Innovative approaches to Rapid Archaeological Site Surveying and Evaluation (RASSE) in the Marine Environment and Transitional Zones

Year One report

For English Heritage

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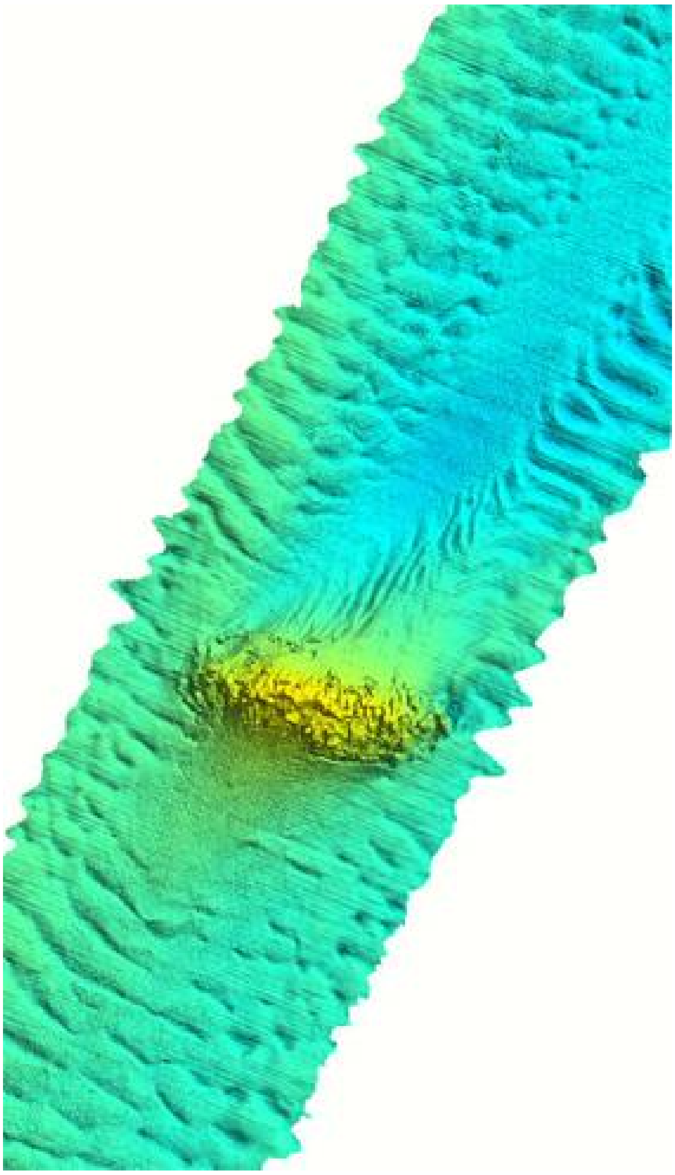

Reson 8125 shaded relief image of Stirling Castle site (April 2005)

30th October 2005

1. Introduction

1.1. This document constitutes a report of work carried out by the RASSE Project (hereafter called ‘the Project’), at the University of St Andrews, during Year One of a three year research project for English Heritage (E.H.).

1.2. The work was conducted in accordance with a Project Design submitted by the University of St Andrews to E.H. (Bates et al., 2004)

2. Project aim and objectives

2.1. The main project aim as described in the Project Design (Bates et al., 2004) is to further develop rapid quantitative assessment methods for submerged archaeological sites through the use of advanced geophysical technologies.

2.2. Towards this aim, the Project identified 12 objectives relating to academic research, curatorial management, and dissemination. Those 12 objectives are listed in Appendix I.

3. Summary of Year One progress

3.1. This report details work undertaken on tasks where progress has been made in Year One. Each section below addresses methodology used, including a summary of results (both relating to methodology and archaeology) and relevant discussion.

3.2. In brief, significant progress has been made on the following tasks:

Task Number	**Description**	**Objectives**
Task M1-1	Project background	1 and 2
Task M2-1	Historic data testing	4 and 5
Task M2-2	Testing of algorithm methodology	1, 4, 5
Task M3-1	Preparation of artificial test site	1 and 4
Task M3-2	Testing sonar types and settings etc., on test site	4
Task M4-1	Review of datasets for *Stirling Castle*	6
Task M4-2	Site survey of the *Stirling Castle*	6
Task M4-3	*Stirling Castle* Site data reduction	7
Task M1-3	Web site creation	12
Task M5-1	Dissemination of results	9,10, 11
Task M5-2	Public dissemination	12

Table 1: Tasks progressed in Year One

4. Tasks undertaken – documentary and laboratory research

4.1. Introduction

4.1.1. In Year One, the Project has undertaken background research into methodology, existing datasets from test sites, and processing techniques. The work has been carried out according to the task list defined in the Project Design (Bates et al., 2004).

4.2. Task M1-1: Project Background

4.2.1. The objective of background research was to refine knowledge and understanding of techniques applicable to the mapping of a wreck site's environmental context, and to determine some of the key environmental features relating to the stability of sites.

Work undertaken and initial decisions

4.2.2. Background research was carried out into datasets gathered from the proposed investigation sites to ascertain the extent and quality of information available to the Project.

4.2.3. Because of the volume and quality of data available for the investigation site of the *Stirling* Castle, much of the background work involved assessment of these datasets. Further information on this is provided in section 4.4.

4.2.4. Preliminary research and previous experience has identified a range of remote sensing techniques applicable to the mapping of archaeological sites and their environmental context. The techniques selected for testing were multibeam sonar (beam forming and interferometric), sidescan sonar and acoustic ground discrimination systems.

4.2.5. Research also specified currently available systems which have a track record of providing high resolution results of a standard suitable for archaeological purposes.

4.2.6. Experience with the sidescan sonar test experiments in Belfast Lough informed decisions relating to the setting up of a test site for the RASSE project (Quinn et al., 2005).

4.2.7. Requirements by E.H. that all data should be gathered from within English Waters persuaded the Project to investigate possible test site locations in the English Channel. The sheltered waters around Plymouth Sound were identified for this purpose because of the availability of an accurate position fixing network and ongoing sonar testing facilities, combined with project members' experience of work in the area.

4.2.8. Existing datasets from Belfast Lough were selected and supplied to project partner Dr Louis Atallah, University of Edinburgh by Dr Rory Quinn. This data has been used to test various algorithms that will automate object testing and matching.

4.2.9. Team members established GIS projects using ArcGIS 8.3. ArcGIS (incorporating ArcMap and ArcScene) was considered the appropriate software for analysing and displaying information generated for each test site.

4.3. Historic Data testing

4.3.1. Work has begun on the testing of historic datasets to maximise the archaeological and environmental detail obtained by high resolution sonar systems during the processing and analysis phase.

4.3.2. All work was carried out by Dr Louis Atallah, at the British University in Dubai and the University of Edinburgh, with some collaboration from MSc students.

Object Matching in images

4.3.3. Object detection and manual processing form a great challenge in sonar imaging as sidescan images vary in terms of intensity, scale and rotation, and are generally blurred with noise. This part of the project aims at automating the process of object detection and matching to address the following issues:

- How can we identify ‘salient’ (or interesting) areas in images? What distinguishes an object from background clutter and seabed structure?

- What features can a computer pick up to tell us that two objects in different images are the same? And can we develop a method that is invariant to resolution variation?

- Having seen objects in a certain image, can we (or the computer) recognize these objects if they are seen from a totally different sonar direction? I.e. is there an object model we can deduce?

Identifying salient areas and working with varying resolution

4.3.4. The initial part of this work used a dataset obtained from a control experiment in Smelt Mill Bay, Belfast Lough, during July and August 2001 (Quinn et al. 2005). Smelt Mill Bay is located in 10m of water in a sheltered cove with a uniform, fine-grained plane sand substrate. A test site of material types was set out on the seafloor and repeat surveys were conducted over the control site using three different side-scan systems (EdgeTech 272-TD: 100/500 kHz, Imagenex 885; 675 kHz, and Geoacoustics 159-A; 100/500 kHz).

4.3.5. Four sonar images were selected, and the sonar parameters (frequency, location, depth) were given for each image. Each image contains 8 objects which include a car tyre (objects 1 and 2 in figure 1), an amphora shoulder and neck (object 3), a ceramic ball (object 4), baskets of different types (objects 5, 6 and 7) and a leather jacket (object 8). Figure 1 shows one of the images.

4.3.6. The method of scale–saliency developed by Kadir and Brady (2001) and described in detail by Kadir (2002). Scale-saliency method was used for the purpose of identifying 'salient' areas in the images. This method defines 'saliency' in terms of local signal unpredictability or complexity. Thus, the most interesting areas in an image are the most unpredictable ones. The images needed de-noising in order to highlight salient areas, and reduce some of the background clutter. Some were used for training in order to select the parameters of the scale-saliency algorithm.

4.3.7. Results of applying the scale-saliency algorithm are given in figure 2. The object parts selected as 'salient' are marked with a red circle (showing the scale of the object selected also). It should be noted that these images are considered quite difficult in terms of object detection and an expert user would find it quite hard to locate salient areas. The method is invariant to rotation and scale variation and achieved success rates of more than 90% in object detection (as compared to the objects marked by an expert).

Object Matching

4.3.8. The scale-saliency method successfully located object parts of the 8 objects present in the control experiment sonar images. The next question was how to match these objects in different images.

Scale saliency matching

4.3.9. An algorithm was developed in order to use scale saliency features to match objects in images. The algorithm first runs the scale saliency method on each of the images and selects areas of high saliency or importance.

4.3.10. Features from each of these areas (object part) are selected. These features are: location, scale of the object part, weighted saliency and normalised histogram. The object parts are matched between different images by using a nearest neighbour algorithm.

4.3.11. The success rates of this method were quite good. The method achieved an error rate of around 5% of incorrect object-part recognition.

4.3.12. However, the Project decided to investigate another method (SIFT) used in camera-image recognition. The method was developed by David Lowe, University of British Columbia (Lowe 2004).

Sale-Invariant Feature Testing (SIFT) and Object matching

4.3.13. The SIFT (sale-invariant feature detectors) method provides image features that are invariant to scaling, rotation and are partially invariant to change in illumination. They are well localized in both the spatial and frequency domains, reducing the probability of disruption by occlusion, clutter, or noise.

4.3.14. The method is quite fast to run on images and includes the following steps:

- Find the interesting areas in terms of scale (how large are the objects) and location (where are the objects);
- Select key-points on the most interesting areas;
- Find out the orientation on each interesting area (how are the pixels oriented?);
- Describe each key point by the strength of the image gradient around it.

4.3.15. To match objects in different images, the method selects key points in both images, and then finds out which ones are most similar.

4.3.16. This method was tested by investigating 10 images from the Plymouth Test site surveyed by RASSE in 2005 (see section 5.4).

4.3.17. The resolution in the images provided is higher than the control experiment images from Belfast Lough, and the objects are clearer.

4.3.18. However, the object type is still difficult to identify. 10 images were provided with varying resolution and sonar direction. Results of matching between different images are given in figure 3 and 4.

4.3.19. Figure 3 shows matching areas between two images. The matching areas are joined with a blue line. It should be noted that this method can find matching areas even if a part of the object was occluded.

4.3.20. Figure 4 shows matching areas between two images a further two images. Matching areas are joined with a blue line. The images are of different sizes, yet the method managed to find the matching areas.

Object Modelling

4.3.21. Research on this part of the project is on-going and is addressing the following issues in relation to sonar imaging.

4.3.22. Although the two methods (scale saliency and SIFT) presented in previous sections appear very successful in matching objects in different camera images, there are several challenges when dealing with sonar images, which can be summarized as follows:

4.3.23. The change of sonar direction can lead to a change in the way a certain object appears in an image. In this case, we are not dealing with a problem of simple rotation or scale variation. When a person looks at a sonar image, he/she tries to form a mental image of what the object really looks like. Shadows around the object give an indication of the object's shape and height. To match this object with another one, the mental images are compared, as well as some features that appear in both images. The next stage of research will tackle this problem. We will use both object models and features from object parts to match different objects in images.

4.3.24. Sonar images show several noisy areas that are selected as key points. These areas are not always object parts or salient areas from a pattern recognition perspective. In addition to that, the seafloor might contain several areas that appear as salient due to bathymetric variation. It will be important in the future to differentiate between these areas and salient object parts.

3D Object Modelling

4.3.25. The aim of this research will be to combine the data from several images to create a clearer 3-D reconstruction of the site, using bathymetric data from multibeam datasets for verification. Results from this work should aid observations of large objects on the seafloor and formation of a model that can be viewed from different directions.

4.3.26. Sidescan images from the *Stirling Castle* site have been provided as testing data for this research.

4.3.27. A bathymetric data file has been provided to enable reconstruction of real bathymetric variation.

4.3.28. The existing model, developed with collaborative help from Dr Yvan Petillot and Dr Enrique Coiras, Heriot-Watt University, can deal with smooth seafloors that have perturbations. Work is on-going to allow this model adapt to large variations on the shape of the shipwreck. Several methods are being tested but no results are yet available.

4.4. Review of historic datasets for the *Stirling Castle*

Work undertaken

4.4.1. The project undertook a thorough review of all the datasets relating to the historic wreck of the *Stirling Castle,* Goodwin Sands. The *Stirling*

Castle dataset incorporates remote sensing work undertaken by various organisations between 1998-2002. A table relating to these datasets is provided in Appendix 2.

Discussion

4.4.2. The Project identified that for the purposes of monitoring and academic research, the most useful datasets were acquired in 2001 and 2002 by the Archaeological Diving Unit (University of St Andrews).

4.4.3. The 2001 dataset included data gathered using an SEA 'Echoplus' Acoustic Ground Discrimination System (AGDS).

4.4.4. The 2002 dataset for the *Stirling Castle* was undertaken using a Reson 8125 multibeam by the ADU (University of St Andrews) and Reson Offshore Ltd. during work in support of the Protection of Wrecks Act 1973.

4.4.5. Assessment of these datasets concluded that one of the most important factors in relation to the stability of the *Stirling Castle* wreck, and thus the long term management, is the movement of sediment in the vicinity of the wreck's complex archaeological deposits. At present, informal observations by the Licensee and others have pinpointed sediment movement as an issue but there is insufficient data to estimate timescales and quantities of movement, or indeed to understand cause and effect.

4.4.6. Analysis of the 2002 multibeam dataset suggested that the data was of a sufficient resolution, and that point data was sufficiently well positioned to justify use of the dataset as a baseline for future comparative purposes. This dataset provides the best historical dataset in terms of monitoring the long term evolution of the *Stirling Castle* wreck in its environment.

4.4.7. A survey programme was compiled to carry out two surveys of the *Stirling Castle* site within the RASSE timescale using remote sensing equipment of a similar specification (if not better) to that used in 2002, combined with sampling of sediments and scientific analysis. The project methodology for this work was designed to quantify any sediment movement process, and to allow the beginnings of discussion on cause and effect.

5. Tasks undertaken – fieldwork research

5.1. Introduction

5.1.1. In Year One, the Project undertook a programme of fieldwork on test sites in the English Channel. A diary of the activities involved in this research programme is included in Appendix 3. The following sections provide a summary of the results of this fieldwork.

5.2. Year One: deployment, surveying, and processing methodology

Survey vessel

5.2.1. The survey vessel for the 2005 RASSE fieldwork was the 12m survey catamaran *Xplorer*, an MCA category 2 work boat operated by SeaTrax, a small survey charter boat company based in Portsmouth (Figure 5).

5.2.2. The vessel was chosen because:

- It could effectively house all survey equipment within the wheelhouse;
- Its size enabled it to manoeuvre effectively over the test sites and the *Stirling Castle*;
- The RASSE mounting framework for deploying the Reson 8125 sonar head bolted directly on to existing mounting points on the hull, thereby considerably reducing mobilisation time on the sites;
- A mounting framework existed on the starboard side suitable for use with the Submetrix bathymetric sidescan;
- It came with a skipper used to the requirements for careful, high definition survey work;
- Its high-speed transit capability enabled mobilisation and deployment of the sonar in Plymouth and then subsequent use at the *Stirling Castle* within a reasonable timeframe.

Position fixing and orientation

5.2.3. For the test site work in Plymouth, the survey and navigation system onboard consisted of an Applanix POS-MV 320 (Position and Orientation System for Marine Vessels) that combined Real Time Kinematics (RTK) with the most accurate of the commercially available motion reference compensation systems.

5.2.4. Positional accuracy to centimetric levels in XY and Z was achieved using the RTK system. RTK works on a similar principle to conventional differential GPS, but phase-based corrections are applied using a dedicated base station instead of publicly available long-distance range-based corrections.

5.2.5. RTK CMR+ correction messages from Sonardyne's semi-permanent GPS base station were provided to the POS-MV via Trimtalk 450 radios. The POS-MV was then able to operate in 'tightly coupled' fixed RTK mode.

5.2.6. The base station is located in Sonardyne's offices in Turnchapel, approximately 3km from the test site on the breakwater at location:

Station	**Easting (UTM 30) [Latitude WGS84]**	**Northing (UTM 30) [Longitude WGS84]**	**Elevation (above WGS84 ellipsoid)**
Sonardyne Turnchapel	418984.503 [50 21.843999 N]	5579730.800 [004 08.344867 W]	93.033

Table 2: Positions of the Sonardyne base station at Turnchapel

5.2.7. On the *Stirling Castle* site and for relevant sites surveyed between Plymouth and the Goodwin Sands, RTK was not utilized however, due to the problems associated with the need to set up RTK base stations within appropriate range. Positioning in these instances was provided by a survey standard DGPS system with an accuracy sub 2m.

5.2.8. Vessel movement was compensated for in all 2005 survey work with the Applanix POS MV utilising two Novatel GPS antennas mounted on the top of the wheelhouse of *Xplorer*, 3m apart to deliver heading and motion information, and a motion reference unit to correct heave, pitch and roll. Great attention to detail was given to the measurement of the lever arms (offsets) between the sonar heads and the motion and positioning sensors.

5.2.9. The tidal variation was exploited to utilise the optimum range between the sonar head and the sites so that the best survey definition was achieved.

Datums

5.2.10. Data acquired onboard the survey vessel used the ETRS 89 Datum (UTM Grid) and heights were adjusted to Ordnance Datum Newlyn (ODN) during post-processing.

5.2.11. The difference in height between the WGS 84 ellipsoid and ODN for the purposes of the Plymouth survey was calculated using proprietary software.

Sonar systems

5.2.12. The RASSE project opted to test a selection of bathymetry (both beam forming multibeam and interferometric) and sidescan system types in 2005:

Multibeam sonar (beam forming type)

5.2.13. Beam-forming multibeam systems form a set of virtual 'beams' mathematically and detect the range to the seabed in each beam. The best archaeological survey results using multibeam systems have involved beam-forming systems. In 2005, the RASSE team trialled a dual head Reson 8125 Ultra High Resolution Multibeam Echosounder.

5.2.14. The Reson 8125 system has an operating frequency of 455khz, and can cover a 120º swath on the seafloor consisting of 240 dynamically focused beams (Figure 6). The 8125 uses focused true time delay beam forming to provide a high level of detail. Up to 240 soundings are collected with every pulse of the multibeam across the swath and this can happen up to 40 times per second depending on the depth of water. The system is designed to record features up to 120 metres beneath the sonar head but at that depth, the point resolution is less than for shallower features.

5.2.15. The 8125 multibeam sonar heads were attached over the port side of the survey vessel on a rigid mounting at the stern quarter designed by an engineer at the University of Glasgow. The twin-pole arrangement prevented free movement of the head relative to the vessel, yet could be dismounted and remounted within minutes without the need for time consuming recalibration. This prototype system proved highly effective in the field and contributed significantly to improved data collection. Furthermore, the easy deployment without extensive re-calibration significantly reduced mobilisation time between successive surveys both on and between sites.

5.2.16. Components of the sonar system comprise the sonar heads themselves, two sonar processor units, Seabird CTD and Navitronic SVP-15 sound velocity probes, and a dual processor PC with increased hard disk capacity for sonar acquisition (see figure 7).

5.2.17. One sound velocity probe was attached near the sonar heads on the pole. The probe provided continuous measurements for the purposes of the beam forming process employed by the Reson system.

5.2.18. A second sound velocity probe was used for obtaining sound velocity profiles through the entire water column at regular intervals during the survey.

5.2.19. Sonar processors that control the acoustic parameters of the sonar heads were placed inside the wheelhouse alongside the system PC. Constant adjustment to these processor units was required during the surveys, aided by a visual display of the raw sonar data. Various settings for range, gain and ping rate limited the number of bad soundings acquired during the survey and facilitated post-processing.

5.2.20. Full calibration of the system was undertaken prior to commencing survey work. Survey configuration details are given in Appendix 3, detailing survey input details, POS-MV GAMS results, patch test results and survey parameters.

Sonar data acquisition

5.2.21. QINSy v7.5 survey and acquisition software running on the PC was used to control the survey with a navigational chart backdrop for the positioning of survey grids and the provision of detailed navigational information (which could be displayed on a separate helm screen) to aid *Xplorer*'s skipper during the running of survey lines.

5.2.22. The QINSy software co-ordinated a database of all aspects of the system setup which included the offset measurements necessary between the various components and also water column sound velocity profile data. The software also created appropriate file folders during data acquisition to aid file management.

5.2.23. The data collected by the system comprises QINSy database files for each individual survey line, and optional point files (as XYZ ASCII text). The point files could be imported immediately into other visualisation software (such as Terramodel Visualiser or Fledermaus) to view the data just collected in three dimensions during or after the survey. This was very useful in determining whether any problems existed with the data during the survey.

5.2.24. The QINSy database files were in effect the end result of the field survey. These files can be subsequently replayed if necessary (generating new XYZ files) following adjustments to certain parameters (such as patch test settings, tidal data, or sound velocity files).

Backscatter data from multibeam

5.2.25. For each ping the Reson 8125 also outputs two channels of backscatter data (multi-beam side scan). One channel represents the sum of the port beams, the other the sum of the starboard beams. The QINSy software stores the backscatter in the same database as the bathymetry data.

5.2.26. Backscatter datasets from the 8125 were acquired for the Plymouth and *Stirling Castle* sites.

5.2.27. QINSy includes the Time Varied Gain (TVG) normalisation technique to dampen the amplitude of the strong nadir values and enhance the weaker outer beam values.

Post-Processing

5.2.28. Post-processing was conducted by Netsurvey Ltd. using QINSy software initially and then Caris HIPS to clean the data and ignore erroneous soundings. This process required an experienced data processor to manually delete bad soundings, using automated processes that perform a statistical analysis of the soundings in each swath. Basic XYZ coordinate positions for each acoustic reflection were recorded in a number of formats, including ASCII text files.

5.2.29. The QINSy software stored all the soundings generated during the surveys.

5.2.30. QINSy database files were used to generate separate XTF files for each of the sonar heads - port and starboard - for use in Caris software.

5.2.31. Patch test values were applied in real-time, as was the single sound velocity value from the Seabird CTD (typically 1520m/sec) for refraction. Sound Velocity Profiles were regularly measured and showed the velocity to be the same throughout the water column. For the Plymouth work QINSy was able to use the GPS RTK height in real-time, so that fully corrected soundings were recorded to processing data files in real-time, and available for editing immediately at the end of each line.

5.2.32. The method employed for the RASSE surveys produced vast numbers of bathymetric points. To ensure that complete coverage was provided for the sites the survey lines often overlapped and therefore any one object was likely to be ensonified a number of times during different survey passes. Errors in the positioning system and/or motion reference unit will be carried through into positioning errors for the individual soundings. Even these small errors will lead to objects appearing 'blurred'.

5.2.33. Therefore single passes at slow speed were used to collect maximum detail of the Plymouth test site and the *Stirling Castle*, rather than combining the soundings from multiple passes to increase data density.

5.2.34. Ideally, positioning provided from RTK systems on this survey is essential for the longer-term comparison of subsequent datasets (i.e. for monitoring purposes).

Visualisation and analysis

5.2.35. The processed XYZ data was transferred to Trimble Terramodel software where it was examined with Trimble Terramodel 3-D Visualiser using point clouds, rather than rendered surfaces. This allowed measurements to be taken and features to be identified for subsequent attention.

5.2.36. The Project has recently acquired industry-standard multibeam 3-D visualisation software, Fledermaus Pro, and once staff have been fully trained in its use, further analysis of the test site data will take place. It is likely that this new tool, specifically designed for multibeam analysis, will provide additional useful information about the capabilities of multibeam sonar than Terramodel, which was designed primarily for road engineers. Data was saved and exported using Geotiff format.

5.2.37. ArcGIS 8.1 software was used to perform any further data analysis in relation to data sets.

Bathymetric sidescan (Interferometric multibeam system)

5.2.38. Interferometric (phase comparison) multibeam systems measure angle for each of a set of ranges (as opposed to measuring the range for each of a set of angles). In 2005, the RASSE project trialled a Submetrix 2000 (SEA Ltd.) bathymetric sidescan (Figure 8).

5.2.39. The Submetrix System 2000 bathymetric sidescan has 117 kHz sonar transducers with an effective survey depth of 150m which under typical survey conditions manifests itself as a 0.25m² ensonified patch and 25cm depth resolution suitable for widearea surveying. Acquisition settings varied with transmit lengths of 8- 100cps (8- 424usec), a ping rate of 3 - 5 per second and 2048 sample receiver length. After testing, it was decided to use the minimum pulse length (8usec) possible for the sonar with the highest ping rate (6 pings per second).

5.2.40. The sonar transducers were mounted on a side pole mount together with the motion reference unit (TSS DMS-05) onto the starboard side of *Xplorer* amidships. Both were connected to the control computer together with a DGPS and magnetic compass for positioning (accuracy less than 20cm). The motion reference unit was a TSS DMS-05 dynamic motion sensor which used solid state sensing elements to measure instantaneous linear accelerations and angular rates of motion change to 0.05º. The magnetic compass used was an Aximuth 1000 produced by KVH Industries, Inc. This fluxgate digital compass provides azimuth information to 0.5º accuracy after compensation.

5.2.41. Sonar processors that control the acoustic parameters of the sonar heads were placed inside the wheelhouse alongside the system PC. The acquisition was accomplished using SEA Swathplus software. The data was constantly monitored during acquisition in order to achieve the best data quality control.

5.2.42. Prior to surveying, a calibration patch test was conducted for the swath-bathymetry system that included calibration for roll, pitch, heave, skew and time lags The patch test was conducted in an area of flat sea floor and an area where there were known objects.

5.2.43. The bathymetric sidescan was also used in a similar manner to the 8125 multibeam with offset lines tested at various survey speeds.

Sonar data acquisition

5.2.44. Swathplus (SEA Products) survey and acquisition software running on the PC was used to control the survey together with navigation software Hypack Max from Coastal Oceanographics Inc., which could be displayed on a separate helm screen to aid *Xplorer*'s skipper during the running of survey lines.

5.2.45. The data collected by the system comprises Swathplus .RAW acquisition files for later processing using the same software.

Backscatter data from swath bathymetry

5.2.46. For each ping the SEA System 2000 also outputs two channels of backscatter data (swath bathymetry side scan). The Swathplus software stores the backscatter sidescan in the same database as the bathymetry data.

5.2.47. Backscatter datasets from the Swathplus were acquired for the Plymouth and *Stirling Castle* sites during the 2005 RASSE fieldwork.

Post-Processing

5.2.48. Post-processing is being conducted by the University of St Andrews using Swathplus and Grid2000 software initially and then IVS Fledermaus to clean the data and ignore erroneous soundings.

5.2.49. Results from the patch test values were applied in preliminary format in real-time but were fully applied in later processing. During this time, tidal corrections together with velocity corrections were applied.

5.2.50. The method employed for the RASSE surveys produced vast numbers of bathymetric points. To ensure that complete coverage was provided for the sites the survey lines often overlapped and therefore any one object was likely to be ensonified a number of times during different survey passes. Errors in the positioning system and/or motion reference unit will be carried through into positioning errors for the individual soundings. Even these small errors will lead to objects appearing 'blurred'.

5.2.51. Ideally, positioning provided from RTK systems on this survey is essential for the longer-term comparison of subsequent datasets (i.e. for monitoring purposes).

Visualisation

5.2.52. The bathymetric sidescan data was first examined with IVS Fledermaus using both point clouds and rendered surfaces, from which measurements were taken and features identified for subsequent attention.

Sidescan sonar

5.2.53. Sidescan sonars transmit a narrow acoustic beam to the side of the survey track line. As the acoustic beam travels outward, the seabed and other obstructions reflect some of the incident sound energy back to the sonar. The travel time of the acoustic pulses from the sonar are recorded together with the amplitude of the returned signal as a time series and sent to a topside console for interpretation and display.

5.2.54. The project used the Klein 3000 side scan sonar, perhaps the best in a new generation of digital sidescan survey instruments that is readily available to the archaeological community (Figure 8).

5.2.55. The Klein 3000 sidescan operates on two frequencies, 100kHz and 500kHz and comprises a surface processing unit, a monitor and 'fish', deployed and towed from the stern of *Xplorer*.

5.2.56. Sidescan sonars transmit a narrow acoustic beam to the side of the survey track line. As the acoustic beam travels outward, the seabed and other obstructions reflect some of the incident sound energy back to the sonar. The travel time of the acoustic pulses from the sonar are recorded together with the amplitude of the returned signal as a time series and sent to a topside console for interpretation and display.

5.2.57. Antennae to fish 'lay-back' distances were calculated from the GPS antennae on board and keyed into the software, to enable accurate positioning of the 'fish'. The fish was not deployed together with a tracker system and this is seen as potentially greatly improving the visual quality and quantitative value of the results in the future.

Post Processing

5.2.58. Post Processing was carried out using Klein Sonar Pro Software and Cheseapeake Sonarweb Pro software. All results were logged on DVD Rom. SonarWeb Pro processing uses amplitude corrections to the amplitude time series based on the work of the USGS. The processing method incorporates the following steps:

- Import raw data from the bathymetric sidescan together with the full navigation information. The lines are imported at the maximum resolution or at a resolution to match the bathymetric model – 1m for the whole site with 10cm for specific areas of detail;
- Geometrical correction and amplitudes adjustment for offset angles from the transducers. Nadir is removed using bottom tracking algorithms with manual adjustment in areas of rapidly changing bathymetry;
- Line projection onto the relevant datum and overlapping data is combined to give a mosaic of the whole site. Overlap data

points are averaged to give the mean amplitude values from all crossing tracks;

- Final output in the form of geo-referenced TIFF and geo-referenced JPEG files together with high resolution single pass sonar lines.

AGDS single beam sonar

5.2.59. Acoustic ground discrimination systems (AGDS) are based on single beam echo sounders and are designed to detect different substrata by their acoustic reflectance properties. AGDS has been used for data acquisition in previous archaeological surveys and has also been commonly deployed in seafloor mapping projects for biological habitat studies.

5.2.60. A dual frequency, single beam sonar with acoustic ground discrimination system (SEA Echoplus™ SEA Ltd, Bath) was used during routine data acquisition. The sonar used with the AGDS was the *Xplorer* Furuno dual frequency echo-sounder operating at 28kHz and 200 kHz.

5.2.61. Since the Echoplus samples approximately four to eight times a second depending on water depth, the position between DGPS fixes (at one second intervals) was then interpolated to give a position for each Echoplus measurement.

5.2.62. The data for roughness (E1), hardness (E2) and position was then reviewed in database format to determine bad data from system noise usually manifested as sudden increases or decreases in Echoplus values, and bad data from navigation jumps.

5.3. Year One: Artificial test site preparation

5.3.1. The objective of setting up was to provide a test area for the refinement of techniques for mapping environmental context, and for maximising the detail obtained from high resolution sonar.

Work undertaken

5.3.2. During project planning, a test site on apparently flat seabed at a depth of 5 - 6m was identified from UKHO charts in a sheltered location close to the Plymouth harbour breakwater, Plymouth Sound. On arrival, this location proved to be rockier and less flat than required. As a result, it was decided to utilise the flattest part of the seabed within the area allocated by Queens' Harbour Master at Plymouth.

5.3.3. The final test site was located close to the east end of the breakwater fort and north of the breakwater on a flat sandy seabed, with a low rocky reef at a depth of 9-10m, somewhat deeper than was initially planned.

5.3.4. The project was able to undertake comparative surveys on a secondary test site located 200m to the west. This test area was developed by Fort Bovisand, Nautical Archaeology Society (NAS) and Sonardyne Ltd. It consists of larger targets up to 4m high distributed around the base of the Breakwater Fort in depths of up to 13 m. The largest objects included a CSWIT lattice framework 8.5m x 2.6m x 3.7m high, two hollow concrete blocks 3m x 2m x 4m high, and a wooden wreck, the *Tavy*, 7.75m long.

5.3.5. The RASSE project team selected 42 targets, ranging in size from an 8-armed cross made up of 0.2m tubes each 1m in length, to a dining fork less than 10mm wide (Figure 10). The test artefacts were made of various materials, generating different acoustic signatures, and representing artefact types commonly present on archaeological sites underwater. These objects were photographed ashore prior to emplacement on the seabed.

5.3.6. The setting up of the site was undertaken over a three day period by Falmouth divers. The dive team deployed a fibreglass-reinforced plastic surveying line for 70m east to west on the seabed. This line was pinned to the seafloor at intervals and test objects were then placed at set positions for 60m along it.

5.3.7. A list of the items deployed, their orientation with respect to the line, and their orientation with respect to the seafloor is given in Appendix 4.

5.3.8. Absolute positions for the targets were calculated from the acoustic data. Four acoustic beacons were placed at 20m intervals from zero on the base line. These were positioned by Sonardyne L.t.d., using a Scout ultra short base line (USBL) acoustic positioning system deployed from one of their survey vessels.

5.3.9. Under supervision from the Project members, all test site material was finally removed by the Falmouth Divers team on 09/04/05, and the seabed was left clear of all objects as required under the conditions imposed by the Queens' Harbour Master at Plymouth.

5.4. Year One: Testing of different sonar types at Plymouth test site

Survey work carried out

5.4.1. The test sites were surveyed over a four day period using all four sonar systems. Multibeam surveying of the test sites took place on 07/04/05 at low water to reduce the distance between the sonar heads and the targets.

5.4.2. Each survey line represented one recorded database file. Each database file was given a unique Sequence Number.

5.4.3. Survey lines were established over the test site to ensure that successive surveys with different equipment could follow the same course over the seabed.

5.4.4. Unfortunately, It was not possible to record the site visually using either an ROV or a diver held stills camera because strong winds prevented anchoring.

Post processing and analysis

5.4.5. Processed multibeam XYZ data was transferred to Trimble Terramodel software and the Visualiser option in the program was then used to interrogate every object in the main test site and also the neighbouring larger targets.

5.4.6. The Project has recently acquired industry-standard multibeam 3-D visualisation software, Fledermaus Pro, and once staff have been fully trained in its use, further analysis of the test site data will take place.

5.4.7. Initial analysis of the sidescan data has been undertaken and images from the test site have been sent to Dr Louis Atallah, University of Edinburgh but results on the automated recognition of objects using this data are as yet limited.

5.4.8. No analysis of the AGDS or bathymetric sidescan data has yet been undertaken.

Results – Plymouth test site

Multibeam

5.4.9. Processing of the multibeam data has generated images of the RASSE test site (figure 11) and the Sonardyne site (figure 12).

5.4.10. Using the Reson 8125 multibeam data, it is possible to identify 14 of the 42 objects, far fewer than was anticipated due to the water being deeper than had been planned

Sidescan sonar

5.4.11. The Klein 3000 sidescan data indicates the presence of objects on the seabed of the RASSE test site. The patterning and orientation of these objects indicates that the presence of a manmade assemblage, and it is possible to identify the star using a naked eye. However, the other objects are not identifiable.

Discussion

5.4.12. Lessons learned from the test site survey are being used to inform a set of guidance notes for EH, curators, and surveyors. In relation to the deployment of multibeam sonar, this fact finding process has so far delineated at least 30 human, environmental, or mechanical factors that affect data quality (see section 7).

5.4.13. In relation to the test site survey, the following comments are pertinent.

5.4.14. The highest standard of bathymetric marine surveying, IHO Special Order, has a minimum size of object detection set at 1m3. Archaeological surveys regularly exceed that requirement. Although a range of cube sizes was not included in the test site assemblage, a near-spherical object (a more difficult object to detect) of 0.6m diameter (diver's helmet) was detected in all five passes, as was the star shape made from eight 0.2m diameter tubes each a 1m long. The system only detected two tubes parallel to the track of the survey of a similar shaped target made with 0.1m x 1m long tubes, indicating that orientation of objects is an important factor.

5.4.15. Results suggest that a twin head Reson 8125 system does not warrant the additional cost and effort of installation in standard configuration. Two heads gives two slightly differing viewpoints of the sonar record but this is only of advantage when viewed as stereo images, something which can now be done by an alternative approach as software like Fledermaus allows virtual stereo images to be produced by calculating the necessary sight lines through the cloud of point data. The distinct disadvantage of two heads is that each sonar head has to wait for the return echoes from the other's transmitted pulse before it can transmit a pulse. This effectively reduces the number of pings from each head and so the overall number of pings per second is not significantly different to a single head system. It might be however that the use of two heads would give significant advantage on a very detailed wreck survey if the heads were both separated by a distance of 1-2m and deployed nearer the targets on a work-class ROV. In this case the two heads would potentially give a greater chance of resolving the full 3 dimensionality of objects

5.4.16. We confirmed that objects of well delineated shape are more easy to identify visually in Terramodel than amorphous shapes but, although that was always likely to be obvious, we learnt that the use of 3-D software which allows objects to be rotated in front of the viewer, e.g. Terramodel or Fledermaus, allows a better understanding of not only how the features are ensonified, but also what form the ensonification takes, and this greatly helps interpretation (figure 12).

5.4.17. It is likely that the lack of object definition evident on the Reson 8125 dataset is a result of surveying in water depth deeper than was originally planned. At a depth of 9-11 metres, the system provides on average slightly fewer than 600 pings within every metre square of the seabed whereas we had hoped to reach the 1800 pings obtainable with range settings of less than 7m. This reduction in potential resolution by more than 1/3 meant that fewer objects at the smaller end of the size scale were detected than anticipated, and far fewer were identifiable.

5.4.18. Range settings of the Reson 8125 is related to depth of water and controls the number of pulses of acoustic energy (pings) that can be placed in the water at any one time because the returning echoes from the first ping have to be received before the next ping is transmitted, otherwise there would be too much noise in the water at any one time. This would result in so much noise in the data that good from bad information would be impossible to separate. For that reason range setting controls the number of pings from 40Hz at 5m, 31Hz at 10m and 17Hz at 20m. Even with the very narrow beam forms of the Reson 8125 of 0.5º across track and 1º along track, range has a measurable effect on the footprint of each beam and the number of beams formed within every square meter of seabed.

5.4.19. Differences in a survey vessel's speed over the ground has an even more pronounced effect on the along-track gap between the footprint of each beam, with more data being collected at very slow speeds when the gap between each set of pings is reduced.

5.4.20. Lessons learned from the other geophysical techniques are still being evaluated.

5.5. Year One: *Stirling Castle* survey

Survey work carried out

5.5.1. Surveying of the wreck site commenced on 15/04/05 and was completed on 19/04/05 using all sonar systems described in section 5.2.12. During this time period calm weather with a low sea state contributed to high quality survey data.

5.5.2. A widearea survey was undertaken of the seabed surrounding the wreck, in order to map the environmental setting for the site.

5.5.3. This was followed by specific slow passes over the wreck site where a number of different acquisition parameters were tested. In particular, the angle of survey over the site was varied as was the offsets. A similar range of conditions were tested for both the sidescan sonar and the bathymetric sidescan.

5.5.4. Survey lines were established in the same way as those for the Plymouth work. When using the multibeam systems however the survey was at times conducted with the vessel skipper making full use of the image of the seabed being generated real-time on the helm monitor to ensure that full coverage and infill etc was achieved. This was necessary because of the changes in depth of the seabed in the vicinity of the *Stirling Castle*.

5.5.5. One survey line represented one recorded database file. Each database file was given a unique Sequence Number. The survey lines recorded were as follows

15/04/05	Goodwin Sands – *Stirling Castle*	149,150	Calibration
15/04/05	Goodwin Sands – *Stirling Castle*	151-159, 164-169	Passes over wreck
15/04/05	Goodwin Sands – *Stirling Castle*	160-162	Wide area survey
16/04/05	Goodwin Sands – *Stirling Castle*	186- 207	Wide area survey
16/04/05	Goodwin Sands – *Stirling Castle*	208 - 215	Wide area survey

Table 3: line information for the *Stirling Castle* survey

5.5.6. It was not possible to obtain ground truth information over the site using either a ROV or still camera as the turbidity of the water was extremely high.

5.5.7. Sediment samples were taken around the wreck site for grain size analysis (see figure XX) at the Facility for Earth & Environmental Analysis, University of St Andrews using a Coulter LS230 laser particle size analyzer.

Post Processing work – *Stirling Castle*

Klein 3000 sidescan data

5.5.8. Captured images from the Klein 3000 sidescan survey have been submitted to Dr Louis Atallah for object recognition purposes.

Reson multibeam data

5.5.9. In the first instance tidally corrected and cleaned XYZ data processed from the April 2005 fieldwork on the *Stirling Castle* by Netsurvey Ltd., was imported into Terramodel (version 10.3) software onto different layers. Each XYZ file imported represented a survey line and each was placed on a different layer within Terramodel. Four line files from the April 2005 fieldwork survey were imported representing the port and starboard sonar head output from lines 151 and 152 (Unique Sequence Numbers).

5.5.10. Importing the XYZ files generated from the multibeam into Terramodel at this stage had the following advantage: It provided a means by which the vast numbers of bathymetric points within each file could be seen to cover the area of interest for specific analysis and seen to be of appropriate quality. Undertaking the same process using ArcGIS would have presented problems purely due to the large numbers of points involved.

5.5.11. Within Terramodel, an area (approximately $50m^2$) immediately surrounding the *Stirling Castle* was chosen and this area then used to select all bathymetric points within it from the four imported files existing on each layer. Larger areas will subsequently be used once the methodology has been shown to be effective.

5.5.12. All selected April 2005 bathymetric points were then output as a single XYZ file in comma separated form (*.csv).

5.5.13. Moving to ArcMap 8.1 the single *.csv file was imported via the 'Add Data' dialogue and selecting the *.csv file. The point data was then displayed in a new workspace within the GIS using the 'ADD XY Data' tool.

5.5.14. Making use of the 3D Analyst within ArcMap a TIN (triangular irregular network) surface was then created using the events derived from the imported XYZ points, making sure that the height source was correctly set to the 'elevation' field of the *.csv file. The points were triangulated as mass points. The resulting TIN for the April 2005 8125 multibeam data is illustrated in Figure 13.

5.5.15. Within ArcMap a series of five points were chosen across the highest points of the *Stirling Castle* as represented by the TIN running from the bow to the stern along the centre line. The elevations of these five points were noted to three decimal places for the purposes of adjusting and matching the elevations of subsequent (un-tidally corrected) datasets for comparative purposes. It was assumed that these five points were of objects on the wreck site that were least likely to have moved over the last three years.

5.5.16. Returning to the Terramodel software, multibeam data from 2002 was imported in the same way as that for the April 2005 data described above. In this instance un-tidally corrected and raw XYZ data from 2002 survey lines 26, 27 and 28 (east-west passes) were imported, necessitating adjustment of the elevations.

5.5.17. The $50m^2$ area surrounding the *Stirling Castle* referred to above was then used to select all 2002 bathymetric points falling within it.

5.5.18. All selected July 2002 bathymetric points were then output as a single XYZ file in comma separated form (*.csv).

5.5.19. Using ArcMap the *.csv file was imported and, in the same way described above, used to create a TIN surface. The resulting TIN representing the July 2002 survey can be seen in Figure 14.

5.5.20. Still within GIS the same five locations across the highest part of the *Stirling Castle* referred to above were revisited utilising the July 2002 TIN and the elevations noted. The average difference in heights observed on the wreck at the points listed in the table below was used to adjust all elevations in the July 2002 *.csv file. The adjusted file was then exported to a new *.csv file in order that it could be directly compared to the April 2005 data.

5.5.21. Comparisons of elevations gathered for the five fixed locations given above are provided in table 4. In summary, the calculated average difference in elevation for the five fixed points (identified as per section 5.5.15) is -0.129 m.

Dataset	Point	Easting	Northing	Elevation	Difference
2005	1	395831.158	5681399.512	-12.140	
2002	1	395831.148	5681399.503	-12.197	-0.057
2005	2	395834.222	5681399.628	-12.004	
2002	2	395834.236	5681399.624	-12.059	-0.055
2005	3	395837.169	5681399.357	-11.733	
2002	3	395837.173	5681399.351	-11.946	-0.213
2005	4	395840.388	5681398.504	-11.890	
2002	4	395840.382	5681398.504	-12.101	-0.211
2005	5	395843.258	5681397.379	-11.857	
2002	5	395843.258	5681397.384	-11.967	-0.110
			Average height difference		-0.129m

Table 4: Differences in elevation for five fixed points from 2002-2005

5.5.22. Returning to ArcGIS the adjusted *csv file for the July 2002 dataset was used to create a revised TIN directly comparable with the 2005 data.

5.5.23. In order to facilitate further processing both the revised 2002 TIN and the 2005 TIN were converted within ArcGIS to raster surfaces using the “Tin to raster’ tool within ArcGIS’ 3D analyst.

5.5.24. Rasters of both July 2002 (adjusted) and April 2005 datasets were imported to ArcGIS Arcscene in order to begin visualising differences apparent between the two.

5.5.25. The raster datasets were also used with the raster calculator tool in ArcMap to produce maps that represented the difference between the two.

Preliminary archaeological Results – *Stirling Castle*

5.5.26. A bathymetric map generated from the 2002 Reson multibeam dataset of the site may be seen in figure 15. This has been produced using the methodology outlined in section 5.5.9 and following.

5.5.27. A bathymetric map generated from the 2005 Reson multibeam dataset may be seen in figure 16. This has been produced using the methodology outlined in section 5.5.9 and following.

5.5.28. There are no results yet relating to algorithm testing of the sidescan data.

5.5.29. Differences in sediment levels across the site compiled according to the methodology stated in section 5.5.20 may be seen in figure 17.

5.5.30. The results of the grain size analysis are given in table 5. A full comparison of these figures with previous results and between the ground truth data and acoustic data will be made in the next quarter.

Sample Name	N	E	Mean	Median
Enh9	5682428	396216	534	372
Enh11	5681400	396134	527	315
Enh8	5681591	395773	335	303
Enh21	5681336	395859	1835	263
Enh20	5681358	395900	345	276
Enh19	5681423	395920	2421	353
Enh18	5681461	395890	3868	1794
Enh17	5681475	395811	780	494
Enh16	5681362	395781	742	477

Table 5: grainsize analysis from the *Stirling Castle* 2005

Archaeological discussion – *Stirling Castle*

5.5.31. Based on the assumption that the elevation of the points on the wreck remains constant between 2002-2005, it is possible to attribute changes in elevation of the surrounding seabed level to real effects, I.e., the movement of sediment.

5.5.32. The datasets (figures 15, 16, 17) suggest that several metres of sediment have accreted in places around the stern, and to the north east of the wreck of the *Stirling Castle* since 2002.

5.5.33. However, at this stage, work to quantify accurately the amount of sediment transported has not been completed. In any case, it is uncertain what if anything these figures signify because of the three year interval between sampling occasions. During the intervening period, seasonal cycles and storm events may have created a far more mobile and complex sedimentary regime than these figures can indicate.

5.5.34. However, the survey and data analysis procedures developed in Year One appear to be robust. Against this background, the Project stands a much better chance of identifying significant patterns of sediment movement by comparing the April 2005, September 2005 (data gathered by the University of St Andrews during non ALSF funded work), and April 2006 data sets.

5.6. Year One: Hastings Shingle Bank test area

Work undertaken

5.6.1. A number of discrete targets were placed on the seafloor prior to the survey by Wessex Archaeology. The targets were tethered and buoyed, their position surveyed prior to the acquisition of the geophysical survey.

5.6.2. The data is currently under review and will be reported when processing is completed. Preliminary results show that the targets are visible however the resolution of the features appears less than originally anticipated.

5.6.3. The original sidescan data has been requested from Wessex Archaeology and the project is waiting on delivery of this.

6. Dissemination

6.1. Task M1-3: Web site creation

Work undertaken

6.1.1. A project web site (www.st-andrews.ac.uk/~wrecks) was designed and created using information already gathered for the project.

6.1.2. The website was made live in June 2005 and the results of the 2005 survey programme will shortly be uploaded onto the site.

6.1.3. Currently the site does not register on major search engines. Steps are being taken to remedy this by removing the ~ sign in the URL (which is not recognised by search engines), and by setting up links from websites that receive high search engine rankings.

6.1.4. The Project is due to submit a summary for inclusion on the EH website.

6.2. Task M5-1 Dissemination of results to EH and ALSF Partners

6.2.1. An introductory presentation to the project was made at the EH ALSF meeting in London on 29/03/05.

6.2.2. On 06/07/05 the results of the project to date were presented at an open ALSF meeting held in SOAS, London. A copy of the Powerpoint lecture presented at this meeting has been uploaded onto the project website.

6.2.3. A third review meeting with Helen Keeley was held at the University of St Andrews.

6.3. Task M5-21 Public dissemination

6.3.1. Martin Dean presented a paper at the Shallow Water 2005 Conference organised jointly by the UK Hydrographic Office and the Maritime and Coastguard Agency in Plymouth in September (Dean et al., 2005).

6.3.2. Dr Louis Atallah presented a paper at the Ocean 05 conference in Brest, France (Atallah et al., 2005).

6.3.3. Stand space has been booked at the IFA conference in Edinburgh in April 2006.

6.3.4. Martin Dean will present a paper on the work of the project at the SHA conference January 2006, at Sacramento.

6.3.5. Martin Dean will present a paper on the work of the project to the Reson Multibeam Russian users group in St Petersburg, in 2006.

7. Methodological lessons learned so far

7.1.1. The lessons learned from use of the sidescan, AGDS and bathymetric sidescan are still being synthesised This review process will culminate in production of Guidance Notes, for curators, archaeologists, managers, and surveyors to be produced as a separate document at the end of the project. The lessons learned will also be incorporated into survey plans for Year Two.

7.1.2. The project has already identified the following human, mechanical and environmental factors that can affect the data quality of multibeam surveys of underwater sites.

7.1.3. Numerous factors influence the quality of high definition multibeam sonar surveys, and the following observations have been grouped into human factors, engineering considerations and the influence of the environment.

7.1.4. Unfortunately, many of the factors are often ignored, or never even considered when the equipment is used for archaeological research. Furthermore, it is often the case that the factors are not appreciated for their relevance by a survey industry that often uses the equipment for different purposes.

7.2. Human Factors

Client's understanding of the survey requirements.

7.2.1. It is important for the person or organisation commissioning the survey to understand the capabilities of the specified equipment and whether it is the correct choice for the survey.

Client's ability to communicate their wishes to the survey team.

7.2.2. It is important for surveyors to discuss with clients the aim and objectives of the proposed survey so that they can advise on choice of appropriate personnel and equipment. The client needs to be advised of advice such as: using twin head systems will not normally give better definition except if viewing the data as stereo images; and most multibeam systems are not useful for searching for small targets in large areas.

Experience of the surveyor

7.2.3. Best results are generally produced by the most experienced surveyors. But a very experienced multibeam surveyor who has no experience of archaeological work may not produce results as good as a relatively inexperienced surveyor who has gained some experience on archaeological surveys.

Skill of the surveyor

7.2.4. Although there is obviously a strong correlation, experienced surveyors are not always the most skilful. One test of a surveyor's skill is whether he or she instinctively handles new software or whether they have to keep referring to manuals.

Enthusiasm of the surveyor

7.2.5. Generally marine surveyors enjoy archaeological surveys because it is different to their normal work and provides them with new challenges. However everyone, including surveyors, can suffer with domestic, financial and other pressures. The best surveyors will demonstrate their professionalism by not letting such external factors influence the quality of their work.

Working conditions of the surveyor.

7.2.6. Good surveyors can put up with having their computers and screens set up in cramped cubby holes, or in the lively forepeak of a small survey launch. While they may not complain too much with such conditions, the situation will not be conducive to the best results.

Survey lines along multiple orientations.

7.2.7. Small cross section linear features may not be visible unless the track of the survey is close to parallel to it. For this reason it is good practice to do three sets of survey lines over a site where small targets need to be detected, with an angle of 120º between each.

Experience of the processor of the survey data

7.2.8. It is best to have the same person acquire and process the data. As above, experience of processing data from similar archaeological surveys is more important than extensive experience of processing data where none has come from archaeological sites.

Skill of the survey processor

7.2.9. It is crucial that archaeological features in the data are not confused with noise (unwanted echoes) that occurs in all sonar data sets, and which is normally edited out at during the initial post processing. (See also 7.2.4 above)

Enthusiasm of the processor of the survey data

7.2.10. (See 7.2.5 above)

Skill of the data interpreter

7.2.11. This analysis of post processed data is best done by a suitably skilled archaeologist rather than a surveyor who is not likely to understand or recognise features of archaeological significance.

Experience of the survey vessel helmsman

7.2.12. The helmsman is a crucial factor in quality of survey and the experience to anticipate what is going to happen ahead is important. A good helmsman should be an integral part of the survey team and be involved in decisions such as which direction survey lines should be run, as the helmsman will have a better understanding of how the vessel behaves in a variety of wind and current situations.

Skill of the survey vessel helmsman

7.2.13. The best will be able to either follow lines precisely when guided by navigation information displayed on the helm monitor, and be able, after one such guided track, to adjust the boat position relative to changes in depth so that the most efficient coverage of the seabed is achieved, and the fewest gaps left to be filled in later.

Enthusiasm of the survey vessel helmsman.

7.2.14. (See 7.2.5 above)

Sufficient funding for the survey

7.2.15. This is a significant factor in the quality of the survey data because, if insufficient resources are available for the most appropriate equipment, etc., then second best equipment will provide second best results. Similarly if there is insufficient time available to collect good data then the survey standard will suffer.

7.3. Engineering Factors

The choice of multibeam system

7.3.1. Although this is related to 7.2.15 above, even the best and most expensive survey equipment can be acquired at odd times for less than the commercial rate. For multibeam sonar, at present the Reson 8125 SeaBat seems to provide the best results for small scale archaeological site survey, and experience has shown that there are no appreciable gains in resolution using a twin head system, but there are additional costs and installation problems. A later version, the 7125 SeaBat, has yet to be tried for archaeological surveying.

The choice of motion reference system

7.3.2. A comparison of all the major systems was recently undertaken for the Shallow Water 2005 Conference and, while many were of comparable standard one, the Applanix POS MV, although more expensive, gave measurably better results.

Choice of positioning system

7.3.3. Most surveys are reliant on calculating positions from constellations of satellites, the most common being the Global Positioning System (GPS), and the positional errors reduced by differential corrections transmitted from public or commercial base stations. A more accurate method of utilising GPS data is to exploit Real Time Kinematics (RTK) using corrections from a survey base station on the shore. In this way repeatable positions and heights can be obtained to within 1cm so that the results of similar surveys can be seamlessly integrated. The Applanix POS MV has RTK capability and currently provides the best solution for inshore archaeological work.

Accuracy of base station position.

7.3.4. If all the benefits of RTK are to be exploited then the base station on shore needs to be positioned to millimetric accuracy, with special attention paid to the height and to what datum it relates.

Distance from base station

7.3.5. The potential accuracy of a survey is better if the base station is relatively close to the site. A distance of less than 5km is ideal.

Choice of survey vessel

7.3.6. Most archaeologists use vessels of opportunity for multibeam surveys and they may not be ideal for the equipment that needs to be installed. The layout of the wheelhouse which allows computers, processors and screens to be positioned rationally is a big advantage when aiming for high quality surveys, as is having the ducting and apertures for cables. It is crucial to have the necessary range of in built power supply (often 12 and 24v DC and 240v AC) rather than ad hoc generators on the deck. Whatever is used adequate safeguards must be in place to prevent electrocution. A catamaran will often give a large wheel house for setting up survey equipment and is often seen to be more stable for surveying. However, their motion is ‘short period’ as compared to a more gentle rolling of a mono-hull. Modern motion reference units are better suited to compensating for slow rolling than rapid movements and so a trade-off must be made

Stability of the survey vessel.

7.3.7. This has two impacts on quality; personnel will be more comfortable and so more able to work to a higher standard if the platform is stable; similarly motion referencing systems have to work less and the output is therefore more accurate in such an environment. Inevitably large vessels are more stable than small boats in a given environment, but small survey boats are often necessary where manoeuvrability and shallow draft are required.

Effectiveness of the motion reference system.

7.3.8. As well as choice, (See 7.3.2 above) the position of the system on a vessel is important. Ideally it should be placed at the centre of motion of the vessel, which is difficult to determine accurately and not always possible if machinery or other equipment is in the way. Another option is to place the system as close to the multibeam sonar head as possible. The ideal solution is to place both at the centre of motion of the vessel.

Rigidity of the mounting of the sonar heads.

7.3.9. When using vessels of opportunity, archaeologists often have to devise suitable sonar head mountings for each survey. Some flexing within a survey vessel is normal and so the greater the distance between the sonar head and the motion reference system, the bigger the problem. Another problem is unwanted flexing of the pole, particularly in side mounted systems, and so the mounting has to be properly designed and engineered. A firmer mount can often be made over the bow, which tends to be easier to set up on mono-hulled vessels, and forward motion helps to keep it secure and in place.

7.3.10. A sonar head in its operational position seriously reduces most vessels’ speed during passage making. Most removable mounting systems are not capable of withstanding the force of water against them at much above survey speeds and so it is advantageous to have a mounting design that allows for rapid recovery and redeployment. This ideally should have sufficient built-in accuracy when redeployed that the time-consuming calibration of the system caused by misalignment on refitting is not necessary.

Accuracy of the measurement of the offsets between sonar heads, reference sensor and GPS antennas.

7.3.11. This is a significant problem during installation on most vessels of opportunity as bulkheads, decks, lockers, and equipment all get in the way. The most accurate solution is to take the vessel out of the water and use laser lines and a total survey station to minimise errors. Placing the motion reference sensor and one GPS antenna above the sonar head helps reduce the measurement problems but could introduce other disadvantages (See 7.3.8).

Hydrodynamics of the sonar head.

7.3.12. This normally only becomes a significant problem at higher survey speeds (>6kn) and where the sonar head mounting is not strong enough to withstand the additional forces generated when there is no streamlining.

Noise generated by the survey vessel and its equipment.

7.3.13. A good survey vessel will have had these problems sorted but it may be necessary for the helmsman to switch off the vessels own echo sounder or other equipment which may cause causing interference. A good surveyor will check the data for extraneous noise before starting a survey.

Frequency of checks of the sound velocity throughout the water column

7.3.14. As well as constant monitoring of the sound velocity through water close to the sonar head, checks need to be made regularly through the water column with a separate sound velocity probe (SVP). This interval can vary with the local environment or the state of the tide and only by sensible testing can the rate of variation be established. Good surveyors know from experience the likely requirement in a given situation but, even where there are no detectable changes, test intervals of no more than 30 minutes are recommended for high quality work.

Operating frequency.

7.3.15. The higher the frequency, the shorter the range and so dual frequency systems can be useful if work has to be done in varying water depths.

Generally speaking the higher the operating frequency, the better the definition, providing the design and manufacturing quality of the electronics is of appropriate quality. Frequencies of at least 400KHz are necessary for high definition work.

Pulse update rate.

7.3.16. Increasing the number of pulses a second generally increases the resolution but echoes from one pulse have to be received back by a multibeam system before the next pulse is transmitted. For example in a high quality high definition system such as the Reson 8125, the pulse rate is 40Hz for range settings of less then 7m and 12Hz for range settings of 30m.

Pulse width.

7.3.17. This has a small but detectable influence on survey definition so, for highest quality, it may be necessary to reduce the pulse width to below that even recommended in the manufacturers handbook. We concluded that such guidance notes were not written for close quarter, high definition work but for the average survey situation.

Distance between sonar heads and the targets.

7.3.18. The pulse update rate (see 7.3.16 above) indicates the optimum range settings. Similarly, even though the beams are relatively narrow on the best equipment (0.5º cross track and 1º along track) this still has an impact on footprint size when, for instance, comparing a range of 5m with a range of 20m.

Speed over the ground.

7.3.19. This is one of the most important factors in achieving high definition surveys. The best multibeam survey detail is obtained at speeds over the ground of 1m per second or less, (approximately 2 knots). Such a low speed is difficult for many survey vessels to achieve and impossible for most helmsmen to consider.

Software used to interpret and display the results

7.3.20. Ideally the data once collected should be analysed using high quality software, such a Fledermaus, Terramodel Visualiser or QINSy. Flying around or rotating 3-dimensional images derived from the survey data is crucial for identifying features and objects of archaeological significance on the seabed or individual parts of upstanding structures. It is important to do this using basic point clouds rather than a visualised surface of the points data, because the rendering can obscure archaeological detail.

7.4. Environmental Factors

Sea state during the survey

7.4.1. The advantage to personnel of flat seas is obvious, but such conditions also have the advantage of making the motion reference systems less prone to error.

Maximum depth of water in the survey area

7.4.2. If the site is deep then it is a problem for hull-mounted multibeam systems to collect high definition data (See 7.3.18 above).

Depth variation in the survey area

7.4.3. If the site has great depth variations within it then the range settings have to cope with what is covered by the beams. It may be possible to treat the shallow areas separately to achieve high definition and then survey the deeper water separately to a lesser quality. If there is great depth variation in close proximity, such as in the case of deep gullies, the range normally has to be set to the deepest water otherwise there can be problems with noisy data. It is also difficult to ensure overall coverage of the bottom of gullies because of shadowing from the sides if the survey vessel doesn't follow the line of each gully, and exactly overhead.

Tidal regime during the survey

7.4.4. It is often possible to exploit the minimum depths at low water to get the sonar head close to the seabed to achieve the highest definition. Similarly, it is possible to survey areas at high water which may otherwise be inaccessible by the survey vessel. Such ploys obviously depend on the range of the tide, but the range itself can lead to variations in survey definition if conducted for more than a few hours.

Variation in current strength during the survey

7.4.5. Current strength can be exploited to bring the survey speed down (7.3.19) for best results, but currents can also be sufficiently strong to throw a vessel off track unless the surveyor has set lines parallel to the direction of water flow.

Variation in current direction during the survey

7.4.6. Irregular variation can make area surveys along fixed tracks difficult but reverse direction flows can assist in keeping survey speed down by choosing to run every line against the current.

8. Bibliography

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Figures

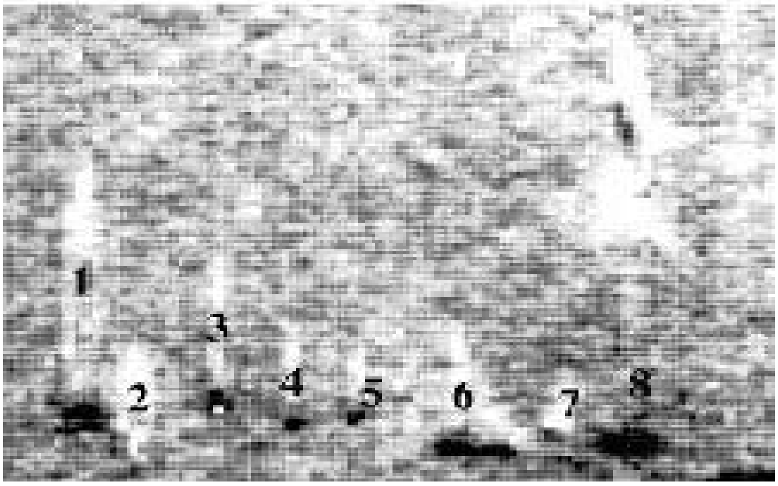

Figure 1: 8 objects can be seen in this image from the control experiment in Belfast Lough

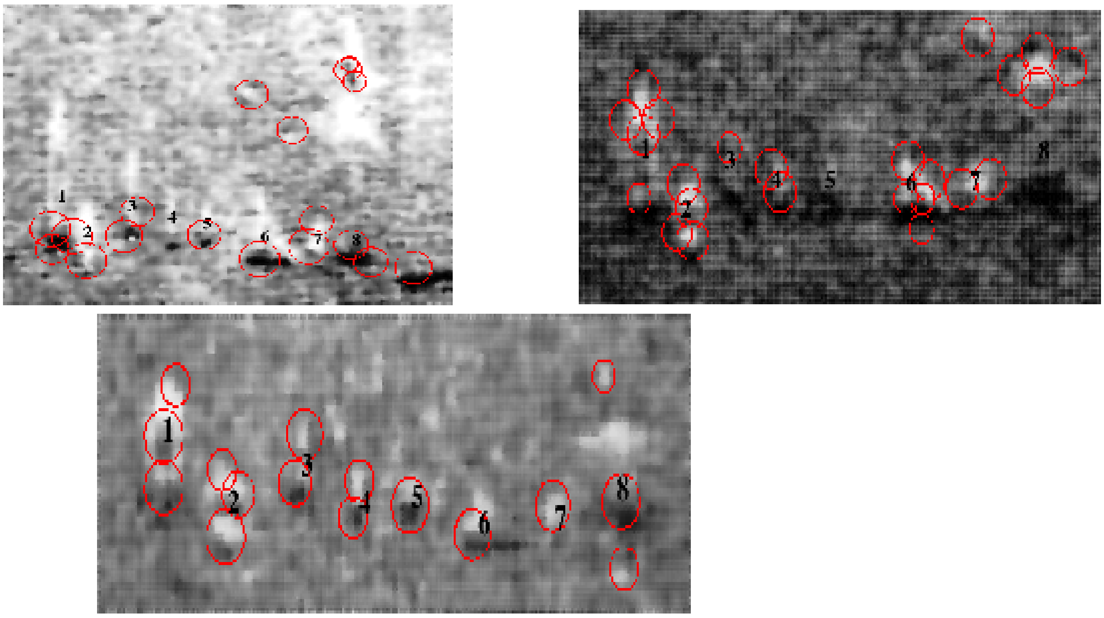

Figure 2: Results of the scale saliency algorithm on images from the Belfast Lough control experiment.

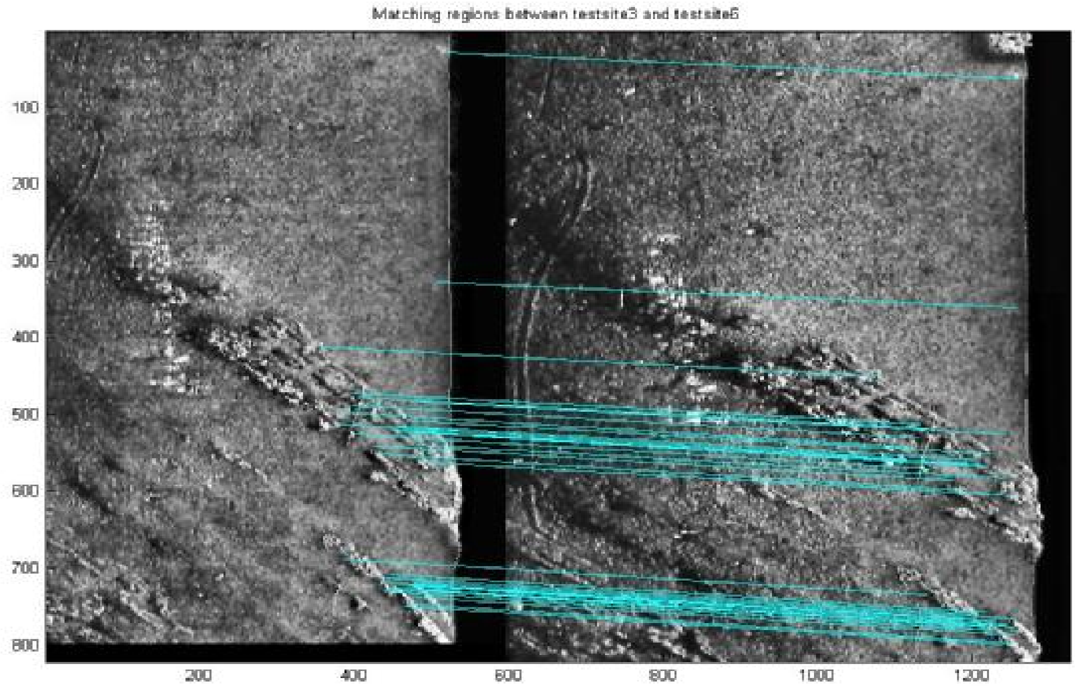

Figure 3: Matching areas between two images (testsite3 and testsite6) identified using the SIFT object matching method (see section 4.3). The matching areas are joined with a blue line.

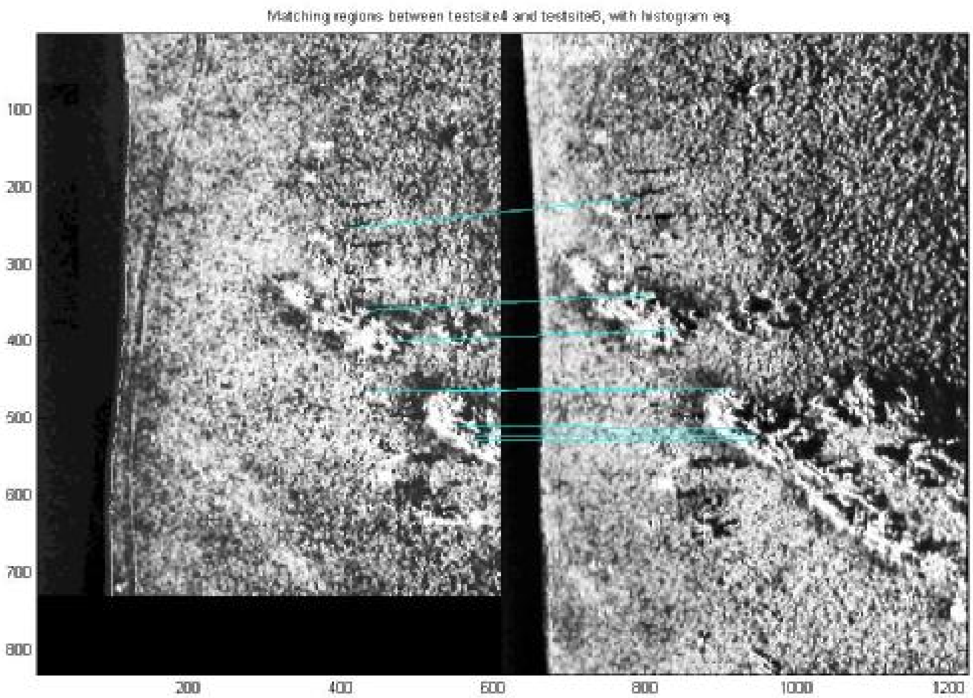

Figure 4: Matching areas between two images (testsite4 and testsite8) identified using the SIFT object matching method. The matching areas are joined with a blue line. The images are of different sizes, yet the method managed to find the matching areas.

Figure 5: Survey vessel *Xplorer*.

Figure 6: Reson 8125 Seabat multibeam system twin sonar head configuration, and wheelhouse data acquisition hardware.

Figure 7: Dual head RESON Installation on board *Xplorer*

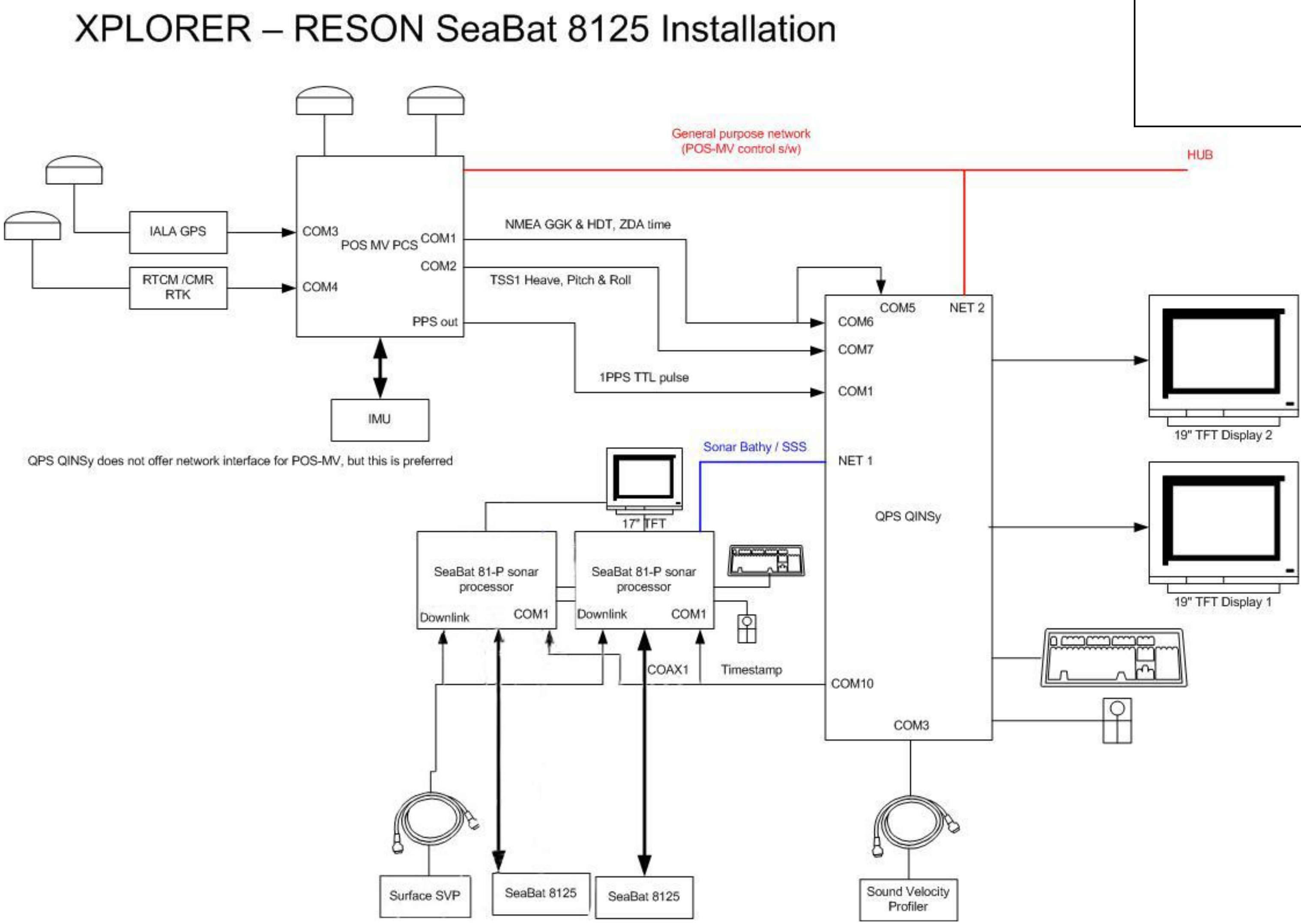

Figure 8: SEA/Submetrix SwathPlus bathymetric sidescan sonar

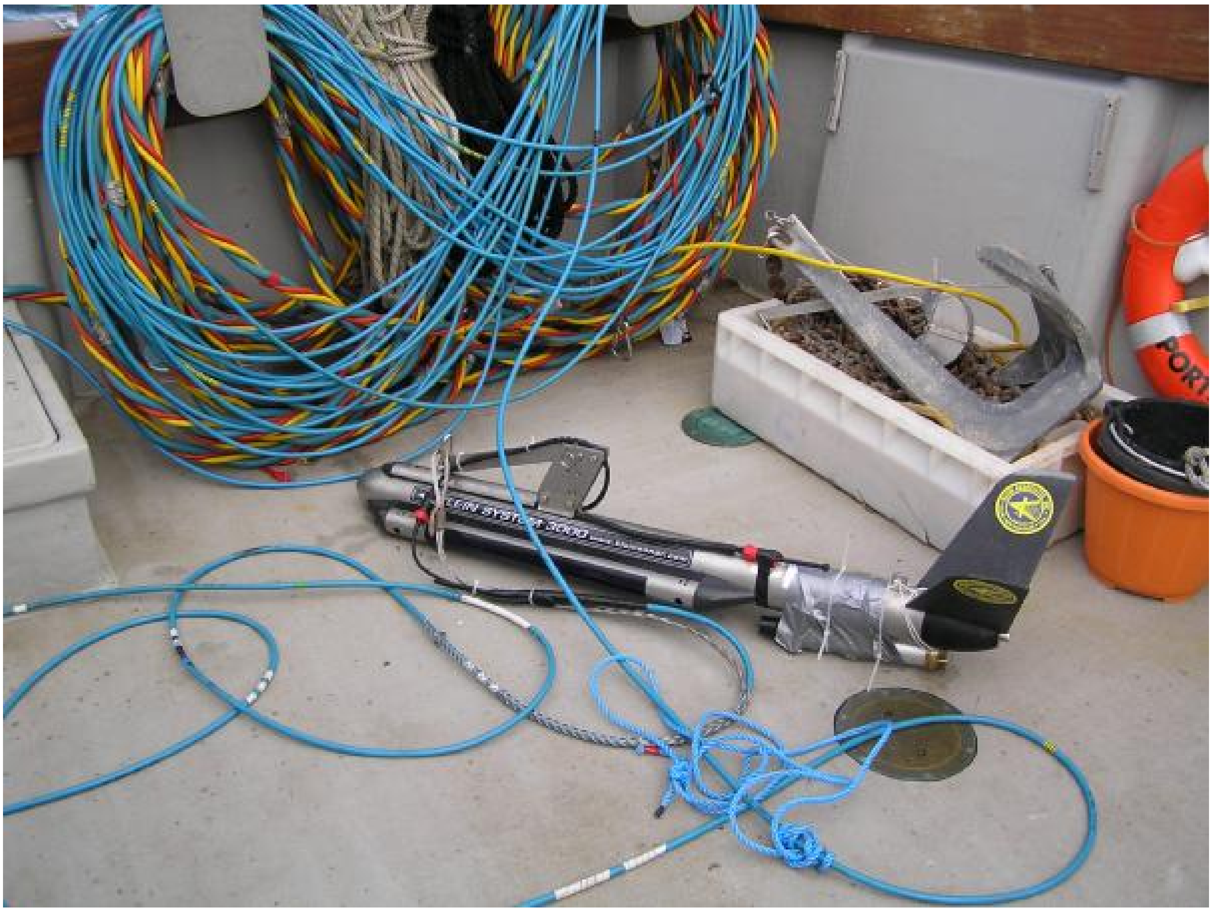

Figure 9: Klein 3000 sidescan sonar

Figure 10: A selection of test artefacts used at the Plymouth Sound test site

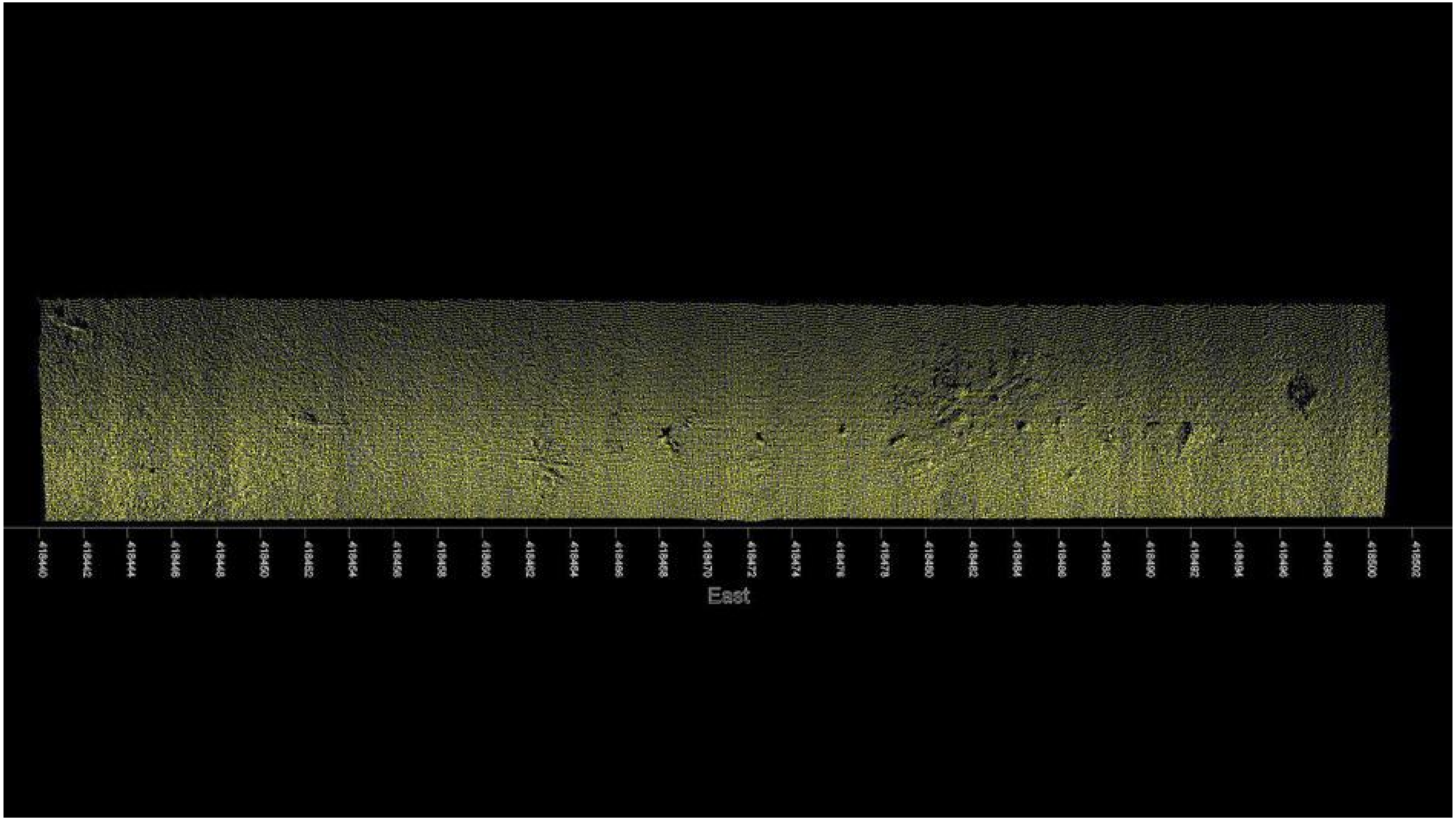

Figure 11: Reson 8125 multibeam image of the Plymouth test site exported from Terramodel.

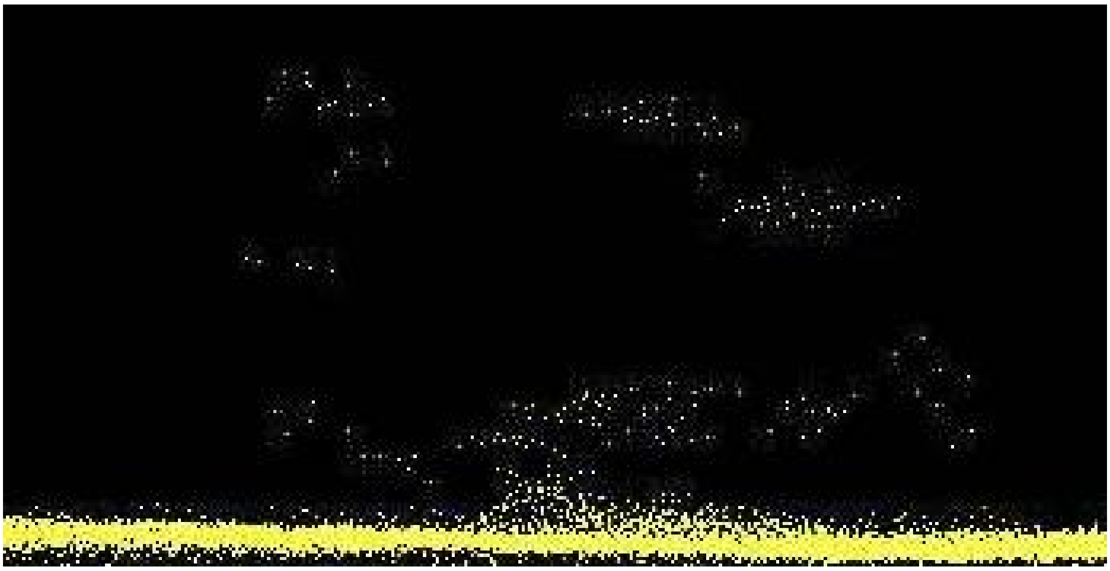

Figure 12: The top image shows Reson 8125 multibeam point data viewed in profile in Terramodel. The image is a record of the bicycle shown below.

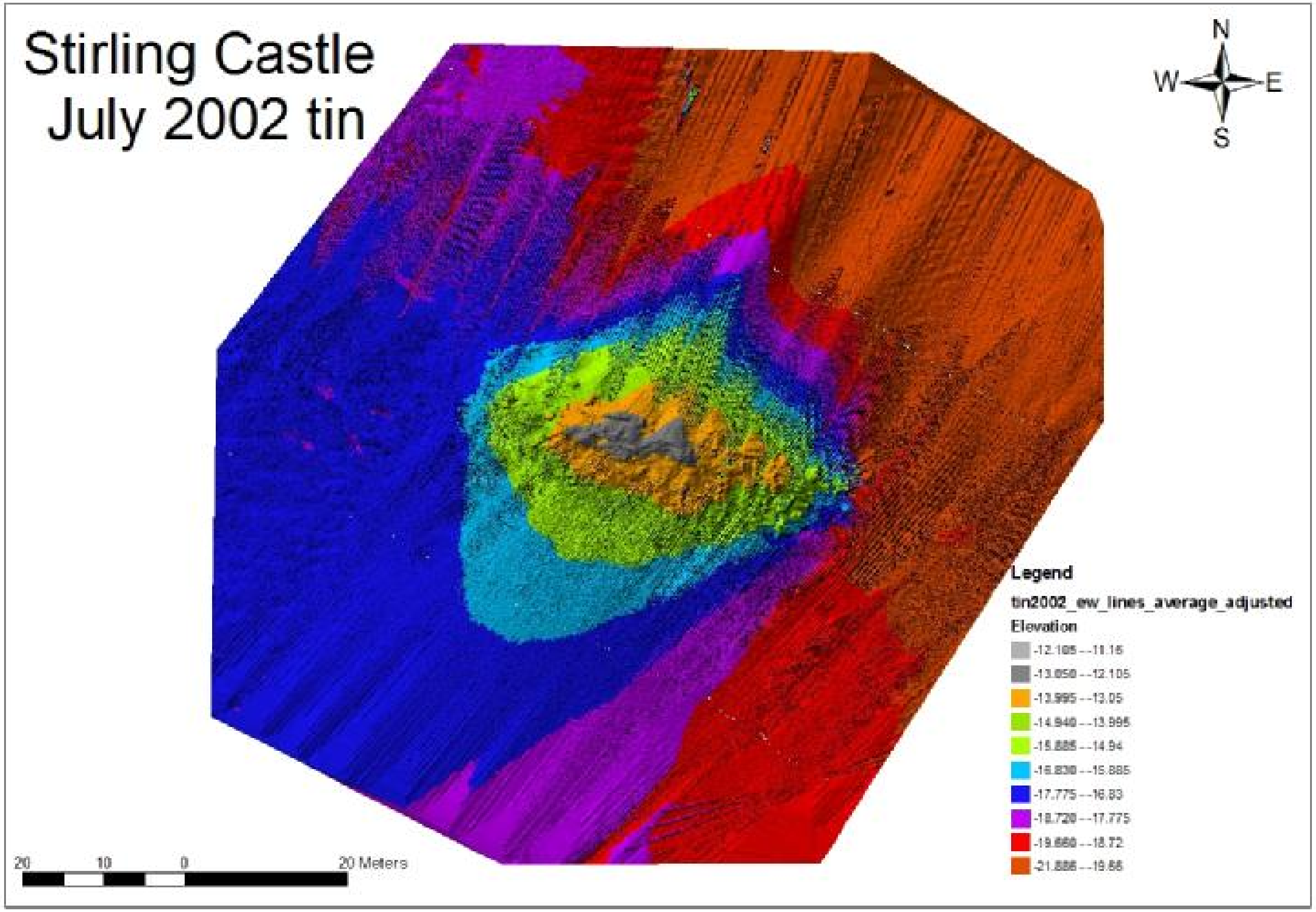

Figure 13: TIN map of the *Stirling Castle* site from Reson 8125 multibeam data gathered in 2002.

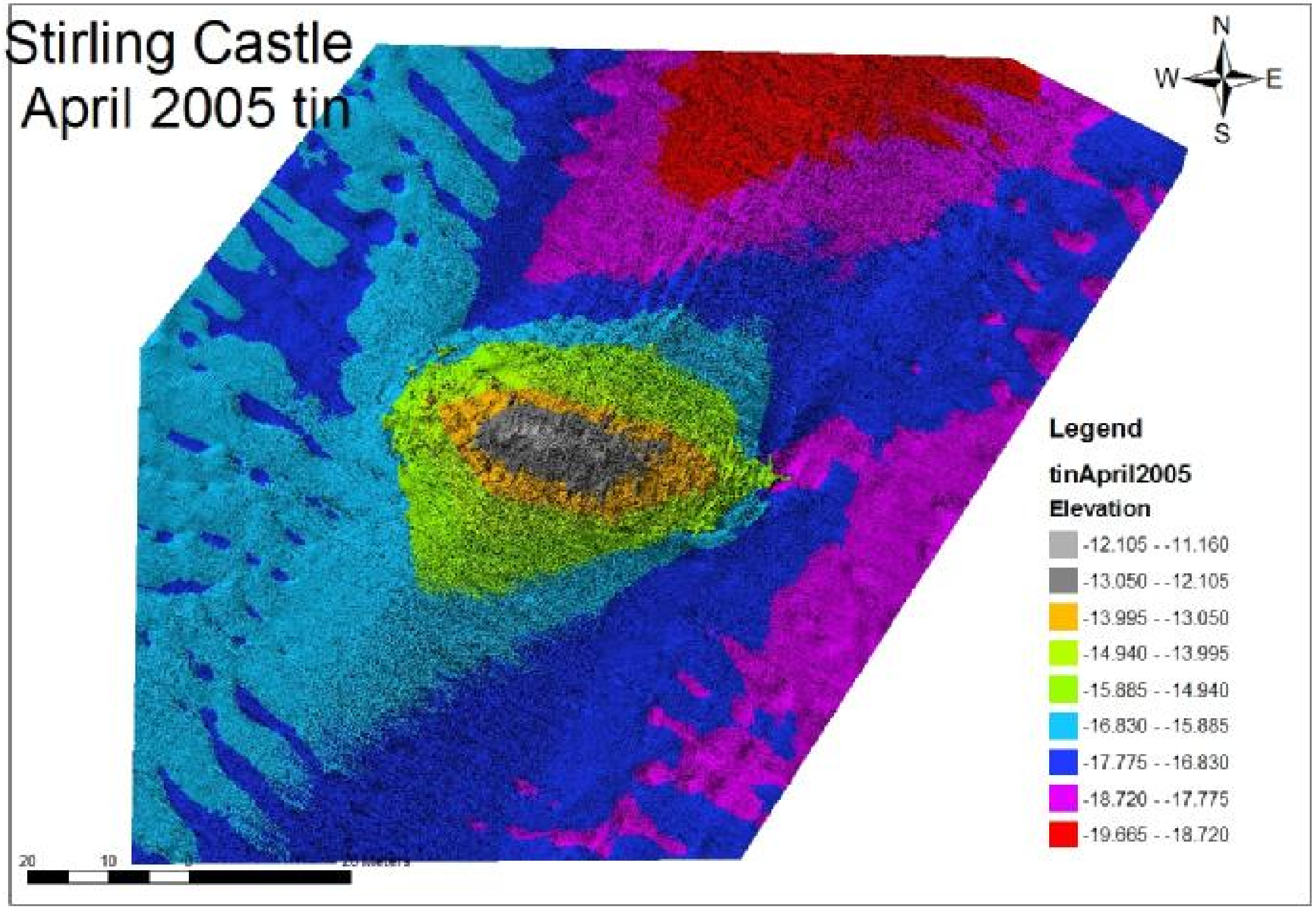

Figure 14: TIN map of the *Stirling Castle* site from Reson 8125 multibeam data gathered in 2005.

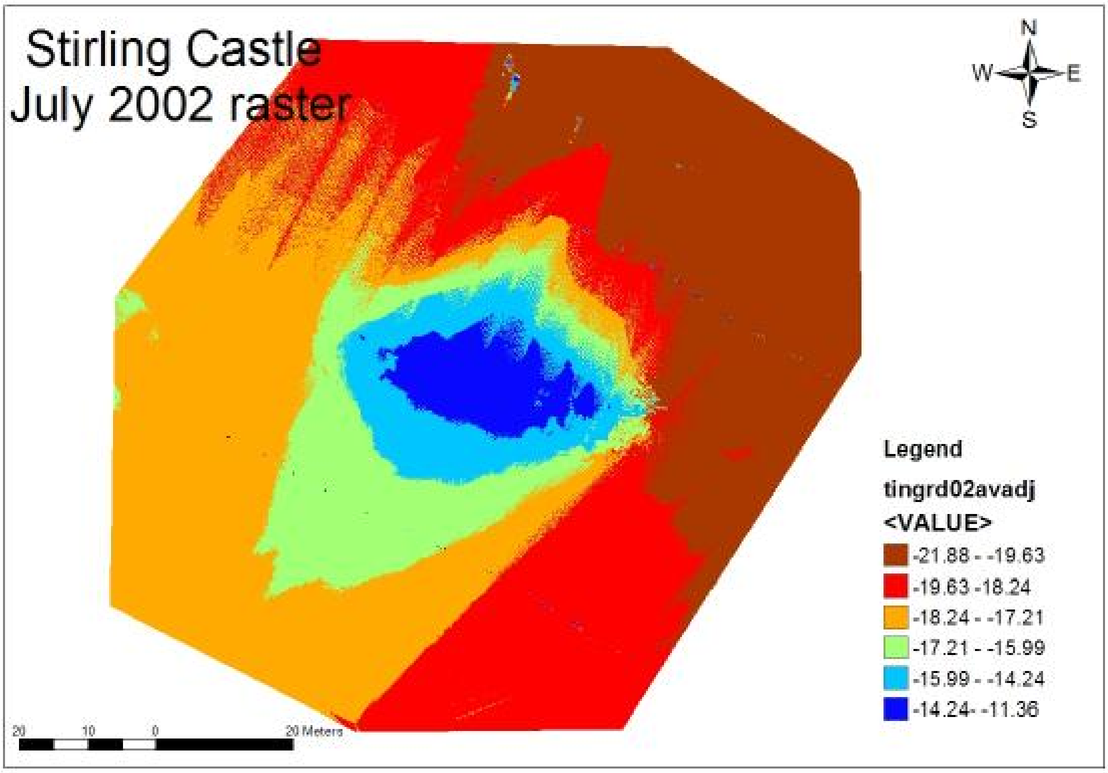

Figure 15: Depth values for the *Stirling Castle* site generated from Reson 8125 multibeam surveys in 2002.

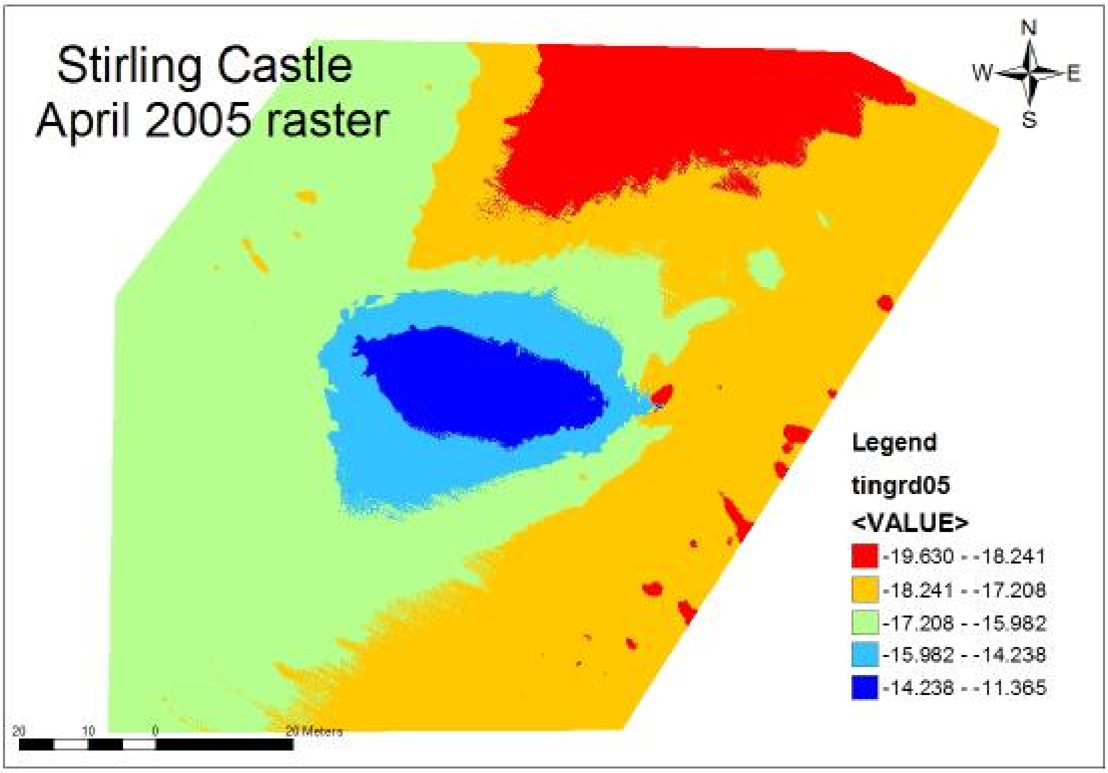

Figure 16: Depth values (below chart datum) for the *Stirling Castle* site generated from Reson 8125 multibeam surveys in 2005

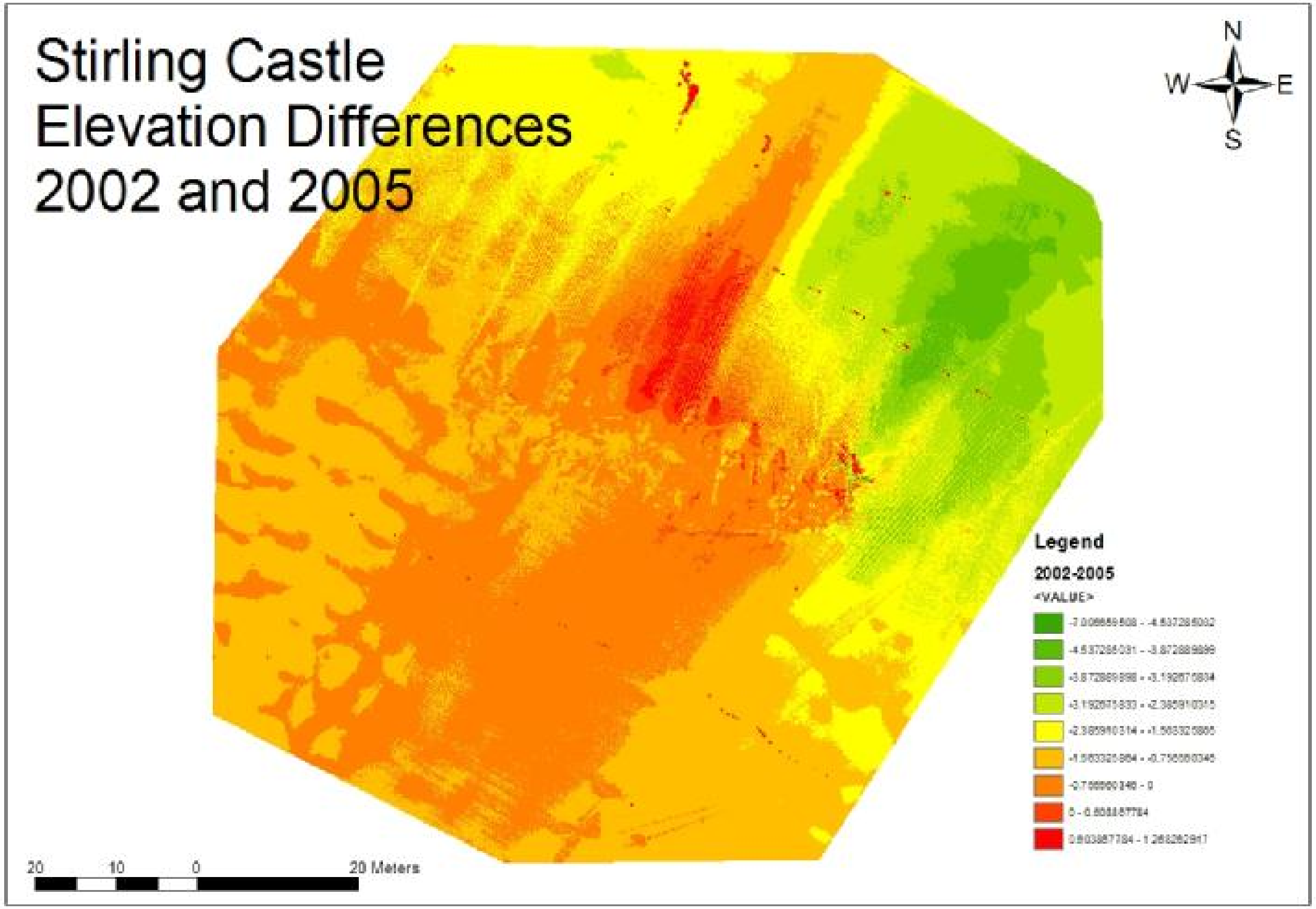

Figure 17: Differences in elevations on the *Stirling Castle* site between 2002-2005

Appendix 1 – Project Objectives

Environmental Setting Mapping Techniques (Objective 1) - To refine knowledge and understanding of the techniques for mapping the environmental context (the sedimentological and broader environmental including biological setting) of a wreck site, in particular in sites of medium to coarse sediment material at or near the sea bed surface.

Environmental and Palaeo-environmental Setting (Objective 2) -To determine key environmental features and environmental stability surrounding submerged archaeological sites.

Environmental Change (Objective 3) - To investigate the rate of environmental change and indicate potential causes (natural and anthropogenic) of change around maritime archaeological sites.

Development of methodologies (Objective 4) to maximise the archaeological and environmental detail obtained by high resolution sonar.

Enhanced methods for Processing Remote Sensing Data (Objective 5) - To refine remote classification methods for mapping the environmental setting, and identifying the material within, submerged archaeological sites.

Environmental Distribution (Objective 6) - To map the distribution of environmental factors surrounding key maritime archaeological sites of significance. Providing critical information on environmental factors to county planners, members of the aggregate industry, heritage managers and academics will enable informed decision to be made on the condition on the sites.

Environmental Change(Objective 7) -To assess the previous and current change in environmental conditions surrounding key maritime sites in order to provide vital information on the long term stability of sites.

Environmental Future Scenario (Objective 8) - To provide appropriate information for the modelling of future changes to wreck sites, to inform the long term management of the sites and the potential impact that future aggregate extraction might have on them.

Development (Objective 9) - To provide enhanced tools for the rapid mapping, and quantitative monitoring of maritime archaeological sites in their surrounding environments.

Dissemination of Data to EH and ALSF Partners (Objective 10) -To share data, results, conclusions and recommendations within English Heritage and the ALSF Partner projects through meetings, reports and digital information.

Dissemination of Results and Recommendations to Curators (Objective 11) - To communicate the results, findings and recommendations to local curators and prepare guidelines on the use of the enhanced geophysical techniques for contract surveyors and wider curatorial staff.

Dissemination of Results to Public Audience (Objective 12) - A Web site will be created for the dissemination of results from the project. The web site will contain information on the sites, the techniques used and the results of monitoring over the course of the project.

Dissemination of Results to Academic Audience (Objective 13) - Publication of the results in academic, peer reviewed Journals and at national and international conferences on maritime archaeology.

Appendix 2 – historic datasets from the *Stirling Castle*

	1979	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Bathymetry (single beam)		ADU	ADU	ADU	Peacock				
Bathymetry (multibeam)							ADU Reson 8125		
Backscatter (multibeam)							?ADU Reson 8125		
Sidescan Sonar			ADU Imaginex 858		GSE Rentals (Wreck Detectives) Klein 2000. ADU Imaginex 858	ADU Imaginex 858	ADU Imaginex 858		
Acoustic Ground Discrimination						SEA's Echoplus- Dual Frequency 192KHz;50KHz			
Magnetometer			ADU - proton			Geometrics Flux	Geometrics Caesium		
Video	Licensee	ADU/ Licensee	ADU/ Licensee	ADU/ Licensee	ADU/ Licensee	ADU/ Licensee	ADU/ Licensee	Licensee	Licensee
Still	Licensee	ADU	ADU	ADU	ADU	ADU	ADU		
Ancillary Reports		ADU 97:26 95:08 93:23 92:23 1991 Licensee reports to ACHWS from designation in 1980	ADU 98:23 Licensee report to ACHWS	ADU 99:15 Licensee report to ACHWS	ADU 00:17 Licensee report to ACHWS	ADU 01:12 Licensee report to ACHWS	Licensee report to ACHWS Lawrence and Bates *Acoustic ground discrimination techniques for submerged archaeological site investigations* ADU 02:15; ADU 02:21	EH/ Wessex Archaeology DBA Licensee report to ACHWS	Licensee report to ACHWS

Appendix 3- Fieldwork diary 2005

APRIL 05	SITE	WORK	COMMENT	PROJECT
1	Plymouth test site	Diving	Set up of targets	ALSF
2	Plymouth test site	nil	Force 8 gale	ALSF
3	Plymouth test site	Diving		ALSF
4	Plymouth test site	Diving		ALSF
5	Plymouth test site	SSS		ALSF
6	Plymouth test site	SSS		ALSF
7	Plymouth test site	MB		ALSF
7	Survey training area	MB	At west end of ALSF test site	ALSF
7	Cattewater wreck	MB	Surveyed as a favour for EH. Moorings observed in protected area	St A
8	Plymouth test site	nil	Too rough to anchor for ROV video recording	ALSF
8	Deadman's Bay	MB	Collaboration with University of Plymouth	St A
8	Barns Poole sites	MB	Collaboration with University of Plymouth	St A
8	Mill Bay site	MB	Collaboration with University of Plymouth	St A
9	Plymouth test site	Diving	Recovery of targets	ALSF
10	*SS Sudan*	MB		St A
10	Salcombe x 2 designated sites	MB	Collaboration with licensees	St A
10	*SS Maine*	MB		St A
11		Passage		ALSF
12	Bouldner Cliff	MB	Collaboration with HWTMA	St A
12	*MV Margaret Smith*	MB		St A
13	*Mary Rose*	MB	Collaboration with licensee	St AHe-111
13	*A1*	MB		St A
14	*Holland V*	MB		St A
14	Unknown wreck Hastings Shingle Bank	MB	Collaboration with University of Southampton	ALSF
14	*Stora* + one other	MB	Collaboration with NMS	St A
14	St A sonar targets Hastings Shingle Bank	MB	Collaboration with Wessex	ALSF
14	Ephemeral features Hastings Shingle Bank	MB	Collaboration with Wessex	ALSF
15	*Stirling Castle*	MB		ALSF
16	*Northumberland*	MB		ALSF
16	*Restoration* mounds	MB		ALSF
16	Goodwins	MB	Area survey	ALSF
17	Goodwins	MB	Area survey	ALSF
17	Uncharted wreck 1	MB	Found in above	ALSF
17	Uncharted wreck 2	MB	As above	ALSF
18		nil	Too rough	ALSF
19	*Stirling Castle*	SSS		ALSF
19	Heinkle He-111 Bomber	MB		St A
19	Unidentified wreck	MB		St A
19	Unidentified wreck	MB		St A

Appendix 4 - Survey equipment configuration

Survey Inputs	Sensor	Remarks
Position Sensor	POS-MV 320, & Trimble RTK	Antennae (3m baseline) on wheel house roof, IMU inside on main deck near centreline, ?m above waterline.
Motion Sensor	POS-MV 320	-“-
Heading Sensor	POS-MV 320	-“-
MBES	SeaBat 8125	Aft, port, quarter, over the side mount.
Surface SVEL	Seabird CTD	
Column SVEL	Navitronic SVP-15	
Software	QPS QINSy v7.5	
PPS Timing (Y/N)	Yes	

POS-MV GAMS results:

Separation	DX	DY	DZ
m	°	°	°

Three POS-MV GAMS calibrations were completed, all three giving near identical results.

Patch Test results:

Latency	Roll	Pitch	Yaw
N/A (GPS PPS)	°	°	°

Bar Check results:

Date & Location	SVEL	Remarks

Survey Parameters:

Item	Value	Remarks
Horizontal datum	WGS-84	
Spheroid	WGS-84	
Projection	UTM	
Central Meridian and Grid Zone	3W Zone 30	
Vertical datum	?	
Sounding line direction (°)		
General water depth (m)	Plymouth 5m – 25m; Stirling Castle	
Sounding line spacing (m)	Typically 50m	
Cross-line direction (°)	-	
Cross-line spacing (m)	-	
Sounding speed (kn)	Typically 5 knots	2 knots over the test site; ?knots over *Stirling Castle*.
Across track overlap	Typically 10%	
Along track overlap	Typically 25%	
Squat correction (Y/N)	No	
MBES Ping rate (Hz)	10 – 30	Sonar range setting dependant.
Survey Parameters:	Survey Parameters:	Survey Parameters:
MBES Frequency (kHz)	455	
MBES Range Scale (m)	10m – 50m	
MBES Pulse length (µsecs)	51	Variations tested in addition were 11, 33
MBES Imagery (Y/N)	Yes, SSS	

Appendix 5 – Test artefacts deployed at the Plymouth Sound test site

	Target description	Target material	Target Dimensions	Offset from Line	Target Orientation	
1	tube	100mm al. tube	1m long	north	horizontal Y-Y	
1	star	12mm coated steel rod	1.6m dia.	south	horizontal	
1	Sonardyne acoustic beacon	plastic	0.3m x 75mm dia.	on the line	horizontal	
2						
2.5	star	25mm al. tube	2m dia.	north	horizontal	
3						
4						
5	star	50mm al. tube	2.1m dia.	south	horizontal	
6						
7						
8						
9						
10	star	100mm al. tube	2.3m dia.	north	horizontal	
11						
12						
13						
14						
15						
16						
17						
18						
19	Shopping bag	woven esparto grass	0.35m x 0.2m x 0.15m	north		
20	star	200mm al. tube	2.6m dia.	south		
20	tube	100mm al. tube	1m long	north	horizontal Y-Y	
20	Sonardyne acoustic beacon	plastic	0.3m x 75mm dia.	on the line	horizontal	
21						
22	step ladder	al.	2m	north	horizontal	
23	flat plate	al. sheet	1m x 1m	south	horzontal	
24	target	al. tubes	1m x 1m	north	horizontal	
25						
26	ladies bicycle	mostly steel	1.7m x 0.6m	south	upright	
27						
28	ladies bicycle	mostly steel	1.7m x 1m	north	horizontal	
29						
30	2 car tyres	rubber	0.6 dia.	south	1 vertical and 1 horizontal	
31	statue	stone	0.75m high	north	horizontal	

	Target description	Target material	Target Dimensions	Offset from Line	Target Orientation	
32	pantiles	ceramic	1m x 1m	south	horizontal	
33						
34	3-bladed propellor	bronze	0.6m dia.	north	horizontal	
35	diver's helmet	copper	0.5m high	south	upright	
36	ship's wheel	wood	0.9m dia.	north	horizontal	
37	ship's bell	bronze	0.3m dia. X 0.4m long	south	on its side	
38	lion's head fountain spout	lead	c.0.4m x 0.15	north	horizontal	
39	wine bottles	glass	1m x 1m	south	horizontal	
40	Sonardyne acoustic beacon	plastic	0.3m x 75mm dia.	on the line	horizontal	
41						
42						
43	gravel	10mm	1m x 1m	north		
44	garden urn	ceramic	0.4m dia. x 0.5m	south	uptight	
45	sand	course	1m x 1m	north		
46	2 radar reflectors	Al.	0.3m octahedron	south		
47	Assorted flower pots	ceramic	1m x 1m	north	upright	
48	chest	wood	0.9m x 0.4m x 0.5m	south	Upright with lid floating up	
49	assorted jars	stoneware	1m x 1m	north	upright	
50	coat	leather	size 12 long	south	45^{O} with arms out	
51	2 boat timbers	waterlogged wood	c.0.8m x 0.15m x 0.15m	north	horizontal	
52	wicker triangle	8mm dia. willow twigs	0.9m x 1.8m	south	45^{O}	
53	skeleton	bone	1m x 1m	north	laying flat	
54	2 mini amphoras	ceramic	0.5m long	south	horizontal	
55	assorted small finds	various	1m x 1m	north	laying flat	
56						
57						
58	target	al. tubes	1m x 1m		floating flat 2m above seabed	
59						
60	Sonardyne acoustic beacon	plastic	0.3m x 75mm dia.	on the line	horizontal	