMU.MarMU
Breakwater	7	50.34005	-4.138917	SX 478 511	14.7	10.15	09/12/98	Grab	IMU.MarMU
Jennycliff Bay	15	50.34792	-4.1318	SX 483 520	9.1	15.3	07/12/98	Grab	IMS.FaMS
Jennycliff Bay	16	50.34758	-4.129317	SX 485 519	8.4	15.5	07/12/98	Grab	IMS.FaMS
Jennycliff Bay	18	50.34693	-4.13095	SX 484 519	8.8	15.22	07/12/98	Grab	IMS.FaMS
Jennycliff Bay	8	50.35025	-4.131817	SX 483 522	6.8	13.14	07/12/98	Grab	IMS.FaMS
Jennycliff Bay	12	50.34942	-4.131433	SX 483 521	7.6	15.4	07/12/98	Grab	IMS.FaMS
Jennycliff Bay	9	50.35072	-4.12945	SX 485 523	9.1	17.3	07/12/98	Grab	IMS.FaMS
Jennycliff Bay	1	50.35382	-4.1312	SX 484 526	6.5	12.25	07/12/98	Grab	IMS.FaMS
Posford Site	10	50.33515	-4.143199	?			10/07/96	Grab & video	IMU.MarMU
Posford Site	11	50.33474	-4.152674	?			10/07/96	Grab & video	IMU.MarMU
Posford Site	23	50.33883	-4.132874	?			10/07/96	Grab & video	IGS.FaS
Posford Site	25	50.34955	-4.130807	?			10/07/96	Grab & video	IMS.FaMS
Posford Site	26	50.34858	-4.136351	?			10/07/96	Grab & video	IMS.FaMS
Posford Site	69	50.33405	-4.153069	?			11/07/96	Dive & video	IMU.MarMU

Table 5. JNCC provided data collected in 1997 (see Figure 1)

Survey	Site	Easting	Northing	Ht/Depth CD.	Spp.	Biotope
242	76	248000	50900	- 5 to - 8	34	Lhyp.Pk
242	76	248000	50900	- 5 to - 8	22	SCAs.ByH
242	76	248000	50900	- 5 to - 8	57	EphR
242	76	248000	50900	- 5 to - 8	13	Lhyp.Pk
242	70	248600	50700	+ 0 to - 1	27	Lhyp.Ft
242	70	248600	50700	+ 0 to - 1	25	SCAs.ByH
242	70	248600	50700	+ 0 to - 1	26	SCAs.ByH
242	70	248600	50700	+ 0 to - 1	32	XKScrR
242	70	248600	50700	+ 0 to - 1	7	CC.BalPom
242	70	248600	50700	+ 0 to - 1	13	Lhyp.Ft
242	D15	248200	50000	to – 12	0	Sell
242	102	247300	50400	+ 1 to - 2	32	Ldig.Pid
242	102	247300	50400	+ 1 to - 3	9	Ldig.Pid
242	102	247300	50400	+ 1 to - 2	5	Ldig.Pid
242	102	247300	50400	+ 1 to - 2	1	Ldig.Pid
242	D9	247200	50500	to - 8	0	AbrNucCor
242	72	247200	50700	- 12 to – 12	16	SpMeg
242	75	248200	51400	+ 3 to + 0	29	SCAs.DenCla
242	75	248200	51400	+ 3 to + 0	2	Lhyp.Ft
336	17	245950	51020	- 5 to - 8	87	Lhyp.TFt
336	14	248590	51870	- 4 to - 8	34	FaMS
336	25	248510	51470	+ 1 to - 4	42	XKScrR

Table 6. Comparison of AGDS track data for the same area of seabed

Start Day 1	E1	E2	DP	Start Day 2	E1	E2	DP
Mean	0.745	0.952	6.683	Mean	0.760	0.908	6.856
Std	0.162	0.308	0.874	Std	0.181	0.290	0.923
Mid Day 1	E1	E2	DP	Mid Day 2	E1	E2	DP
Mean	0.695	0.963	6.478	Mean	0.733	0.857	6.623
Std	0.171	0.325	0.635	Std	0.182	0.227	0.891
End Day 1	E1	E2	DP	End Day 2	E1	E2	DP
Mean	0.813	0.981	6.666	Mean	0.793	0.883	6.740
Std	0.168	0.283	0.820	Std	0.158	0.222	0.935

Table 7. Assigned clusters of E1 and E2 values

Class ID	Biotope	Habitat
1	CMX	Mixed sediment
2	?IGS.Mob or IGS.NcirBat	Gravel & sand
3	?IGS.NcirBat or ?IGS.Mob	Gravel & sand
4	IGS.?Sel (based on presence of *Chamelea gallina*)	Gravel and sand
5	CGS	Bedrock with coarse sand
6	IMU	Mud
7	IMU?	Mud
8	?IGS/?ECR.PomByC	Rock and sand
9	?IGS/?ECR.PomByC	Rock and sand
10	?IGS.Mob	Mobile Sand
11	?MIR.XKSerR or ?EIR.CC.BalPom	Bedrock, boulders and coarse sand
12	MIR.Lhyp.Pk. Adjacent sand wave areas = CGS	Bedrock & cobble Coarse Sand
13	MIR.Lhyp.Pk	Bedrock, cobble & sand
14	MCR.?ErSEun	Bedrock, cobble & boulders
15	?IGS.FaS	Gravel & sand
16	?IMU?	Mud
17	IMX.FaMX	Mixed sediment
18	?IMS?	Mixed sediment
19	IMU.MobMud	Mud
20	IMU?	Mud

Table 8. Comparison of output for the calibration box

	AGDS	Sidescan	Swath-Bathy	
			amplitude	bathy.
Habitat complexes identified	5 (high)	3 (moderate)	2 (low)	n/a
Temporal variation of habitat complexes	High	Moderate	Low	Low
Most likely sources of error giving rise to either low habitat complex discrimination or high temporal variation	Interpolation procedures, large acoustic footprint, varied orientation of the sonar to the seabed	Subjective interpretation, varied orientation of the sonar to the seabed, varied grey-scale (amplitude) values for the same object when observed on separate swaths	low resolution due to data redundancy, subjective interpretation, the orientation of sonar to the seabed, varied grey-scale (amplitude) values for the same object when observed on separate swaths	

Table 9. Total area system comparison (between systems)

Comparison		Area (Ha)	Percentage
AGDS (RoxAnn) vs. Sidescan	Classified the same	181.3025	62%
	Classified differently	113.445	38%
	IMX/CMX with EIR/ECR/MIR/MCR	42.625	38%
	IMX/CMX with IGS/CGS	20.44	18%
	IMX/CMX with IMU/IMS	5.335	5%
	IGS/CGS with EIR/ECR/MIR/MCR	36.395	32%
	IGS/CGS with IMU/IMS	8.2325	7%
	EIR/ECR/MIR/MCR with IMU/IMS	0.4175	0%
AGDS (RoxAnn) vs. Interferometry	Classified the same	65.22954	18%
	Classified differently	306.4039	82%
	IMX CMX/EIR MIR	78.29026	26%
	CSG IGS/EIR MIR	108.9004	36%
	IMX CMX/CGS IGS	43.78216	14%
	Unclassified (submetrix)	75.43105	25%
Interferometry vs. Sidescan	Classified the same	96.2125	30%
	Classified differently	223.6125	70%
	IMX CMX/EIR MIR	30.58	14%
	CSG IGS/EIR MIR	82.5	37%
	IMX CMX/CGS IGS	54.2325	24%
	Unclassified (submetrix)	56.3	25%

Table 10. Calibration box temporal comparison (within system repeatability)

Comparison		Area (Ha)	Percentage	Stdev.	
AGDS (RoxAnn)	Classified the same	6.44	76%	0.63	
	Classified differently	2.05	24%	0.63	
	CGS/IGS	0.98	50%	0.3999	6
	CGS/IMX	0.01	1%	0.0158	
	EIR/IGS	1.04	49%	0.601	
	EIR/MIR	0.00	0%	0.0012	
	IGS/IMX	0.01	1%	0.013	
	IGS/MIR	0.01	0%	0.0078	
Sidescan (EG&G)	Classified the same	6.78	79%	0.27	
	Classified differently	1.77	21%	0.24	
	IMX CMX/EIR MIR	1.33	77%	0.3319	3
	CSG IGS/EIR MIR	0.12	7%	0.1288	
	IMX CMX/CGS IGS	0.32	17%	0.2918	
Interferometry (amplitude)	Classified the same	7.57	89%	0.14	
	Classified differently	0.92	11%	0.14	
	CSG ISG/EIR MIR	0.92	11%	0.14	1
Interferometry (bathymetry)	Classified the same	6.52	76.48%	0.26	
	Classified differently	2.00	23.52%	0.26	

Table 11. Plymouth biotope mapping: a comparison of techniques

	ROXANN (SeaMap)	INTERFEROMETRIC (Submetrix and SSRG)	MULTIBEAM BATHYMETRY (Simrad)	SIDESCAN SONAR (Emu)	VIDEO & GRAB SAMPLING (Emu)
Date Tested	18/01/00 - 19/01/00	18/01/00 - 19/01/00	25/01/00 - 26/01/00	21/01/00 - 24/01/00	23/01/00 - 24/01/00
Weather	F1-2 NW Smooth Sunny	F1-2 NW Smooth Sunny	F3-4 S Slight-Moderate Fine	F4-5 N-NW Smooth-Slight Fine	F3-4 N-NW Slight Fine & Sunny
Time Start Mob.	8:50 AM	8:30 AM	8:00 AM	7:20 AM	8:00 AM
Time Finish Mob.	10:45 AM	10:40 AM	2:00 PM	11:00 AM	12:00 PM
External Sensor Set-up	Easy one-man set-up of sensor mounted on scaffold pole to side of vessel (15 min.). Pole and fixtures provided by vessel.	More complicated sensor set-up requiring 2-man team. Bow-mounted sensors on specially-designed poles provided by Submetrix. (60 min.).	The sensor and the motion reference unit were placed on the bow mount. This arrangement required a large heavy mounting bracket that needed four people to put in place. It also took several attempts to adjust the bracket to fit the vessel correctly. The Seatex seapath system was mobilised concurrently with the swath system taking about (60 min.).	The side-scan fish was fitted and supplied with a soft tow cable which was simply plugged into the surface data processing unit. (15 min).	Easy one-man set up of camera onto sled or drop frame. Simple attachment of umbilical and tow cable. (15 min).
Data Logging Equip. Set-up	One lap-top computer and one echo-sounder monitor to set-up. Mob. took longer than usual due to fault finding a blown fuse and an interfacing problem between the navaid and the RoxAnn system which required a GGL message. (120 min.)	One computer monitor and hard-drive and interface unit. Mob. is more complicated than RoxAnn as more cables are required. An navaid interfacing problem was also encountered as the ISIS 2000 system requires a GAA nav. string message. (90 min.).	One sun work station and a lap top to run the motion reference unit were installed. (30 min). The equipment required a GGL navigation string.	Triton monitor and hard-drive (digital data logger) and sonograph thermal paper recorder. The system was more bulky than the others tested and Mob. took 2 hours longer than usual due to interfacing problems between the navaid and the Triton recorder. (220 min)	Umbilical from camera plugs into control box. Signal is passed to video overlay unit which is connected to DGPS/Hydro laptop. Video with DGPS and GGA navaid string overlaid then recorded on Hi8 VCR/TV unit. (60 mins)

	ROXANN (SeaMap)	INTERFEROMETRIC (Submetrix and SSRG)	MULTIBEAM BATHYMETRY (Simrad)	SIDESCAN SONAR (Emu)	VIDEO & GRAB SAMPLING (Emu)
Survey Set-up e.g. Calibration	No calibration required. No bar check for echosounder depth carried out.	Compass calibration required (10 mins). Compass reading incorrectly therefore repositioned twice and re-calibrated. Six calibration lines run for swath data. (30 mins)	Six survey lines were run to calibrate for roll pitch and heave. Four lines were run on a flat seabed in different directions and at different speeds and four lines in different directions and at different speeds on a seabed with a pronounced slope. The seapath motion reference unit was calibrated whilst the swathe system was being mobilised. (40 mins)	No calibration required - but nav. check is required. Tow line distance needs to be measured and recorded for correct positioning at post processing stage. (10 mins)	No calibration required.
During Survey Comments	System left to log data continuously with very few checks. No logging on and off in between survey lines.	Set-up windows showing information for swath, SSS & boat. Logged on & off between survey lines. Sound Velocity Profiling (SVP) required for processing of data - taken at 16:00 on 18/01/00.	SVP data was collected at he start middle and end of the day. On the second day SVP data was collected at the start and end of the day.	Towing sidescan sonar fish in shallow busy waters more hazardous than hull-mounted systems. The tow cable snagged on an unmarked mooring of a pot line which was close to an identifiable wreck.	Towing the camera sled can be hazardous when the seabed is very uneven due to the presence of boulders or if large numbers of pot lines are present. The use of the drop down video eliminates these problems to a large extent.
Post-Survey Comments	Equipment can be left on vessel as installed.	Equipment can be left on vessel as installed. Compass calibration required at the start of each new survey day.	Equipment can be left on vessel as installed	Sidescan sonar fish needs to be brought onboard the vessel at end of survey and stowed away securely.	System securely stowed away every evening for security reasons.
De-Mob	Took approximately 30 mins. to de-mob whole system.	Took approximately 40 mins. to de-mob computer equipment and 60 mins. to de-mob the sensors.	The computer equipment was demobilised in approx. 40 mins. and the sensor in approx. 60 mins.	Took approximately 60 mins. to de-mob the Triton computer and sidescan sonar system.	Took approx. 30 mins. to de-mob. the video system.

	ROXANN (SeaMap)	INTERFEROMETRIC (Submetrix and SSRG)	MULTIBEAM BATHYMETRY (Simrad)	SIDESCAN SONAR (Emu)	VIDEO & GRAB SAMPLING (Emu)
Post - Processing	Well established (routine) procedures for storing, analysing and finally reporting the data in MapInfo (GIS) format. Classified output followed the procedures described in Foster-Smith. Et al., (1997). The output from the SeaMap group in Newcastle was the first to be delivered and was correct first time. The data was gridded on a 5 m pixel resolution. The timely response and relatively low charge rate results in a relatively low post-processing cost.	The procedures for handling, analysing and presenting the data were not as routine (established) as the SeaMap group. The bathymetric and amplitude data were easily gridded as xyz (bathy and amplitude) text files which were then readily mapped within ArcView (GIS) 3D Spatial Analyst. The bathymetric and amplitude (reflectance) data were gridded on a 1 m pixel resolution. The QA procedures which were required to ensure that the amplitude data was coincidental with the bathymetric data resulted in a large amount of amplitude data being dropped out. This not only caused a significant delay in acquiring the final output but also reduced the value of the amplitude data when compared to the equivalent reflectance data obtained by sidescan sonar. The resolution of the output was first supplied on a 5 m grid but was later provided as 1 m gridded data. The combined classification of the bathymetry and amplitude data provided a habitat classification map that had ambiguous classes, i.e. the same habitat complex type was assigned to two separate colours. Time and hence financial cost are relatively high.	The post-processing of this data was not undertaken as it did not form part of the contract.	The procedures for the classification of sidescan data are well established (Fish and Carr, 1990) when using visual interpretation of the sonograph. Because this procedure is dependent on having an experienced interpreter skilled at recognising different features from the sonograph it is therefore subject to some variation between individual analysts. Nevertheless, for well defined features such as bedrock, sand waves etc. there should not be much difference between individual classifications. Both digital and hard copy sonograph data were recorded providing a useful source of back-up data. The digital data was gridded as GeoTif files within the proprietary software ISIS and DelpMap. Each swath was gridded on a 0.2 m pixel resolution basis. Each swath was then mosiaced using ERDAS Imagine software. Classification was obtained by interpreting (by eye) the mosiaced image alongside a table of ground truth data. The (objective) Triton sidescan classification system proved not to be useful. Time and hence financial cost are relatively high.	The underwater cameras were deployed for ground truthing purposes and the techniques for this have reported elsewhere (Holme and McIntyre, 1984).
Cost To Map	£2,000	£2,600	£2,600	£2,600	

	ROXANN (SeaMap)	INTERFEROMETRIC (Submetrix and SSRG)	MULTIBEAM BATHYMETRY (Simrad)	SIDESCAN SONAR (Emu)	VIDEO & GRAB SAMPLING (Emu)
1 Km^2 Of Seabed (See Note In Text)					
Repeatability	One standard deviation of 6 pair-wise comparisons of calibration box classifications. (+/- 0.632 Ha)	One standard deviation of 4 pair-wise comparisons of calibration box classifications. (+/- 0.14 Ha)	N/A	One standard deviation of 4 pairwise comparisons of calibration box classifications. (+/- 0.277 Ha)	N/A
Habitat Discrimination	5 (high)	2 (low)	N/A	3 (moderate)	N/A
Unit Area Surveyed (Km^2.H^{-1})	0.05 (low)	0.93 (high)	N/A	0.93 (high)	N/A
Seabed Feature Resolution (M)	5 (low)	1 (moderate)	N/A	0.2 (high)	N/A

Table 12. Plymouth biotope mapping: % rank assessment of techniques based upon Tables 8, 9, 10 and 11

	ROXANN (SeaMap)	INTERFEROMETRIC (Submetrix and SSRG)	SIDESCAN SONAR (Emu)
Date Tested	18/01/00 - 19/01/00	18/01/00 - 19/01/00	21/01/00 - 24/01/00
Weather	F1-2 NW Smooth Sunny	F1-2 NW Smooth Sunny	F4-5 N-NW Smooth-Slight Fine
Time Start Mob.	8:50 AM	8:30 AM	7:20 AM
Time Finish Mob.	10:45 AM	10:40 AM	11:00 AM
External Sensor set-up	33	17	50
Data Logging Equip. set-up	33	50	17
Survey set-up e.g. Calibration	17	33	50
De-Mob	50	17	33
Post - Processing	50	17	33
Cost	60	20	20
Repeatability	17	50	33
Habitat Discrimination	50	17	33
Unit Area Surveyed ($Km^2.H^{-1}$)	20	40	40
Seabed Feature Resolution (M)	17	33	50
Overall Rating	<u>347</u>	<u>294</u>	<u>359</u>