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**Ensuring continuity in the development
of broad-scale mapping methodology -
direct comparison of *RoxAnn* and
QTC-VIEW technologies**

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CEFAS Lowestoft Laboratory

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Ensuring continuity in the development of broad-scale mapping methodology - direct comparison of *RoxAnn* and *QTC-VIEW* technologies

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1	Introduction	8
1.1	Requirement for broad scale mapping	8
1.2	Broad-scale vs. fine-scale maps	9
1.3	Background to the present project.....	11
1.4	Purpose of the study and structure of this report.....	12
2	Overview of acoustic ground discrimination systems (AGDS)	12
2.1	Background	12
2.2	<i>RoxAnn</i>	14
2.3	<i>QTC-VIEW</i>	15
2.4	The nature of AGDS track data	16
3	Survey design & data acquisition.	18
3.1	Equipment	18
3.2	Planning the survey	19
3.2.1	AGDS	19
	Track spacing	19
	Maintaining data quality during field survey	20
3.2.2	Field Sampling.....	22
	Choice of field sampling technique	22
	Selecting field sample sites	23
3.3	SEAMAP/CEFAS survey examples	24
3.3.1	Description of survey areas and acoustic equipment used	24
3.3.2	Hastings Shingle Bank survey	26
	Acoustic data acquisition	26
	Sidescan sonar interpretation	26
	Ground-truthing.....	27
	Sample processing.....	29
3.3.3	Hastings-Dungeness survey.....	29
	Acoustic data acquisition	29
	Ground-truthing.....	30
4	Analysis of field samples	32
4.1	Ground-truthing data	32
4.2	SEAMAP/CEFAS survey examples	33
4.2.1	Hastings Shingle Bank Survey	33
	Biological data analysis.....	33
	Sediment characteristics and environmental variables	33
	Biological data interpretation.....	35
	Biotopes	38
4.2.2	Hastings-Dungeness Survey.....	40

5	Preliminary treatment of acoustic data and quality control.	41
5.1	Introduction.....	41
5.2	Within system analysis	41
5.2.1	<i>RoxAnn</i>	41
5.2.2	QTC	41
5.3	Quality control after data export.....	42
5.4	Exploratory data analysis.....	44
5.5	SEAMAP/CEFAS survey examples - Preliminary treatment of the Hastings Shingle Bank and Hastings-Dungeness data sets	46
5.5.1	Editing data associated with low speed, erratic position and depth, scatterplots 46	
5.5.2	Track plots	50
5.5.3	Data standardisation and correction to chart datum.....	50
5.5.4	Scatterplots	50
5.5.5	Variogram	53
5.5.6	Variability of track data.....	54
5.6	Summary of data following initial analysis.	58
6	Interpolation: point-to-area conversion	61
6.1	Introduction.....	61
6.2	Interpolation method.....	62
6.3	Grid size, track spacing and resolution.....	66
6.4	Interpolation to produce digital images.....	67
6.5	SEAMAP/CEFAS survey examples	67
6.5.1	Interpolation of the Hastings Shingle Bank data	68
6.6	Digital images of the Hastings-Dungeness data sets	71
7	Classification	72
7.1	Discrimination procedures in proprietary AGDS software	72
7.1.1	<i>RoxAnn</i> and Microplot/RoxMap.....	72
7.1.2	<i>QTC-VIEW</i> and <i>QTC-Impact</i>	72
7.2	Unsupervised classification.....	73
7.3	Supervised classification.....	74
7.3.1	Maximum likelihood classification.....	74
7.3.2	Training sites and signature development	75
7.4	Assessment procedures.	76
7.5	SEAMAP/CEFAS survey examples: Classification of the Hastings and Hastings-Dungeness data sets.....	78
7.5.1	Introduction: Strategy for classification of data sets	78
7.5.2	Unsupervised classification of the Hastings data sets.....	79
	Classification.....	79
	Performance.....	83

7.5.3	Supervised classification of the Hastings data set with sidescan training sites	87
	Classification.....	87
	Performance.....	88
7.5.4	Supervised classification of the Hastings data set with video training sites	89
	Classification.....	89
	Performance.....	92
7.5.5	Unsupervised classification of the Hastings-Dungeness data sets.....	94
	Classification.....	94
	Performance.....	94
7.5.6	Supervised classification of the Hastings-Dungeness data set with sidescan training sites.....	95
	Classification.....	95
	Performance.....	95
8	Conclusion and recommendations	105
9	Future work	108
10	References	110

Executive summary

Maps that show the distribution of habitats and biota, together with accompanying data and statistics, are central to many aspects of environmental appraisal, but particularly for the assessment of the natural heritage (conservation) interest and the impacts of human activities on biological resources. Broad scale survey and mapping can provide a basic level of knowledge of the biological resources of an area where there is little existing information. This knowledge, and the spatial distribution maps produced from such surveys, are of tremendous value in many areas of environmental management, impact assessment and monitoring. Ultimately, broad scale maps can provide an elegant way to display complex information which is of use in many applications.

Early mapping studies, along with most other benthic surveys, have traditionally used grabs and/or dredges to describe the invertebrate fauna of the sea floor. Such techniques provide single, geographically separated points of data across the area of seabed under investigation. In order to produce spatial distribution maps of sediments and assemblages from such sources of data it is necessary to interpolate between these data points. However, interpolation has the potential to overlook discrete seabed features and/or biological assemblages, which may lie between sampling stations. Recent developments in acoustic technologies may provide a solution to this problem, particularly when attempting to describe the spatial distribution of habitats/assemblages over an area of seabed, and are offering new insights and opportunities to explore and map seabed habitats.

There are many sonar devices currently on the market which can be used to map various seabed properties (e.g. sediment type, topography, surface texture). In recent years the development of techniques for broad-scale mapping in UK coastal waters has focused on the use of Acoustic Ground Discrimination Systems (AGDS) to map seabed biotopes (physical habitats and associated biological assemblages). This approach uses AGDS to produce an image of the seabed and information about certain attributes of the seabed at selected sites is then collected by direct or remote sampling methods (e.g. grabs, video etc.). The distribution of these attributes is inferred from the relationship between the sample data and associated characteristics of the image.

This collaborative project between SeaMap and CEFAS was established to produce guidelines for AGDS survey and analytical routines that can be applied to two types of AGDS, *RoxAnn* and *QTC-VIEW*. The aim was to develop comparable methods for each AGDS so that the two systems could be compared and contrasted on an equal footing. Tried and tested methodology, developed over a number years for processing *RoxAnn* data sets using various image processing software packages, were applied to both *RoxAnn* and *QTC-VIEW* data sets

collected at two sites in the eastern English Channel. The two sites were surveyed at different intensities to address issues of scale and evaluate the suitability of this approach for use on data sets collected at different densities. The first site, a relatively small area of seabed 12km x 4km in size crossing Hastings Shingle Bank, was surveyed at a relatively high resolution, with survey tracks spaced 400m apart. In contrast the second study site covered a large area of seabed between Hastings and Dungeness and was surveyed at much lower resolution, with survey tracks spaced 2km apart. Sidescan sonar and underwater video data were also collected at both sites to ground-truth the AGDS data sets.

Both *RoxAnn* and *QTC-VIEW* data sets from each of the study areas were processed in identical ways. Data sets were subjected to stringent quality assurance and cleaning processes before a number of post-processing techniques (supervised and unsupervised classification methods) were applied to the data using various image processing software packages. Full spatial coverage maps were produced at the Hastings Shingle Bank site using the two AGDS data sets, but this approach was deemed inappropriate for the Hastings-Dungeness data sets due to the wide survey line spacing making interpolation of the data meaningless. In this case data was only interpolated to a short distance either side of the survey lines, and resulted in the failure to allocate habitat/biotope classes to large areas of seabed which fell between the lines.

The AGDS output maps showing the spatial distribution of habitats/biotopes produced using the various classification techniques at each study site were compared with each other, and with the spatial distribution of habitats determined from the sidescan sonar data to assess/compare accuracy of the two systems. Both systems performed equally well and classified the study areas in similar ways. The post-processing methods developed for analysis of *RoxAnn* data sets appeared to work equally well when applied to *QTC-VIEW* data sets. Supervised classification methods (maximum likelihood classification) out performed unsupervised classification methods for both types of AGDS, and the output from such analyses agreed closely with the sidescan sonar data.

In conclusion it was deemed that AGDS remains a useful tool for broad-scale survey based on remote sensing and ground-truthing. However, it should be recognised that AGDS do have inherently limited powers of discrimination. It would appear that, despite the apparent scope for increased discrimination of the *QTC-VIEW* system, neither system performed markedly better than the other. Despite differences in the types of data each system produces, treating the Q values in a similar manner to E1 and E2 posed no problems with respect to interpretation/analysis of the data sets, and both systems produced very similar outputs. This opens up *QTC-VIEW* to all the advantages of analysis that external software provides, ranging from easy application of data editing and quality control procedures through to the use of powerful image processing software. Finally, this work reiterated the point that quality

control of the data is vital: AGDS are often unstable irrespective of type and careful editing of dubious data must be undertaken prior to full analysis. Some of the reasons for this variability can be linked to equipment set-up and field survey design and it is vital that standard procedures are followed to ensure that the data collected are of high quality.

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1 INTRODUCTION

1.1 Requirement for broad scale mapping

Maps which show the distribution of habitats and biota, together with accompanying data and statistics, are central to many aspects of environmental appraisal, but particularly for the assessment of the natural heritage (conservation) interest and the impacts of human activities on biological resources. Broad scale survey and mapping can provide a basic level of knowledge of the biological resources of an area where there is little existing information. The purpose of broad scale mapping is to identify the basic resources of an area in terms of major physical habitat characteristics and community types and to map their distribution and extent. The justification for this level of survey is given as providing a knowledge of the location, extent and distribution of wildlife and associated habitats which forms an objective baseline for (1) determining which sites might deserve consideration for protection and warrant a more detailed survey; (2) determining the strategic importance of sites to nature conservation, including those sites of relatively limited conservation interest; and (3) making an assessment of the environmental impacts of human activities. This knowledge enables planners to respond quickly to proposals for development, accidents and to save time and money through anticipation and avoidance of controversy (Nature Conservancy Council 1990). Broad scale survey also provides data for developing management plans for marine protected areas and have a key role in defining site boundaries and, at a coarse level, boundaries of specific features of conservation importance (Downie *et al.* 1999).

Underlying this statement is the importance of dialogue between all those concerned with environmental management and involved in environmental appraisal, impact assessment and monitoring. A common understanding of biological resources is necessary for the resolution of conflicting demands upon the environment. Broad scale maps can provide an elegant way to display complex information for this purpose.

Broad scale surveys conducted over large areas are useful in alerting coastal managers to the potential conservation interest of a site, perhaps identifying the site for the first time. Such data, especially if accessed through map-based enquiry systems, could serve as the primary route for retrieving information about specific locations when reacting to issues with potential implications for conservation management. Perhaps the most valuable use of broad scale maps is to highlight where more detailed information is required and what type of survey would be most suitable. Mapping and associated surveys should not, therefore, be seen in isolation but as part of a larger integrated survey strategy.

1.2 Broad-scale vs. fine-scale maps

Efforts to describe and interpret the variability and distribution of benthic fauna over large geographical areas date back to the classic studies of Petersen and co-workers in Danish waters (e.g. Petersen 1918). These early mapping studies, along with most other benthic surveys, have traditionally used grabs and/or dredges to describe the invertebrate fauna of the sea floor. Such techniques provide single, geographically separated points of data across the area of seabed under investigation. In order to produce spatial distribution maps of sediments and assemblages from such sources of data it is necessary to interpolate between these data points. However, interpolation has the potential to overlook discrete seabed features and/or biological assemblages, which may lie between sampling stations. Recent developments in acoustic technologies may provide a solution to this problem, particularly when attempting to describe the spatial distribution of habitats/assemblages over an area of seabed, and are offering new insights and opportunities to explore and map seabed habitats.

There are many sonar devices currently on the market which can be used to map various seabed properties (e.g. sediment type, topography, surface texture), and these acoustic systems can generally be divided into the following categories: a) broad-acoustic beam (swathe) systems such as sidescan sonar; b) single beam acoustic ground discrimination systems (AGDS) such as *RoxAnn* and *QTC-VIEW*; c) Multiple beam swathe bathymetric systems; d) multiple beam (interferometric) sidescan sonar systems. The development of many of these systems stems from rapid improvements in acoustic electronics in the 1970s and 80s, which led to major enhancements in data quality. Whilst the use of such systems was originally focused on geological studies of the seabed, it was at this stage that the potential use of acoustic techniques for studying benthic ecosystems was recognised (e.g. Warwick and Davies 1977; Holme and Wilson 1985; Davault and Clabaut 1988).

Recent improvements in acoustic systems in the 1990s, in particular with swathe and multibeam systems as a result of increased digital processing power offered by modern computers, have led to very high resolution and affordable systems entering the market place. This development is reflected in the number of recent investigations which have used acoustic techniques as a means to infer the biological status of the seabed (e.g. Magorrian *et al.* (1995), Greenstreet *et al.* (1997), Davies *et al.* (1997) using *RoxAnn* systems; Prager *et al.* (1995), Anderson *et al.* (1998) using *QTC-VIEW* systems; Service (1998), Service and Magorrian (1997), Wildish and Fader (1998), Phillips *et al.* (1990), Schwinghamer *et al.* (1996, 1998), Tuck *et al.* (1998) using sidescan sonar; Todd *et al.* (1999), Kostylev *et al.* (2001) using multibeam bathymetry.). Although the outcomes of these studies are, in general, encouraging, the approaches have not yet reached the stage of uncritical, routine application. However, these developments are offering the opportunity for researchers to move away from a process of inference around a matrix of spot samples into the realm of spatially continuous mapping using spot sampling for ground-truthing.

The scale at which the seabed is mapped depends primarily on the aims of the survey and the techniques employed to produce the maps. Although there is no hard and fast distinction between broad and fine scale mapping, the following account highlights the main differences between these two approaches. Broad scale generally implies that large areas of the seabed are mapped, showing the approximate disposition of broadly defined classes of habitats or biotopes (small scale). Fine scale implies that small areas are mapped to a higher level of detail and accuracy (large scale). The distinction between broad and fine scale mapping can be linked to survey techniques, particularly in the subtidal environment. An area is mapped to a fine scale if a complete coverage map of biotopes is obtained through direct observation or high-resolution swathe acoustic coverage (e.g. sidescan sonar). Such studies, using swathe acoustic systems, allow 100% coverage maps to be produced of an area. For this reason the use of acoustic techniques to assist in mapping the geographical distribution of biotopes (e.g. physical habitats and associated biological communities) can be seen to have many potential advantages, including the prospect of 100% coverage of the seabed as resources allow or priorities dictate. Using such methods it is possible to identify boundaries between discrete benthic habitats/communities with some precision throughout the mapped area (Brown *et al.* 2001). Clearly, such intensive survey is expensive if conducted over large areas.

An alternative approach adopted for broad scale mapping is based on lower resolution and cheaper acoustic techniques (e.g. single beam AGDS). An image of the seabed is obtained using AGDS and information about certain attributes of the seabed at selected sites is collected by direct or remote sampling methods (e.g. grabs, video etc.). The distribution of these attributes is inferred from the relationship between the sample data and associated characteristics of the image - a process called ground truthing. There are two important points here: Firstly, the aim of this process is to give an attribute to every possible location within the surveyed area (in other words, to generate a continuous coverage). Secondly, the objects or attributes to be mapped are not directly measured at all locations, but are estimated from the remotely sensed image. The word 'estimated' is emphasised since it is important to realise that there will be a level of uncertainty about any estimate and that the maps are predictive. Further sampling will be needed based on these predictions to indicate just how valid the map is (how accurate the predictions are).

Attention must also be drawn to the distinction between maps that are produced from point samples of biotopes alone and maps derived from remote sensing (both swathe and single beam AGDS acoustic methods). In the former case boundaries can only be drawn around sample points with the position of the boundary lying approximately half way between it and adjacent dissimilar samples. Boundaries drawn on such a basis are of little use when there is a large variation between one sample point and the next. Remote sensing, on the other hand,

provides a basis for drawing boundaries between point samples and, by extrapolation, for interpreting parts of the image where little or no ground truthing exists.

1.3 Background to the present project

SeaMap perspective

SeaMap have been instrumental in the adoption of broad scale biotope mapping by the statutory country conservation agencies. Biotope mapping using AGDS formed part of the EU funded BioMar *Life* project in 1993 and this led to a second project, the BROADSCALE Mapping Project (BMP), which was initiated by the Countryside Council for Wales, English Nature and Scottish Natural Heritage together with the Crown Estates and supported by the European Commission's *Life* programme (Foster-Smith *et al.* 2000). The objective was to develop and promote the use of methodologies for broad scale mapping of sublittoral habitats and biota (biotopes) based on acoustic remote sensing. SeaMap continue to develop new techniques for the analysis and interpretation of acoustic data through contract survey and research programmes.

CEFAS perspective

Between April 1998 and March 2001, CEFAS undertook a 3 year research and development project (AE0908) funded by the Ministry of Agriculture Fisheries and Food (MAFF; now DEFRA) to investigate the utility of acoustic techniques, used in conjunction with biological sampling, to map seabed biotopes. This work was of direct relevance to the development of policy for extraction of aggregate resources from the seabed ensuring sustainability of the associated ecosystem, and therefore focused on mapping areas of the seabed that comprised predominantly of gravel and sand deposits. A range of acoustic techniques are investigated; including side scan sonar and two acoustic ground discrimination systems - *RoxAnn* and *QTC-VIEW*. Using these acoustic data sets, in conjunction with biological and sediment data collected through targeted sampling using a range of sampling gear, the utility of acoustic techniques for mapping gravel biotopes was evaluated. The work contained within this report formed part of this project.

The similarity between the habitat mapping work conducted by SeaMap and CEFAS in the projects described above, in terms of both the mapping approach and survey techniques (both groups using a combination of sidescan sonar and AGDS techniques ground-truthed using grabs and underwater video) lead to the current collaboration. It was envisaged that through collaboration there would be:

- An exchange of expertise and information in the post-processing methodology for *QTC-VIEW* and *RoxAnn* data sets.
- Further development of analytical techniques for processing AGDS data sets, particularly *QTC-VIEW* data.

- Further evaluation of the utility of AGDS in producing broad scale habitat maps.

1.4 Purpose of the study and structure of this report

This report is a working document for CEFAS and SeaMap in order to establish guidelines for AGDS survey and analytical routines that can be applied to *RoxAnn* and *QTC-VIEW* data sets. Comparable methods were applied to each of the AGDS so that the two systems could be compared and contrasted on an equal footing. The merits of various procedures and their applicability to particular survey scenarios are discussed.

The document discusses the stages in deriving broad scale maps under the following headings:-

- Survey design and quality assurance.
- Preliminary data treatment and quality control.
- Interpolation - choosing interpolation procedure.
- Classification - choosing classification procedure.
- Performance – assessing accuracy.

The document is not intended to be an instruction manual and the procedures are described in general terms. A companion manual has also been produced (*Guidance notes for classification of AGDS data*, White *et al.*, 2001) which gives explicit instruction for carrying out analysis using specified software and versions. This document provides guidelines for the collection and analysis of AGDS data under each of the sections listed above, followed by worked examples from data sets collected specifically for use in this SEAMAP/CEFAS collaborative programme.

2 OVERVIEW OF ACOUSTIC GROUND DISCRIMINATION SYSTEMS (AGDS)

2.1 Background

Acoustic ground discrimination systems (AGDS) are based on single beam echo sounders and are designed to detect different substrata by their acoustic reflectance properties. An echo sounder generates a short pulse of sound at a single frequency that travels through the water and rebounds off the seabed (Urick 1983; Mitson1983). The echo is detected by the transducer which converts the acoustic energy into an electrical signal that is displayed on a screen. The transducer shapes the pulse of sound into an approximate cone directed towards the sea floor. The area ensonified (analogous to the term 'illuminated') by the echo sounder directly under the vessel is approximately circular, although sounders produce many side-lobes that make the footprint a more complex shape in practice. The area depends upon the diverging beam angle (angle of the apex of the cone of sound) and depth of the sea floor.

Sound waves travelling in the centre of this cone will hit the seabed first (assuming the seabed is level) and depth is measured from time taken for this returning sound energy to be detected by the transducer (Figure 1). The strength of the echo and the way it decays with time produces a complex signal whose shape depends to a large degree on the nature of the sea floor and this is the basis upon which echo sounders have been used for sea floor classification (Orlowski 1984; Burns *et al.* 1985; Jackson and Briggs 1992; Keeton and Burle 1996). The extent to which sound is absorbed or reflected by the sea floor depends upon the hardness of the seabed: Hard surfaces produce strong echoes whilst soft surfaces (and this may include rock substrata that are acoustically softened by overgrowth of biota) results in a weak signal. The sound energy that spreads away from the centre of the cone produces a weaker echo. This wave energy takes slightly longer to reach the seabed because of the extra distance travelled and this time lag increases with increasing angular distance away from the vertical axis of the transmission pulse. Rough surfaces will produce an echo that decays slowly since sound spreading some distance from the vertical may reflect off inclined surfaces angled towards the transducer (a property termed 'backscatter') whilst flat surfaces will reflect sound away from the transducer. The decaying echo may also contain an element that depends on the reflectance of sound from subsurface features. This is particularly the case for low frequency sounders where there is greater penetration through soft surface sediment. The shape of this returning pulse or first return forms the basis for AGDS systems that map acoustic seabed properties to physical seabed properties

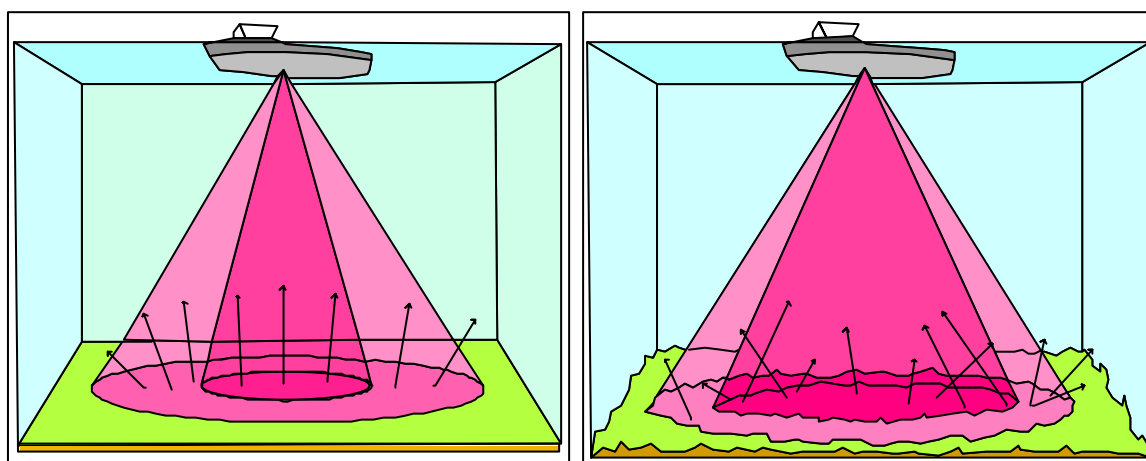


Figure 1. The behaviour of sound reflected from smooth and rough ground. The light pink cone represents the cone of emitted sound and the dark pink cone that part which is reflected back and received by the transducer. Rough ground creates a greater opportunity for sound at the extremities of the acoustic footprint to be reflected back towards the transducer off angled surfaces.

Additionally, there may be multiple echoes as the returning sound energy bounces off the water surface and rebounds from the sea floor a second (or third) time. The significance of the second echo (first multiple echo) for ground discrimination is debatable, but it has been considered to be more sensitive to hardness than the initial reflectance of the first echo (Chivers *et al.* 1990; Heald and Pace 1996).

Two proprietary AGDSs have been used extensively for surveying biotopes – *RoxAnn*[™] (Marine Micro Systems Ltd, Aberdeen) and *QTC-VIEW*[™] (Questor Tangent Corp – Sidney BC Canada). *Echo Plus*[™] (SEA Ltd, Bath) is a third system new on the market that is a dual frequency, digital system similar in principle to *RoxAnn*. Other ground discrimination systems are known to the authors: Olex (based in Bergen, Norway) have a two parameter system measuring hardness and roughness of the first return. The data are logged in real time in a LINUX based environment and overlain on an electronic chart. *Echoplus* is a digital evolution of the *RoxAnn* method. Simrad have a UNIX based system (TRITON) operating on large areas (patches) in which characterisation is derived from the backscatter data of a multibeam sonar operating over a swathe using 5 parametric measurements.

2.2 RoxAnn

The *RoxAnn* system uses analogue signal processing hardware to select two elements from the echo and measures signal strength (in millivolts) integrated over time (Burns *et al.* 1985; Chivers *et al.* 1990). The first selected segment of the echo is the decaying echo after the initial peak. This measure of time/strength of the decaying echo is termed 'Echo 1' (or 'E1') and is taken to be a measure of roughness of the ground. The beam width of the sounder is important for E1 since a wide beam will give greater scope for measuring signal decay away from the perpendicular than a narrow beam. For this reason it is recommended that AGDS operate with a sounder of moderate beam width (15° – 25°). The second segment is the whole of the first multiple echo and is measured by the *RoxAnn* processor as 'Echo 2' (or 'E2').

The two paired variables (E1 and E2) can be displayed on a Cartesian XY plot, and this is the basis of the *RoxAnn* real-time display as used in the data logging and display systems *Micropilot*[™] and *RoxMap*[™]. Rectangular areas on the Cartesian plot can be marked out so that records lying within that section of the plot can be colour-coded and displayed on the track plot.

Echo sounders show characteristics of the return signal as a visual display from which qualitative information about ground hardness, roughness and other ground characteristics can be obtained. Acoustic ground discrimination systems analyse the signal and quantify selected parameters. Figure 2 shows what an echo sounder screen might look like as a

vessel tracks over smooth, soft ground on the left of the screen to rough, hard ground on the right. The echo traces shown either side of the central display illustrate a single pulse and its return signal corresponding to each of these two ground types. The strength of the peak of the first echo (not the same as E1; see Figure 2) depends on ground hardness. However, it is claimed that the strength of the second echo is more sensitive to hardness (Chivers *et al.* 1990). The second echo results from sound reflected from the seabed rebounding off the water/air interface and reflecting off the seabed for a second time. The *RoxAnn* signal processor integrates time and signal strength of the second echo (E2) to derive a value that is taken as a measure of hardness. Other AGDSs, however, do use the first echo to measure hardness properties of the sea floor.

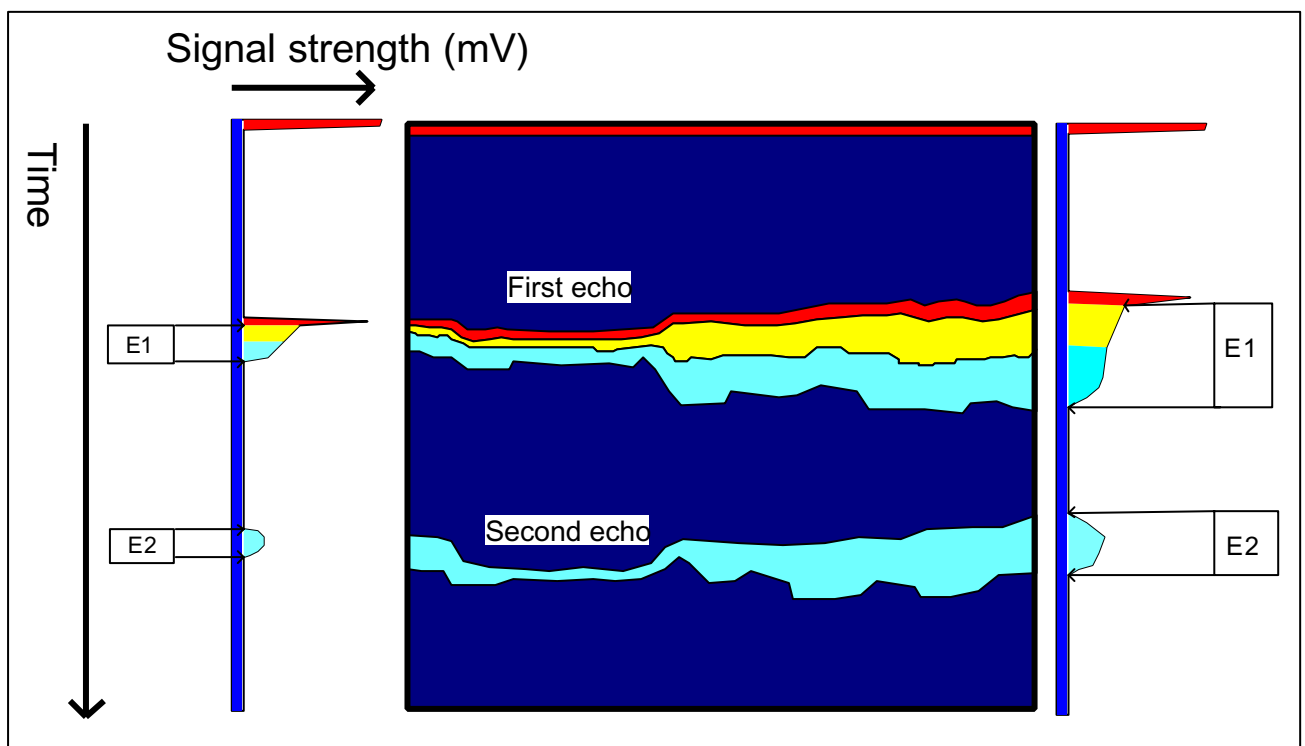


Figure 2 The relationship between an echo sounder screen display, the echo trace and the parameters measured by E1 and E2 by *RoxAnn*.

2.3 QTC-VIEW

QTC-VIEW operates in a very different way to *RoxAnn*. The echo is converted from analogue to digital form and is then subjected to analysis using a large number of algorithms for waveform analysis (Collins *et al.* 1996; Collins and McConnaghey 1998). The choice of algorithms

and the way they are applied to the echo is considered commercially sensitive. However, the second echo is not used. The system can be run in one of two settings; 1) supervised or 2) unsupervised mode.

1) In the supervised mode the system is designed to be calibrated (ground-truthed) by positioning the vessel over known ground types and a sample dataset collected. The exercise is repeated for different ground types and the combined datasets subjected to principle components analysis. The data are displayed on a three-dimensional plot of the first three principal components, termed 'Q space'. The Q space is then divided up into regions that relate to the ground type classes by forming a catalogue. This catalogue can then be applied to subsequent survey data collected at the site to classify the tracks in real time. If new ground types are covered further ground truthing is necessary.

2) The unsupervised mode offers greater flexibility without the use of calibration. The signal is subjected to the same algorithms within the *QTC-VIEW* system, but all variables are logged for later principle components analysis to be applied to the complete dataset. The software package *QTC-VIEW IMPACT* is then used to identify 'natural' clusters which are acoustically different, within the dataset, which can then be attributed to ground types as dictated by the field sample data. The clusters can be further split by running *IMPACT* again. This process of finding 'natural' clusters is termed 'unsupervised classification' and is covered in greater detail later under the section on classification procedures (section 7).

2.4 The nature of AGDS track data

It follows from the above description of the way an AGDS works in conjunction with a single beam echo sounder that a set of measurements (E1, E2 and depth in the case of *RoxAnn*, Q values in the case of *QTC-VIEW*) is made for each echo. The values are taken from an area of sea floor covered by the footprint of the signal, but the area will increase with depth.

Not all measurements are logged, however. In the case of *Microplot*, if data are saved every 2 seconds, then average values for E1, E2 and depth are calculated over a 2 second interval. These average values are logged together with the ships' position at the moment when the values are saved. In the case of *RoxMap*, only the values from the echo preceding the save are logged. No average is calculated and the majority of the data are not saved, nor do they contribute to the saved values. Thus, with *Microplot*, the recorded values can be regarded as an average (and hence smoothed) value returned at the trailing edge of a variably shaped oblong of sea floor. In contrast, with *RoxMap*, the recorded values are not smoothed and there will be gaps on the sea floor between successive save points for which there are no data.

The *QTC-VIEW* is logged in unsupervised mode which creates a pair of files (the FFV - containing the features which acoustically describe the acoustic pulse reflected from the seabed, and the CAL file which contains navigation and system information).

In the case of *QTC-VIEW* a number of pings are used to make the FFV and depth measurement (sounder dependant but currently 5 pings). FFV records are time-stamped based on adjacent navigation records within the CAL file. Ideally there is one navigation record for each FFV record. GPS and echosounder updates are not synchronous, when the update rate is not one-to-one an interpolated time is assigned, based on the most recent GPS entry before and after the FFV record.

These differences between the three logging systems could result in greater variability in the data set recorded in *Roxmap* than for *Microplot* or *QTC-VIEW*. Similarly, different save rates selected for *Microplot* would lead to different degrees of smoothing.

The data are, strictly speaking, in the form of single sets of values recorded from an area of sea floor of variable shape and size whose location corresponds with the ship's last calculated position (taken from the DGPS) prior to saving the data. The combined ellipse of DGPS error, footprint size and/or gap between saved data gives the maximum resolution of the AGDS in the direction of travel of the vessel. Thus, for a vessel working in about 10m of water at 10 km/h with a beam angle of 15° and a DGPS error of 10m, one might expect a set of E1, E2, Q and depth values saved every 2 seconds to represent an area of approximately 13m wide by 20m long. Any increase in depth, speed or save rate would lower the resolution further. However, for most purposes, the recorded values can be regarded as centred on a series of points following the ship's course. It is not until the track data are displayed at a very fine scale that this approximation becomes apparent.

Acoustic data is collected as the survey vessel travels backwards and forwards across a survey area. Since it is unlikely that parallel tracks will lie closer together than the maximum along-track resolution (15m in the example above), it follows that the between-track distance imposes a far greater limit to the resolution of an image than along-track resolution.

AGDS based on single beam echosounders have some substantial disadvantages: They give coarse resolution images of the sea floor and an interpolated coverage introduces estimated values to a greater or lesser extent. However, they have many positive attributes which make them an attractive option for survey:-

1. AGDS are relatively inexpensive compared to many other acoustic systems.
2. They are relatively easy to operate.
3. The quantity of data produced is less than for swath systems and this facilitates data handling and analysis.

4. The analysis of a single vertical beam for measuring sediment properties is more straightforward than for swath systems.
5. Large areas can be surveyed (although at low resolution) quite rapidly.
6. AGDS is an established mapping system that is tried and tested.

Many of the drawbacks of AGDS can be compensated by using high resolution swath systems (such as sidescan) and the authors see the two approaches to acoustic survey as complementary. Until such time as swath systems can reliably detect equivalent acoustic properties of the sea floor, AGDS will have a role to play in broad scale mapping.

3 SURVEY DESIGN & DATA ACQUISITION.

3.1 Equipment

The following is a list of equipment required for AGDS surveys:

1. A survey vessel suitable for work in the locality with adequate cabin space for electronic equipment. (Some survey and fisheries patrol vessels have the relevant equipment permanently fitted). Small vessels are adequate for sheltered inshore waters, but a stable working platform is essential.
2. Power supply. The power supply from boats cannot always be relied upon. Peculiarities of wiring systems can affect electronic equipment. Unless absolutely confident, it is best to rely on an independent power supply (generator or batteries with inverter).
3. AGDS signal processor (*RoxAnn*, *QTC-VIEW* or similar).
4. Computer with appropriate logging software.
5. GPS (at time of writing selective availability has been switched off and an accuracy within 5m without the use of a differential system is acceptable). It is best to be self reliant as not all vessels have appropriate systems fitted which can be used for the acquisition of AGDS data. Position the GPS antennae as far above the transducer as possible to minimise heading errors.
6. Echosounder. It is likely that each AGDS will have its own echosounder, although they can be adapted to different systems. If AGDS are to be deployed from vessels of opportunity then portable systems with dedicated sounders are required. The choice of frequency and power will depend upon the working depths expected. Systems set for deep water will not work well in water less than about 3-5m and systems set for shallow water may return invalid readings much below 30m.

7. Means of deploying the transducer from the boat. On smaller vessels the usual method is to mount the transducer on a pole strapped to the side or the bow of the boat (scaffolding poles are ideal being cheap, readily available and very rigid). This often limits vessel speed although fairings may reduce aeration and drag. Care should be taken to stop air bubbles being drawn through the pipe-end whilst underway and interfering with the signal. The use of ratchet straps to pull the pole into the side of the boat and brace the top and lower end of the pole fore and aft is usually sufficient to keep the pole stable at working speed (7-8 knots). Larger vessels can also have overside pole mounts but with increased draft this invariably means heavier longer mounts are required, often custom made for the task. Some vessels may have suitable transducers already hull-mounted, or access to a suitable host echosounder. Finally, a means may be available of deploying through the hull via a moonpool or instrument tube. It is essential to have an experienced AGDS technician inspect such vessel facilities to ensure they are compatible with the survey aims and the AGDS equipment. Some surveys have been conducted with towed transducers but those AGDS systems reliant on the second return cannot use this method, due to varying tow depths. In all cases the sounder should be at least 1m below the water level and twice this in open seas. It should also be lower than the vessel's deepest hull structure to avoid multipath interference
8. Field sampling equipment (see later section).

3.2 Planning the survey

Field survey is considered in two parts: AGDS survey and field sampling (ground truth).

3.2.1 AGDS

Track spacing

The quality of AGDS coverage is determined by track spacing (and the way in which coastlines are tracked around – particularly important for complex coasts). The intensity of tracking required will depend upon the heterogeneity of the ground. Whilst this cannot be determined prior to a survey, inspection of hydrographic charts will give some indication of the nature of the ground likely to be encountered. Although a series of regularly spaced parallel tracks may be desirable for consistency in analysis, the need to concentrate survey effort where most needed in the limited time available may dictate that some sectors of the survey area will be more intensively tracked than others. The decision about tracking intensity may need to be made whilst conducting the survey, especially if poor weather reduces available survey time.

Real-time visualisation available through *Microplot*[™], *RoxMap*[™] or other logging software can be used to keep a check on ground variability, consistency between tracks and

discrimination (with reference to field sampling). *QTC-VIEW* operated in unsupervised mode (CAPS software) cannot display this information. Surveyors can plan the position of their tracks in such a way as to reduce problems for data analysis (ideally, one of the surveyors should also be involved with subsequent data analysis). Planned track pattern should take account of the following:-

1. Track spacing should be related to along-track variability. The aim should be to see patterns emerging between adjacent tracks. Where track variability is high, close tracks will be needed. Track spacing might vary over very large areas with different patterns of variability. Track orientation should allow for the possibility of missing linear track features formed by underlying geology or tidal transport mechanisms.
2. Cross tracks and/or some close parallel tracks should be run at times throughout a survey to check for consistency.
3. Geographic coverage should be comprehensive at the maximum track spacing.
4. Track spacing wider than 1km is likely to present problems when generating a coverage from the AGDS data and should be avoided if interpolation is required for data analysis (see worked example below).
5. Tracks should extend beyond the main area of interest since interpolation is often poor around the outside of a data set.
6. Ground is usually very variable close in shore, particularly where the shoreline is complex. Ideally, the shoreline should be surveyed as far inshore as possible. This is particularly important to avoid spurious interpolation of data around islands and headlands. Minimum depths apply to AGDS systems especially QTC.

Maintaining data quality during field survey

Maintaining the quality of the data is vital. AGDS can give variable data because of changing sea conditions or internal variability in the AGDS itself. The effects on the data may not be obvious unless a careful check is kept during the survey. Unless this is done, dubious data may only come to light in subsequent post-survey analysis when there is no possibility of collecting new data. The following should be continually monitored:-

1. The sounder screen can give valuable information on ground type which cannot be easily seen on the AGDS plot. A good log will help interpretation and reassure analysts that the AGDS data accords with the surveyor's impressions of ground type.
2. The sounder screen may also indicate if there is interference with other acoustic systems. Any potential interference should be eliminated and all personnel alerted to the problems caused by switching on other sounders during a survey.
3. Deteriorating sea conditions may create aeration under the sounder, resulting in interrupted signals from the sounder and erratic depths recorded by the AGDS. Too many erratic depth readings will usually mean that all the data for the whole track will

be invalid. However, AGDS can work in quite rough sea conditions and this alone should not prevent the survey from continuing.

4. Cross tracks and/or some close parallel tracks should be run at times throughout a survey to check for consistency in the operation of the system.

If the surveyor has reason to suspect that the track data are inconsistent then attempts should be made to trace the cause. This may be due to aeration, and lowering or altering the position of the transducer may help. Electrical connections between the transducer and the AGDS are particularly prone to stress and intermittent faults can give misleading data – all electrical connections that are regularly made during equipment set up should be checked. If sea conditions have deteriorated, then the survey should be suspended. However, some variability is only temporary and may be due to very slow vessel speed (such as when the vessel stops for sampling) or rapid changes in direction. It is not advisable to stop saving the AGDS data since these records can easily be identified post-survey and removed from the data set. There is always the risk that the operator may forget to turn the save back on, resulting in subsequent loss of data.

Variability between days is a more difficult issue to address. It is good practice to repeat a track over a patch of homogeneous ground at the start and finish of each day. This is only possible when the vessel uses the same port throughout the survey. If different sections of a large survey area are covered each day, then the sections should overlap and attempts made to ensure tracks coincide. These overlapping data can be compared for consistency.

A log should be kept of the equipment set-up, the parameters which are used, any changes made during the survey, and the performance of the survey equipment. Although logging systems allow for notes to be entered electronically as waypoints, it is strongly advised that a separate written log be kept. A log is vital for tracing possible causes of variable performance discovered during subsequent data analysis and to ensure that repeat surveys can follow the original survey with confidence. The log should have records of:-

1. Details of the equipment, power sources used and their position on the survey boat.
2. Draft of the echo sounder transducer and height of the GPS antenna.
3. Settings selected on the echo sounder (power and depth settings).
4. The co-ordinate system, units and datum set in the GPS (e.g., OSGB36; UTM zone 30; latitude/longitude in decimal degrees with WGS84).
5. Position and time of any changes to the equipment settings, operator, interruptions of power supply or GPS signal, problems encountered with equipment and remedial action taken.
6. Sea conditions.
7. Description, position, time and depth of any event (field sample, ground as observed on the echo sounder, shoals of fish or other mid-water echoes on the echo sounder)

screen). Description of field samples should detail sediment characteristics, topography and conspicuous species observed with an approximate assessment of abundance/cover. Although this information will be available from post-survey analysis of samples, this analysis may take place some time after a survey and a preliminary interpretation may be needed before the completion of the project.

The written log also provides a valuable alternative account of field sampling that can be compared with the electronic log in the case of confused or lost data. Where possible metadata standards for data collection methods should be used. Metadata authoring tools are available and should be preferred to free-form written records, for example:

GCMD Metadata authoring tool <http://www.gcmd.gsfc.nasa.gov>

Metamaker tool <http://www.nbio.gov/datainfo/metadata/tools/metamaker.html>

3.2.2 Field Sampling

Choice of field sampling technique

The choice of sampling techniques must match the expected nature of the sea floor and the purpose of the survey. For example, if the main objective is to survey bedrock reefs it may be sufficient simply to record where sandy habitats occur from underwater video without the need to take sediment samples.

Drop down or passively towed video systems are ideal for rapid sampling. Rapid sampling is important since successful analysis of the AGDS data depends upon the collection of a large number of field samples, accurately located on the acoustic map. Video permits the observation of conspicuous sea floor characteristics at a scale appropriate to the echosounder footprint. The position of the video system must be estimated. Therefore it is best deployed for a short duration rather than for long tows as this reduces the positional error (layback) caused by the relative movement of the sledge to the ship's position in tidal streams as more umbilical is paid out. The use of non-contact 'dunking' video systems drifting with the prevailing current can minimise these layback errors. Numerous short drops (point data) on homogeneous ground are far easier to post-process than fewer long tows covering a wide variety of habitats. However, short and carefully positioned tows can be useful to explore sharp transitions in acoustic ground types.

Although video is ideal for areas of seabed that are primarily characterised by their epifauna and flora, it is also useful for determining surface features of sediment (sand waves, shell fragments and evidence of bioturbation or biogenic sand reefs). Thus, video is almost universally applicable to surveys except where visibility is likely to be extremely poor. However, other sampling methods must also be used if the biotopes are characterised by

inconspicuous infauna. A standard grab sampling program can be run in conjunction with a remote survey.

Sidescan sonar data can also be used to ground-truth AGDS data sets, in addition to being a useful mapping tool in its own right. However, to ensure that an accurate interpretation of the sidescan sonar record has taken place it should be noted that the sidescan sonar data will also require ground-truthing using one of the above methods. Nonetheless, there are benefits to using sidescan sonar data to ground-truth AGDS; Sidescan sonar data covers a swathe of seabed, and this eliminates the need to create a buffer zone around point or line data sets when creating training sites for supervised classification of AGDS data (see section 7.3). Regions of known, homogeneous substrate type should be targeted from the sidescan sonar data when selecting such training sites.

Selecting field sample sites

AGDS have been designed to give real-time discrimination between habitats and, although it is strongly advised to use post-processing of the data for interpretation (see below), this facility is very useful for gaining knowledge of the distribution of biotopes during the survey which is necessary for designing stratified field sampling. Surveyors should edit the real-time display (e.g., the arrangement of the boxes in E1/E2-space) to identify acoustic ground types which may be related to particular habitats. In this way field sampling will have an element of prediction as the survey progresses. The following points should be considered when selecting field sampling sites:-

1. The full range of acoustic ground types should be sampled (E1/E2-space for *RoxAnn* or Q-space for *QTC-VIEW*).
2. The samples should cover the geographic range of the survey.
3. There should be at least 5 samples for each of the main habitats or biotopes. Even if the surveyor may feel that a particular ground type can be very confidently predicted (e.g., kelp forest in shallow water on hard ground) these habitats should still be sampled a minimum number of times. Failure to do this will compromise subsequent analysis.
4. However, survey effort may be focused on particular biotopes if real-time prediction of these biotopes is low.
5. Sites should be selected in areas where the acoustic data is consistent along tracks, rather than in areas where the along track data is changeable. This will alleviate problems of wrongly attributing acoustic values to particular biotopes due to positional uncertainty.
6. Field samples should lie on AGDS tracks so that they can be associated with real data rather than interpolated acoustic values.

3.3 SEAMAP/CEFAS survey examples

3.3.1 Description of survey areas and acoustic equipment used

Two surveys were conducted in the eastern English Channel at two different scales in order to provide working data sets with which to evaluate the post-processing methodology (Figure 3). A broad-scale survey was conducted between Hastings Shingle Bank and Dungeness in the eastern English Channel. A finer-resolution survey was also conducted bisecting Hastings Shingle Bank, covering an area of seabed 12km x 4km in size. Details of these surveys are given below:

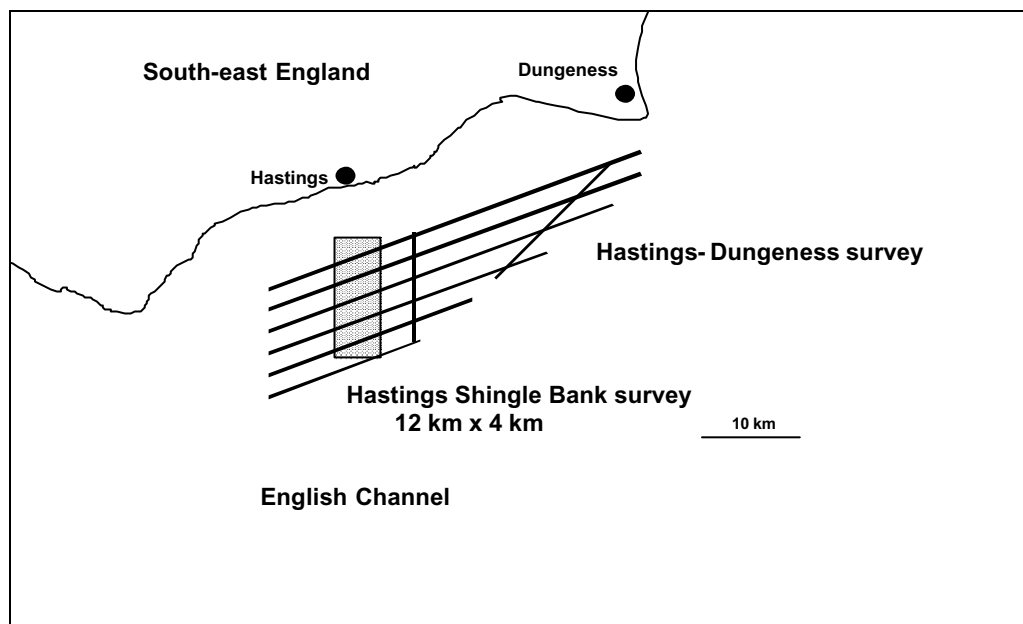


Figure 3. Location of the Hastings-Dungeness and Hastings Shingle Bank survey areas

Sidescan sonar: Surveys were conducted at each of the sites using a Datasonics™ digital chirps sidescan sonar with a Triton Isis logging system. Delphmap™ post-processing software was used to mosaic the imagery. The system was operated on a 400m swathe range. Towed sensor position was calculated from vessel heading, towcable layback and towfish depth, all of which were logged in real time by the Isis system.

AGDS: Following the sidescan sonar survey, tracks were re-run first using a 200khz QTC-VIEW system and then using a 200khz RoxAnn system. Survey lines were run using the same navigational software (Sextant) to ensure maximum overlap of AGDS data between the two systems. Details of the AGDS survey methodology are listed in Table 1. Schematic diagrams of the set up of both the RoxAnn and QTC-VIEW systems are shown in Figures 4

and 5. Data from both systems were logged for analysis at a later date. Vessel position was provided by the Veripos™ Differential Global Positioning system (DGPS).

	RoxAnn	QTC-VIEW
Frequency	200kHz	200kHz
Transducer	Koden CVS-8112	Furuno FCV582
Record rate	Every 50m	1/second
Vessel speed	8kts	8kts
Vessel	RV Corystes	RV Corystes
Sounder depth	4m	4m
Positioning	VERIPOS Differential chain	VERIPOS Differential chain
Logging software	<i>Microplot</i>	CAPS

Table 1. AGDS system settings and survey details

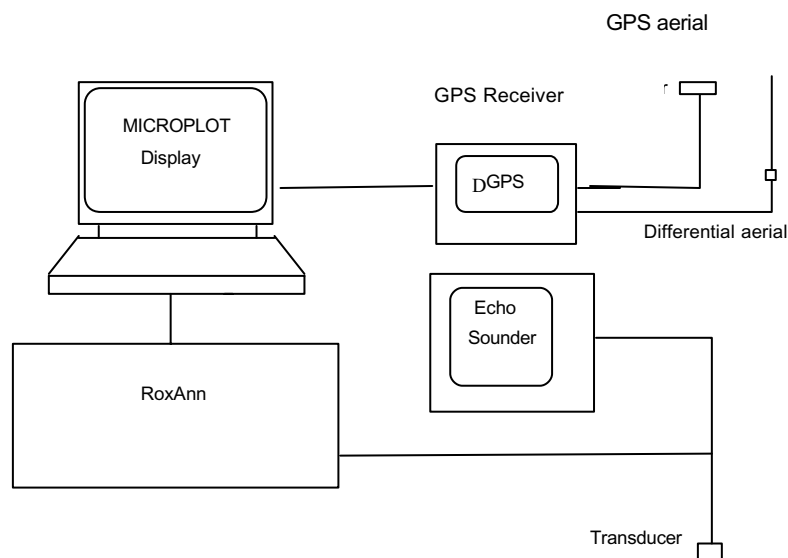


Figure 4. Schematic diagram of the single frequency *RoxAnn* AGDS and survey equipment

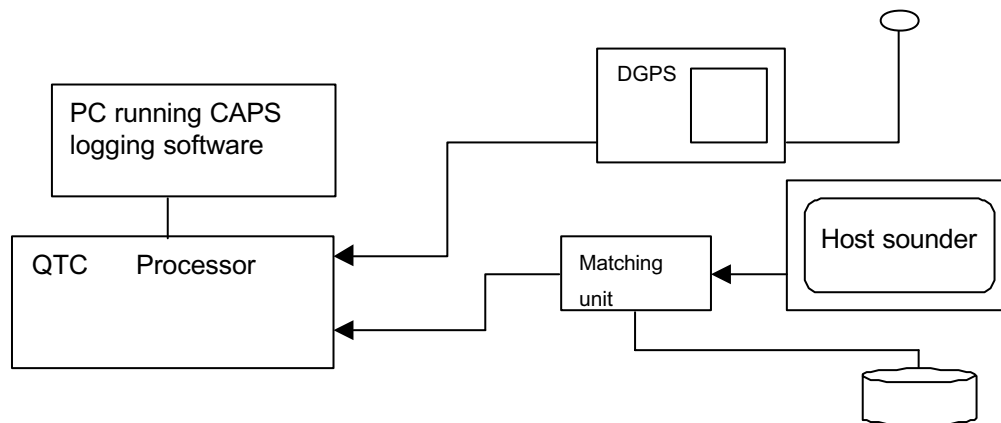


Figure 5. Schematic diagram of the *QTC-VIEW* AGDS and survey equipment

3.3.2 Hastings Shingle Bank survey

Acoustic data acquisition

Using the acoustic systems described under section 3.3.1, a high-resolution survey was conducted at Hastings Shingle Bank by CEFAS in 1999, covering an area of 12km x 4 km, as part of the DEFRA funded A0908 project. This survey was initially carried out to evaluate the utility of sidescan sonar as a tool for mapping seabed biotopes, but AGDS data sets were also collected from this site. The collection of these data sets has enabled accurate evaluation of the ability of AGDSs to discriminate between regions of discrete benthic habitats/communities during the current CEFAS/SeaMap collaborative programme.

Sidescan sonar lines were spaced at 400m intervals in a north-south orientation in order to ensonify 100% of the survey area. Delphmap post-processing software was used to mosaic the imagery and classify texturally different regions. Following this survey the sidescan tracks were retraced, first using *QTC-VIEW* and then using *RoxAnn*.

Sidescan sonar interpretation

The survey site crossed Hastings Shingle bank, and the structure of the bank was clearly discernible from the sidescan mosaic. Seabed features (sand ripples, rough ground, bedrock outcrops etc.) and an indication of the sediment characteristics (soft or hard sediments) could be identified from the sidescan mosaic. The presence of these features/characteristics was confirmed through the collection of underwater video data at a number of ground-truth stations using a drop-camera frame fitted with a video camera and lights. The camera system was suspended above the surface of the seabed as the vessel was allowed to drift. Deployments were made at slack water when currents were less than 1 knot in order to achieve good quality video footage. Using this approach, the survey area was divided into 4 acoustically distinct regions that represented distinct physical habitat types (labelled HA, HB, HC and HD - Figure 6). The Shingle Bank could be divided into two regions that, following ground-truthing with the underwater video camera, related to areas of coarse gravel (region

HB) and of dense dredge tracks in coarse gravel infilled with sand and silt (region HC). The regions to the north and south of the Shingle Bank both appeared from the sidescan record to consist of rippled sand. However, ground-truthing revealed that the inshore region consisted of fine-medium sand at water depths of less than 20m (region HA), whereas the offshore region was predominantly slightly gravely rippled sand at water depths greater than 20m (region HD). Boundaries between adjacent regions were clearly defined, and the substrata within regions HA, HB and HD tended to be homogeneous in their distribution. Examples of the sidescan sonar data from each region are shown in Figure 7.

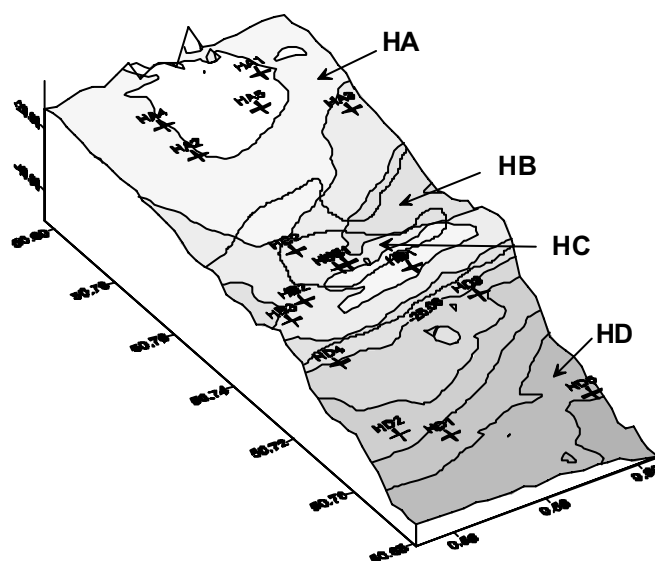


Figure 6 Bathymetric plot of the Hastings survey area showing the 4 acoustically distinct regions (HA, HB, HC, HD) determined from the sidescan sonar data, and locations of the sampling stations.

Ground-truthing

The design of the biological and ground truthing survey was structured around the acoustically distinct regions identified from the output of the sidescan sonar survey. The main sampling tool was a 0.1m² Hamon grab fitted with a video camera and light. This was the preferred type of sampling gear due to its ability to collect samples on coarse, unconsolidated sediments. The grab was fitted with a video camera in order to record an image of the seabed adjacent to the collection bucket of the grab, thus providing information about the undisturbed surface of the substrate at each sampling station. Sampling stations were randomly positioned within each acoustic region, and the number of stations within each region was linked to the size of the area.

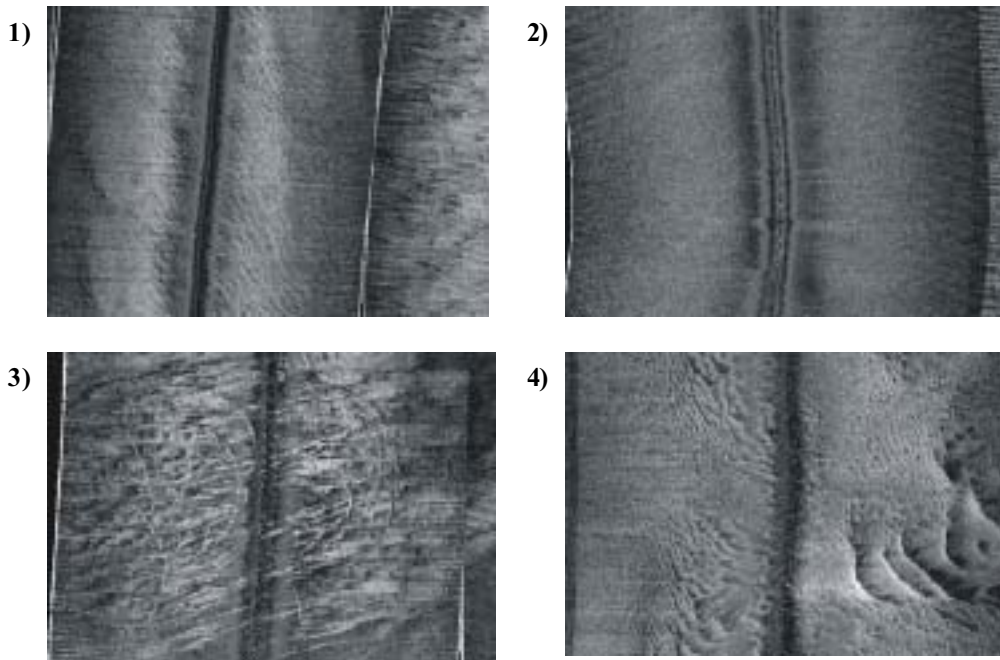


Figure 7. Examples of sidescan sonar images from the acoustically distinct regions. 1) Region HA - Inshore fine-medium sand <20m; 2) Region HB - Cobbles and gravel - undredged Shingle bank; 3) Region HC - Disturbed gravel - dredged Shingle bank; 4) Region HD - Slightly gravelly rippled sand >20m.

A total of 16 Hamon grab samples were collected from across the study area in October 1999. Following estimation of the total volume of each grab sample, a 500ml sub-sample was removed for laboratory particle size analysis. The remaining sample was washed over 5 mm and 1 mm square mesh sieves to remove excess sediment. The retained macrofauna were fixed in 4-6% formaldehyde solution (diluted with seawater) for laboratory identification and enumeration.

A beam trawl survey was also conducted in order to characterise the larger and mobile epifaunal species in July/August 2000. A modified 2m beam trawl, with a heavy-duty steel beam, chain mat and a 4mm knotless mesh liner fitted inside the net (see Jennings *et al.* 1999 for design specifications) was deployed at selected sampling stations within each acoustically distinct region. The beam trawl was deployed from the stern ramp of the research vessel using a warp length of three times the water depth. Each tow covered a fixed distance of 120m across the seabed, which was determined using Sextant software linked to the ship's Differential Global Positioning system. The speed of the ship and the time that the gear was on the seabed was also recorded. On retrieval of the trawl an estimate of the sample volume was made.

Sample processing

In the laboratory, Hamon grab samples were first washed with freshwater over a 1mm square mesh sieve in a fume cupboard to remove the excess formaldehyde solution. Samples were then sorted and the specimens placed in jars or petri-dishes containing a preservative mixture of 70% methanol, 10% glycerol and 20% tap-water. Specimens were identified to species level, as far as possible, using standard taxonomic keys. The number of each species was recorded, and colonial species were recorded as present or absent. For each positive identification a representative specimen was retained in order to establish a reference collection.

Each beam trawl sample was washed over a 5mm square mesh sieve and macrofaunal species were identified and enumerated at sea. Colonial species were recorded as either present or absent. Any specimens which could not be identified at sea were fixed in 4-6% formaldehyde solution and returned to the laboratory for identification.

The sediment sub-samples from each grab station were analysed for their particle size distributions. Samples were first wet sieved on a 500 micron stainless steel test sieve, using a sieve shaker. The sediment fraction less than 500 microns, along with water from the wet sieving, was allowed to settle in a bucket for 48 hours. Excess water was then removed using a vacuum pump and the fraction was washed into a sterile petri dish, frozen for 12 hours and freeze dried. The >500 micron fraction was washed from the test sieve into a foil tray and oven dried at ~90°C for 24 hours. It was then dry sieved for 10 minutes on a range of stainless steel test sieves at half phi intervals, down to 1 phi. The sediment on each sieve was weighed to 0.01g and the results recorded. The weight of the sediment below 500 microns was also recorded. A sub-sample of the <500 micron freeze dried fraction was analysed on a laser sizer. The results were combined with the dry sieved results to give the full particle size distribution. The mean, sorting and skewness values were calculated from these results.

Analysis and interpretation of all ground-truthing data is covered under section 4.2 of this report.

3.3.3 Hastings-Dungeness survey.

Acoustic data acquisition

A broad-scale survey was conducted in the eastern English Channel in 1999 between Hastings Shingle bank and Dungeness. Six survey lines were run at 2km intervals in a south-west to north-east orientation (Figure 3) using the sidescan sonar system described under section 3.3.1. Tracks were then re-run first using the *QTC-VIEW* system, and then using the *RoxAnn* system. Although the survey lines were run at different times using the two AGDSs,

39% of the *QTC-VIEW* data were within 25m of the *RoxAnn* data (considered to be an acceptable level of coincidence for direct comparison).

Ground-truthing

Eight acoustic ground types were identified from the sidescan sonar data from across the broad-scale area, and these are listed below with examples (Figure 8). In order to ground-truth these acoustic regions a number of passive video tows, using the drop camera frame described above, were conducted at each of the acoustically distinct sites. These sites were subsequently used as 'training' sites in the supervised classification of the AGDS data sets (see sections 7).

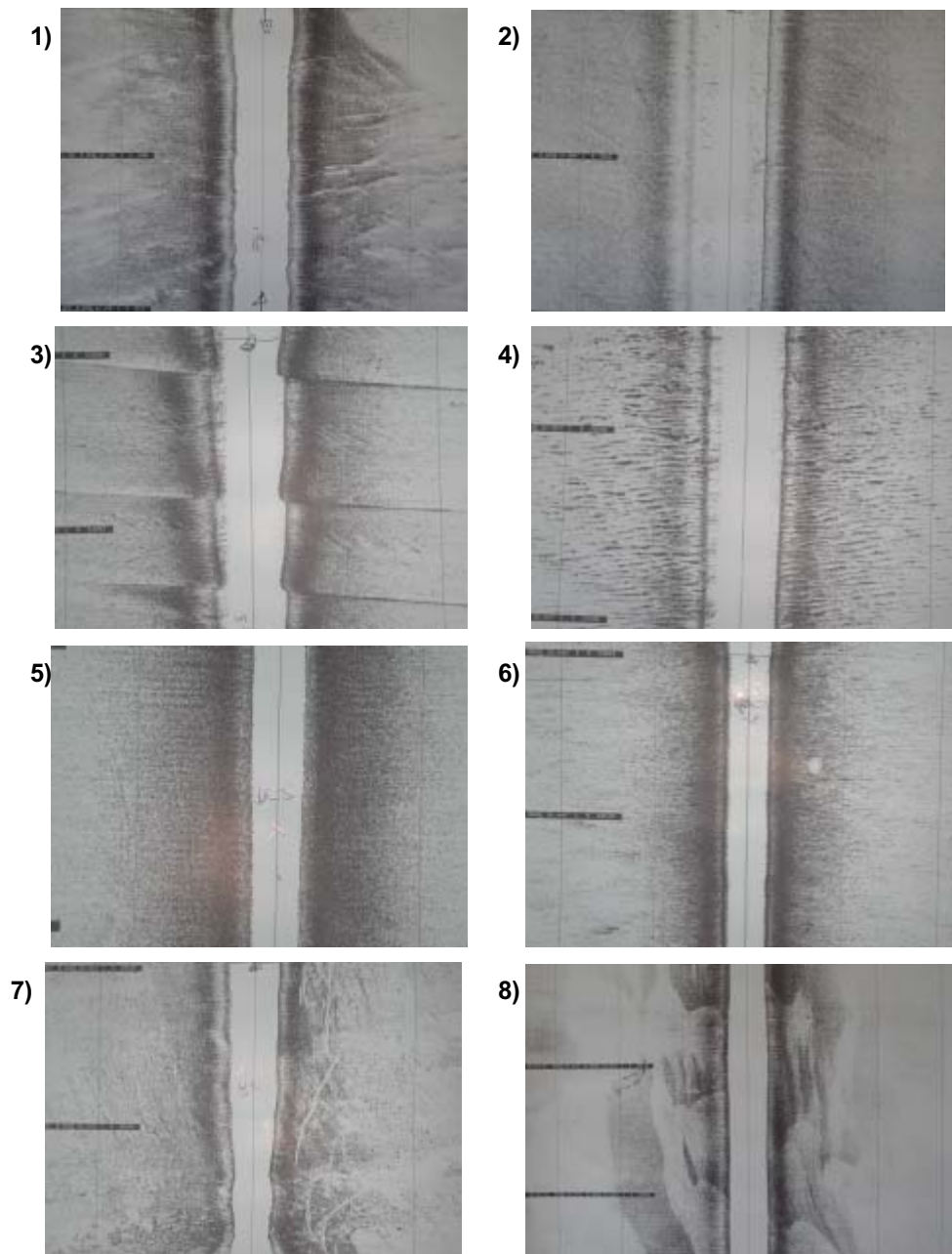


Figure 8. Examples of sidescan sonar data representing each of the 8 acoustic ground types identified between Hastings and Dungeness: 1) Gravel patches; 2) Smooth seabed; 3) Large sand waves; 4) Sand waves; 5) Gravel; 6) Small sand ripples; 7) Rough and stoney; 8) Gravel ribbons

4 ANALYSIS OF FIELD SAMPLES

4.1 Ground-truthing data

A wide range of methods are appropriate for ground-truthing AGDS data sets (and other acoustic data sets) as described under section 3.2.2. However, the degree to which ground-truthing data are analysed will depend on the nature of the mapping activity. For example, ground-truthing data sets may be used in a purely qualitative context (e.g. video data) to describe and classify a particular seabed habitat, or they may be analysed in greater detail to obtain quantitative data (e.g. macrofauna data from grab surveys listing species compositions of an area). The time and resources spent on the analysis of the field samples will depend on the level of detail required in the final habitat map.

Misclassification of the field data can undermine data interpretation and is a major source of uncertainty in interpretation. This is particularly important for interpretation of acoustic data since it is likely that the field records will be summarised as biotopes or habitat classes for the purposes of data analysis (see section 7).

Video data can be categorised into biotopes and the records tagged with the predominant biotope. A more subtle estimate of the percentage cover of biotopes which are present within a video clip can also be derived. Categorical data is easy to use in classification. Video data can also be used to measure frequencies of occurrence/counts. The data are thus either continuous variables or ranked.

Macrofauna data collected by grabs, dredges or trawls can provide a source of quantitative, or semi-quantitative information. Macrofaunal data can be subjected to the standard multivariate analysis to discover natural groupings of samples, or to test whether statistically distinct communities exist within an acoustic region. These statistical groupings can be regarded as categories that can be used as the basis for classification (see section 4.2.1 and section 7).

Sediment data collected by grabs may also be used to derive habitat classes using standard classification systems (e.g. Folk), or simply using the relative percentages of different size categories of sediments (e.g. % silt/sand/gravel).

In supervised classification ground-truth data can be used as training sites for the development of signatures for the classification of the AGDS data from across the survey area (see section 7.3). With the exception of sidescan sonar data, the data generated from ground-truth sampling falls into one of two categories: point data or line data.

4.2 SEAMAP/CEFAS survey examples

Ground-truth data from each survey were used to classify the AGDS data sets. Ground-truth data were analysed, and sites were chosen for the AGDS supervised classification procedure (see section 7). In the case of the Hastings Shingle Bank Survey the 100% sidescan sonar coverage was used to test the accuracy of the AGDS classification.

4.2.1 Hastings Shingle Bank Survey

Biological data analysis

Associations between benthic assemblages and acoustic regions were examined using multivariate statistical methods. Sample and species associations across the survey were assessed by non-metric multi-dimensional scaling (MDS) ordination using the Bray-Curtis similarity measure on 4th root transformed data using the software package PRIMER (Clarke and Warwick 1994). Low abundance species (i.e. with fewer than three individuals recorded through out the survey area) were removed in order to reduce the variability caused by these infrequently occurring species. Removing these species was also necessary to conform to certain limitations in the total number of species which can be used during certain tests within the PRIMER software (e.g. SIMPER - see later). The majority of species collected during the beam trawl surveys were epifaunal species. Statistical analysis was therefore conducted on all taxa excluding colonial organisms using identical statistical methods as above on 4th root transformed data.

Analysis of similarities (ANOSIM, Clarke 1993) was performed to test the significance of differences in macrofauna assemblage composition between samples. The nature of the groupings identified in the MDS ordinations were explored further by applying the similarity percentages program (SIMPER) to determine the contribution of individual species to the average dissimilarity between samples.

A correlation-based principal components analysis (PCA) was applied to ordinate results from the sediment particle size analysis. Prior to analysis, environmental variables were converted to approximate normality using a $\log(1+M)$ transformation. Analysis of similarities (ANOSIM, Clarke 1993) was performed on particle size data to test the significance of differences in particle size composition between acoustic regions.

Sediment characteristics and environmental variables

Examination of the grab samples on deck, and in-situ study of the undisturbed seabed surface by the video camera attached to the side of the grab, confirmed the interpretations from the acoustic data. Results from the particle size analysis of grab samples, used in conjunction with information derived from the sidescan sonar mosaic and video footage,

provided a clear understanding of the physical habitat characteristics within each acoustic region.

An ordination by PCA of the particle size data from the Hamon grab samples is illustrated in Figure 9. Samples collected from the Shingle Bank (regions HB and HC) had a much higher percentage of coarse material than samples collected from regions to the north and south of the bank (HA and HD), which comprised mainly of sand (Table 2). This is reflected in the PCA ordination by the separation of HA and HD from HB and HC. The particle size distribution of samples from within regions HA and HD were also more consistent, as depicted by the tight clustering of samples in the PCA ordination (Figure 9). In contrast there was a much higher degree of particle size variability between replicate samples collected from regions HB and HD, as depicted by the much wider spread of samples from these regions in the PCA ordination (Figure 9) and as shown in Table 2. Table 3 shows the analysis of similarities results (ANOSIM, Clark 1993) for particle size data between samples from the four acoustic regions. All regions were statistically distinct from one another, with the exception of regions HB and HD. However, in terms of seabed morphology, region HC was visually and acoustically distinct from region HB, and dense dredge tracks were clearly visible on the side scan record within this region (Figure 7).

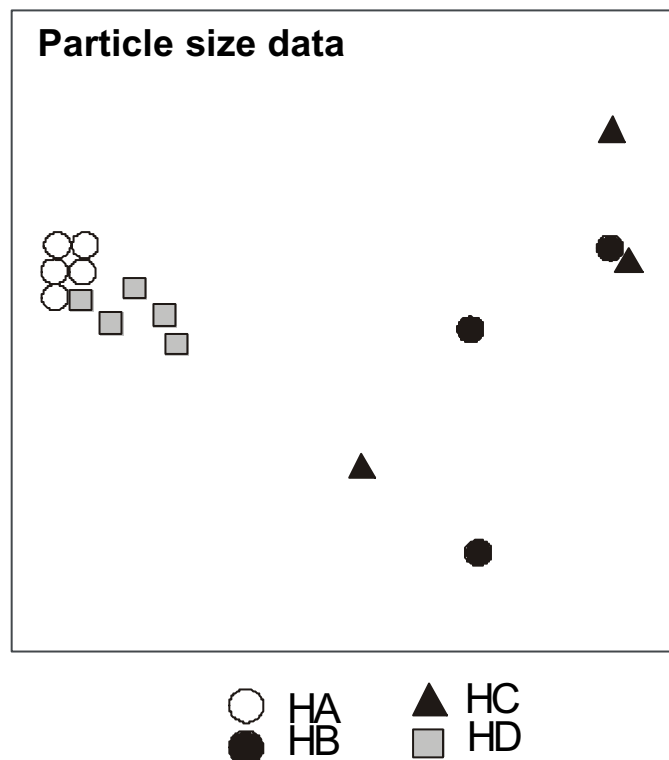


Figure 9. PCA ordination of particle size (mean diameter in mm, sorting coefficient, % gravel, % sand and % silt/clay) distributions.

Acoustic region	Replicate	% gravel	% sand	% silt/clay	Mean particle size (mm)	Sorting
HA	1	2.03	97.67	0.30	0.31	0.84
	2	0.04	99.96	0.00	0.27	0.38
	3	0.03	99.97	0.00	0.28	0.38
	4	1.32	98.68	0.00	0.32	0.64
	5	0.02	99.98	0.00	0.26	0.37
	mean	0.69	99.25	0.06	0.29	0.52
HB	1	36.97	55.87	7.16	0.89	2.95
	2	52.52	44.64	2.83	1.97	2.83
	3	65.61	31.18	3.21	4.19	3.13
	mean	51.70	43.90	4.40	2.35	2.97
HC	1	25.48	70.33	4.18	0.64	2.86
	2	70.93	25.28	3.79	4.01	2.89
	3	84.96	13.11	1.93	4.32	2.13
	mean	60.46	36.24	3.30	2.99	2.63
HD	1	3.55	95.58	0.87	0.44	1.10
	2	10.57	89.43	0.00	0.53	1.34
	3	1.85	98.15	0.00	0.31	0.68
	4	12.95	85.68	1.37	0.56	1.59
	5	12.22	86.93	0.85	0.59	1.47
	mean	8.23	91.15	0.62	0.49	1.24

Table 2. Particle size analysis data from Hamon grab samples collected from each acoustic region at the Hastings study site.

	HA	HB	HC
HB	**		
HC	**	n.s.	
HD	**	**	**

Table 3. Analysis of similarity for particle size (mean diameter in mm, sorting coefficient, % gravel, % sand and % silt/clay) distributions between acoustically distinct regions (n.s. not significant; * Significant at $p < 0.1$; ** Significant at $p < 0.05$). Performed on 4th root transformed data.

Biological data interpretation

A total of 172 taxa were identified from the 16 Hamon grab samples collected from across the survey area, and a total of 91 taxa were identified from the beam trawl survey. Figure 10 shows the output from non-metric multi-dimensional scaling ordination of data from both the Hamon grab and beam trawl surveys. Grouping of replicate samples from each acoustic region is clearly visible and, following analysis of similarities (ANOSIM, Clark 1993) illustrates that there were significant differences in macrofaunal assemblage structure between all acoustic region, with the exception of regions HC and HB from the beam trawl data (Table 4).

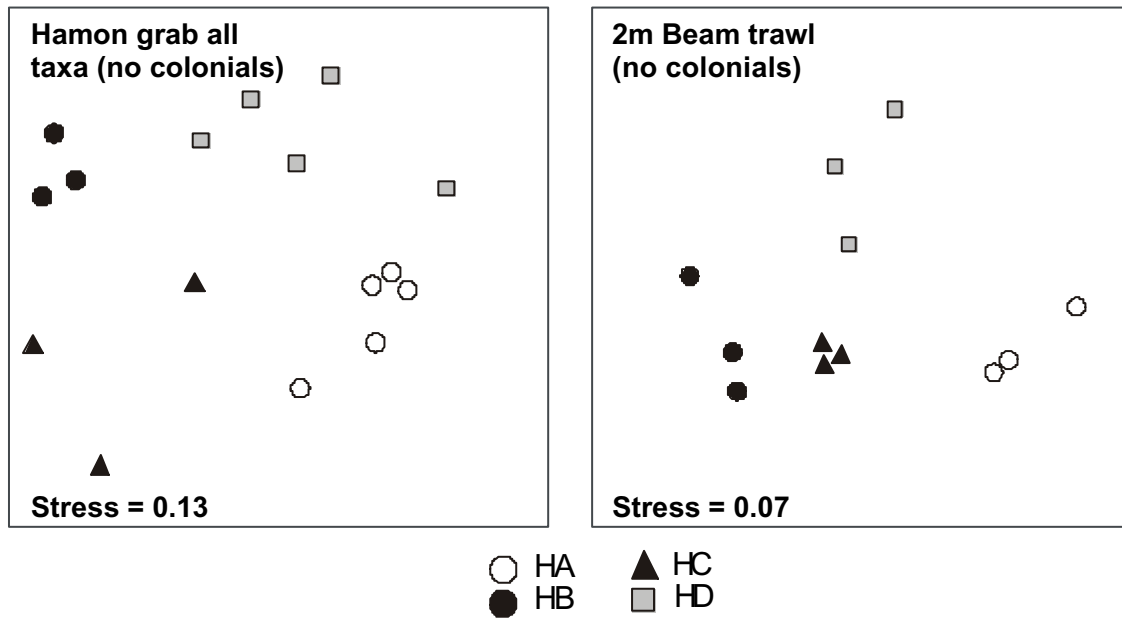


Figure 10. MDS plots for macrofaunal assemblages from the Beam trawl and Hamon grab surveys. All taxa except colonials included, data was 4th root transformed.

	HA	HB	HC
Hamon grab: All taxa - colonial species			
HB	96**		
HC	91**	84*	
HD	82**	86**	91**
Beam trawl: All taxa - colonials species			
HB	71*		
HC	57*	45	
HD	64*	60*	55*

Table 4. Dissimilarities (%) between assemblages (colonial species removed) from acoustically distinct regions based on 4th root transformed data (* denotes significant difference at $p < 0.1$. ** denotes significant difference at $p < 0.05$)

Community groupings were explored further using the similarity percentages program SIMPER. Results revealed that the average similarity between replicate samples collected within an acoustic region was relatively low, particularly for the Hamon grab data (Table 5 and 6), and that characterising species from each acoustic region identified from the Hamon grab survey were unsurprisingly very different from those identified from the beam trawl survey.

Acoustic Region		Average Abundance	%	Cumulative %	Average Similarity
HA	<i>Spiophanes bombyx</i>	18.20	25.01	25.01	42.33%
	<i>Magelona johnstoni</i>	20.80	23.63	48.63	
	<i>Nephtys cirrosa</i>	2.40	17.65	66.29	
	<i>Bathyporeia gracilis</i>	10.20	15.99	82.28	
HB	<i>Pomatoceros triqueter</i>	17.67	10.62	10.62	43.61%
	Asciacea	11.67	8.49	19.11	
	<i>Echinocyamus pusillus</i>	5.00	7.73	26.85	
	<i>Lumbrineris gracilis</i>	5.00	7.57	34.42	
	<i>Aonides paucibranchiata</i>	2.67	6.55	40.97	
	<i>Caulleriella alata</i>	2.33	6.55	47.51	
	<i>Scalibregma inflatum</i>	2.00	5.85	53.36	
	<i>Glycera lapidum</i>	2.00	5.85	59.22	
	<i>Poecilochaetus serpens</i>	1.67	5.50	64.72	
	<i>Syllis (Type B)</i>	1.00	5.50	70.22	
HC	<i>Caulleriella alata</i>	4.33	55.87	55.87	16.53%
	<i>Scolelepesis squamata</i>	1.33	18.82	74.68	
	<i>Ampelisca spinipes</i>	2.67	13.75	88.44	
HD	<i>Lumbrineris gracilis</i>	3.40	22.83	22.83	27.23%
	<i>Nephtys cirrosa</i>	2.60	13.41	36.24	
	<i>Spisula elliptica</i>	1.60	11.02	47.26	
	<i>Eurydice pulchra</i>	0.80	10.70	57.96	

Table 5 Results from SIMPER analysis of Hamon grab data at the Hastings site (all taxa excluding colonial species, 4th root transformed), listing the main characterising species from each acoustically distinct region. Average abundance, similarity percentage, and cumulative similarity percentage for each species and the overall average similarity between replicate samples from within each region are listed.

Acoustic Region		Average Abundance	%	Cumulative %	Average Similarity
HA	<i>Pomatoschistus minutus</i>	54.33	13.31	13.31	66.38%
	<i>Pagurus bernhardus</i>	25.67	11.60	24.91	
	<i>Aphrodita aculeata</i>	21.00	11.23	36.14	
	<i>Pontophilus</i>	14.00	10.79	46.93	
	<i>Hinia</i>	15.67	9.36	56.29	
	<i>Buglossidium luteum</i>	11.67	8.50	64.79	
	<i>Callionymus</i>	4.67	7.72	72.51	
	<i>Echiichthys</i>	4.67	7.06	79.57	
HB	<i>Psammechinus miliaris</i>	101.00	10.86	10.86	56.16%
	<i>Pagurus bernhardus</i>	27.00	10.36	21.22	
	<i>Ophiura albida</i>	19.33	8.76	29.98	
	<i>Buccinum</i>	7.33	7.23	37.21	
	<i>Macropodia</i>	5.67	6.45	43.66	
	<i>Nudibranchia</i>	13.33	6.16	49.82	
	<i>Chlamys</i>	4.33	5.90	55.73	
	<i>Pisidia</i>	6.67	5.86	61.59	
	<i>Pomatoschistus minutus</i>	2.67	5.68	67.27	
	<i>Metridium senile</i>	4.33	5.25	72.52	
HC	<i>Pagurus bernhardus</i>	31.33	9.17	9.17	68.37%
	<i>Hinia</i>	20.00	8.12	17.28	
	<i>Pomatoschistus minutus</i>	21.00	7.49	24.78	
	<i>Chlamys</i>	8.67	6.88	31.66	
	<i>Macropodia</i>	8.00	6.45	38.11	
	<i>Galathea</i>	7.00	6.39	44.51	
	<i>Liocarcinus</i>	11.67	6.38	50.88	
	<i>Buccinum</i>	6.33	6.22	57.10	
HD	<i>Pagurus bernhardus</i>	66.33	16.62	16.62	52.5%
	<i>Ophiura albida</i>	85.67	14.44	31.06	
	<i>Liocarcinus</i>	14.00	10.61	41.66	
	<i>Ophiura ophiura</i>	25.33	10.27	51.93	
	<i>Crangon allmanni</i>	14.33	7.87	59.81	
	<i>Pomatoschistus minutus</i>	4.67	7.84	67.65	
	<i>Macropodia</i>	4.67	7.61	75.25	

Table 6 Results from SIMPER analysis of beam trawl data at the Hastings site (all taxa excluding colonial species, 4th root transformed), listing the main characterising species from

each acoustically distinct region. Average abundance, similarity percentage, and cumulative similarity percentage for each species and the overall average similarity between replicate samples from within each region are listed.

Biotopes

The derivation of biotopes was based on the statistical analysis and interpretation of the biological, video and geophysical data sets described above. Both Hamon grab and beam trawl data were used to obtain a good cross section of the benthic assemblages from each physical habitat. In some cases, the assemblages identified by one sampling method (e.g. grab) from an acoustic region were statistically distinct, but when sampled by a different method (e.g. trawl) were judged to be similar to assemblages from surrounding regions. Under such situations it was necessary to take account of all available data from the region (underwater video, AGDS) and make a subjective decision as to whether the region should be classed as a distinct biotope or not.

Using all the available information it was possible to identify 4 discrete biotopes from across the survey area, which were contained within each of the sidescan regions (biotopes HA, HB, HC and HD). However, biotope HC (the dredged region on the Shingle bank) appeared to be a degraded form of biotope HB (the undredged Shingle bank) and should possibly be classed as the same biotope. The geographical distribution of these biotopes is shown in Figure 11, and a comprehensive description along with a visual example of each of the biotopes identified from each acoustic region is listed below:

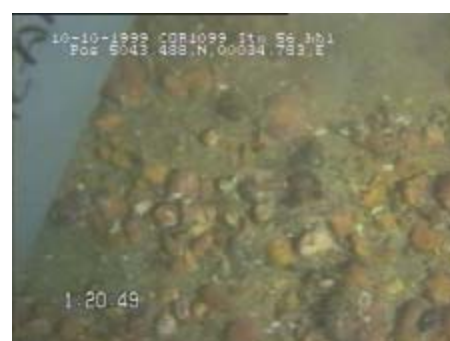
Biotope HA (Hastings): - Shallow water, polychaete dominated fine sand

The inshore area of the Hastings study site (Region HA), consisting of fine shelly sand in which polychaete tubes were visible on the underwater video footage, was identified as a discrete biotope. The species composition was characterised by polychaete worms such as *Spiophanes bombyx*, *Magelona johnstoni*, *Nephtys cirrosa* and *Aphrodita aculeata*. Burrowing amphipods of the genus *Bathyporeia* were present as was the sand goby *Pomatoschistus minutus*.



Biotope HB (Hastings): - Gravel with attached epifauna

Region HB was the undredged region of Hastings Shingle bank. There was an abundance of attached epifauna, the soft coral, Dead Man's Fingers (*Alcyonium digitatum*) in particular distinguished this



biotope from the others found at Hastings. Other characterising species included the sea urchin *Psammechinus miliaris*, the sea anemone *Metridium senile*, the hydroid *Sertularia*, the serpulid polychaete *Pomatoceros triqueter* and the encrusting bryozoan *Schizomavella*.

Biotope HC (Hastings): - Disturbed (dredged) sandy gravel

Region HC was the dredged area in the middle of the Shingle bank, surrounded by region HB. The gravel within this region was sandier and less coarse than that of region HB, and there were fewer sightings of large epifaunal species on the underwater camera footage from this area. This was confirmed by a



marked absence of many of the sessile epifaunal species in the grab and trawl data that were abundant in biotope HB. Whelks of the genus *Hinia* were a characterising species of HC. Biotope HC may represent a degraded version of biotope HB.

Biotope HD (Hastings): - Deeper water, coarse sand with *Ophiura ophiura*

HD was the region furthest offshore at this study site. The sediment was mainly coarse sand with low proportions of gravel in some areas, and the particle size distribution was similar to that of region HA. However, the biotic component of this region was distinctly different, with fewer polychaete species, although the polychaete worms *Nephtys cirrosa* and *Spiophanes bombyx* were present as they were in region HA. The brittle stars *Ophiura albida* and *Ophiura ophiura* were identified as characterising species from this habitat.

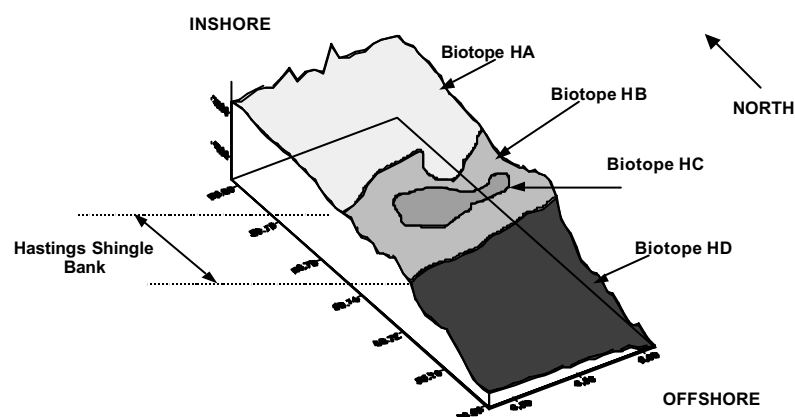


Figure 11. Bathymetric plot of the study site at Hastings showing the spatial distribution of the 4 biotopes and the Shingle bank (area 12km x 4km)

From within these 4 biotopes, training sites for the classification of the AGDS data were selected. Two or three sites from within each of the 4 regions, representing approximately 20% of the total area of each region, were selected from the sidescan mosaic for use as training sites in the supervised classification procedure (see Section 7.5.3). Each of the Hamon grab stations, along with stations where underwater video footage had been collected using the drop camera frame, were also used as training sites in the supervised classification procedure (see Section 7.5.4).

4.2.2 Hastings-Dungeness Survey

Areas from the sidescan sonar data (approximately 1-2km x 400m in area) representing each of the 8 ground types listed under section 3.3.3 (which were confirmed through the deployment of the underwater camera system) were selected as training sites for the supervised classification of the AGDS data sets. Sites represented a homogeneous area of seabed typical of the each of the substrate types identified from across the survey area. Training sites selected for use in the supervised classification procedure are shown in Figure 36.

5 PRELIMINARY TREATMENT OF ACOUSTIC DATA AND QUALITY CONTROL.

5.1 Introduction

There are two main purposes for preliminary data treatment:-

1. Quality assurance: to ensure that the data are of sufficient quality for the advanced processing required for data classification through the:
 - a. removal of records considered being of dubious quality (e.g., due to sea conditions);
 - b. removal of records with high positional inaccuracies;
 - c. correction of depth records to chart datum;
 - d. application of standardisation procedures if two or more data sets are to be amalgamated for classification.
2. Exploratory data analysis: to explore the nature of the data in order to plan the most appropriate route for advanced processing by the:
 - a. exploration of dependencies between variables that might compromise classification and the application of data transformation if considered necessary;
 - b. investigation of patterns of spatial correlation between data to assess if and how spatial interpolation should be applied to the data;
 - c. derivation of secondary attributes from the data that might be useful for classification (e.g., variability, slope).

The first is concerned with an extension of quality control of the data that starts within the signal processing system (respectively the hardware of the *RoxAnn* signal processor and the *QTC-VIEW* software).

5.2 Within system analysis

5.2.1 RoxAnn

The *RoxAnn* signal processor may reject some returns (using electronic 'gimbals' (Burns *et al.* 1985) and then makes adjustments to the raw E1 and E2 values to compensate for depth within the signal processing system itself. These adjusted values are exported as an NMEA string and logged, interleaved with position and time. Thereafter, editing the data can be undertaken in the logging and display software (e.g., *Microplot* or *RoxMap*) or the data can be exported to other software.

5.2.2 QTC

The situation is not as straightforward for *QTC-VIEW* since the system is designed to be used with specific software for analysis and classification of the data. *QTC-VIEW* applies gating or

blanking to the returns and selects those where the bottom has been successfully detected for processing. The digitised signal is processed by applying numerous algorithms for characterising the echo to result in 166 components termed Full Feature Vectors (FFVs). The details of this processing are commercially confidential and, therefore, the primary outputs from *QTC-VIEW* are not available for analysis outside of the system in the same way the E1 and E2 values are for *RoxAnn*. Instead, the output must be subjected to principal components analysis (PCA) within the *QTC-VIEW Impact* software. PCA is a multidimensional statistical technique for reducing a large number of variables to a smaller number without significantly reducing the total variability in the original data. In *QTC-VIEW* 166 variables are reduced to three new axes termed Q1, Q2 and Q3 that explain over 99% of the total variability.

Because the PCA describes the acoustic diversity of the echoes (including dubious records), all editing of the FFVs must be done prior to performing PCA. *Impact* allows the following operations to be performed before running the PCA: The sonar and navigation raw data are merged on a one-to-one basis into a new FFV file and this allows the data to be clipped or filtered by depth, geographic position, time and (if the files are large) reduced through decimation.

The eigenvectors (Q values) can be exported to other software for exploratory and advanced analysis. Alternatively, classification of the data can be performed by clustering techniques within *Impact* (see Section 7).

5.3 Quality control after data export

There are many potential sources for changes in performance and their effects are often insidious and, unless the data is checked carefully, only make themselves apparent in the later stages of data interpretation. For example, data can be adversely affected by vessel speed, sea conditions and GPS error and their effects can be hard to detect within the logging and display software. Spreadsheets and other programs can be used to identify poor track data using macros or visual techniques. The following procedures should be applied:

- 1. Highlighting data associated with low boat speed or erratic GPS positions:**
Macros can be applied to the eastings and northings to check for apparent boat speed between records to highlight sections of track where (1) there are large jumps in apparent position due to GPS error and (2) there is little change in the position of the survey vessel. The distance between two consecutive points is calculated, and positions are highlighted where there is a jump in distance much greater than that expected from the speed of the vessel, or where the vessel slows to a speed below the acceptable minimum for recording AGDS (about 1 metre per second). Highlighted records can then be checked to see if they should be deleted.

2. **Highlighting erratic depths:** A record is compared to the average value of the two previous track points together with the two following points. Track points where a large difference occurs are highlighted and inspected. If a point appears to be out of step with its neighbours, then it is deleted. An alternative technique is to plot the depths as a time series and pick outlying data visually (easily done in *MapInfo* using non-earth coordinates). This latter method is more time consuming, but gives more control over data quality.
3. **Track plots of acoustic data:** Plotting the track point data colour coded to show values of the acoustic data is invaluable for spotting likely problems caused by inconsistent performance of the AGDS. Some surveys exhibit whole tracks which are notably inconsistent with neighbouring tracks and may need to be discarded.
4. **Scatterplots to check for outliers:** An especially useful procedure for highlighting inconsistent performance is to create scatterplots in a GIS (e.g., *MapInfo*) using non-earth co-ordinates, select outliers and then display these geographically. Outliers may occur on a particular track that is inconsistent with neighbouring tracks, or may occur on cross-tracks, or may be associated with ship manoeuvres.
5. **Data standardisation:** It may be necessary to amalgamate two or more data sets (e.g., geographically overlapping surveys or surveys conducted at different times). E1 and E2 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). Scatterplots of the standardised data can be overlain to check for compatibility. This technique has been found to produce a good match between surveys and works best when tracks over the same area can be used for inter-calibration. In some cases, data obtained from systems with very similar ground-response characteristics can be amalgamated even though the magnitude of the values varies between systems. In other cases, the response characteristics are different and standardisation will not make the data sets directly comparable. Other methods for amalgamating surveys under these conditions have been devised (Foster-Smith *et al.* 2000).

QTC-VIEW operates a depth correction that is related to a reference depth which is obtained from the median or mean of the depths expected over the survey area. The reference depths must be set prior to data collection and only data sets with similar reference depths can be compared with each other. If surveys are to be amalgamated, this must be done by combining FFV files **prior to PCA** because the dynamic range of the Q values are set by the range of the FFV values.

6. **Correcting depths to vertical chart datum:** Depths are tidally adjusted to chart datum by applying corrections calculated from the tidal prediction program using the simplified harmonic method produced by the UK Hydrographic Office (Anon 1991). The corrections are applied at time intervals between 10-30 minutes. However, using

10 minute intervals eliminates steps in the depth track records that can be apparent if longer time intervals are used. This is particularly important for the construction of digital elevation models. It should be stressed that the resulting depths may not be very accurate and may conflict with the soundings on Admiralty hydrographic charts which are naturally cautious in defining minimum depths. This must be expected since atmospheric conditions affect tides and, additionally, the nearest reference port may be some distance away.

5.4 Exploratory data analysis

It is important to explore the nature of the track data through visualisation and descriptive statistical techniques in order to plan and justify further detailed analysis and classification.

1. **Scatterplots to check for dependencies between variables.** Weak relationships between variables (compared to the overall variance in the data) might not affect interpretation significantly. But strong relationships (particularly depth dependent relationships) will dominate classification. Dependant variables may be discarded for classification or data can be transformed. For example, if E1 and E2 are not independent variables, and if the correlation between them is strong, a simple principal components transformation might be required ($PC1 = E1+E2$; $PC2 = E1-E2$). Since PCA has already been performed on the *QTC-VIEW* data, equivalent transformation is not possible nor is it possible to apply any transformation before PCA. If any strong dependencies are apparent some data may be excluded from analysis or the dataset could be divided and processed separately (see Section 5.5).

2. **Variography:** This is a graphical technique for showing the spatial correlation between data. It shows how the similarity between values decreases as distance between points increases. The variogram illustrates the overall pattern of spatial correlation for the whole data set. It does not show very broad scale spatial trends or local variations in spatial correlation. The variogram shows:-
 - a. Noise (the variance within the close-range, minimum sampling distance): this should not be too large in relation to the maximum variance of the data set. If it is, then the variability within the minimum point-to-point distance is so high that one point is independent of its near neighbours – in other words, no local patterns will be seen and interpolation is impossible.
 - b. The range (the lag distance where the sill is considered to have been reached): The range gives the maximum distance where some spatial correlation over intermediate distances might be expected to be present. Whilst interpolation is possible over distances at the limits of the range, it is better to limit interpolation to distance well within the range.
 - c. Small scale spatial trends: There may be spatial correlation between points over large distance that reflect spatial trends across a survey area best

described by quadratic or polynomial surfaces rather than the use of distance-weighted interpolation.

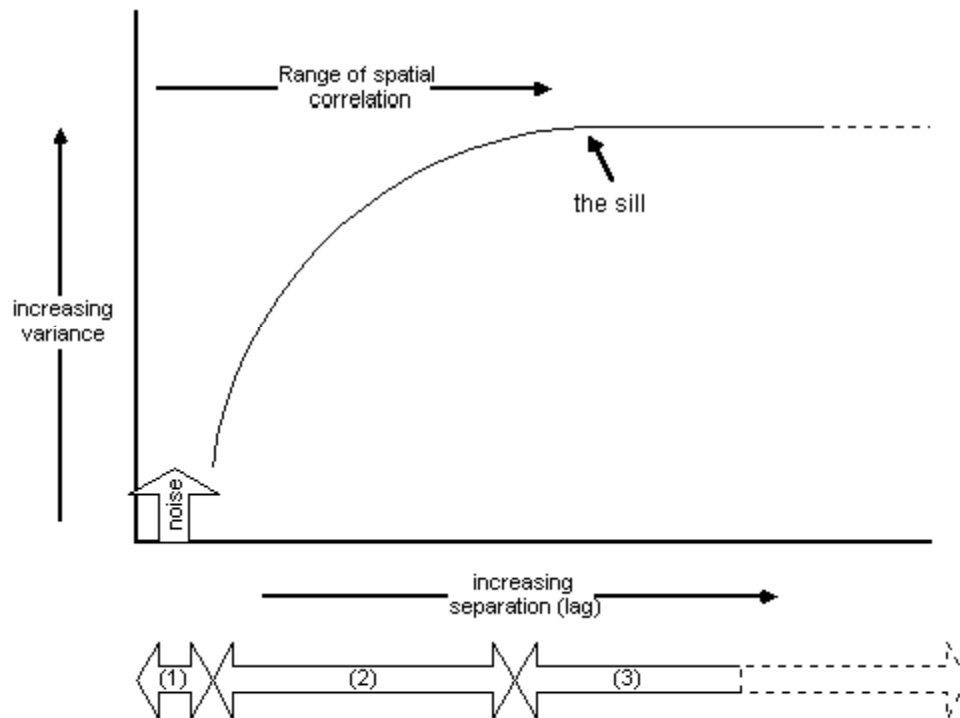


Figure 12. A general form of the variogram which illustrates the points referred to in the text.

The shape of the relationship between variance and lag distance illustrated in Figure 12 is only one of many models that might be found in practice (see Burroughs and Donnell 1998). The graph starts at a minimum distance representing the maximum spatial resolution of the AGDS (1) and the variance below this distance is 'noise' (also called the 'nugget effect'). Variance may then rise quite steeply initially over the range of spatial correlation indicating that the strongest links between data are over short distances and correlation dwindles rapidly as distance increases. The point where the graph levels off (the 'sill') marks the maximum distance (2) over which spatial correlation can be detected and is called the 'range'. However, the correlation is very weak at distances approaching the maximum range and a smaller working range for interpolation may be chosen. At distance greater than the range (3) no interpolation is possible.

Exploration of these spatial patterns is important for a number of reasons: Firstly, it is reassuring to demonstrate that the variance within the maximum resolution (noise) is small in comparison to the overall variance of the data set. If this was not the case,

then any attempt to interpret the AGDS data would likely be unsuccessful. Secondly, it is fundamental to broad scale mapping that some generalisation about the distribution of acoustic characteristics and hence biotopes can be made at an intermediate scale throughout a survey area on the assumption that some spatial dependence operates. If this were not the case, then each location on the map would be entirely independent of its neighbours and broad scale mapping through the interpretation of acoustic data would be impossible. Thirdly, it indicates the distances over which interpolation can be justified.

3. **Variability in data:** As stated, the variogram gives a good idea of what the overall variability is in the data set. What is also important is how variability changes throughout the area. This can be measured by looking at point-to-point differences or standard deviation over a number of consecutive points (e.g. 5 points). Data should be selected where the ship speed is relatively constant so that inter-point distances are roughly similar. Variability can be related to the average for the whole data set and displayed to show areas where variability is above or below the average. Thus, it shows where interpolation is likely to perform better/worse than expected from the variogram. Additionally, an index of along-track variability can be useful in restoring a measure of local variability where interpolation excessively smoothes the data and hides real and significant fine scale features (see later section on interpolation). In this case, variability can be regarded as a derived attribute of the data and therefore incorporated into classification.

5.5 SEAMAP/CEFAS survey examples - Preliminary treatment of the Hastings Shingle Bank and Hastings-Dungeness data sets

Preliminary treatment and exploratory data analysis was carried out on the data sets obtained from (1) the Hastings shingle bank and (2) the Hastings-Dungeness area. The procedures adopted together with some of the outputs are shown in this section to illustrate the procedures outlined above. A summary description of the complete acoustic data sets is given in Section 5.6.

5.5.1 Editing data associated with low speed, erratic position and depth, scatterplots

Macros highlighting data associated with these three sources of poor quality data were run within spreadsheets of the data. A threshold for erratic heights of 3m was chosen to allow for the detection of sand waves. In all, less than 1% of the data were eliminated and this low level of rejection was reassuring as to the quality of the data as collected. Scatter plots did not indicate any outlying data that warranted further investigation.

Figure 13. Track plots of the Hastings Shingle Bank for RoxAnn and QTC data

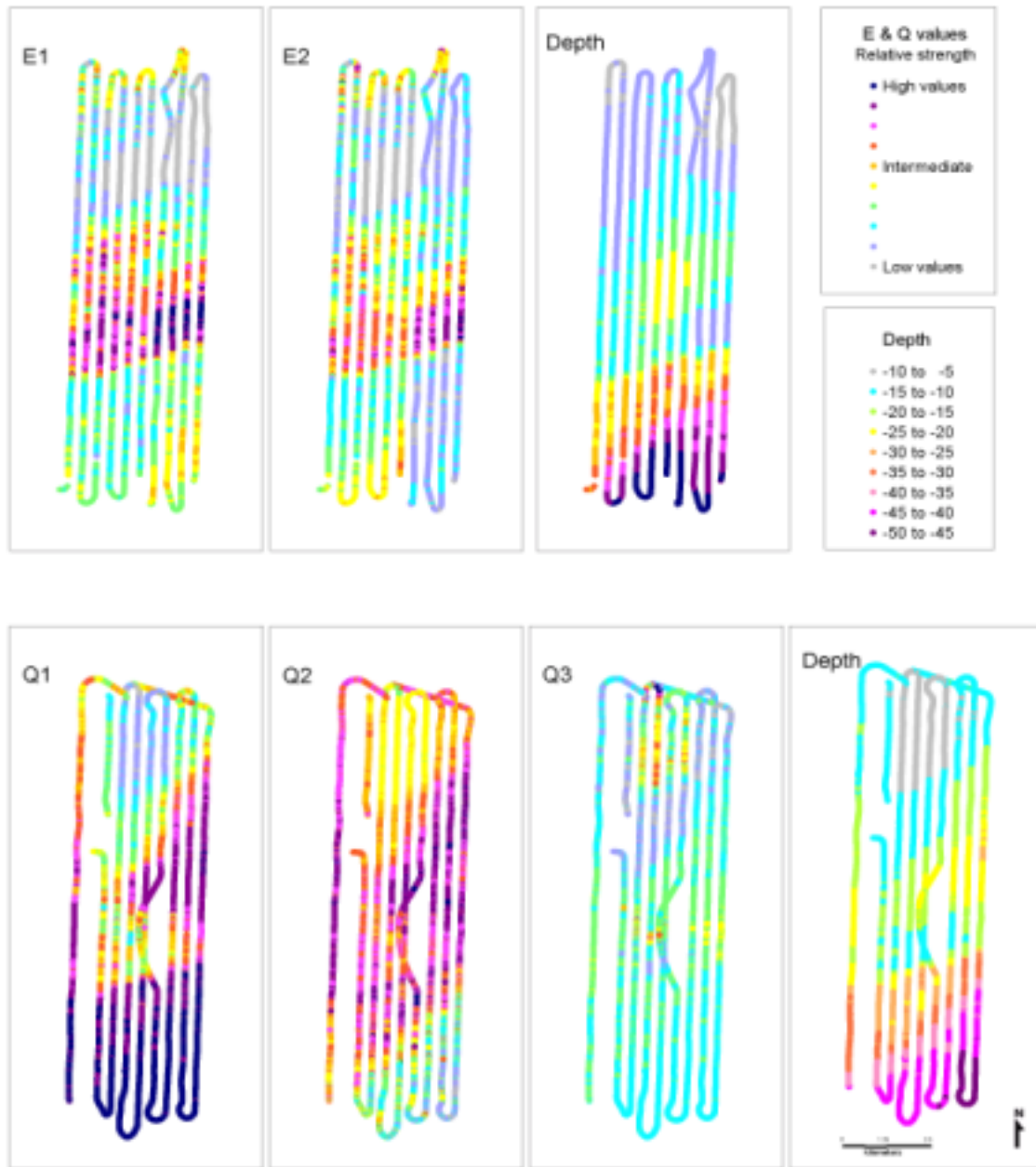
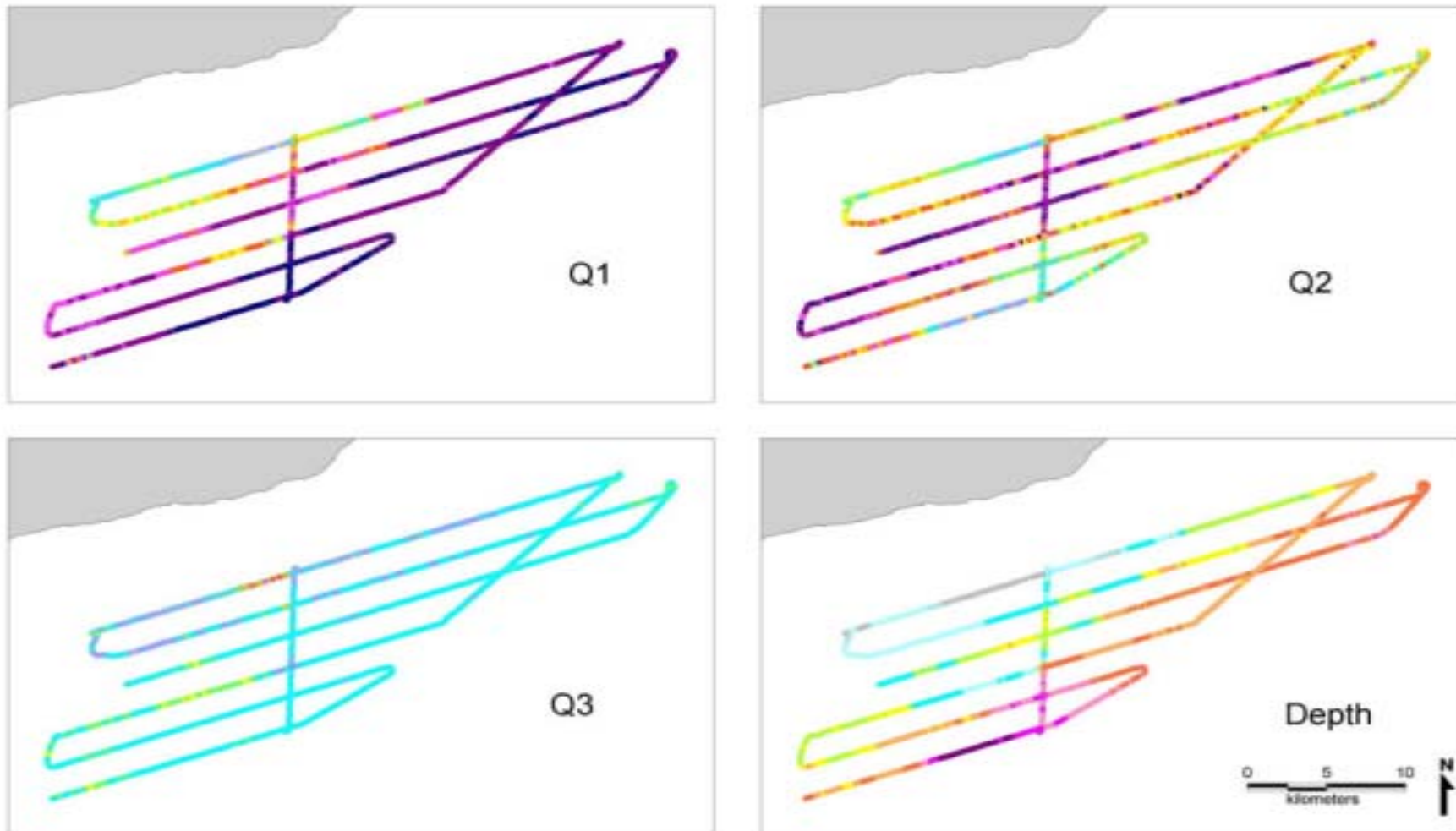


Figure 15. Track plots for the QTC Hastings-Dungeness data set.
See Figure 13 for legend.



5.5.2 Track plots

Track plots coloured to depth and selected variables from E1/E2 or Q1/2/3 are shown in Figures 13-15. These track plots revealed some anomalies that needed to be addressed throughout the analysis and classification of the data at the Hastings Shingle bank site. The western track of the *QTC-VIEW* data set gave results that did not correlate well with the adjacent tracks to the east. It is possible (although unlikely) that the differences might be due to the larger track spacing between this and the adjacent track.

The broad scale data set also showed a track running north east/south west that crossed the main east/west tracks that gave anomalous records for both *RoxAnn* and *QTC*. The cause is not clear: It is unlikely to be caused by changing sea conditions since *QTC-VIEW* and *RoxAnn* were run at different times. It is possible that the orientation of the sea floor features with respect to the sounder footprints influenced the data.

However, since the values associated with the anomalous tracks did not appear as outliers in the scatterplots (i.e., the records were anomalous because of their geographic position, but not their values), it was decided to retain all tracks and reject them later in the interpretation if this seemed appropriate.

5.5.3 Data standardisation and correction to chart datum

The *RoxAnn* data were standardised in order to combine separate track files. The depth data were also corrected to chart datum. No standardisation was carried out on the *QTC-VIEW* data (see point '5' in Section 5.3). Time data was not available for the *QTC-VIEW* data and no correction to chart datum was made.

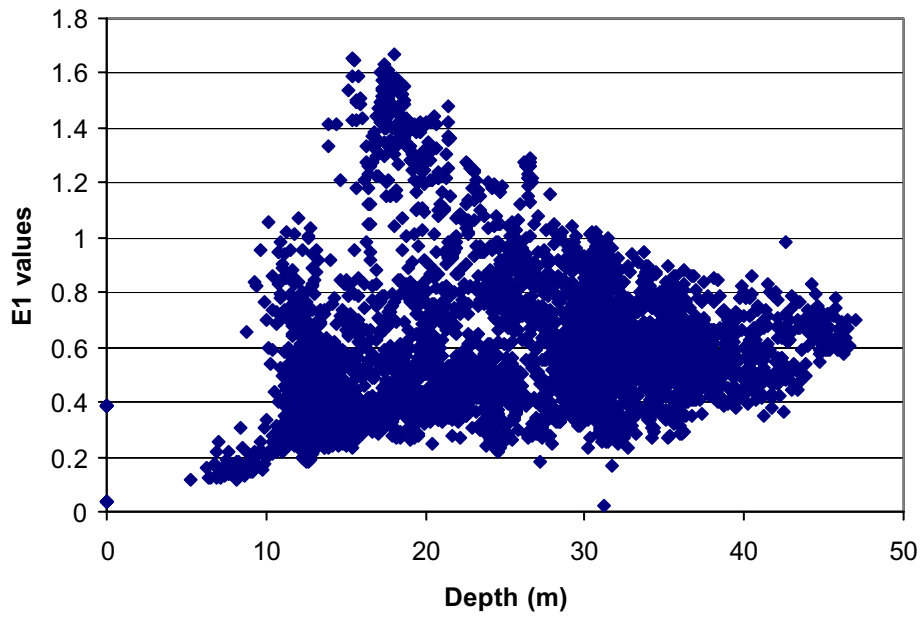
5.5.4 Scatterplots

It was expected that E1 and E2 were not independent variables. However, the spread of data perpendicular to the main axis (E1 + E2) was considered sufficiently large so that no transformation of the data was performed (Figure 16). There was no marked depth dependency with either E1 or E2.

The Q space scatterplots are shown in Figure 17. The data are typical of many *QTC-VIEW* data sets: The records are concentrated in a region that forms a shape described as a 'silk scarf' (see Figure 25 section 7.1.2). The primary axis of this plot (Q1) explains a very high proportion of the total variability within the data. However, Q1, Q2 and Q3 were treated as variables with equal weighting in the interpretation.

Of concern was the relationship between depth and some of the Q values (particularly Q1). This showed a marked depth dependency at depths shallower than about 17m (Figure 17). It was concluded (after discussion with Quester Tangent) that the system was not set up to work optimally in shallow depths and all records less than 17m were excluded from further analysis.

Relationship between E1 and depth



Relationship between E1 and E2

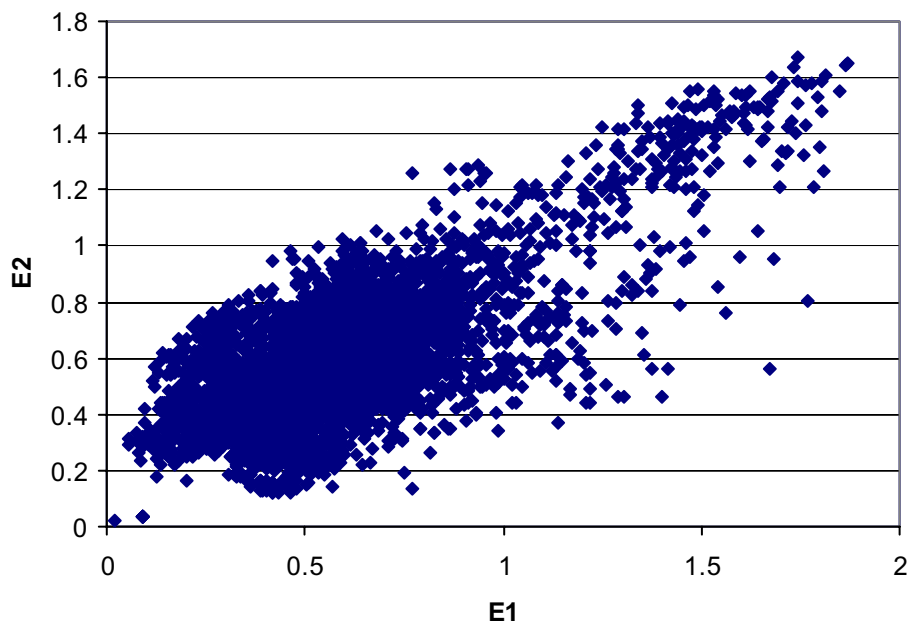


Figure 16. Scatterplots of E1/depth and E1/E2 for the *RoxAnn* data from Hastings Shingle Bank

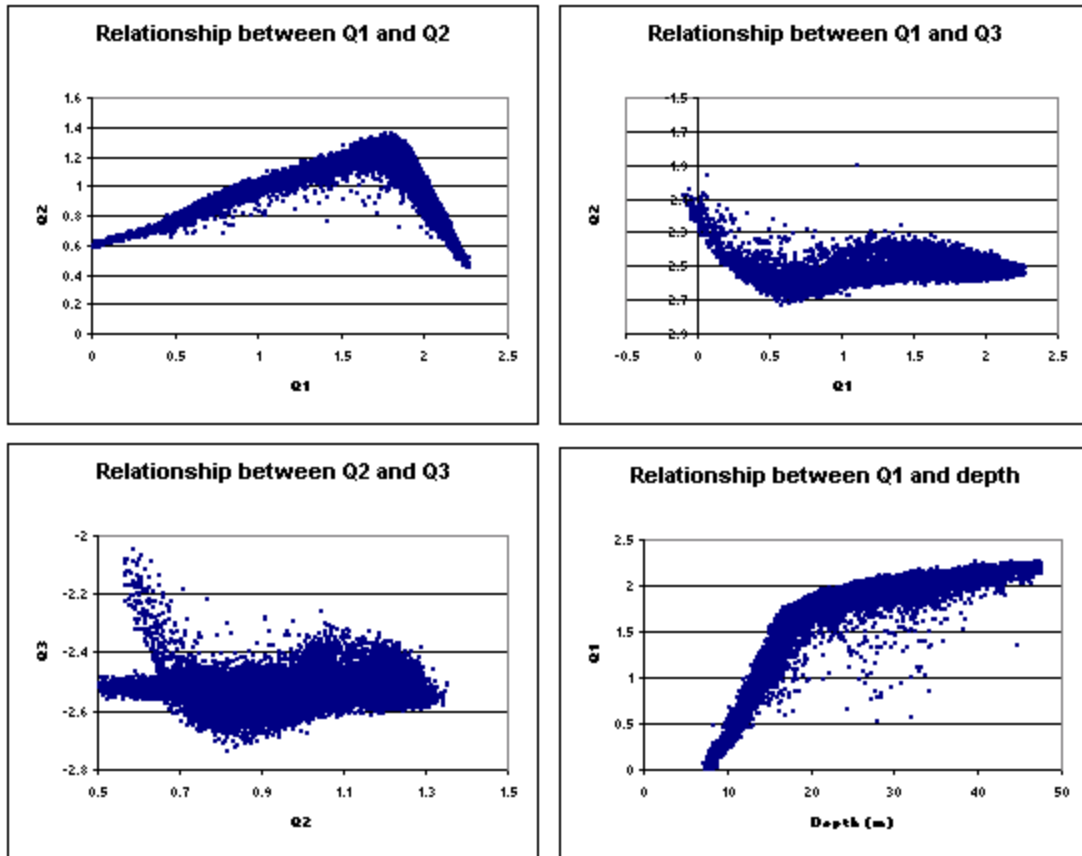


Figure 17. Scatterplots of Q1/Q2, Q1/Q3, Q2/Q3 and Q1/depth for the *QTC-VIEW* data collected during the Hastings Shingle Bank survey.

5.5.5 Variogram

The variogram analysis was performed using the default settings in the *Surfer* variogram module. A maximum lag distance of 500m (slightly larger than the 400m track spacing) was selected. The results show a similar pattern for both *QTC-VIEW* and *RoxAnn* Hastings data with a sill at the 300-400m range (Figure 18). This would indicate that interpolation between tracks at 400m (200m from the nearest data at the mid-point) is within the range, but near the upper limit. Thus, interpolation is justified, but the estimated values might be expected to vary quite markedly away from the tracks.

The variance of the *RoxAnn* data set at the sill range is much lower than for *QTC-VIEW* (both data sets have much the same spread of values for E1 and Q1 respectively). Likewise, the noise (variance at minimum lag distance) is much lower for the *RoxAnn* data set, although the averaging performed in *Microplot* and larger minimum lag distance might account for some of the difference between the systems. These comparisons point to a greater variability in the *QTC-VIEW* data set and this must be taken into consideration when the data are interpreted in the classification process.

The variograms for the Hastings-Dungeness data sets show a more or less distinct sill with similar ranges to the smaller data set (Figure 18). Thus, interpolation between tracks 2km apart cannot be justified. However, both variograms show that variance rises again at the larger lag distances of 2km. A final set of variograms has been prepared with much larger maximum lag distance (15km) for the Hastings-Dungeness data set to illustrate the pattern of variability of the whole data sets (Figure 18). Again, the *QTC-VIEW* data set has much greater overall variance. But the patterns are quite distinct and they are informative about the *RoxAnn* and the *QTC-VIEW* data. The *RoxAnn* data set indicates a steep but steady rise towards the overall variability of the data set and then levels off at a lag distance that is about equivalent to crossing three adjacent tracks. However, the *QTC-VIEW* data shows a regular series of sills at distances equivalent to track spacing. In other words, the variability increases with every additional track encompassed as the lag distance is increased. This suggests a marked difference between tracks in the *QTC-VIEW* data that is not so apparent with the *RoxAnn* data. It is likely that the overall larger variability with *QTC-VIEW* will have implications for both the interpretation of data and performance of the two systems.

5.5.6 Variability of track data

Variability of the track data has been assessed using point-to-point differences and standard deviation. The patterns of variability for the *RoxAnn* data (Figure 19) are visually quite distinct whilst those for *QTC-VIEW* are less clearly defined. Applying variability measures to Q values is probably not justifiable and this avenue has not been pursued further.

The variability in the *RoxAnn* data is highest over the Hastings Shingle Bank (seen in both the fine and broad scale data sets) and seabed to the south west (seen in the broad scale data). It is felt that these patterns are robust in that they cross adjacent tracks and are seen in both the broad and fine scale data sets where these overlap. It is felt that variability can justifiably be used as a useful track attribute derived from the original data.

Legend to Figure 18.

The variograms for the Hastings Shingle Bank show an exponential or linear rise in variance until a sill is reached at lag distances of about 400m for both E1 and Q1 (Figures 18 a and b). The interpretation of these two variograms is relatively simple and indicates that interpolation can be justified over distances less than 400m.

The variograms for the Hastings-Dungeness data sets are more difficult to interpret: The variograms incorporating the maximum lag distance (Figures 18 e and f) might suggest a sill at quite large lag distances. However, variograms of data over smaller lag distances (Figures 18 c and d) indicate an initial sill at lag distances of 500-1000m for E1 and 750-1250m for Q1.

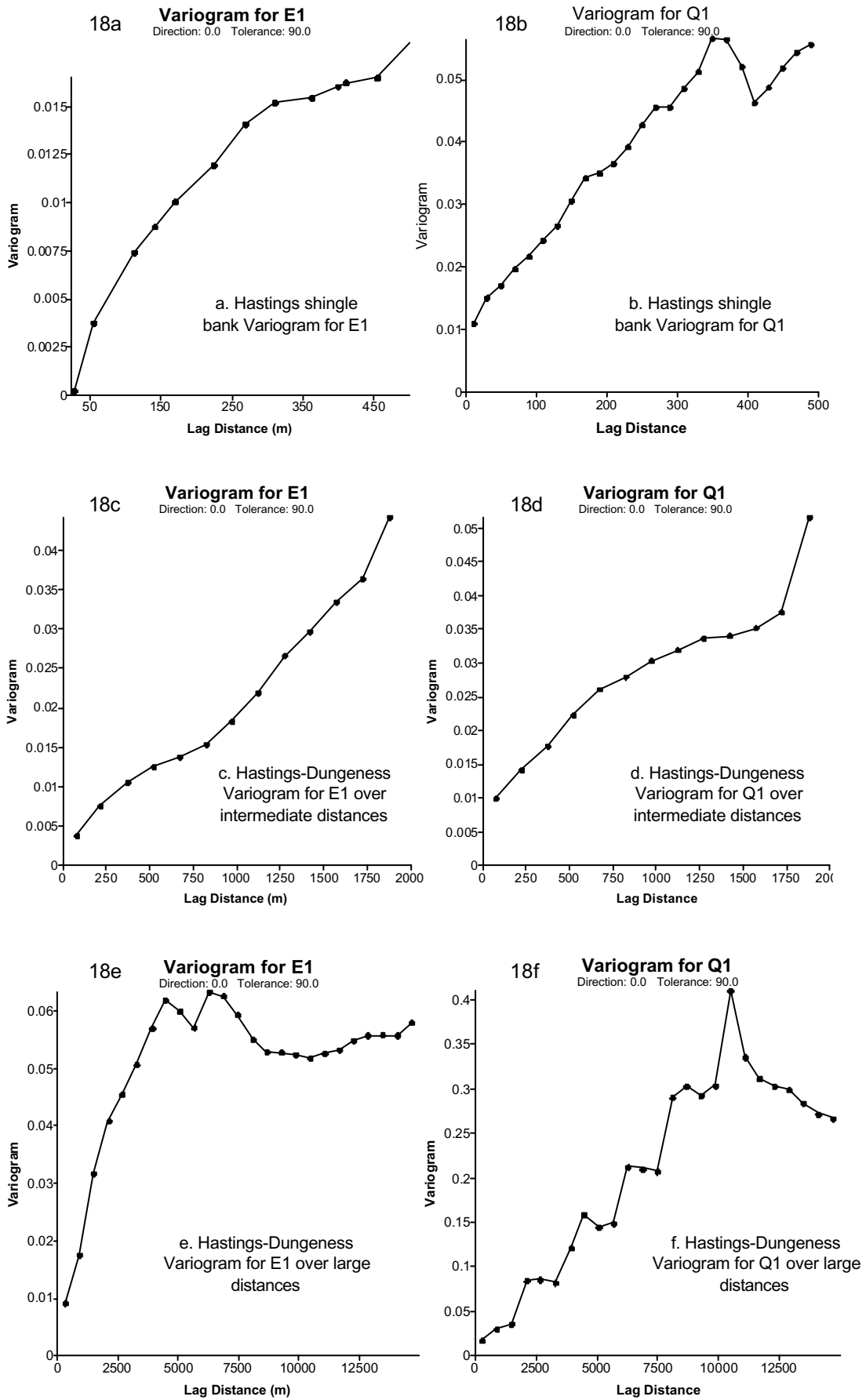
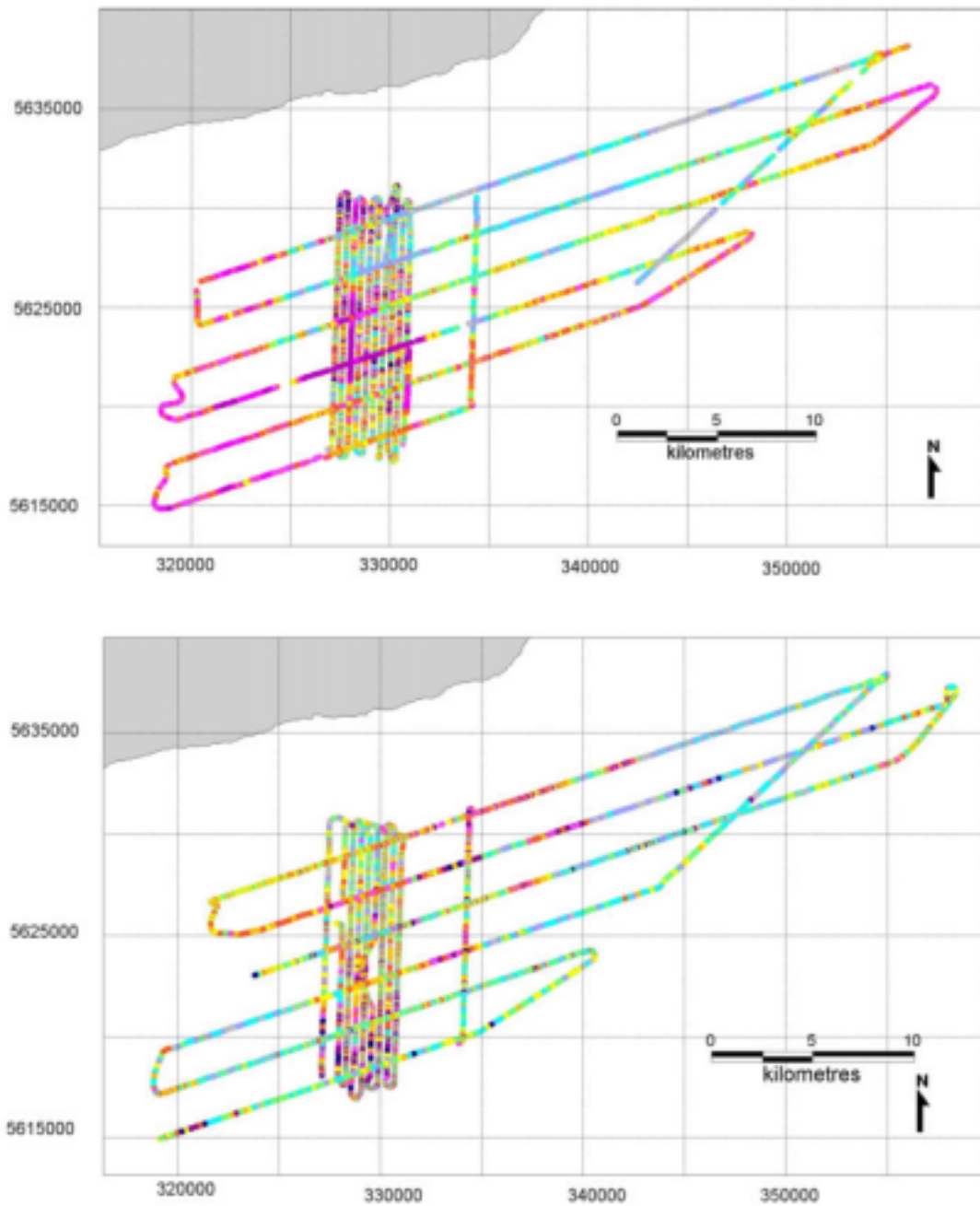


Figure 18. Variogram Plots

Figure 19: Track variability.



Both survey areas are shown. A relative scale has been used to facilitate the comparisons between the data. Purple indicates high variability, blue and grey low variability.

Datum: WGS84 Projection: UTM zone 30 Originated by: CEFAS and SeaMap Date: April 2001

5.6 Summary of data following initial analysis.

Although E1 and E2 are not independent variables, a degree of correlation between variables is expected in multispectral data (Wilkie and Finn 1996). Although E1 and E2 can be subject to a simple PCA transformation, there is no obvious improvement in discrimination and transformation does not appear to be necessary. Depth is very important in structuring biological communities and may be directly related to sediment type through hydrography and seabed topography. It is doubtful if depth should be regarded as equivalent to E1 and E2 in image processing. It could be argued that E1 and E2 on their own should, in the first instance, be used for classification and that bathymetry should subsequently be overlain to reclassify the biotopes by depth. However, this would appear to be unnecessarily complicated and depth has been included with E1 and E2 in signature development. Variability is a measure of the acoustic properties from more than one acoustic record. This would seem to make variability substantially different in kind from E1, E2 and depth. However, the latter are themselves averaged through the acoustic footprint and the process of interpolation. All of these parameters are treated as equal variables after normalisation. A summary of the data is given in Table 7.

Variable	Data type and units	Treatment	Measurement
E1 & E2	Arbitrary units based on integration of signal strength (millivolts) and duration; signal compensated for depth in processor. Maximum value 2.02mv. Possibly not entirely independent of depth, especially E2.	E1 and E2 are not independent, but scattergram showed wide spread within the data and a principal components transformation was not used. Data standardised using 95 th percentile.	Regarded as Independent continuous variables.
Depth	Metres below transducer	Depths corrected to chart datum	Continuous variable regarded as independent of E1 and E2
Variability	Arbitrary units derived from E1 and E2. Measures ground variability and useful for compensating for smoothing out of local variability through interpolation.	Measure used was the point-to-point differences (double square root transformed) in E1 and E2 combined.	Derived attribute continuous considered as a useful additional track variable.

Table 7. Summary of the *RoxAnn* data and their preliminary treatment.

The plots in Figure 17 (Q1/Q2/Q3/Depth relationships) indicate a strong relationship with depths less than about 17m. The first return signal amplitude (envelope) is digitised prior to feature extraction into 256 readings. *QTC-VIEW* normalises the spread of pulse length with depth, by adjusting the effective digitising rate acting on the pulse envelope. There are limitations to this rate adjustment in shallow water which is thought to contribute to this shallow depth relationship. Some dependency is also thought to be due to limitations in the initial electronic signal processing. Large reflected signals can be met in shallow waters, particularly if a narrow beam (searchlight) transducer is used as there is a high degree of specular (mirror-like) reflection with little scattering of energy. This can also lead to little pulse shape variability and corresponding reduction in feature variability, accentuating the changes in reflected pulse due to depth.

The Initial analysis indicated that all soundings less than 17m were to be rejected. The variability in Q values is not used, and the Q values are derived from a stack of 5 successive soundings. However it may be argued that depth variability (specifically the first derivative, gradient or slope) may be a useful indicator of seabed reflectance angle, which in turn has been observed as a modifier of AGDS data. Correction for slope is another problem and beyond this discussion, therefore slope is not considered. A summary is given in table 8.

Variable	Data type and units	Treatment	Measurement
Q1, Q2 and Q3	Eigenvectors derived from PCA of 166 attributes of the echo. These are normalised prior to PCA.	No transformation (done as part of PCA). Independence from depth of at least some C values is in doubt for some data sets. Data shallower than 17m rejected.	Regarded as independent continuous variables for purposes of classification outside <i>QTC-Impact</i>
Depth	Metres below transducer	Allowance made for depth of transducer. Not corrected to chart datum	Continuous variable regarded as independent of Q values in selected data subsets.
Variability	Derived from Q values.		Not used

Table 8. Summary of the *QTC-VIEW* data and their preliminary treatment.

The track spacing varied between the data sets and, as has been discussed, interpolation prior to classification is not justified in all cases. A summary of the data sets with regard to interpolation and classification is given in Table 9. Section 6 considers whether and how the data should be transformed from points to area.

Survey area and system	Track spacing	Interpolation justified	Other caveats to the data sets
Hastings: <i>RoxAnn</i>	400m	Yes	Some depths poorly correlated with chart depths
Hastings: QTC	400m	Yes	Possibly high noise; poor correlation between some adjacent tracks
Hastings-Dungeness: <i>RoxAnn</i>	2000m	No*	Dubious cross-track
Hastings-Dungeness: QTC	2000m	No*	Possibly high noise; dubious cross-track

* N.B., Interpolation was used to produce a digital image of the track point data (see Section 6.4).

Table 9. Data sets and key points to be carried forward for analysis and classification

6 INTERPOLATION: POINT-TO-AREA CONVERSION

6.1 Introduction

Whilst it is possible to interpret track point data and show the results on a map, it is far easier to see spatial patterns in data if these are displayed as a continuous picture. In this process blank areas on a map of the acoustic track data are filled in with an estimate of the most likely values, a process termed interpolation. New values are calculated at regular grid nodes 'placed' over the survey area from the scattered and often widely separated track point data. These estimates can be made using simple distance weighting models or from more complex models that are based on an analysis of the spatial patterns in the real data. (The reader is referred to Burroughs and McDonnell (1998) for a detailed discussion of this subject.)

Note that interpolation cannot improve the quality of the real data and, indeed, will almost certainly introduce uncertainty into the derived continuous image. This raises the question as to whether interpolation should be undertaken at all. Interpolation might be considered for the following reasons:-

1. **For cosmetic purposes:** The maps look better. This is perfectly valid if it makes the maps more persuasive for management (as long as the maps do not misrepresent the data).
2. **To show broad patterns:** Possible error in the detail is acceptable if the map shows general patterns well.
3. **Spatial modelling:** The process is used to generate hypotheses about spatial patterns that can be tested.

It is probably best to work with track point data rather than an interpolated grid if none of these reasons apply.

If a continuous coverage is required, then the next step is to choose the interpolation process most appropriate to the data. Note, for example, that interpolation using any form of distance weighted averaging cannot work for categorical data. This would apply to *QTC-VIEW* data that had been classified using *QTC-VIEW IMPACT*. There are other forms of interpolation based on nearest neighbour or Voroni polygons that may be more suitable to categorical data. However, if the Q values (eigenvectors) are assumed to be variables, then interpolation using interpolation methods may be appropriate.

The question should be asked as to whether interpolation is likely to introduce too much uncertainty and/or spurious artefacts? If the point data are dense then interpolation will be

successful no matter which interpolation model is used. If data are sparse, careful selection of interpolation methods (models and parameters) will be needed since the outcome will be sensitive to the choices made. As the amount of data in an area decreases, the emphasis changes from filling in missing values with obvious estimated values to one of extrapolation using spatial modelling. In most AGDS surveys the situation is somewhere between the two extremes. The characteristics and effects of narrow and widely spaced tracks are:-

1. Track spacing narrow: There is low variability along the track relative to track spacing and there is a similarity between adjacent tracks. Interpolation is likely to be robust when:
 - a. Track spacing is well within half the range of the sill (see variography – Section 5.4).
 - b. The nugget effect is small relative to the variance at the sill.
 - c. As a general rule, track spacing should be less than 0.5km.

2. Track spacing wide: High along-track variability relative to track spacing. There are few obvious patterns that are consistently reflected in parallel tracks. Interpolation is likely to be problematic when:
 - a. Track spacing is greater than the half-range distance.
 - b. The Nugget effect is large relative to the sill.
 - c. In general, track spacing is greater than 1km.

Additional problems will arise if (1) the data are not truly continuous variables so that averages are meaningless and (2) two or more data sets need to be amalgamated and it is uncertain if they are directly comparable.

6.2 Interpolation method

The basic process of interpolation is illustrated in Figure 20. Interpolation estimates values at regular grid nodes. The grid spacing is chosen by the analyst and this sets the minimum pixel size thereafter. Grid spacing is set so that the grid files are not so large as to make processing difficult nor so widely spaced that significant local variation in the data is lost through averaging. A search radius is set to encompass data from different tracks (unless the radius is larger than the range justified by the variogram). The distance weighting used depends upon the interpolation algorithm chosen and inverse distance square weighting is shown in the box below the track data. However, not all data within that search radius need be included if the maximum number of data points is set at a small number. The search method can also stipulate that data from different quadrants must be included so that the calculation is forced to take account of data from adjacent tracks. The weightings given to the real data around the grid node vary with the type of interpolation algorithm used.

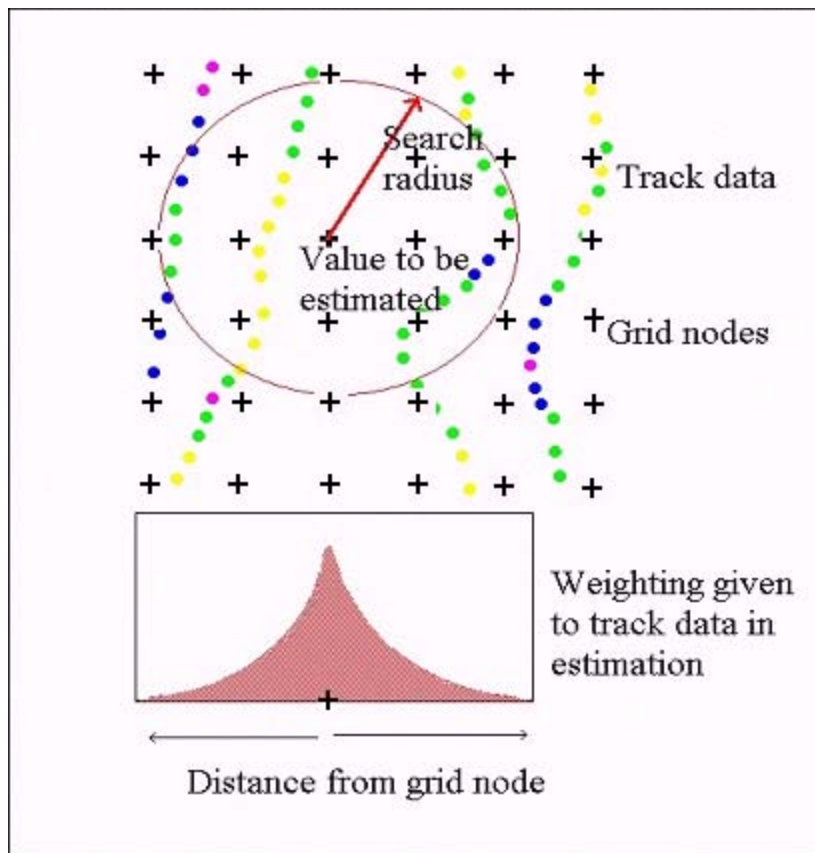


Figure 20. A small section of track with grid superimposed illustrating the main parameters to be set for interpolation. The grid nodes are indicated by the crosses. The bold cross indicates the grid node for which an estimated value is to be calculated. The search radius has been set to encompass data from three tracks. The box beneath the example track data indicates the distance weighting model.

Kriging is said to give the mathematically optimal distance weighting, but is dependant upon choosing the correct model (Burroughs and Donnell 1998). Inverse distance gives acceptable results and allows greater choice of parameter settings that can suit particular situations and requirements. In practice, as the example in Figure 21 illustrates, the difference is not marked where the inter-track spacing is well within the range of the data. Since Kriging makes many assumptions about the spatial nature of the data that are hard to verify, it is more prudent to use the simpler method of inverse distance.

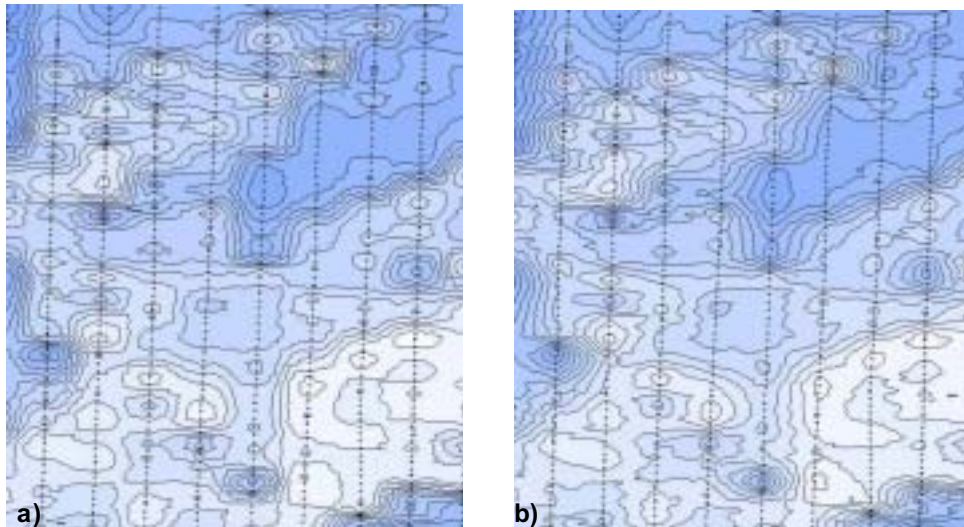


Figure 21 a & b. Interpolated depth data, with tracks superimposed. Inverse distance square was used for Figure 21a and Kriging in Figure 21b.

Distance weighting can be considered as ranging from heavily weighted towards the nearest data to no weighting (local average within search distance). In the extreme, weighting can be so heavily biased to the nearest point that it is effectively performing a nearest neighbour interpolation and choices have to be made on distance weighting, as the examples below show:-

1. Nearest neighbour.

Advantages: No values are calculated from averaging of real data which can often result in values that are not often found in reality. With nearest neighbour the classification will not be affected by such spurious values and this interpolation method ensures that field samples a short distance away from track data will be associated with real AGDS data for signature development.

Disadvantage: The resulting interpolation can look very unreal as distance from track data increases giving the maps a crystalline look that is visually unacceptable. This is particularly noticeable half way between two adjacent tracks whose values do not correspond well.

2. Inverse distance squared (or a power greater than 2 may be used to give strong weighting to nearest data).

Advantages: Interpolated values are faithful to nearest data and the averaging effect between tracks associated with weaker distance weighting is reduced. It is suitable if there are doubts about whether the data are truly continuous variables.

Disadvantage: Can create noticeable distortion around data hot spots (isolated values substantially different from neighbouring values).

3. Inverse distance to a power between 1 and 2 (weak distance weighting).

Advantages: Gives very smooth result where hot spots are averaged out. Suitable for showing general trends especially where track spacing is wide and there is a reasonable expectation that the ground between is likely to be homogeneous or with gradual trends in values.

Disadvantages: Smoothing may be at the expense of local variability (which might be significant). The use of variability measures might redress the smoothing effects somewhat. Averaging between real values can create unlikely estimated values. In an extreme case, adjacent 'rock' and 'mud' tracks will create average 'sand' values in between where sand may never exist.

The choice of interpolation algorithm, search radius and the number of real data accepted will clearly affect the interpretation of the track data. The effect of changing the parameters is demonstrated using an example of interpolation of E1 data from widely spaced track data (2km between tracks) taken from the Hastings-Dungeness data set (Figure 22). There is no single correct solution and the final choice might depend upon experimenting with different parameters and selecting those that smooth some of the obvious jumps in values between tracks without losing real features from the image. In the first example (top left) inverse distance square has been used with a search radius of 2500m, but accepting the first 15 points in the estimation of interpolated values. The result is often a marked change in interpolated values half way between adjacent tracks. Increasing the number of points in the calculation to 100 produces a smoother effect (top right) and using a inverse distance to the power of one rather than inverse distance squared smooths the data further, although many of the more extreme low E1 values are poorly represented (bottom left). The last example (bottom right) uses Kriging as the interpolator with the same search radius of 2500m and using 100 points in the estimation.

A working compromise in situations where the tracks are variably and sometimes widely spaced might be to select inverse distance to the power of 1.5 or 2, and a search radius sufficient to bridge adjacent tracks (but no larger). The search pattern and the number of records accepted might be set so that there is a reasonable expectation that a representative selection of records are included from the adjacent tracks and not just the nearest track.

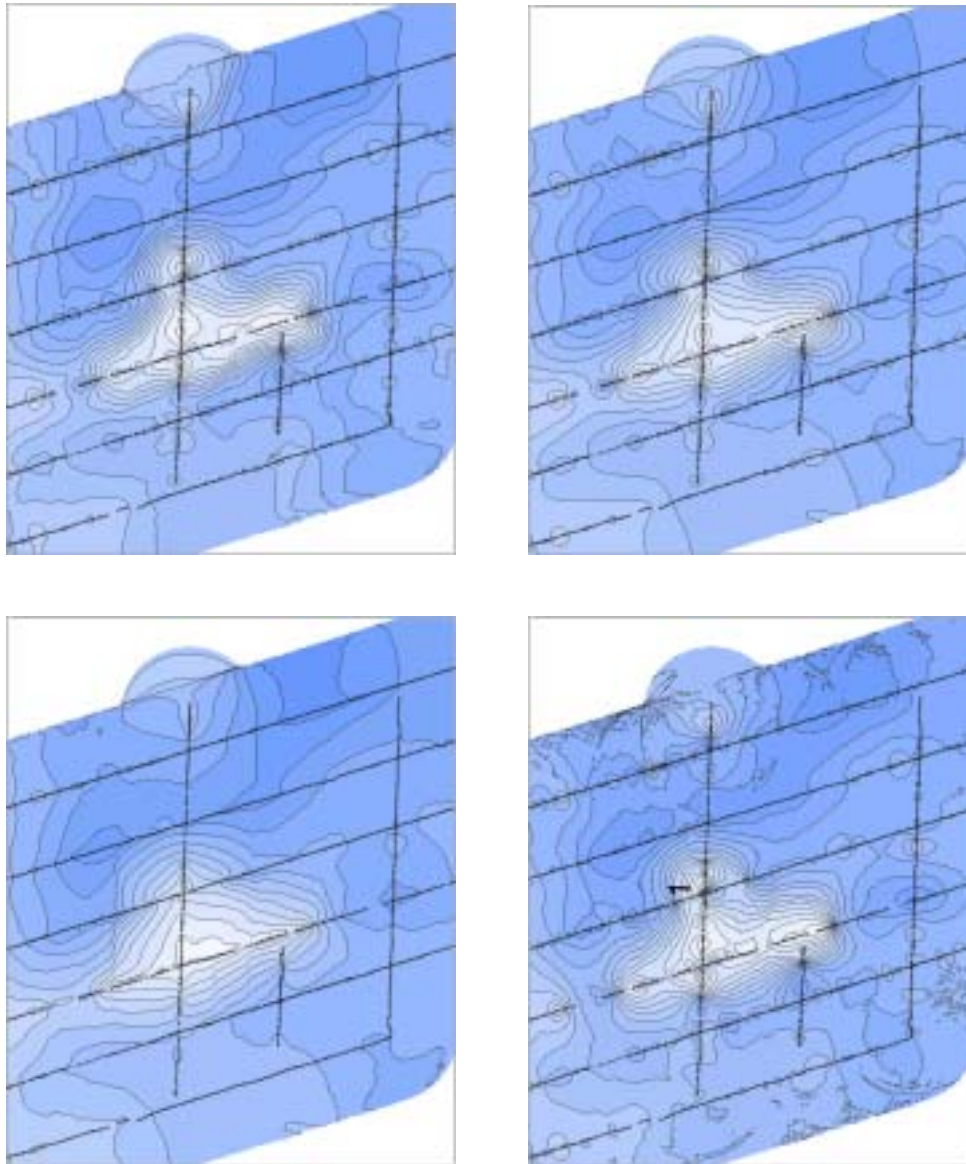


Figure 22. An example from the Hastings-Dungeness data set showing the effects of different interpolation parameters on the final image. Top left - inverse distance square, search radius 2500m, accepting first 15 points; Top Right - inverse distance square, search radius 2500m, accepting first 100 points; Bottom left - inverse distance to the power of one, search radius 2500m, accepting first 100 points; Bottom right - Kriging, search radius 2500m, accepting first 100 points.

6.3 Grid size, track spacing and resolution

Grid spacing in itself does not affect the accuracy of the estimates. Choosing fine grid spacing simply adds more estimated grid values to an image. However, grid spacing should reflect the resolution of an image. From a practical viewpoint there is a cost in terms of the size of the images and the processing times required for large images and it is not worthwhile to fill an

image up with numerous grid points based on few real data. On the other hand, valuable information is lost when the grid spacing is very wide relative to the track data.

Whilst grid size is not a measure of resolution, it is important to estimate the resolution of maps. Although maximum resolution is determined by the remote sensing technology, track spacing will, in most surveys, set the maximum resolution at a lower level than the technical maximum. This is especially true for broad scale surveys because of the time and cost involved collecting closely spaced tracks. Often, track spacing will vary over the map with some areas being intensively surveyed compared to others and this creates additional problems. Clearly, features smaller than the track spacing may go undetected. Therefore track spacing can be used as an indication of minimum resolution. Although closely spaced tracks will support a more detailed map than widely spaced tracks, there is no simple direct link between track spacing and resolution since heterogeneity (the patch size of biotopes) also must be considered.

6.4 Interpolation to produce digital images

Perhaps one of the most compelling reasons for interpolation is that it opens up the use of proprietary image processing software for further analysis (Sothoran *et al.* 1997). A grid of interpolated values can be treated as a digital image where each grid node becomes a centroid of a pixel. Note that the same pixel arrangement is required for all images which are to be analysed together. That is, geographic boundaries, search and display radius and grid spacing need to be standardised. If the images are to be trimmed, this process must also be standardised for all images.

However, digital images can be produced of the tracks alone without generating estimated values for the blank areas between tracks. This is achieved by selecting a grid spacing that is approximately the same as the spacing between successive track points and a similar search and display radius used in conjunction with nearest neighbour interpolation. The tracks are reproduced as 'smart' pixels (i.e., pixels with values) against a blank raster background.

6.5 SEAMAP/CEFAS survey examples

The conclusion from Section 5 was that it was justifiable to use interpolation to produce a continuous coverage of estimated acoustic values for classification of the Hastings Shingle Bank data set but not the Hastings to Dungeness data set. The interpolation method chosen and the parameters selected are summarised in Table 10. These were used consistently for all parameters of both data sets to ensure that all images and their derived products coincide exactly.

	Hastings	Hastings to Dungeness	
Method	Inverse distance	Inverse distance	Nearest neighbour
Power	2	2	N/A
Grid spacing (m)	25	50	50
Search radius (m)	100mNS, 500mEW	500	50
Number of sectors	4	4	N/A
Max points/sector	15	3	N/A
Min points per sector	2	1	N/A
Min X*	326,600	317,700	317,700
Max X*	331,600	358,900	358,900
Min Y*	5,616,900	5,614,250	5,614,250
Max Y*	5,631,300	5,638,800	5,638,800

*Coordinates in UTM zone 31.

Table 10. Parameters and algorithms used to produce interpolated and/or digital images from the original track data.

6.5.1 Interpolation of the Hastings Shingle Bank data

The interpolation has produced coverages which show some signs of being disjointed between adjacent tracks (Figure 23 and 24) (Note that where this effect is very marked, correlation between adjacent tracks is poor and it is questionable if interpolation is justified.) However, interpolation using the selected parameters illustrates general trends and local variation quite well: greater averaging would reduce the blocky effect, but at the sacrifice of local variation. The 'crystalline' effect at the margins of the images is due to extrapolation away from the tracks and this margin should be disregarded. Indeed, it can be trimmed from the mapped outputs but has been retained in these studies to underline the ever-present artefacts introduced through interpolation.

The patterns of high and low values of E1 and E2 are similar, with the exception of the southern part of the survey area (Figure 23). E2 shows a discontinuity between adjacent tracks that might be spurious. This must be noted in future interpretations. The strong association between E1 and E2 is, if these parameters are interpreted as roughness and hardness respectively, not unexpected given the limited range of sandy sediments in the survey area. However, the apparent lack of variables available for discrimination in the classification process must also be noted.

The Q values cannot be interpreted directly in terms of roughness or hardness. The high and low values for Q1 and Q2 are geographically distinct and show strong spatial patterns that

Figure 23. Interpolated RoxAnn data displayed as raster images

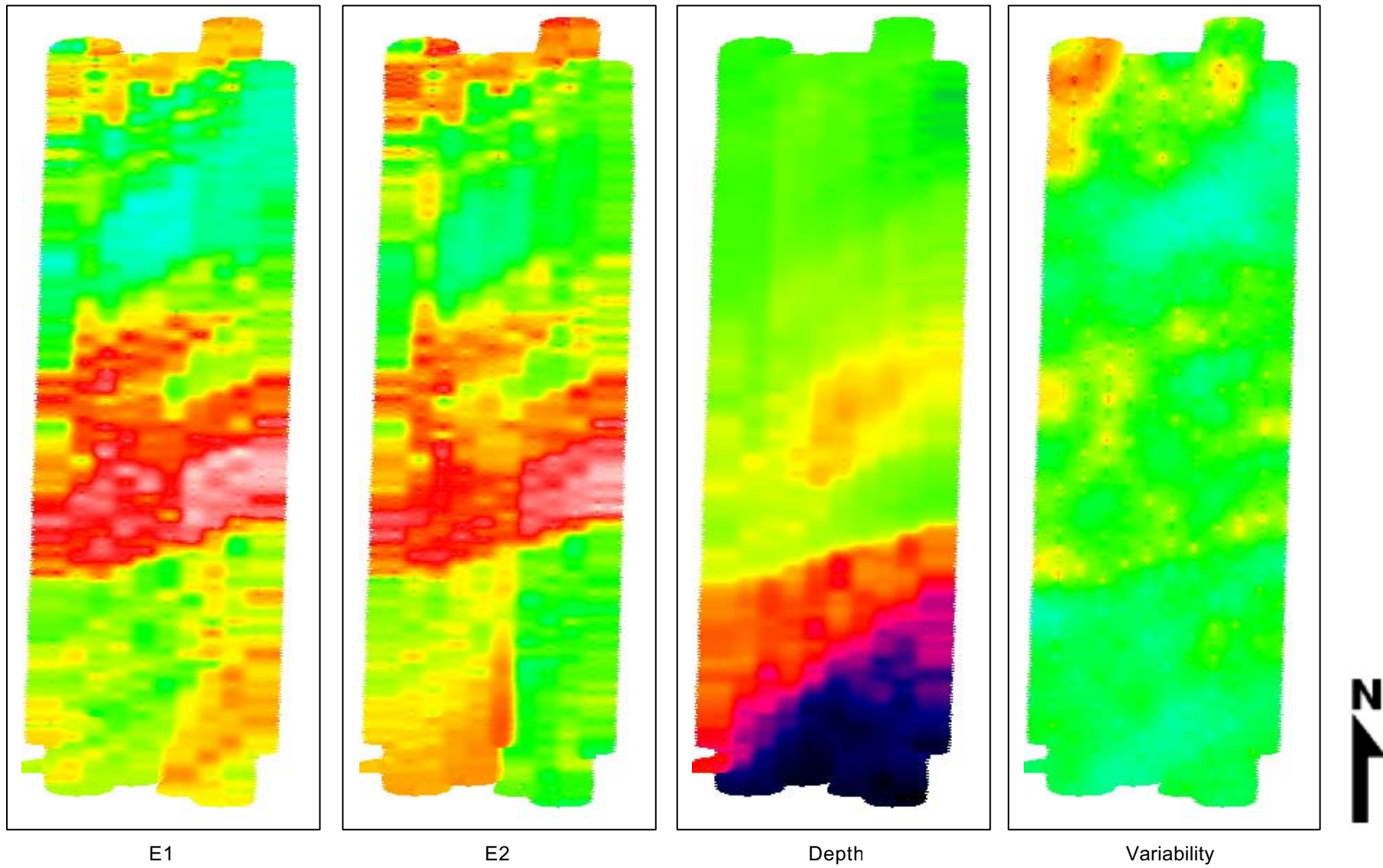
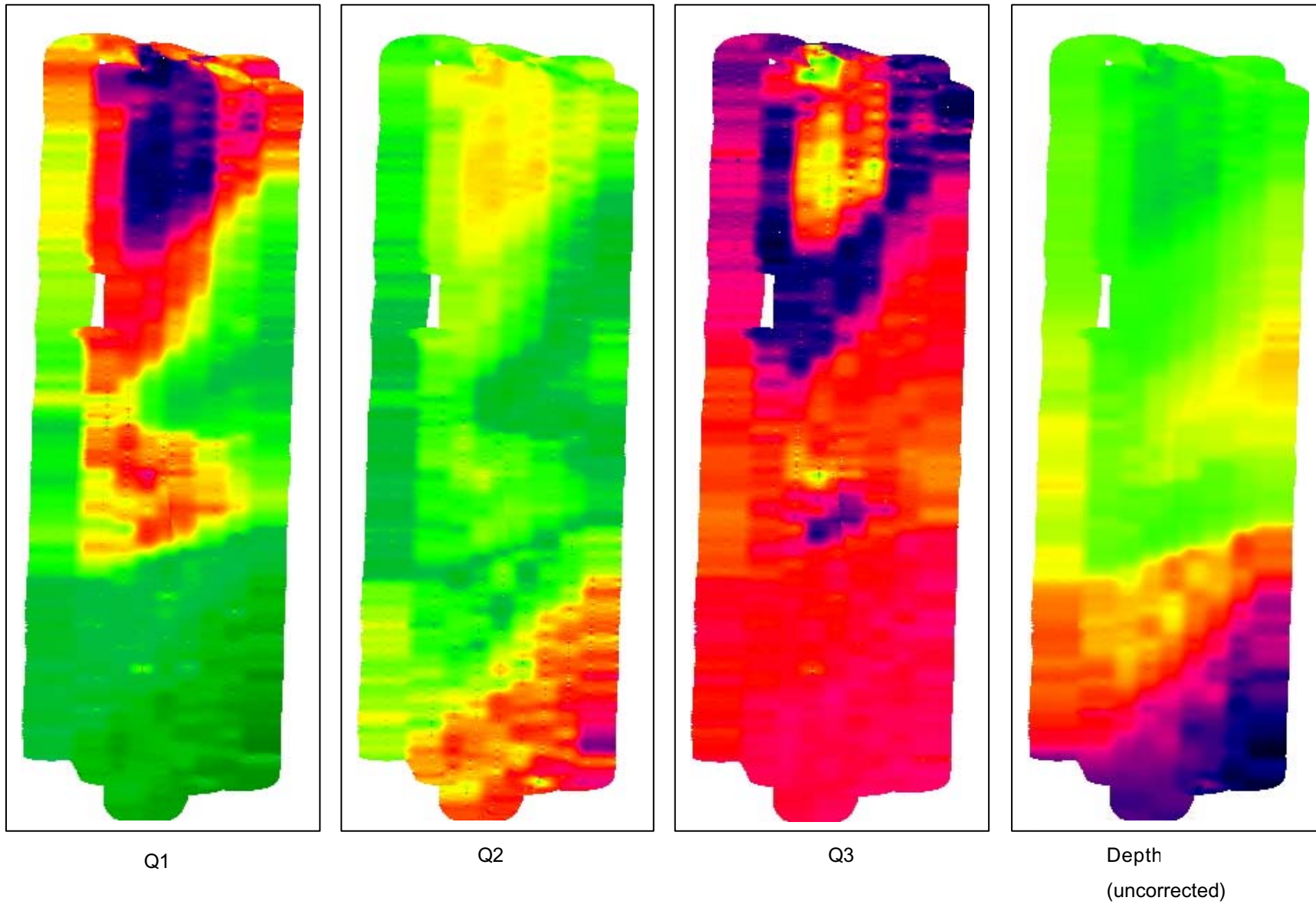


Figure 24. Interpolated QTC data displayed as raster images



span the tracks, which is reassuring (Figure 24). The track farthest to the west, however, appears very different from the next track to the east.

6.6 Digital images of the Hastings-Dungeness data sets

Digital images of the broad scale data set were created using interpolation in order that *Idrisi* image processing software could be utilised. Two interpolation regimes were used for processing the data and their details are given in Table 10. The first employed a generous search area to ensure that the ground truth records encompassed sufficient data for generation of signatures (see Section 7) and this involved a level of averaging of the point data at nodes lying a short distance from the track points. The effect on classification of this averaging was unexpected and will be discussed in Section 7.5.6. A second set of parameters was used with a much smaller search radius to avoid averaging. Note that figures illustrating the digital data for the Hastings-Dungeness data sets have not been included since these are essentially mirrors of the track point data (Figures 14 and 15).

7 CLASSIFICATION

Classification is the main procedure for interpreting the multidimensional acoustic data in which acoustic characteristics are used to assign individual pixels to classes. The definition has been adopted from satellite multispectral classification and the same procedures and software are used for acoustic images. However, there are many other approaches for analysing data for discriminating sea floor characteristics, particularly calibration (Murphy *et al.* 1995; Magorrian *et al.* 1995; Greenstreet *et al.* 1997; Caddel 1998) and the use of univariate bivariate plots for contouring attributes, such as silt content (Pinn and Robertson 1998; Kaiser *et al.* 1998; Hull and Nunny 1999). This discussion is restricted to (1) discrimination procedures in proprietary AGDS software (e.g., *Microplot* and *QTC-VIEW IMPACT*); (2) unsupervised classification, and; (3) supervised classification.

7.1 Discrimination procedures in proprietary AGDS software

7.1.1 *RoxAnn* and *Microplot/RoxMap*

Microplot and *RoxMap* display E1 and E2 as a Cartesian plot that can be divided up into rectangular areas (boxes) to colour code the track data. The dimensions of the boxes can be modified based on the results of field sampling so that parts of the E1/E2 space are associated with particular sea floor types. This simple classification technique is quite flexible and multiple boxes of the same colour can be used to create complex shapes covering the desired records. The track data are assigned a numeric code that can be correlated with the colour code and this is exported with the acoustic, GPS and time data. Discrimination using *Microplot/RoxMap* is useful as a real-time survey tool for targeting areas for sampling and becoming familiar with the data set as it develops.

7.1.2 *QTC-VIEW* and *QTC-Impact*

QTC-VIEW and *QTC IMPACT* offer far greater scope for analysis and classification of the data than *Microplot* and *RoxMap*. *QTC-VIEW* and *QTC IMPACT* use clustering to classify the data, although the raw parametric data is hidden from the analysts due to commercial confidentiality. The three Q values are plotted in Q space, and natural clusters of points within the 3-dimensional plot are identified and classified statistically under direction of the analyst. The Cluster module in *Impact* successively performs a generalised K mean split which is then used to update the original single-class catalogue file with multi-class information. The decision as to which cluster to split and along which axis the split is to take place are under operator control (Figure 25). The cluster statistics are displayed to aid decision making (see Table 11).

This process generates a multi-class catalogue that can then be applied to the full data set or, indeed, another data set. *Impact* assigns records depending on where they map in Q-space. A filter can be used to decimate the original data set to speed up data processing, but this can be cancelled to allow classification of the full data set using the newly generated catalogue.

Statistic	Interpretation
Total score: sum of scores of each class	Measure to determine when no more splits are justified
Class score: product of the number of classes and Chi^2	A measure of 'clumpiness' in the distribution. It may be appropriate to split a class of low score
Cluster Performance Index (CPI): the ratio of the distance between cluster centres and the furthest extent in Q-space	Signal (separation) to noise (cluster variance) ratio that tends to a maximum at the optimal split level

Table 11. Statistics available to help with the derivation of clusters for classification within *QTC-VIEW/Impact*.

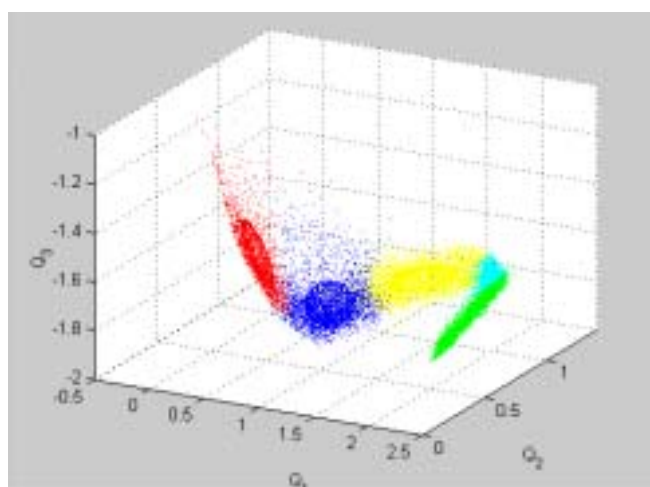


Figure 25. Three dimensional 'Q-space' following clustering of *QTC-VIEW* data using *IMPACT*. Note the characteristics 'silk-scarf' shape of the of the data within the 3-dimensional plot.

7.2 Unsupervised classification

Unsupervised classification uses statistical clustering techniques to group data (or pixels derived from interpolating the track data) into classes according to the degree of similarity of

magnitude of the values in each image. These classes do not necessarily represent a real habitat or biotope class, but a more or less distinctive cluster in the data. If the clusters are very distinct and discontinuous then it is likely that they represent a unique feature of the sea floor. However, it is unusual to find very distinct clusters in AGDS data, especially if a large and heterogeneous area of the sea floor is surveyed. The more typical situation is for the data to form a 'cloud' of points (see Figures 16 and 17) in which case clusters are indistinct and their interpretation in terms of sea floor classes is ambiguous. For this reason unsupervised classification has limited application for interpreting AGDS data. Nonetheless, unsupervised classification can be used to show broad patterns of acoustically similar ground. These acoustic classes may correspond well with visually distinct ground types and/or boundaries. However, the unsupervised classification may suggest that ground thought to be homogeneous consists of more or less acoustically distinct patches that are worthy of further investigation.

The *Idrisi* ISOCLUST module provides a powerful self-organising classifier similar in concept to Cluster in *QTC-VIEW IMPACT*. However, the classification is seeded by 'real' clusters selected from a histogram of a composite image rather than through segmentation directed by the operator, as in *QTC-VIEW IMPACT*. The operator chooses the number of clusters required and the program finds the most appropriate splits. This is thought to give a more accurate and efficient placement of clusters than other methods (Eastman 1999). A suitable number of classes might be approximately the number of ground truth classes. However, as the number of classes increases, the significance of the additional groups becomes less clear. One visual effect of increasing class number is often that the unsupervised classes become divided along geographical gradients (giving a contoured appearance) rather than represent distinctive acoustic types.

7.3 Supervised classification

7.3.1 Maximum likelihood classification

Supervised classification generates a thematic map (e.g., of biotope or sediment classes) directly from the acoustic data by assigning each pixel to a class on the basis of an acoustic 'signature' derived from training sites. Although there are a number of classifiers, maximum likelihood is universally acclaimed as the most satisfactory (Bailey and Gatrell 1995; Wilkie and Finn 1996; Eastman 1999). Supervised classification of the images is quite straightforward for *RoxAnn* data, assuming that the variables (which are standardised from 0-255) are independent. Supervised classification using maximum likelihood is a very convenient route for analysis since it is well supported by proprietary software and gives good results. This method of classification can also be applied to *QTC-VIEW* data, using the three Q values and depth as variables in the classification procedure.

The main steps in supervised classification are:-

1. Selecting training sites for the biotopes: Training sites are created by drawing a circular buffer zone around the points (or lines if the sample is a video tow, dredge etc.). Alternatively, irregular shaped polygons can be drawn around homogeneous features from sidescan images. The buffer must be large enough to capture sufficient acoustic data to complete the next stage successfully, but not too large that data are wrongly attributed to the biotope.
2. Developing acoustic signatures for the biotope classes: The process of supervised classification calculates, for each biotope class, an 'n' dimensional probability distribution based on the mean and standard deviation of all the data included in the training sites. The probability distribution is calculated through a process of maximum likelihood.
3. Classifying the whole survey area: Each pixel in the whole image is matched to the biotope signatures in turn and classified according to which biotope has the highest probability value.

7.3.2 Training sites and signature development

The first stage, selecting training sites, is probably the stage where most variability enters the classification process and requires some further discussion. The usual approach to signature development is to digitise polygons directly from either the remote image or other land class map having first identified suitable training sites. These polygons are then used to extract spectral information. This is impractical for subtidal acoustic surveys using point ground samples since there is no direct observational evidence to support the construction of extensive training polygons. Instead a small buffer is created around the sample position that is used to extract acoustic data that are assumed to be associated with the biotope identified from the field record. The resulting acoustic signature may include data that are unlikely to be associated with the observed biotope and this will inevitably lead to signature overlap between biotope classes. This is exacerbated when (1) the ground is very heterogeneous; (2) different biotopes lie close together on the seabed (e.g., either side of a biotope boundary); (3) samples are not located near any real acoustic data (which may be the case if field data from a separate survey are used); (4) the buffers are too large, and; (5) ground samples are close together so that buffers overlap.

Records from very heterogeneous areas can be excluded from signature development. Some authors have calibrated their AGDS on homogeneous patches of ground and then used the boxes constructed for E1/E2 to detect the ground types in other areas (Chivers *et al.* 1990). Likewise it is possible to develop signatures for homogeneous areas and apply these to the whole image (Collins *et al.* 1996). However, these signatures cannot be applied with

confidence to heterogeneous areas since the footprint of the sounder system and interpolation will result in average reflectance values that do not match to any pure signature. Thus, it is unlikely that such procedures will overcome the problem of heterogeneity in practice.

Editing signatures based on the knowledge of environmental limits of certain biotopes (e.g., depth limits to algal growth) can mitigate some of these problems (Hull and Nunny 1999). Inspection of the frequency histogram of E1 and E2 for discrete and widely separated peaks in the data may suggest which values are obviously not associated with the biotope (e.g., low values of E1 and E2 where the ground type was of rock). This approach must be used cautiously, if at all, since it assumes that there is already some knowledge of what the correct values should be.

7.4 Assessment procedures.

Accuracy and confidence are extremely hard to assess and there is no single measure of accuracy that can be applied to a map. Nevertheless, some assessment of accuracy is required so that potential users of maps can make their own judgement as to the degree of confidence they can place in a map. No map should be taken on trust without at least having knowledge of the data upon which it is based, how the data were collected and analysed and what are the potential sources of error. Accuracy can be measured by finding the proportion of ground truth samples that match the habitat or biotope map compared to the proportion that do not match. These accuracy assessments take the form of an error matrix constructed by matching the predicted biotopes or habitats from the map with the actual categories (the ground truth samples or external sample data set). These accuracy assessments must be interpreted with caution. Small areas with only a few habitat or biotope classes will always return higher accuracy values than will be the case for large diverse areas.

Two digital images that are co-registered and have the same pixel size can be overlain and the pixels from one image compared with those of the other. This is an extremely useful facility for the comparison of two images. These comparisons are made through the construction of a matrix of ground truth data (columns) and mapped data (rows). The row totals give the number of pixels in the map image that have been classified as particular habitat or biotope classes (but only counting those pixels for which there are corresponding ground truth pixels). The figures in the various columns of that row give the break down of this total in terms of the classes as indicated by the ground truth data. The column totals give the number of pixels that have been assigned to a particular class from the ground truth data whilst the figures in the rows give the break down of this total in terms of how these pixels were interpreted by image processing. The diagonal gives the tally of correct predictions and the percent correct calculated as an overall figure for the accuracy measure (total correct

matches/total pixels used in the comparison). The percentage correct can also be calculated for each individual biotope. Other indices can be used (e.g. Kappa and Tau) that gives probability of a match over and above chance.

Internal accuracy is a measure of the internal consistency between the field samples used in classification and the resulting biotope map. Thus it uses the same field sample data set for classification and accuracy assessment. Although of little use for assessing the predictive capability of a map, these measures can give an idea of relative performance. However, the accuracy measures can be surprising. Quite high internal accuracies can be achieved with only a small number of field samples if these have been selected from homogeneous acoustic ground since the signatures generated will not have the spread of values from a more extensive field data set. Thus, it is important to use internal accuracy measures to compare similar data sets.

External accuracy assessment uses a different set of field records from that used for classification and measures the predictive performance of a biotope map. Benthic samples for large survey areas are hard-won and it is often difficult to avoid using all the data for classification of the acoustic images. This is, admittedly, unsatisfactory since it would be expected that internal accuracy would be higher than predictive accuracy. Dividing the field data set into two subgroups used for (a) classification and (b) external accuracy assessment is also unsatisfactory since the subgroups will probably have too few samples per class and not represent the whole survey area evenly.

Crosstabulation process can also be used to measure the **similarity** between two interpreted maps of the same area for comparing the results from repeat surveys or the results of different analyses of the same data set.

7.5 SEAMAP/CEFAS survey examples: Classification of the Hastings and Hastings-Dungeness data sets

7.5.1 Introduction: Strategy for classification of data sets

Classification brings together the various acoustic data sets and the ground truth data to map the likely distribution of the ground types. The nature of the acoustic data sets and the type of ground truth observations varied between the relatively fine scale Hastings Shingle Bank survey and the broader scale Hastings-Dungeness survey and it is probably instructive at this stage to outline the classification procedures adopted (Table 12).

Acoustic data sets	Classification type	Ground truth data	Purpose
Hastings shingle bank (fine scale): interpolated coverages of the acoustic variables	Unsupervised	Classes compared with comprehensive sidescan coverage	Are there distinct acoustic ground types that correspond to sediment features? Does unsupervised classification indicate differences in ground that are difficult to distinguish using sidescan?
Ditto	Supervised	Signatures from selected sidescan training sites	Can supervised classification establish extent and boundaries of sediment features?
Ditto	Supervised	Signatures from video training sites	Can supervised classification establish extent and boundaries of sediment features?
Hastings-Dungeness (broad scale): Digital images of track point data	Unsupervised	Classes compared with sidescan image	Are there distinct acoustic ground types that correspond to sediment features?
Ditto	Supervised	Signatures from sidescan training sites	Can supervised classification establish extent and boundaries of sediment features?

Table 12. Summary of the main analyses carried out on the Hastings shingle bank and Hastings-Dungeness data sets together with the primary purposes of the analyses.

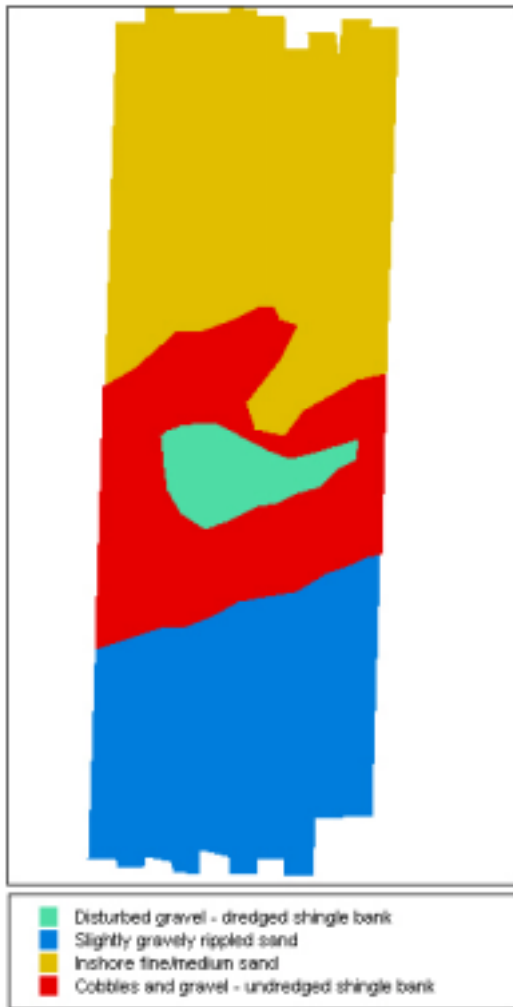


Figure 26. Digital image of the areas occupied by the four ground types that can be discerned from the sidescan data. This image has been used in the determination of accuracy measures in many of the performance assessments for the classification of the Hastings shingle bank data sets. The image has the same coordinates and numbers of rows and columns as all other images from the Hastings shingle bank.

7.5.2 Unsupervised classification of the Hastings data sets

Classification

The unsupervised classification carried out with a cluster number of 3, 4, and 6 to reveal how major classes subdivide as the clusters are increased and these were crosstabulated with a digital image of four ground types derived from the sidescan images (Figure 26). Figures 27 and 28 show the results for *RoxAnn* and *QTC-VIEW* respectively. In all cases, the outline of the boundaries of the major sediment features identified from the mosaiced sidescan image for Hastings shingle bank have been superimposed as a reference.

Figure 27: RoxAnn unsupervised classification of the Hastings Shingle Bank data.

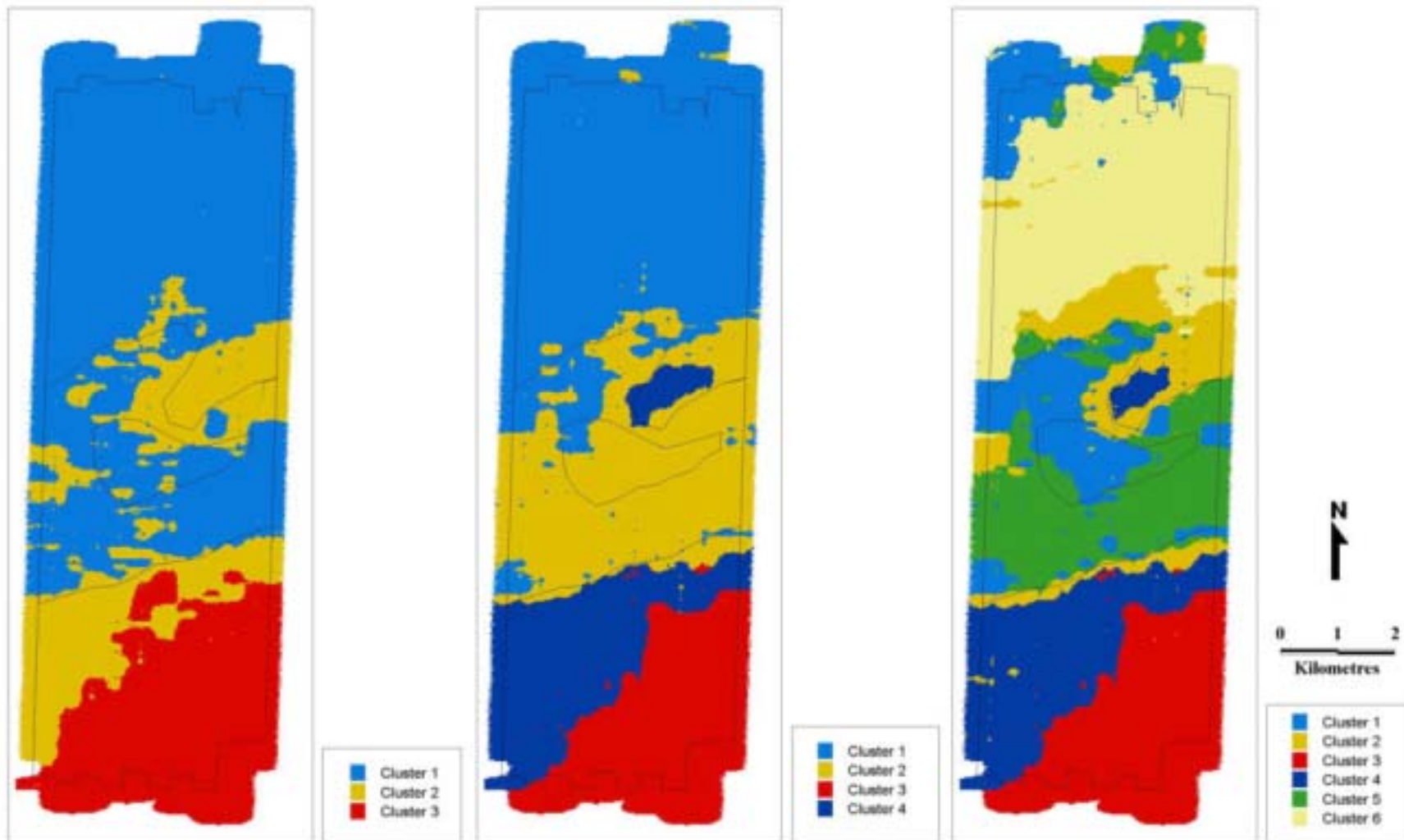
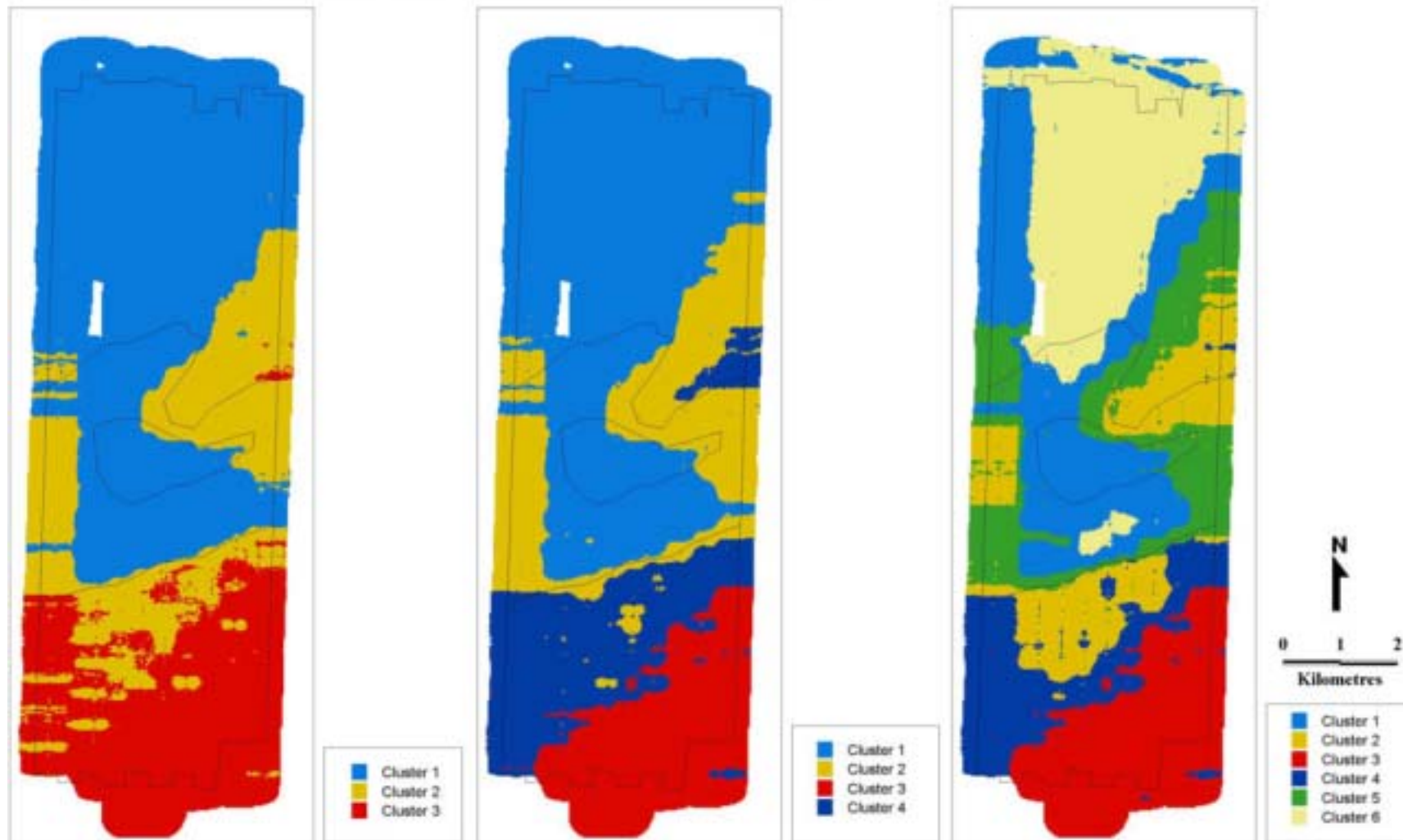


Figure 28: QTC unsupervised classification of the Hastings Shingle Bank data.



The following observations have been made:-

1. *RoxAnn*:
 - a. There is a good correspondence between the distribution of the 4 clusters and sidescan categories, especially between clusters 3+4 and slightly gravelly rippled sand.
 - b. The dredged area (category 'Disturbed gravel – dredged shingle bank') has not been discriminated acoustically although when 6 clusters were used, there was partial correspondence with cluster 1.
 - c. The south-westerly intrusion of Inshore fine/medium sand into cobbles and gravel is partially picked up by clusters 2+4+6 when 6 clusters were selected. However, the island of cluster 4 is a distinct feature (which persists in other classifications) that does not correspond with any sea floor category. Its similarity to deeper water slightly gravelly rippled sand may be real or an artefact of bathymetry.
 - d. The slightly gravelly rippled sand category has been subdivided even with 3 clusters along a northeast/southwest line that might correspond to bathymetry. There is no obvious change in sea floor features coincident with this boundary.

3. *QTC-VIEW*:
 - a. The boundary between 3+4 (4 clusters) corresponds with slightly gravelly rippled sand.
 - b. The boundary between clusters 3 and 4 (with 4 clusters) lies in a similar position to the equivalent *RoxAnn* boundary and may also be related to bathymetry.
 - c. The intrusion of inshore fine/medium sand only approximately corresponds with cluster 2 and, similar to *RoxAnn*, there appears to be some affinity to the deeper water ground types.
 - d. The western-most track has resulted in an obvious unconformity with the remaining data set. However, with 6 clusters, there may be a correspondence between cluster 1 and the dredged area (slightly gravelly rippled sand).
 - e. Increasing the number of classes above 4 has added gradations between clusters.
 - f. There would appear to be some affinity between parts of the ground that intrudes into 'cobbles and gravel' with the deeper water sediment, similar to *RoxAnn*. Again, this may be related to bathymetry.

In general the clusters 'make sense' in terms of (1) the knowledge of the sea floor and (2) the underlying acoustic parameters (E1/2, Q1/2/3 and depth).

Performance

Both systems give outputs which are similar in many respects. Overlaying the images shows that there is, in fact, an overall 74% overlap. However, the difference in the ability of the two systems to pick out acoustically distinct ground types that correspond to habitat categories is markedly different for some categories. To test this, the clusters of the unsupervised classification were matched to the sea floor categories from the sidescan mosaic by laying the classified image (4 clusters) over a raster copy of the sea floor category polygons (Figure 26). This was used to find the percentage of overlap [percent shared pixels = 100 x (2 x number of pixels in overlapping area between selected cluster and best fit category/ number of pixels in cluster + number of pixels in category)] as a measure of the relative performance of *RoxAnn* and QTC. The results (Table 13) indicate that *RoxAnn* out-performs QTC. However, both systems discriminated 'slightly gravely rippled sand' to the south of the area well whilst neither discriminated the central dredged area satisfactorily.

Cluster number	<i>RoxAnn</i>		QTC	
	Best fit category	% shared	Best fit category	% shared
1	Inshore fine/medium sand	82	Inshore fine/medium sand	61
2	Cobbles and gravel	58	Cobbles and gravel	32
3 & 4	Slightly gravely rippled sand	87	Slightly gravely rippled sand	91

Table 13. The categories have been matched to clusters and the percentage of shared pixels calculated.

Depth as a variable for classification

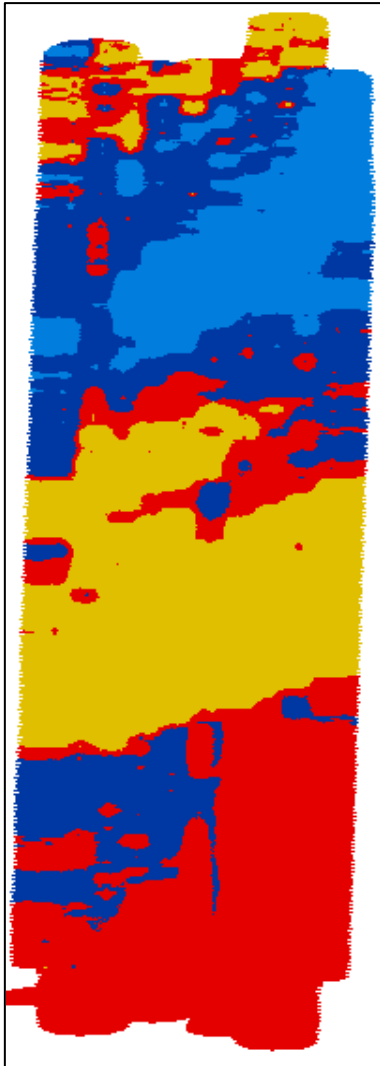
It is questionable whether depth should be included as a variable to discriminate sediment habitats since *a priori* these might be expected to occur at any depth. Thus, the northeast/southwest division of the slightly gravely rippled sand (the southern-most ground type in the Hastings shingle bank survey area) might be due to depth rather than differences in reflectance properties of the ground. To test this the unsupervised classifications were repeated without depth (E1 and E2; Q1, Q2 and Q3) based on four clusters. The classification changed substantially for the *RoxAnn* data (Figure 29a) with the inshore fine-medium sand, previously predominantly just one cluster, being subdivided into clusters. However, the slightly gravely rippled sand is still divided, although the boundary is less well defined.

The *QTC-VIEW* image is hardly changed at all (Figure 29b). This indicates that depth is already strongly represented in Q1, Q2 and Q3 variables. This is quite disturbing for the assessment of the performance of *QTC-VIEW* since it is to be hoped that depth would not

contribute substantially to the acoustic characterisation of the sea floor habitats. The scattergrams show depth dependencies with the Q values so that this result, though disappointing, is not entirely surprising. The last classification used Q2 and Q3 alone (Figure 29c) gives a similar distribution pattern of the clusters, but with a more random distribution of the classes indicating that the ground types, though similar to the previous classification, are less distinctive.

Figure 29. Unsupervised classification without including depth as a variable.

a. RoxAnn data set; E1 & E2



b. QTC data set; Q1, Q2 & Q3



c. QTC data set; Q2 & Q3



Summary

Both *RoxAnn* and *QTC-VIEW* systems demonstrate that there are links between acoustic ground types and some of the habitats (e.g., fine rippled sand). However, the correspondence is not exact or equally expressed by both systems. It would appear that *RoxAnn* out-performs.

The importance of a correspondence between acoustic ground types and habitat is often neglected as a classification tool since supervised classification is preferred (Wilkie and Finn 1996). However, it adds confidence to supervised classification if it can be shown that there is some inherent acoustic distinctiveness between habitat classes.

However, there is no *a priori* reason why acoustic ground types might mirror visually distinct habitat types. Indeed, it might be that AGDS can demonstrate acoustic differences within a habitat class that was hitherto regarded as uniform. An example of this would be the division of fine rippled sand into two acoustic clusters by both *RoxAnn* and QTC. Inspection of the sidescan mosaic has failed to find any clues as to the causes for this, but further sampling could be directed to establishing if the two ground types are, indeed, distinct.

The strong depth dependence of Q1 (at least) is worrying for the operation and interpretation of QTC. It must be borne in mind that records for shallow water had already been eliminated from the analysis to reduce depth dependence. The problem may be due to the way this particular system has been set up or is an inherent characteristic of QTC. Experience with another *QTC-VIEW* system suggests the latter (Foster-Smith and White 2001).

7.5.3 Supervised classification of the Hastings data set with sidescan training sites

Classification

The training sites (Figure 30), which were considered to be unequivocally typical of the sea floor feature categories were few in number, but occupied about 20% of the survey area enabling them to capture sufficient acoustic data for successful signature development. The purpose of this classification, apart from comparing system performance, was to see if the process would place boundaries between the categories in a similar disposition as the boundaries drawn by eye from the complete sidescan mosaic. The classified maps (Figure 32) show these latter boundaries for reference.

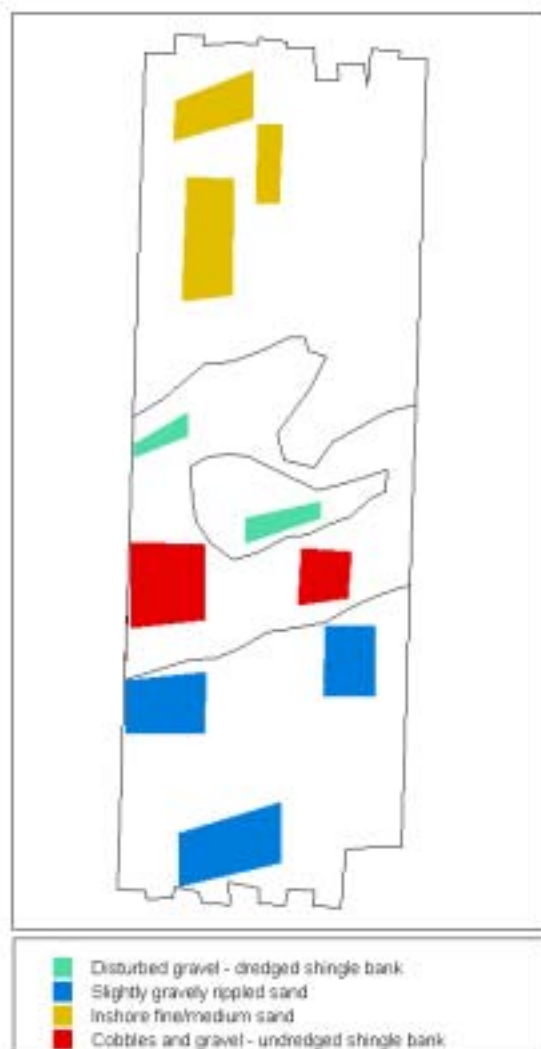


Figure 30. Selected polygon training areas digitised from the sidescan sonar image that represent ground typical of the four habitat categories. The overlaying boundaries are taken from Figure 26 and were used for making the assessment of performance of the classification (Table 14).

Similarity between the *RoxAnn* and *QTC-VIEW* classifications is high, and there are also similarities between the AGDS boundaries between classes and the sidescan boundaries.

1. The dredged area (Disturbed gravel – dredged shingle bank) has been discriminated, but with both systems this ground extends northwards and also merges into ‘cobbles and gravel’.
2. Overall, there appears to be a fair correspondence between the classification of the *RoxAnn* and the *QTC-VIEW* data.
3. Both systems show the intrusion of sand into the ‘cobbles and gravel’ ground to have affinities with the deeper ‘slightly gravelly rippled sand with shell’ category.
4. The unconformity along the western edge of the *QTC-VIEW* data set is probably an artefact due to variability in data collection.

Performance

The sidescan image used for reference in the above analysis was also used for an external accuracy assessment for the supervised classification. Although the sidescan image is not totally independent of the training sites (which are a subset of the whole image), there is sufficient area outside the training sites for external validation.

Sea floor category	Match (% correct)	
	<i>RoxAnn</i>	QTC
Disturbed gravel – dredged shingle bank	33.0	19.0
Slightly gravelly rippled sand	83.2	86.6
Inshore fine/medium sand	98.6	94.5
Cobbles and gravel	87.9	87.1
Overall	83.0	73.4

Table 14. Performance as measured by the percent of the classified pixels that (‘correctly’) lay within the corresponding polygons digitised from the mosaiced sidescan image (Figure 26).

RoxAnn outperformed *QTC-VIEW* in the external accuracy, although the anomalous top left margin of the *QTC-VIEW* data undoubtedly contributed to the poor performance of this system. Overall there is a 68% match between the *RoxAnn* and the *QTC-VIEW* classified images.

7.5.4 Supervised classification of the Hastings data set with video training sites

Classification

The video records were assigned to similar sea floor categories as those used for the sidescan training sites so that the final maps were more comparable. However, being essentially point data, the training sites were created using buffers of 100m around either the Hamon grab sites or the tow-lines from the drop camera frame (Figure 31).

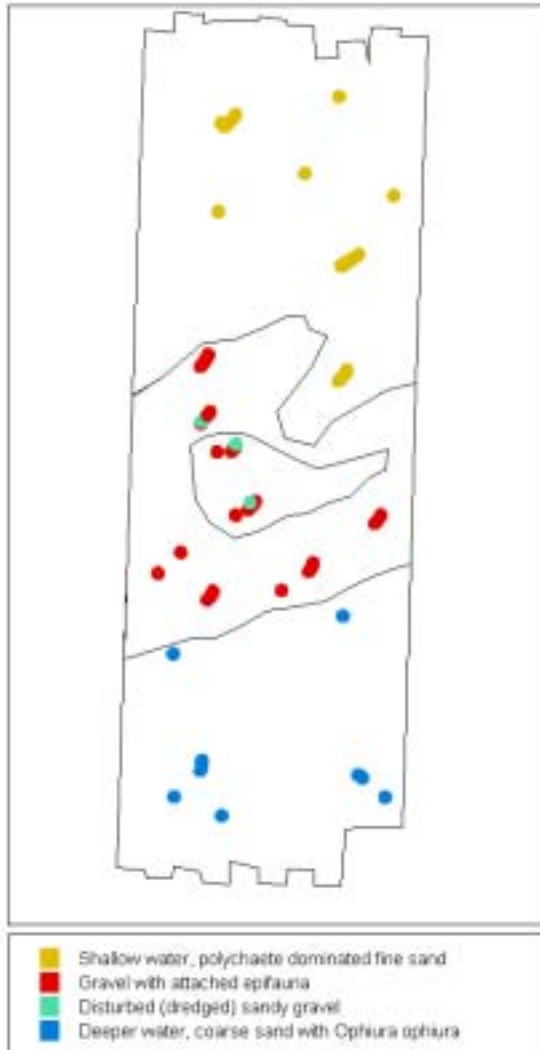


Figure 31. Training sites created by drawing a buffer of 100m around the video ground truth sites. The overlaying boundaries are taken from Figure 26 and were used for making the assessment of performance of the classification (Table 15).

The classification of the *RoxAnn* and the *QTC-VIEW* data sets are shown in Figure 33. The video training sites result in a strong correspondence between the pixels classified to habitat type and the matching sidescan polygons used for accuracy assessment.

1. Overall, there appears to be a fair correspondence between the classification of the *RoxAnn* and the *QTC-VIEW* data.
2. The dredged area (disturbed sandy gravel) has been discriminated, but merges into 'gravel with attached epifauna'. This is notably in contrast to the unsupervised classification which failed to discriminate this area.

Figure 32: Supervised classification of the Hastings Shingle Bank data using sidescan as ground truthing.

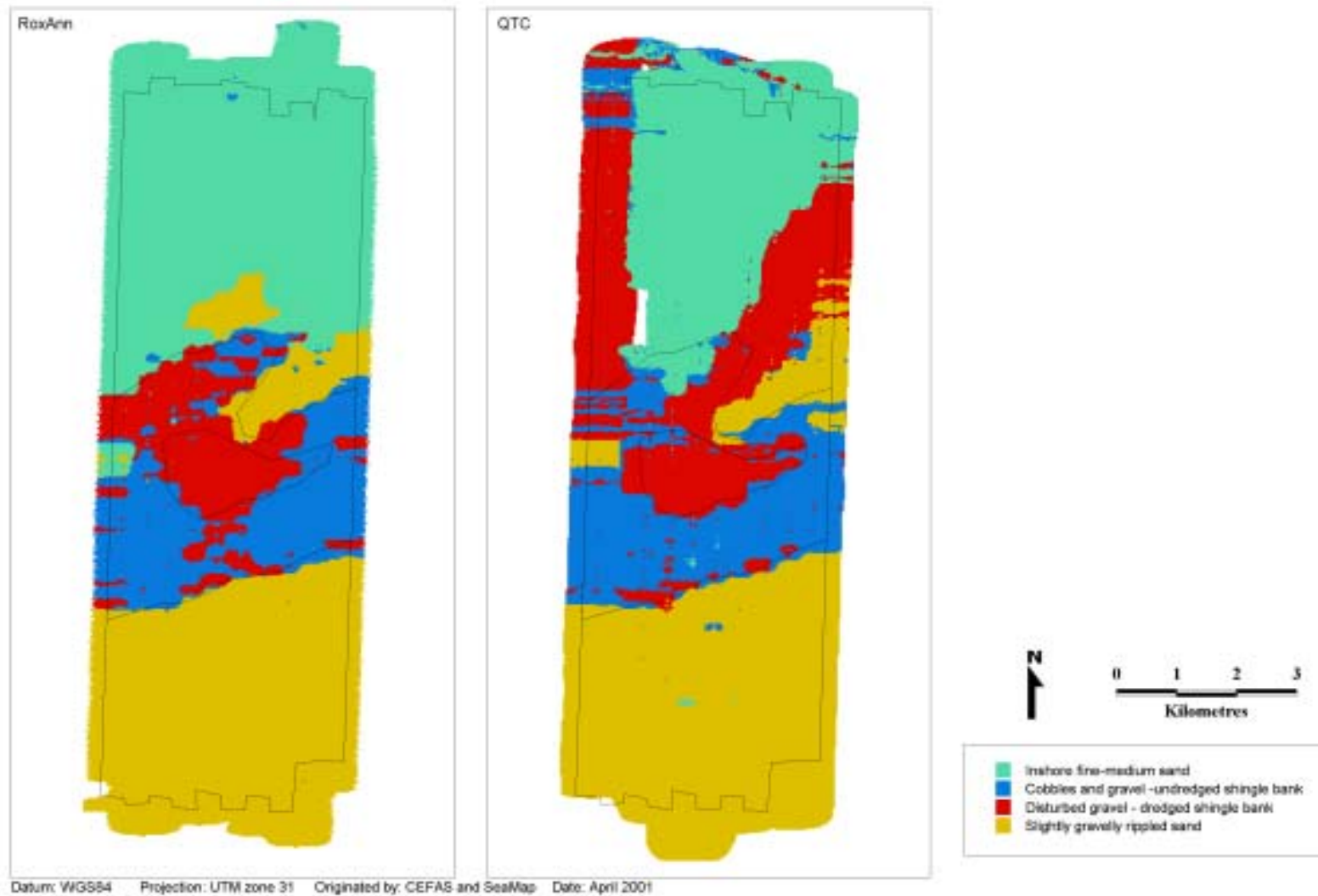
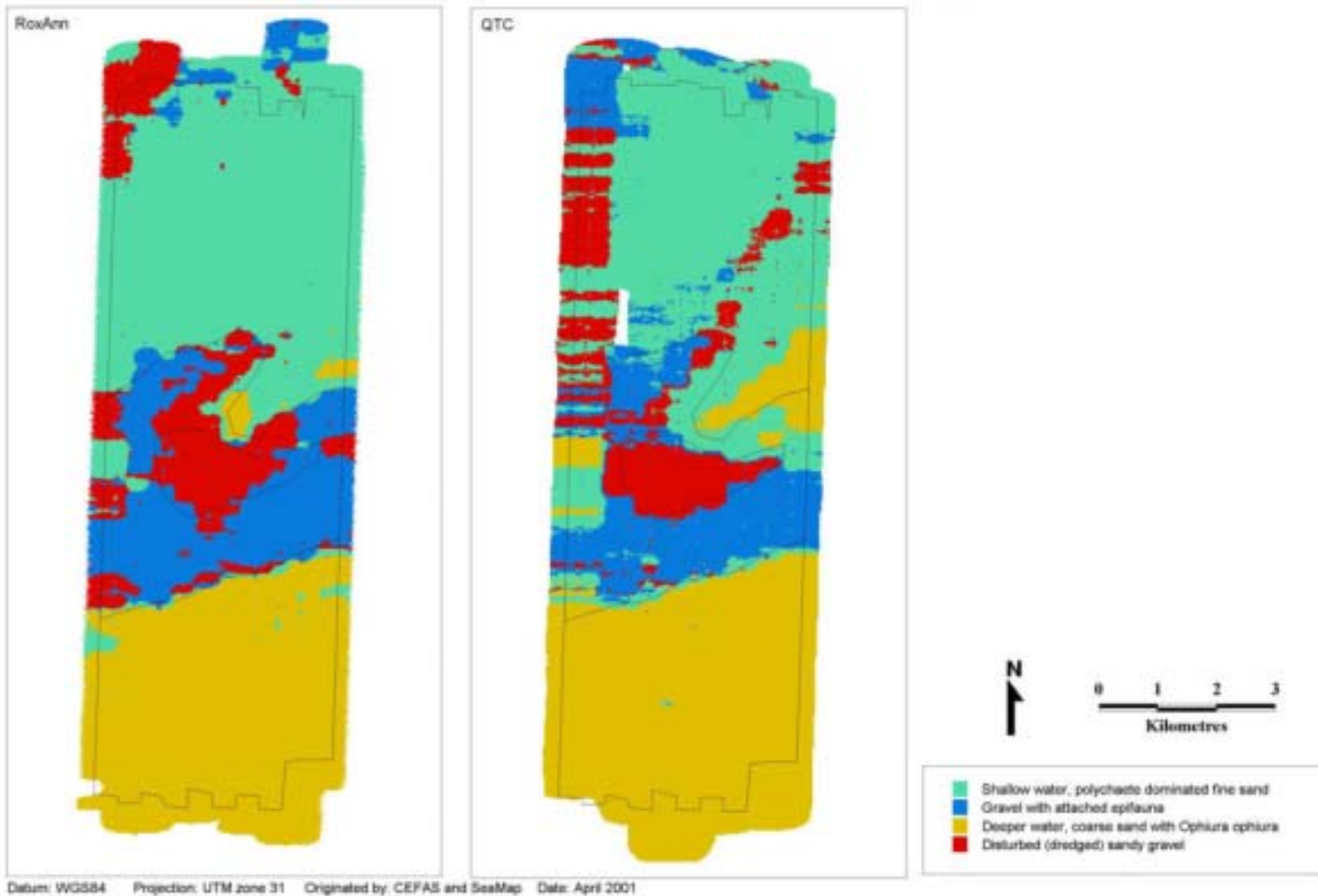


Figure 33: Supervised classification of the Hastings Shingle bank data using video as ground truthing.



3. Both systems show the tongue of sand into the 'gravel with attached epifauna' ground in the central part of the survey area to be predominantly 'fine sand', although there are affinities with the 'deeper water, coarse sand with *Ophiura ophiura*' category.

Performance

The sidescan image (Figure 26) was used for an external accuracy assessment for the supervised classification. The sidescan image can be regarded as independent of the training sites. The performance of the classification is summarised in Table 15.

Sea floor category	Internal accuracy (% correct)		External accuracy (% correct)	
	<i>RoxAnn</i>	QTC	<i>RoxAnn</i>	QTC
Deeper water, coarse sand with <i>Ophiura ophiura</i>	100	88.48	96.4	87.2
Shallow water, polychaete dominated fine sand	99.5	96.81	93.7	81.6
Gravel with attached epifauna	98.9	85.2	87.5	81.3
Disturbed (dredged) sandy gravel	98.6	89.6	86.2	77.4

Table 15. Performance as measured by the percent of the classified pixels that ('correctly') lay within the corresponding polygons digitised from the mosaiced sidescan image (Figure 26).

Once again, *RoxAnn* outperformed *QTC-VIEW* both in the internal and the external accuracy, although the anomalous top left margin of the *QTC-VIEW* data undoubtedly contributed to the poor performance of this system. Overall, there is a 73% match between the *RoxAnn* and the *QTC-VIEW* classified images.

Summary of the supervised classification using sidescan and video training sites

The coincidence of the boundaries between the supervised classification of the visual and sidescan classifications is high between certain habitat types for both *RoxAnn* and *QTC*. However, both systems show the central dredged area to be less distinct from the ground to the north west than the original interpretation of the sidescan. However, inspection of the image does reveal that many of the features (dredge marks) extend further north west. Visual interpretation of sidescan images is an imprecise art and hard boundaries are drawn around ground types that are, in reality, not clearly distinct. AGDS provides information that is more 'fuzzy' and is complementary to the artificially hard interpretation of the sidescan. However,

there is always the risk that sidescan images will be reinterpreted to reinforce the results from AGDS classification where this may not really be justified. Nevertheless, if carefully used, AGDS could provide useful guidance in drawing boundaries by indicating whether they are hard or soft and where there is uncertainty in the visual interpretation.

The results using sidescan and video training sites are similar. This is reassuring in that it demonstrates that both ground truthing techniques can be used to observe the same sea floor sediment features. Perhaps more importantly, it also shows that, since the two sets of training sites differed in size, position and number (compare Figures 30 and 31) supervised classification was not heavily influenced by differences in the acoustic data used for signature creation. Similar results have been reported for other studies into ground truthing intensity, although the actual percentage match between interpretations is lower than might be expected from the overall visual similarity of the maps (Foster-Smith *et al.* 2000). This might be due to the emphasis on variability around edges of classified areas that is inherent in the comparison of maps through image overlay and crosstabulation.

7.5.5 Unsupervised classification of the Hastings-Dungeness data sets

Classification

Four clusters have been selected for unsupervised classification and the original eight ground types reduced to four (see Table 16) since the classifications using eight clusters and classes were interpretable. The results for *RoxAnn* and *QTC-VIEW* have few points of similarity although the northeast/southwest boundaries between cluster 1 and other clusters are approximately consistent between systems (Figure 34 and 35). The *QTC-VIEW* data show mixing between clusters along the tracks that might reflect high variability of the underlying track data.

Performance

The clusters of the unsupervised classification were matched to the sea floor categories from the sidescan images by laying the classified image over a raster copy of the sidescan training polygons and determining the number of the ground truth pixels that fell within each of the clusters (Table 16).

Match between acoustic clusters and sidescan ground truth habitat types								
Habitat	RoxAnn (acoustic clusters – Fig. 34)				QTC (acoustic clusters –Fig. 35)			
	1	2	3	4	1	2	3	4
Gravelly	241	30	0	1237	301	45	754	120
Smooth	480	111	0	0	276	0	32	348
Sand features	163	1310	18	145	254	364	764	436
Rough stoney	17	17	0	0	14	0	0	0

Table16. Matrices of the numbers of ground truth pixels for the four major habitat category (reduced from the original eight) that fell within each cluster.

There is a clearer link between clusters and habitat classes for *RoxAnn* than *QTC-VIEW* where the overlap appears random. However, the significance of values is hard to determine since the numbers of pixels in each class and cluster varies considerably.

Summary

Unsupervised classification of more than four classes becomes almost uninterpretable and reducing the number of classes only marginally improves the interpretability of the outputs. This might have been expected since the process of amalgamation of the habitat classes was somewhat arbitrary. The apparently better performance of *RoxAnn* can only be a tentative

conclusion without more intensive investigation. It is unlikely that unsupervised classification is very instructive as the numbers of classes increases.

7.5.6 Supervised classification of the Hastings-Dungeness data set with sidescan training sites

Classification

The supervised classification of the *RoxAnn* and the *QTC-VIEW* data sets using sidescan training sites (Figure 36) representing the eight habitat types are shown in Figures 37 and 38 respectively. Although the overall similarity between the two classifications would appear to be good and the internal accuracy assessment shows the classification to have a high internal accuracy measure (Table 17), the percentage overlap between the two images is modest (52%). However, twice as many sea floor features were distinguished from the sidescan images (and other associated observational data) of the Hastings-Dungeness survey area than the smaller Hastings shingle bank (8 and 4 respectively) and this undoubtedly contributed to the poor match between the two data sets.

One feature of the maps that gave concern on first inspection was the difference between the classification of the pixels lying nearest to the position of the original tracks and the pixels lying some distance on either side. This can be seen as a series of single pixels running through the centre of the classified 'ribbons' of a different colour to the pixels either side. This is caused by the averaging involved with interpolation which results in estimated values being faithful to the nearest track data where the nodes lie close to real track records, but taking on average values of numerous point data at nodes lying further away from the track.

To overcome this, the conversion of track data to digital images was repeated for data sets using a much smaller search radius (50m) and the use of nearest neighbour interpolation (which effectively duplicates the track data but in a form suitable for conversion to a digital image) and the classification repeated. The results (Figures 39 and 40) were somewhat unexpected. In general, the classifications are very similar to the previous treatment. However, one category (large sand waves) hardly appears at all (even at locations coincident with the 'large sand wave' training sites).

Performance

The performance of both the classification using interpolations that smoothes data (inverse distance squared) and reproduces data faithful to the original track data (nearest neighbour) produces interesting results (Tables 17 and 18). Smoothing improved classification performance quite markedly, contrary to expectations. This raises the interesting possibility that many features (particularly the large sand waves) are larger than individual acoustic footprints and are composed of mixtures of track points that classify as other sea floor

Figure 34: RoxAnn unsupervised classification of the Hastings-Dungeness data (4 classes) with the sidescan training sites overlain.

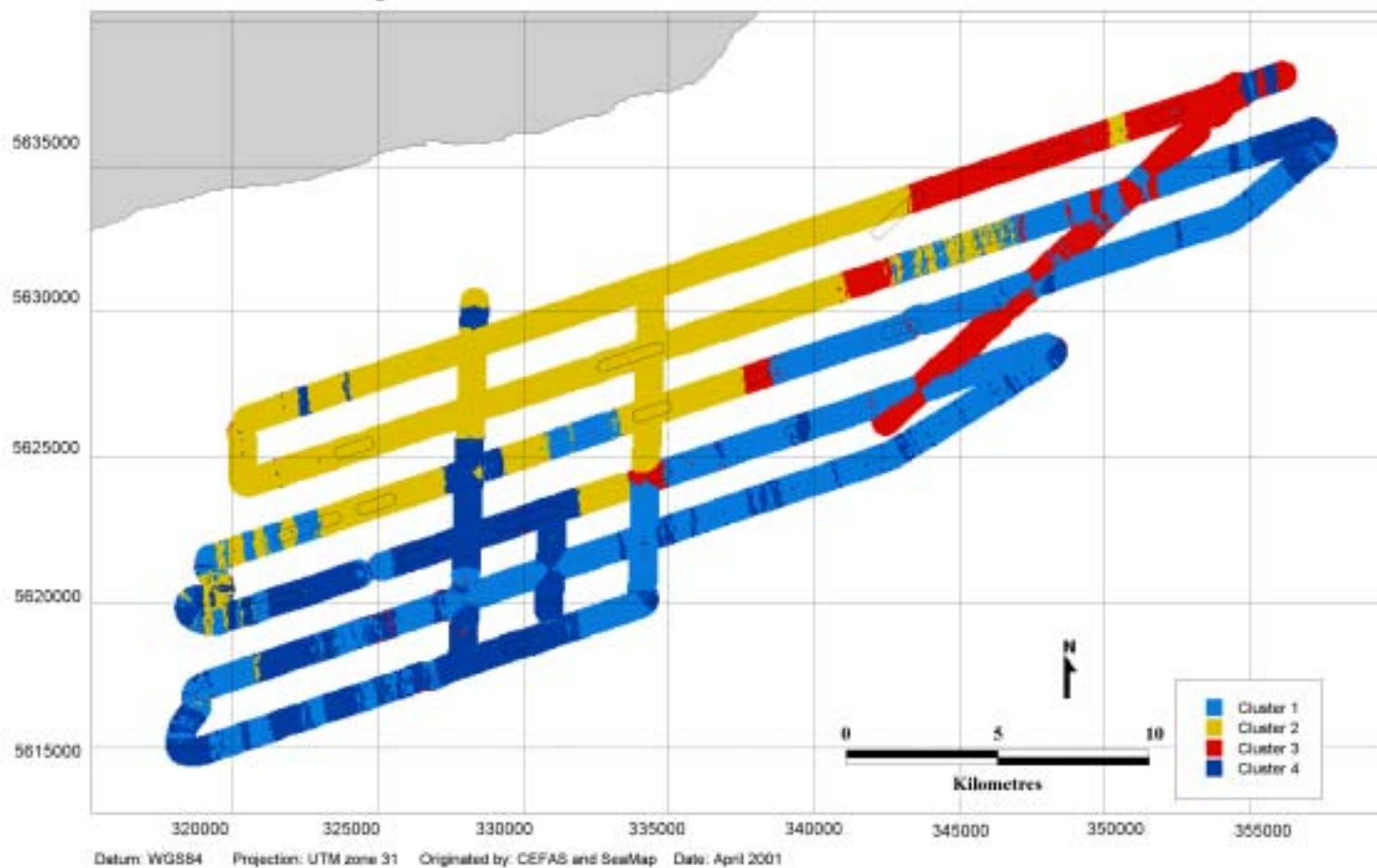


Figure 35: QTC unsupervised classification of the Hastings-Dungeness data (4 classes) with the ground truthing tracks overlain.

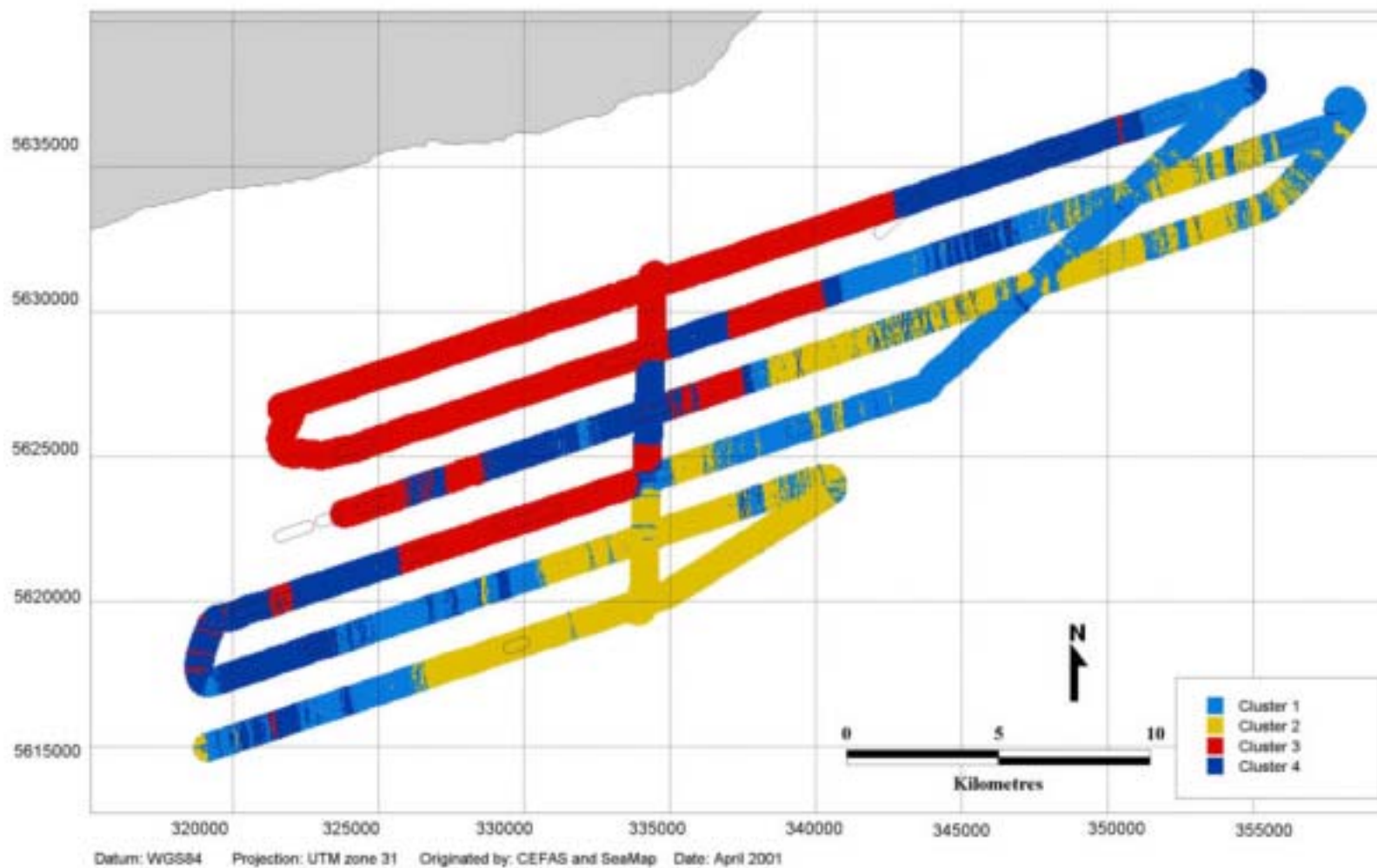


Figure 36: Positions of sidescan training sites used for ground truthing AGDS data.

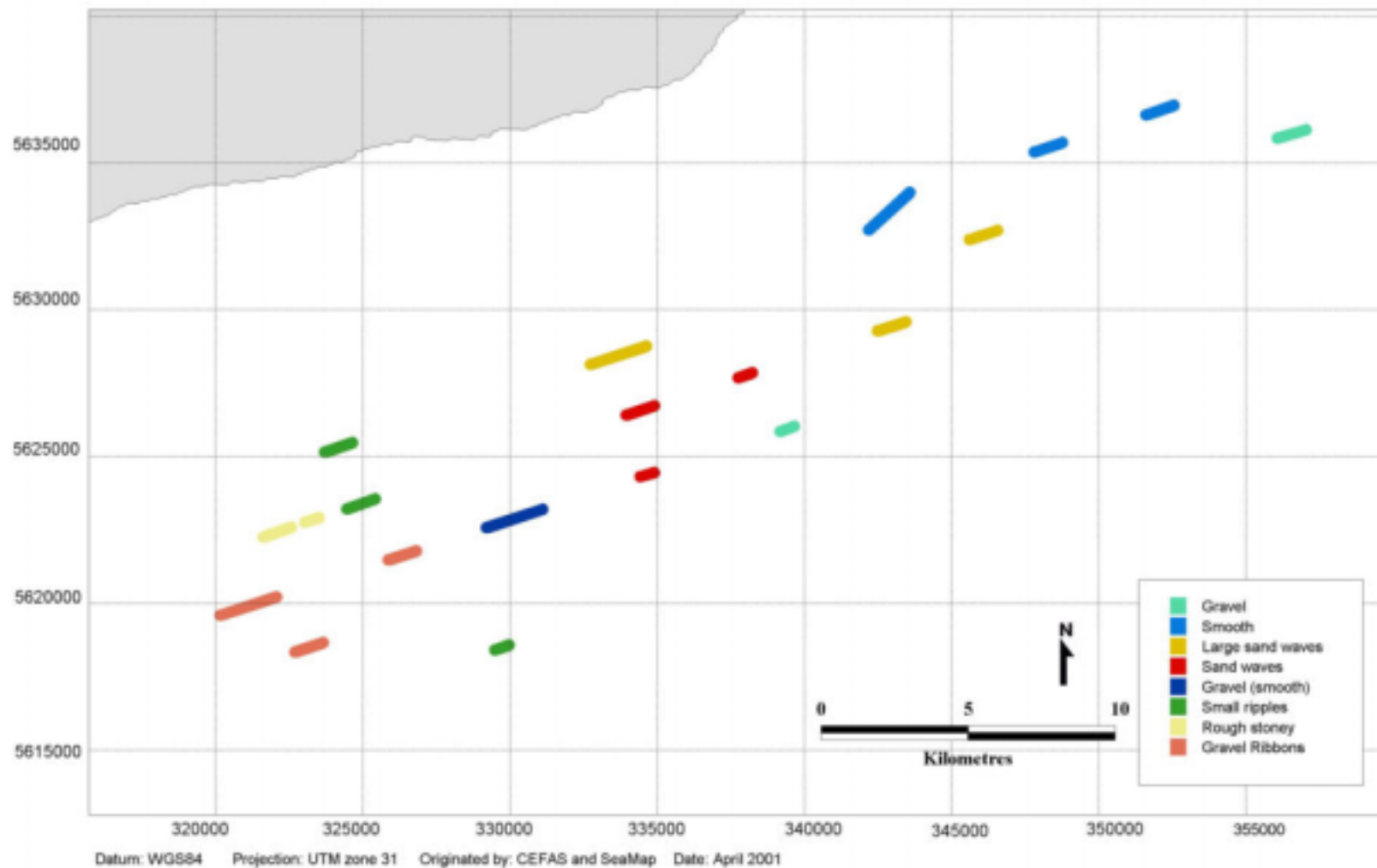


Figure 37: RoxAnn supervised classification of the Hastings-Dungeness data with the sidescan training sites overlaid.

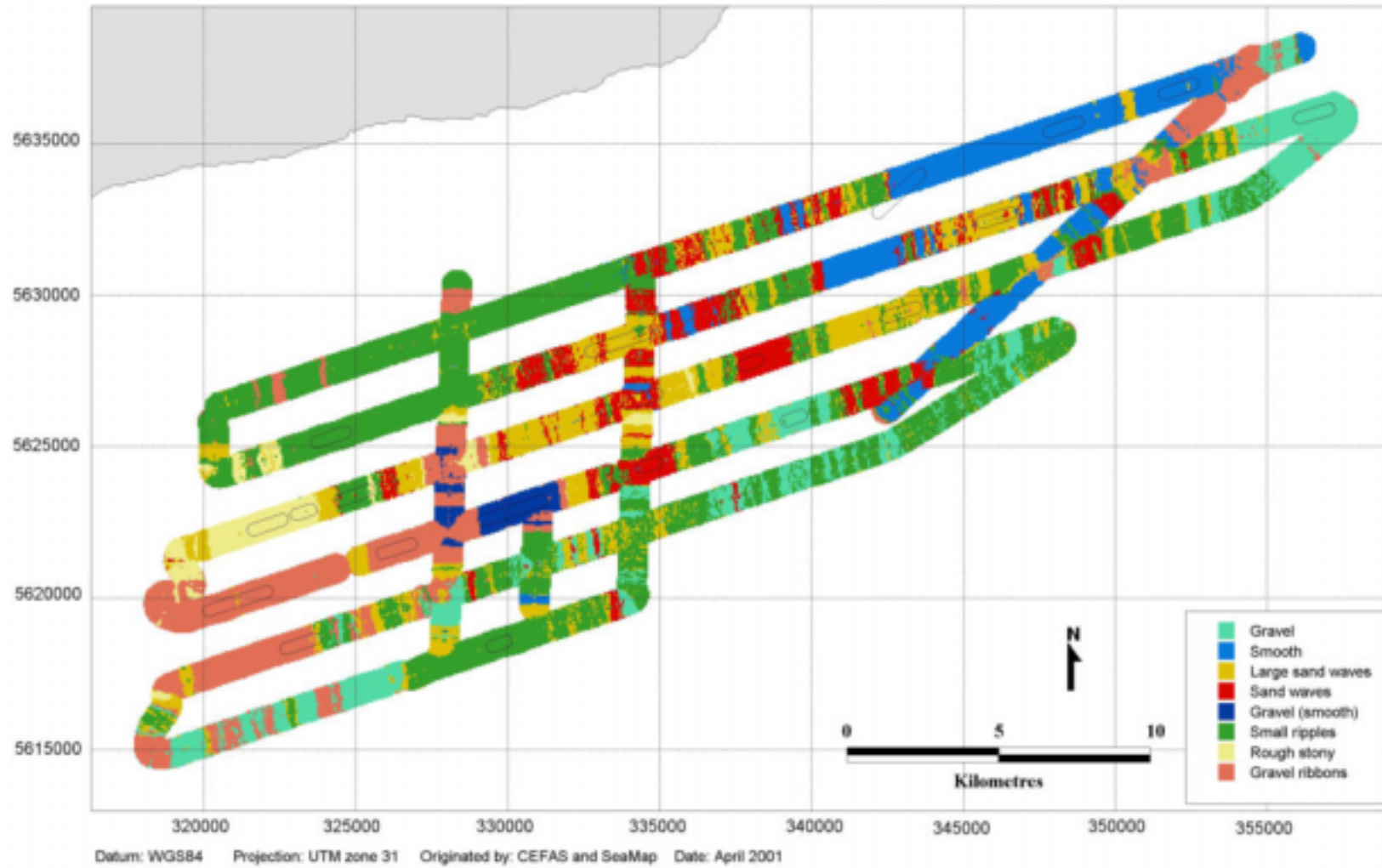


Figure 38: QTC supervised classification of the Hastings-Dungeness data with the sidescan training sites overlaid.

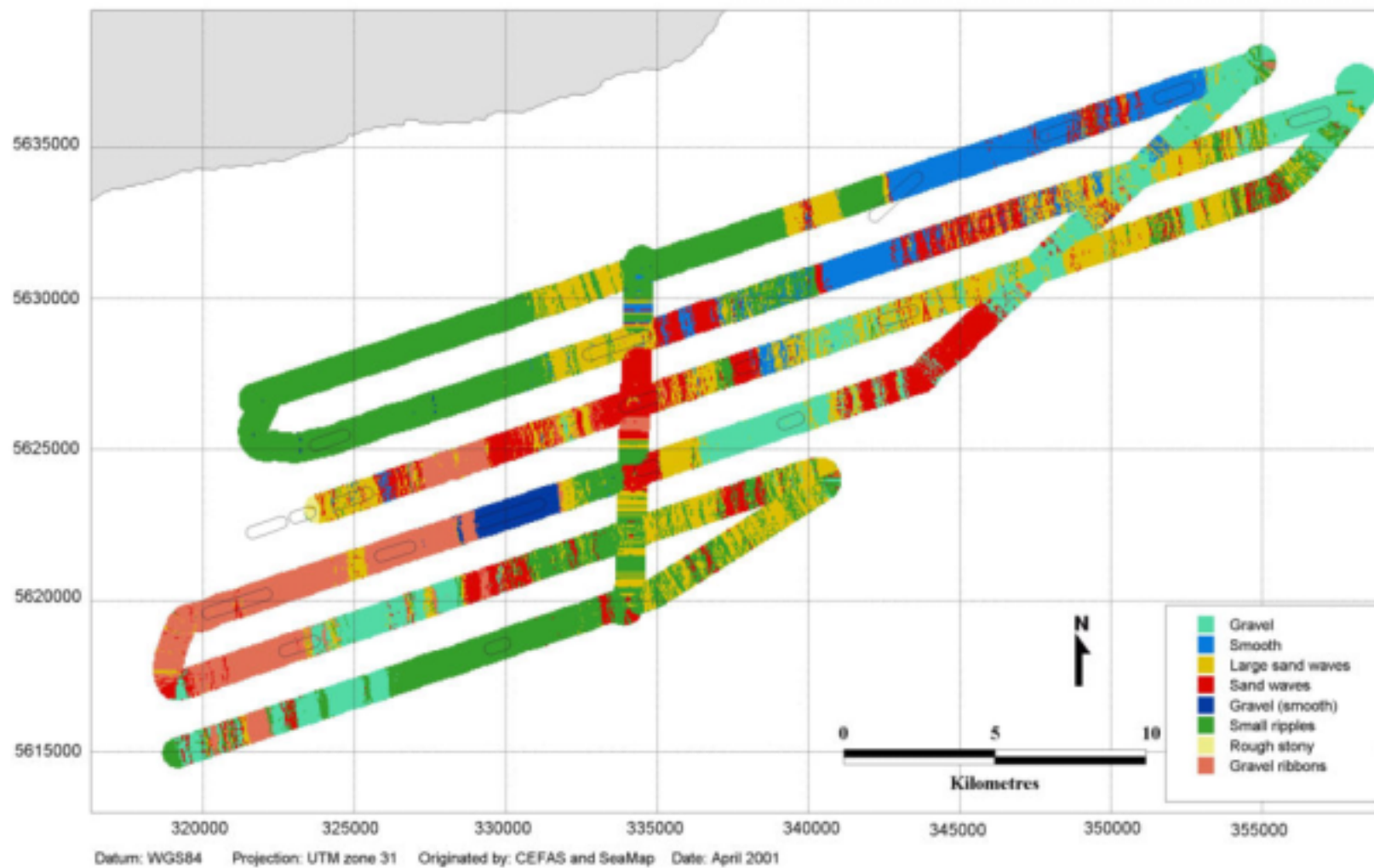


Figure 39: RoxAnn supervised classification of the Hastings-Dungeness data using nearest neighbour.

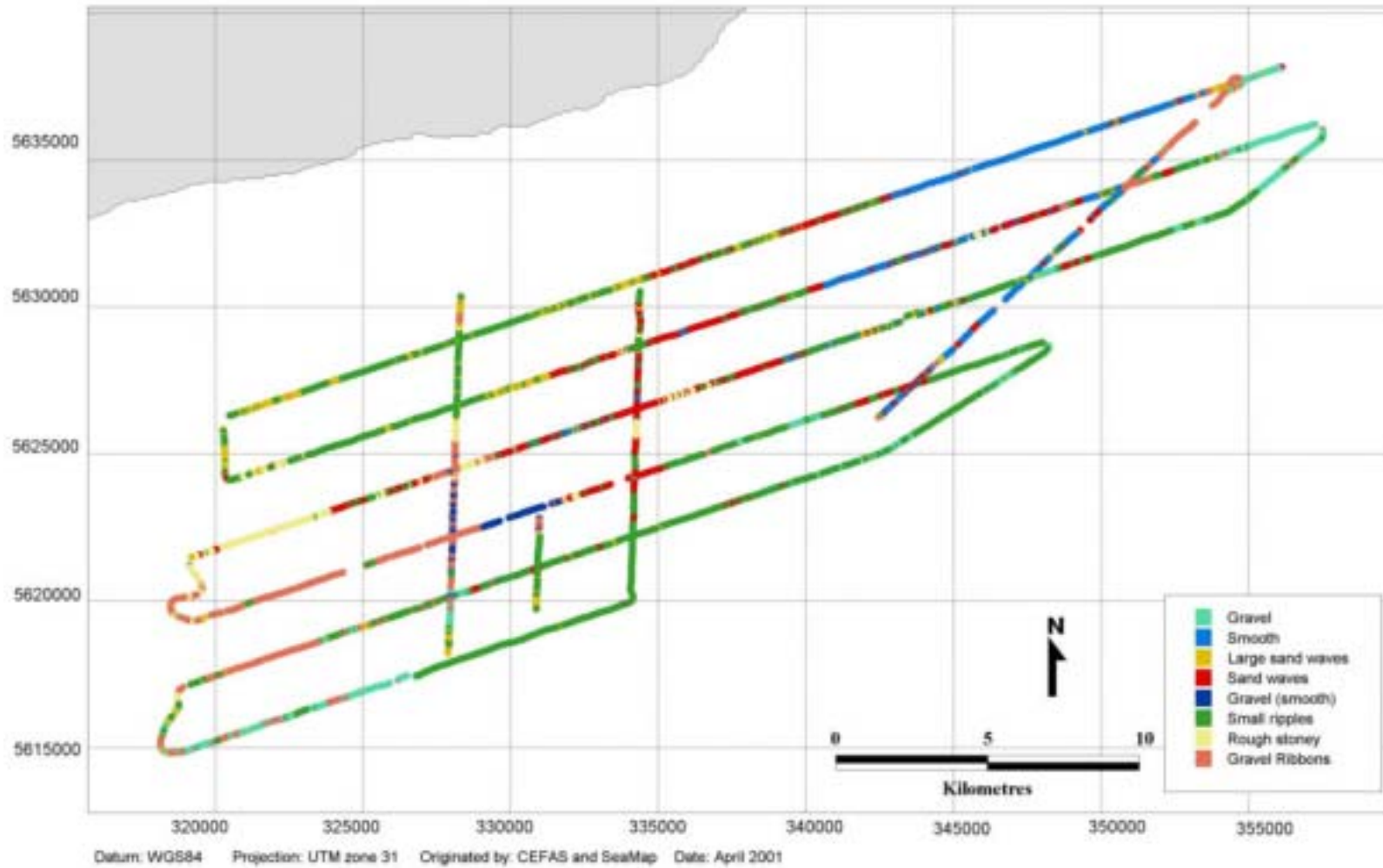
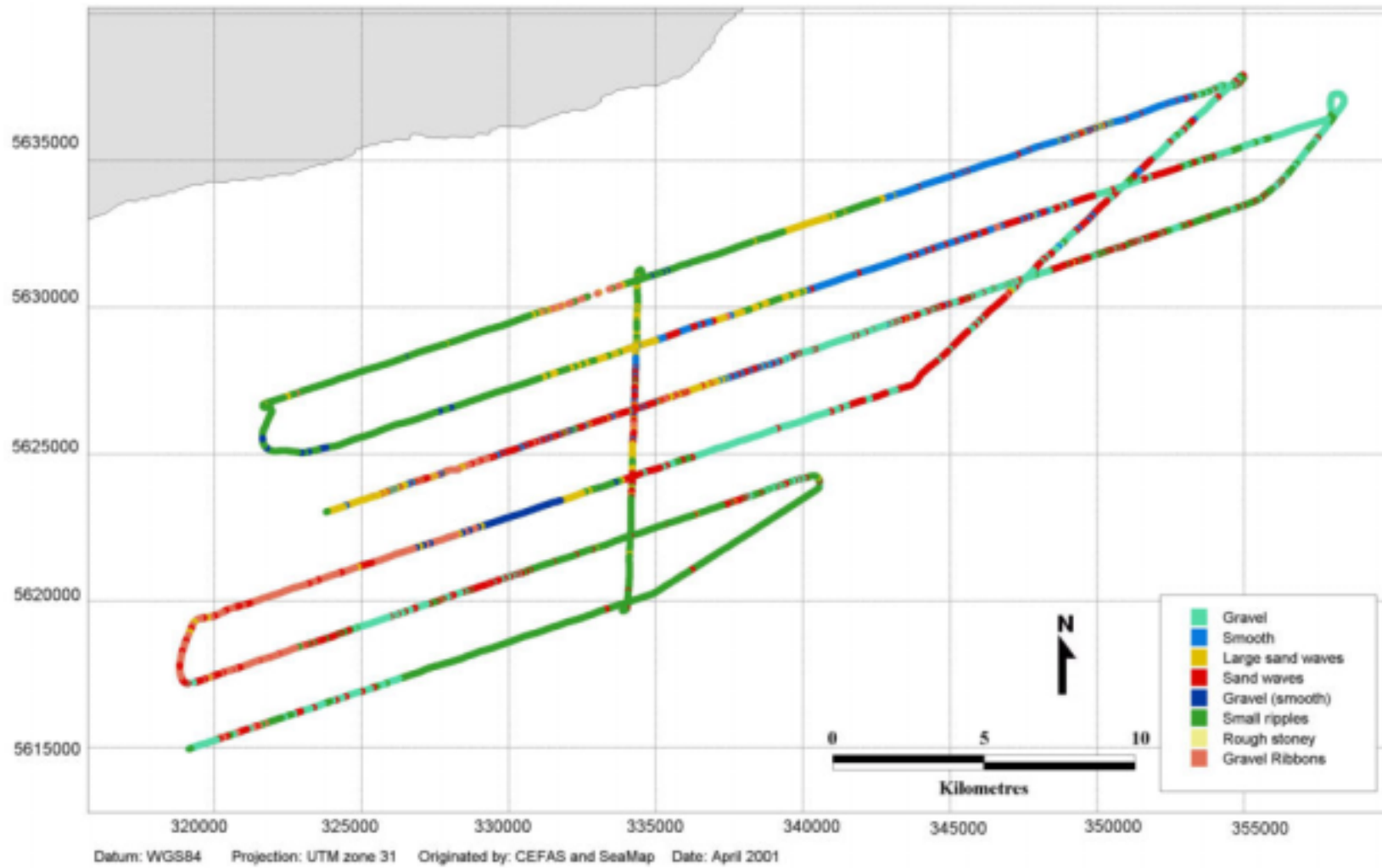


Figure 40: QTC supervised classification of the Hastings-Dungeness data using nearest neighbour.



categories. Averaging creates new values unique to these features that can be used for successful classification.

Sea floor category	Internal – <i>RoxAnn</i>	Internal – QTC
	% correct	% correct
Gravel	98.6	84.3
Smooth	96.9	94.0
Large sand waves	85.7	69.2
Sand wave	82.7	67.5
gravel (smooth)	100.0	100.0
Small ripples	87.4	85.1
Rough stoney	92.1	100.0
Gravel ribbons	98.4	93.5
Overall	92.3	83.72

Table 17. Internal accuracy: The digital data have been prepared using inverse distance squared as the interpolation algorithm and a search radius of 500m, resulting in the original track data being smoothed.

Sea floor category	Internal <i>RoxAnn</i>	Internal QTC
	% correct	% correct
Gravel	92.5	77.2
Smooth	82.6	72.8
Large sand waves	55.6	56.3
Sand wave	57.1	51.7
Gravel (smooth)	100.0	92.4
Small ripples	52.6	72.7
Rough stoney	62.0	0.0
Gravel ribbons	93.7	17.0
Overall	72.0	49.6

Table 18. Internal accuracy: The digital data have been prepared using nearest neighbour as the interpolation algorithm and a search radius of 50m, resulting in the original track data being faithfully reproduced in the digital data.

Summary

The lack of clear significance in the relationship between unsupervised classification and habitat classes (Section 7.5.5) is in contrast to the fair performance of the supervised

classification. This reinforces the superiority of the latter classification. The better performance obtained using smoothing was unexpected but highly significant: It suggests that ground types are best characterised by averaging values over areas larger than the footprint of the echosounder. One of the criticisms of AGDS is the lack of spatial resolution. The results indicate, on the contrary, that a broader perspective is needed for ground characterisation at the scale of habitat description adopted in this survey.

8 CONCLUSION AND RECOMMENDATIONS

AGDS is now widely used for habitat surveys, although few are repeat surveys where consistency of methodology is critical. Again, very few studies have set out to compare different systems with the objective of combining datasets into a single interpretation of habitats. However, surveys are expensive and increasingly there will be the need to make use of previous surveys (either as a re-working of data or the original interpretation) and for collaboration between research groups on topics that require a very broad scale perspective. The main purpose of the CEFAS/SeaMap project was to establish common procedures for survey and data analysis that would enable the different research groups to compare outputs from surveys. Both CEFAS and SeaMap have adopted a very similar approach to broadscale survey using a combination of AGDS, high resolution sidescan and ground truthing primarily based on remote video. If agreed procedures result in comparable interpretations of acoustic data, then the way is open for collaborative studies on a very broad geographic scale where the interpretations are directly compared and even amalgamated to create composite maps from adjacent surveys.

A vital step along this route is to explore many of the concerns about the limitations of AGDS as survey tools. Clearly, AGDS have low spatial resolution and this is a major factor influencing survey design that is inherent in all AGDS. But more serious concerns have been expressed over the differences in operation between proprietary systems and also the uniqueness of each individual AGDS system. Some systems, as exemplified by *RoxAnn*, measure only two parameters of the echo (which are not entirely independent of each other). This limits the scope for discrimination. QTC, on the other hand, is claimed to measure far more parameters and this (theoretically) increases the scope for discrimination. Does one system outperform the other to the extent that it is the clear preferred choice? Do differences between systems and units preclude the comparison of surveys that have employed different AGDS systems?

The comparison between two different *RoxAnn* systems has previously shown that data collected over the same survey area can be analysed using a standardised procedure to create similar interpretations (Foster-Smith *et al.* 1999). However, *RoxAnn* and *QTC-VIEW* differ not only in the echo parameters measured, but also in the way the data is processed and output. The raw data (after depth compensation) can be exported from *RoxAnn* and this allows for considerable flexibility in the way the data can be post processed, particularly through interpolation and image processing. Exported data can also be edited to ensure quality control.

Much of the analysis of the *QTC-VIEW* data is integral to the system and this may impose limitations on the establishment of common forms of data analysis. In particular, *QTC-VIEW* is designed for unsupervised classification where 'natural' clusters are identified within the data sets and attributed to habitat classes. However, unsupervised classification has many inherent limitations. It is commonly found in many multispectral datasets from satellite and airborne remote sensing systems that the data form a 'cloud' of points rather than distinct clusters (Wilkie and Finn 1996). This is certainly borne out by the scattergrams illustrated for both the *RoxAnn* and *QTC-VIEW* datasets. In these circumstances attributing habitats to poorly defined nodal groups does not work successfully and unsupervised classification within *Idrisi* has shown that attributing habitat classes to clusters results in a poor overall performance, particularly when the eight habitat classes for the Hastings-Dungeness survey area are used. It is generally acknowledged that supervised classification using maximum likelihood is the most powerful statistical technique for classification (Wilkie and Finn 1996; Green *et al.* 2000). These techniques are available through the use of proprietary image processing software. However, the data must be suitable for maximum likelihood statistical analysis and available as digital images. Whilst this is straightforward for *RoxAnn* data a parallel process had not been attempted for *QTC-VIEW* data before this project.

In order to compare analysis of *RoxAnn* and *QTC-VIEW* data with the view to standardising procedures, an assumption has been made that the Q values can be treated in a similar way to E1 and E2. This assumption could be challenged on the grounds that the eigenvectors are not continuous 'raw' variables in the same way that E1 and E2 are. However, without this assumption any comparison between the systems would be based on the outcomes of using completely different forms of analysis. In practise it would appear that the export and post-processing of the Q values results in similar outputs to *RoxAnn* and is justified on this basis.

By contrast to the poor performance of unsupervised classification, supervised classification performs well and this illustrates the need for data export and post processing of the *QTC-VIEW* data. However, the unsupervised classification is instructive: It might be expected that the Q values, being based on many more parameters, might have resulted in more acoustically distinct clusters. In the event, the results show that the links between the clusters identified in the *RoxAnn* data were more strongly linked to habitat classes. The results from unsupervised classification supports the general consensus amongst users of remote imagery that, whilst it may add some confidence to other forms of analysis by showing some level of acoustically distinct ground, its primary use is to suggest areas where differences in habitat may be found through ground truthing.

Thus, the most meaningful assessment of the performance of the systems is made through the comparison of the outputs from supervised classification. The overall performance was greater than 70% for both systems and this compares very favourably with other AGDS

surveys (e.g., Foster-Smith *et al.* 2000). However, performance can only be a relative measure between two very similar data sets and, strictly speaking, should not be used to compare absolute performance between surveys. Nevertheless, it is reassuring that the survey has resulted in acceptable levels of accuracy. In general, both systems classified the survey areas in a similar way, although there are differences in detail. *RoxAnn* consistently out performed *QTC-VIEW* although the differences in performance were not great. Nevertheless, these results are contrary to what might have been expected from the larger number of parameters measured by QTC. The depth dependency of Q1 is of particular concern and requires explanation.

The limits to spatial resolution applies to all AGDS. By contrast, sidescan sonar gives a swath image of high resolution that can be mosaiced together to give total coverage. Why use AGDS at all? In some ways the current survey is perhaps not ideal for contrasting the complementary nature of the data from AGDS and sidescan since the latter was used to ground truth the former (and the video ground truth data was analysed using similar sea floor characterisation). It can only be expected that the AGDS analysis would result in habitat distributions similar to the analysis of the sidescan images. Nevertheless, AGDS returns values for reflectance and absorption that can be treated statistically with relative ease so that AGDS analysis is more objective than the visual interpretation of sidescan. AGDS analysis has pointed up areas of uncertainty in the sidescan interpretation and particularly on the boundaries between habitat types. Sidescan interpretation is based primarily on features large enough to create acoustic shadows and on the strength of reflectance. However, many features are too small to produce clear and definitive patterns on the sidescan image and reflectance is determined by many sediment properties. AGDS measures sound absorption normal to the sea floor as well as reflectance and this gives greater scope for discriminating sediment type. This has been more clearly demonstrated in other surveys: For example, trials over *Sabellaria spinulosa* reefs have shown that these are more clearly shown using AGDS than sidescan (Foster-Smith and White 2001). The two types of sonar system are complementary and, as was the case in the Hastings Shingle Bank and Hastings-Dungeness surveys, can be run together

It is concluded that the data from *RoxAnn* and *QTC-VIEW* are similar in their scope for habitat discrimination and that the data can be treated in a parallel fashion. The analyses were performed separately by the CEFAS and the SeaMap groups on both the *RoxAnn* and the *QTC-VIEW* datasets. This enabled the groups to ensure that there was agreement on procedures through hands-on experience of all stages and that both groups achieved similar outcomes. Although there are undoubtedly many unresolved issues, the project has established a common methodology for broad scale survey and this will form the basis for future collaborative work that could include many other research groups.

There are a number of main conclusions from the project:-

1. AGDS remain useful tools for broadscale survey based on remote sensing and ground truthing. This is likely to remain the case until swath systems prove themselves to have similar powers of discrimination and a consistency of interpretation across the whole swath.
2. However, AGDS have inherently limited powers of discrimination and it would appear that, despite the apparent scope for increased discrimination of the *QTC-VIEW* system, neither system performs markedly better than the other.
3. Despite the differences in the types of data each system produces, treating the Q values in a similar manner to E1 and E2 results in very similar interpretations. This opens up *QTC-VIEW* to all the advantages of analysis that external software provides, ranging from easy application of data editing and quality control procedures through to the use of powerful image processing software.
4. Quality control of the data is vital: AGDS are often unstable irrespective of type and careful editing of dubious data must be undertaken prior to full analysis. Some of the reasons for this variability can be linked to equipment set-up and field survey design. Again, standard procedures should be followed to ensure that the data collected are of high quality.

9 FUTURE WORK

Collecting spatially comprehensive data in the marine environment is both difficult and expensive and there is a strong financial incentive to make use of existing data and to avoid repetition of survey effort. At one level this might be addressed by locating data sets and then attempting to piece together different interpretations (but without re-working the original data) to derive a very broad scale map of large sea areas. However, these maps are not designed to be precise or of a high spatial resolution but more an expression of a consensus view of major habitat distribution.

Broad scale survey based on remote sensing bridges the gap between biogeographical distribution maps and intensive surveys of small areas and has the potential to provide moderately detailed distribution maps for habitats and/or biotopes over large areas. This level of detail and resolution would provide useful information for management at an intermediate scale relating to specific sites or areas rather than whole seas.

We are now in a position to make use of existing data sets and to design collaborative surveys of large areas where this is required to complete distribution maps. Reaching a consensus between the two research groups about the use of the survey techniques and the analysis of the data has been straightforward with no major issues unresolved to date. The

two groups see no reason why this consensus should not be extended to a much wider range of potential collaborators. Studies could make use of existing data sets to amalgamate surveys from different areas, although it is likely that retrospective data quality control would be needed. In the future, this may not be required if research groups are aware of the need for stringent quality control.

One step along this route is the use of image processing: This opens up the possibility of using the probability images as a common denominator for all outputs. This has the advantage that similar format outputs (albeit at different scales, resolutions and levels of discrimination) can result from the use of very different approaches to survey ranging from desktop studies of large areas based on published maps and charts through modelling to detailed, high resolution survey. Thus, the statistics used has the potential for facilitating the development of a strategy for moving between scales and levels of available information to produce predictive maps (with varying levels of confidence and specificity) on habitat and biotope distribution. The investigation of statistics based on conditional probability as applied to survey outputs and other forms of existing knowledge will mark the next major step in the application of survey technology to management of the marine benthic environment.

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