

Procedural Guideline 1-3

Seabed mapping using acoustic ground discrimination interpreted with ground truthing

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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 (Urlick 1983; Mitson 1983). 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 ensonified⁴ – known as the *footprint* – by the echo-sounder directly under the vessel is approximately circular, although in practice, echo-sounders produce many side-lobes that make the footprint a more complex shape. 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. 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) give a weaker signal return. 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 echo-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.

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 AGDS have been used extensively for surveying biotopes – *RoxAnn*TM (Marine Micro Systems Ltd, Aberdeen) and *QTC-View*TM (Quester Tangent Corporation, Sydney, Canada). *Echo Plus*TM (SEA Ltd, Bath) is a third system new on the market that is a dual frequency, digital system similar in

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4 Analogous to the term 'illuminated'.

principle to *RoxAnn*.

The *RoxAnn* system uses analogue signal processing hardware to select two elements from the echo and measure signal strength (in millivolts) integrated over the 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 echo-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 echo-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 software *Microplot*TM and *RoxMap*TM. 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.

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 wave-form analysis (Collins *et al.* 1996; Collins and McConnaghey 1998). The *QTC* 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: supervised or unsupervised mode.

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 principal 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.

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 principal components analysis to be applied to the complete dataset. The software package *QTC 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 detail later under the section on classification procedures).

Purpose

Since the purpose of survey based on remote sensing is to extrapolate from direct observations to unobserved areas, uncertainty is unavoidable. No remote survey will give detailed, precise and accurate information. Uncertainty may be high with AGDS surveys, but the adoption of realistic objectives for a survey can reduce uncertainty to acceptable levels. AGDS measure acoustic properties of the sea floor and do not directly measure sediment or biological characteristics. These must be interpreted from the acoustic data through the use of field sampling (such as videography, diver observations, physical sampling using grabs etc). As with all remote sensing systems, the extent to which AGDS can discriminate between biotopes (e.g. physical habitats and their associated benthic communities) is dependant on the spatial distribution and degree of disparity between adjacent biotopes. For example, it might be expected that AGDS will be able to detect the difference between a limited number of discrete biotopes with clearly defined faunistic/habitat boundaries, whereas a but large number of subtly different biotopes that merge into each other will be poorly discriminated using these systems.

With this in mind suitable objectives for AGDS surveys include:

- Very broad-scale survey of large areas to map the approximate distribution and extent of a limited range of broadly defined biotope types (no more than 15). This type of survey is useful for gathering information in areas where there is little available data, and broad-scale survey has been the most common use of AGDS.
- AGDS maps may stratify the selection of suitable sites for more detailed survey. AGDS surveys can identify areas where there is a greater likelihood of finding a particular biotope of interest and thus reducing subsequent survey effort and cost.
- Rapid repeat survey of a small number of broadly defined biotope types to assess gross change over time. Although uncertainty will undermine the significance of apparent changes between similar biotopes, it must be remembered that gross changes can and do occur.

- The survey of a small number of distinct biotopes: whilst this might be useful for monitoring changes in boundary, this specific application for monitoring may be very limited.

AGDS are of limited use where repeat surveys are required to assess small and subtle changes in biotope composition.

Applicable to the following attributes

Generic attributes that could be addressed by AGDS surveys are:

- The geographic range, extent and number of major habitat types supporting features of interest within an SAC;
- The geographic range, extent and number of biotopes or biotope complexes present in an SAC; and
- The geographic range and extent of the important biotopes (such as rare, fragile or rich biotopes) within an SAC.

Applicable to the following survey objectives

- Map and re-map the extent of major substratum features including major biotope complexes.
- Compile an inventory of biotopes or biotope complexes present in an SAC (including the extent of organisms with a distinctive acoustic signal such as kelp, sea grass, mussel beds and maerl).
- Map or re-map the area occupied by all or selected biotopes or biotope complexes in an SAC.

Advantages

- AGDS are relatively inexpensive compared to other acoustic systems.
- The quantity of data produced is less than for many other acoustic systems and this facilitates data handling and analysis.
- The analysis of a single vertical beam for measuring sediment properties is more straightforward than for swath systems.
- AGDS can be deployed from a variety of vessels of opportunity.
- Large areas can be surveyed (although at low resolution – see below) quite rapidly.

Disadvantages

- AGDS do not give a complete coverage of the sea floor since the data are essentially points directly under the survey vessel as it tracks over the survey area.
- The wide beam width results in large acoustic footprints in deep water.
- The quality of the data is prone to the effects of poor weather conditions, and changes in acoustic properties such as tide and suspended load, perhaps more so than other acoustic systems.

These first two issues mean that the resolution of AGDS is poor as compared to swath systems. Although close track spacing can increase resolution, it is unlikely that a survey will result in a resolution greater than about 25m.

Equipment

The following list indicates the equipment required for AGDS data collection.

- (1) A *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 on boats cannot always be relied upon where, for example, the peculiarities of wiring systems can affect electronic equipment. Unless absolutely confident of the reliability of the vessel's power, it is prudent to rely on your own power supply (generator and/or batteries, plus an inverter for higher voltage). All operators should be aware of the electrical safety implications of using mains powered equipment in marine conditions.
- (3) An *AGDS signal processor* (*RoxAnn*, *QTC* or similar).
- (4) A *computer* with appropriate *data logging software*.

- (5) A *differential GPS*.⁵ Although the vessel's system may provide suitable navigation data, it is often better to be self-reliant for two reasons. Firstly it will avoid problems interfacing unfamiliar systems, and secondly, it is then possible to position the antennae above the transducer as far as is possible to minimise heading errors.
- (6) *Echo-sounder*. It is likely that each AGDS will have its own echo-sounder, although they can be adapted to different systems. If AGDS are to be deployed from vessels of opportunity then portable systems with dedicated echo-sounders are required. The choice of frequency and power will depend upon the working depths expected. Systems set for deep water (generally low frequency) will not work well in water less than about 3–5m deep and systems set for shallow water (generally high frequency) may return invalid readings much below 30m.
- (7) *A means of deploying the transducer from the boat*. 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 the vessel's 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. A range 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 (typically 7–8 knots). The transducer should be at least 1m below the water level and twice this in open seas to reduce aeration. It should also be lower than the vessel's deepest hull structure to avoid multipath interference.
- (8) *Field sampling equipment* (see later section).

Personnel/time

Skilled and experienced operators are needed to run the AGDS and field sampling equipment. This is necessary to cope with any malfunctions, to ensure that the correct settings are used, and to increase the likelihood of detecting any spurious data being recorded. Numbers of operators will vary according to survey circumstances and whether 24-hour working is planned. On chartered boats where field sampling will also be undertaken, at least two experienced persons are advised.

Staff with good IT skills are needed for post-processing of data. They should also have sufficient understanding of sedimentology and marine ecosystems to use the most appropriate settings to derive the most suitable displays of the data.

Method

These guidelines are based on more extensive technical reports than can be found on the SeaMap internet site.⁶

Planning the survey

AGDS coverage is determined by track spacing and the way in which complex coastlines are surveyed. The intensity of tracking 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 on survey, especially if poor weather reduces available survey time.

Real-time visualisation available through *Microplot*TM, *RoxMap*TM or other proprietary logging software can be used to keep a check on ground variability, consistency between tracks and discrimination (with reference to field sampling). QTC operated in unsupervised mode cannot display this information. Surveyors can plan their tracking 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:

- 5 At the time of writing, selective availability has been switched off and an acceptable accuracy to within 5m is possible without the use of a differential system.
- 6 See: <http://www.ncl.ac.uk/seamap>

- 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.
- Geographic coverage should be comprehensive at the maximum track spacing.
- Track spacing wider than 500m 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 later section).
- Tracks should extend beyond the main area of interest since interpolation is often poor around the outside of a data set.
- Ground is usually very variable close inshore, particularly where the shoreline is complex. Ideally the shoreline should be tracked as far inshore as the safety of the vessel permits. This is particularly important to avoid spurious interpolation of data around islands and headlands. Minimum operating depths do 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:

- The echo-sounder screen itself provides valuable information on ground type that 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.
- The echo-sounder screen may also indicate if there is interference with other acoustic systems (normally shown as interference on the screen). Any potential interference should be eliminated and all personnel alerted to the problems caused by switching on other echo-sounders during a survey.
- Deteriorating sea conditions may create aeration under the transducer, interrupting the signals from the echo-sounder; erratic depths recorded by the AGDS are a clear symptom. Too many erratic depth readings will usually lead to all the data for that whole track being considered invalid. However, AGDS can work in quite rough sea conditions and this alone should not prevent the survey from continuing.
- 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 pole 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, 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 recording 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 restart the recording resulting in a loss of data.

Variability between days is a more difficult issue to address. It is good practice to 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 should be made to ensure tracks coincide. These overlapping data can be compared for consistency.

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 videography 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 echo-sounder footprint. The position of the video system must be estimated. Therefore, it is best deployed for a short duration rather than for long tows. This will reduce 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 videography is ideal for biotopes 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, sediment sampling methods must be used to validate sedimentary areas, particularly when the biotopes present are characterised by infauna. For example, a standard grab sampling programme can be run in conjunction with a remote survey.⁷

Side scan sonar can also be used as a tool for ground validation and areas of habitat type recognised from the traces can be used to interpret AGDS data.

Selecting field sample stations

AGDS are designed to give real-time discrimination between habitats. Whilst it is strongly advised to use post-processing of the data for interpretation (see below), the real-time facility is very useful for gaining knowledge of the distribution of acoustic ground types during the survey. Such knowledge is essential for designing an efficient, stratified field sampling programme to validate the acoustic data. 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 or biotopes. In this way field sampling will have an element of prediction as the survey progresses. The following points should be considered when selecting sampling stations:

- (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 habitat or biotopes (for each geographic region). Even where a 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) If necessary, the survey effort may be focused on particular biotopes if real-time prediction of these biotopes is low.
- (5) Stations should be located in areas where the acoustic data are consistent along tracks rather than in areas where the along track data are 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 closely associated with real data rather than interpolated acoustic values.

Data analysis

Editing track data in real-time either within the logging software (*RoxAnn* logged on *Microplot* or *RoxMap*) or in near real-time with the processing software provided with the AGDS (*QTC-View*) may be the limit to which data analysis needs to be taken. One example is where AGDS data are used primarily to stratify a field sampling programme. However, detailed post-survey analysis of the data is required where biotope maps must be derived from an interpretation of AGDS data linked with ground samples.

Data analysis is a vast subject and many routes can be taken through the process of data interpretation. The following account is by no means exhaustive and is intended to raise awareness of important issues that must be addressed. Data analysis has been divided into three sub-sections: (1) preliminary data treatment and data exploration; (2) interpolation, and; (3) classification.

Software requirements for data analysis and interpretation

Specific software will be required to carry out the following recommended analytical techniques (apart from the usual statistical packages):

- *data filtering and exploration*: standard spreadsheet software (or database)
- *interpolation and statistical spatial analysis*: *Surfer*TM and *VerticalMapper*TM will perform interpolation and variogram analysis
- *classification*: image processing software such as *ERDAS Imagine*TM and *IDRISI*TM are suitable for classification
- *spatial analysis and map production*: geographic information systems such as *ArcInfo*TM, *ArcView*TM and *MapInfo*TM provide the most appropriate software tools

⁷ See PG 3-9 'Grab sampling'

Preliminary data treatment and data exploration

The purposes of this stage are:

- check that the data are of sufficient quality for further analysis and remove data that are considered dubious (known as *filtering*)
- explore the nature of the data and check for dependencies between variables that might compromise analysis, transforming data if required
- check for patterns of spatial correlation in the data that need to be considered when deciding the most appropriate route for further analysis
- standardise data prior to amalgamation of different data sets or to facilitate comparison between data sets
- correct depth data to chart datum (to account for tidal variation)
- derive other attributes that might be useful for interpretation (e.g. along-track variability, slope)

The raw AGDS data must first be exported from the data logging software in a format suitable for import into a spreadsheet (e.g. as comma-delimited text). These data will normally include geographic position (either as easting/northing or longitude/latitude), time, date, depth and AGDS parameters (E1 and E2 for *RoxAnn* or the Q values (eigenvalues) for *QTC-View*).

Thereafter the following procedures are recommended:

- (1) *Correcting depths to vertical chart datum, referenced to an appropriate local port:* recorded depth is tidally adjusted to chart datum by applying a correction, which is calculated from the tidal prediction program using the simplified harmonic method produced by the UK Hydrographic Office (Anon 1991). 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. If accurate bathymetric data are required, it will be necessary to instal a local tide gauge or use the elevation data provided by real-time kinematic GPS.⁸
- (2) *Filtering data associated with low boat speed or erratic positions.* An estimate of boat speed can be calculated from the position data in sequential records (eastings and northings are most suitable). Sections of track should be highlighted where either there are large skips in apparent position due to GPS error, and/or there is little change in the position of the survey vessel. The distance between two consecutive points also shows where the vessel slows to a speed below the acceptable minimum for recording AGDS (about 1 metre per second). These calculations and the highlighting process can be automated via a macro. Highlighted records can then be checked to see if they should be deleted.
- (3) *Filtering erratic depths.* Each depth 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 (normally >5m) occurs are highlighted and inspected. If a point appears to be out of step with its neighbours, then it is deleted.
- (4) *Scatterplots.* Scatterplots of E1/E2/depth or Q1/Q2/Q3/depth are useful:

To check for dependencies between variables. Weak relationships, given the overall variance in the data, might not be too serious for future analysis. But strong relationships (e.g. depth and another parameter) will dominate classification and careful selection of variables will be required. Note that E1 and E2 can be transformed to eliminate dependencies, but QTC data are already transformed through PCA.

To check for outliers that might be spurious. An especially useful procedure 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 or cross-tracks, or may be associated with ship manoeuvres.

Scatterplots are also useful for indicating if two data sets appear to be compatible prior to amalgamation.

- (5) *Variogram.* This is a graphical technique for showing the degree of spatial correlation within the data. It shows how the similarity between values decreases as distance between points increases. A variogram illustrates the overall pattern of spatial correlation for the whole dataset and not local variation (Figure 1). It does not show very broad-scale spatial trends or local variations in spatial correlation. The variogram shows:

Noise (the variance within the minimum sampling distance): this should not be too large in relation

⁸ See PG 6-1 'dGPS'.

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.

The *range* (the lag distance to the sill): the range gives the maximum distance where some spatial correlation might be expected to be present. Whilst interpolation is possible over distances represented by the range, the interpolated data are not likely to be much better than the local average. If interpolation is required, the *search radius* (see below) should be the range equivalent to half the sill variance.

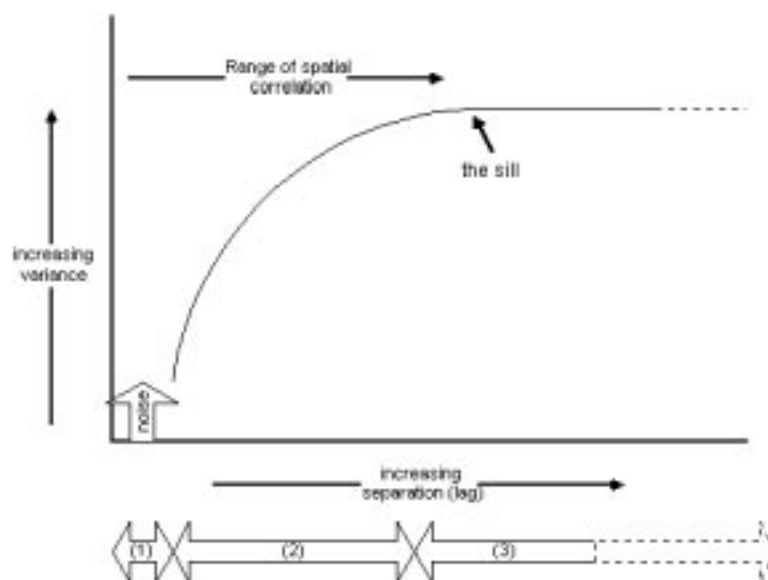


Figure 1 A general form of the variogram that illustrates the points referred to in the text. The shape of the relationship between variance and lag distance illustrated is only one of many models that might be found in practice (see Burroughs and Donnell 1998), but is the general shape found with AGDS data. 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.

Interpolation: point-to-area conversion

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. Interpolation is a process of converting point data to areal coverage in which new values are estimated for locations where there are no track records on the basis of spatial patterns within the real data. The reader is referred to Burroughs and McDonnell (1998) for a detailed discussion of this subject. Interpolation might be considered for the following reasons:

- 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).
- to show broad patterns (i.e. possible error in the detail is acceptable if the interpolation clearly shows general patterns).
- spatial modelling: the interpolation process is used to generate knowledge about spatial patterns to generate testable hypotheses.

If none of these reasons applies, it is probably best to work with track data rather than an interpolated continuous coverage. If a continuous coverage is required, then the next step is to appraise the nature of the data. Note that interpolation using any form of distance weighted averaging cannot work for categorical data. This would apply to QTC View data which had been classified using QTC Impact. However, if the Q values (eigenvalues) are used for Q1, Q2 and Q3 then interpolation using these methods may be appropriate. There are other forms of interpolation based on nearest neighbour or Voroni polygons that may be more suitable for categorical data.

Assuming the data can be interpolated using some form of distance weighted averaging, is interpolation likely to be problematic? If there are many point data, 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. The emphasis changes from filling in missing values with obvious estimated values to one of spatial modelling. In most AGDS surveys the situation is somewhere between the two extremes. It is important to have some idea of the problems interpolation might cause:

- Interpolation is robust when there is low variability along the track relative to track spacing, and there is a similarity between adjacent tracks. Normally:
 - the track spacing is well within half the range of the sill (see variogram); generally, track spacing should be less than 0.5km;
 - the nugget effect is small relative to the variance at the sill.
- Interpolation is likely to be problematic when there is high along-track variability relative to track spacing, or there are few obvious patterns that are consistently reflected in parallel tracks. Normally:
 - track spacing greater than the half-range distance;
 - the nugget effect is large relative to the sill;
 - in general, track spacing is greater than 1km.

Additional problems will arise if the data are not truly continuous and two or more data sets need to be amalgamated where it is uncertain if they are directly comparable.

Interpolation method If data can be interpolated, what sort of distance weighting should be used? Kriging is considered to give the mathematically optimal weighting, but is dependent upon choosing the correct model. *Inverse distance* gives acceptable results and allows greater choice of parameter settings that can suit particular situations and requirements.

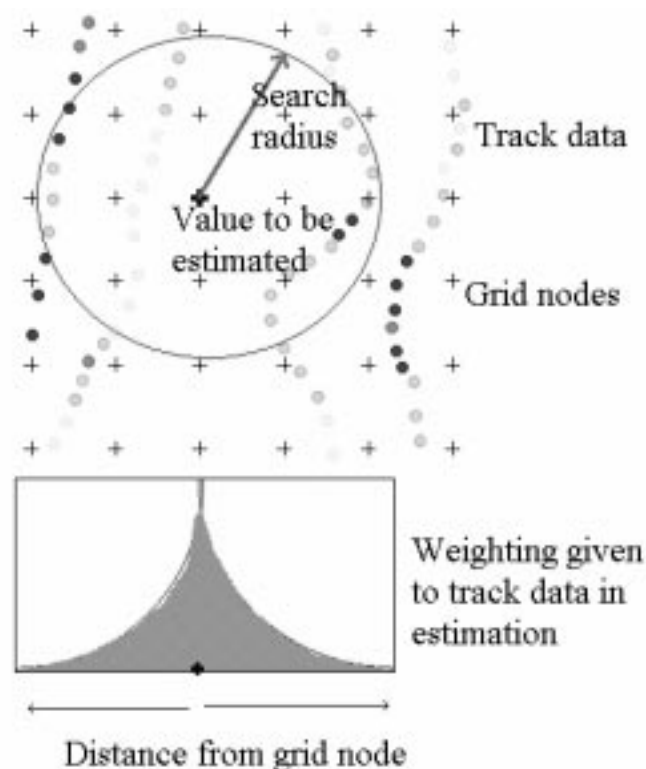


Figure 2 A small section of track with grid superimposed, illustrating the main parameters to be set for interpolation. Interpolation replaces real data with values estimated at regular grid nodes. The grid spacing can be set by the analyst, which sets the minimum resolution (pixel size) for all images thereafter. The grid nodes are indicated by the crosses. Grid spacing is set so that the image files are not too large for processing nor so widely spaced that valuable local variation in the data is lost through averaging. The bold cross indicates the grid node for which an estimated value is to be calculated. 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; 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 can also stipulate that data from different quadrants must be included so that the calculation is forced to take account of data from different tracks.

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. Here are some choices along the weighting spectrum:

(1.) *Nearest neighbour*

Advantages: no values 'made up' so that classification will not be affected by unreal data; ensures that field samples that lie a short distance away from track data will be associated with real AGDS data for signature development.

Disadvantage: if interpolated over some distance away from data, gives a very blocky and crystalline look that is visually unacceptable.

(2.) *Inverse distance squared* (or power above 2 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: this 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 at variance with 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.

Disadvantage: smoothing may be at the expense of local variability (which might be significant); superimposing other variability measures might redress the smoothing effects somewhat.

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 (Sotheran *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 that 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.

Classification

There are many ways in which AGDS data might be classified using the ground truth data ranging from univariate or bivariate analysis of continuous variables (e.g. silt content of sediments) to multivariate classification techniques.

Calibration

The simplest form of classification is an extension of the real-time calibration as used in Microplot. E1/E2 space is divided up into rectangular (or other shaped) areas whose dimensions can be modified by experience. Although useful for real-time data exploration, it is not recommended for producing biotope maps.

Univariate/bivariate plots

Variables, such as silt content, species counts, etc., can be plotted against E1 or E2 and the acoustic variables used to predict the variable. This can be extended to E1/E2 plots by plotting contours of silt content (for example) and then classifying track data by the contour plot. This approach can be applied to categorical data (e.g. biotopes) if the frequency of their occurrence is plotted in E1/E2-space and the results contoured as above.

Unsupervised classification

Detecting 'natural' clusters in data and then assigning biotopes to these clusters is the basis behind unsupervised classification.

RoxAnn Data can be clustered, but there are not many variables available for multidimensional clustering. Clusters may appear in small data sets, but as the range of biotopes increases, the data resembles a 'cloud' without clear nodes and the division of the data cloud into classes therefore becomes somewhat arbitrary. Unsupervised classification is most useful as a guide to the collection of ground samples.

Once this information is available, supervised classification is preferable.

QTC *QTC View* and *QTC Impact* do use clustering 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 (Figure 3). The decision to split and merge clusters is assisted by provision of statistical information of each cluster.

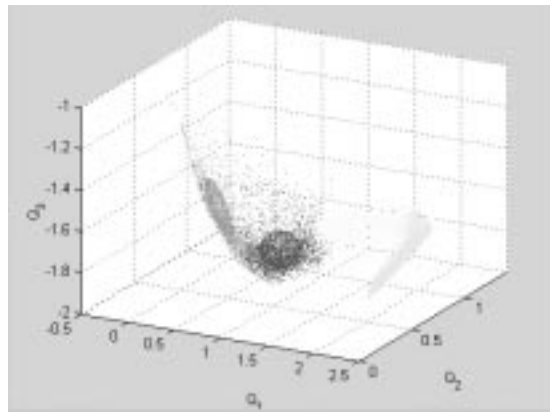


Figure 3 An example of the three-dimensional display of QTC data classified into 5 clusters.

Supervised classification

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 generally gives good results. This method of classification can also be applied to QTC data, using the three Q values and depth in the classification procedure.

The main steps in supervised classification are:

- (1) *Selecting training sites for the biotopes.* Training sites are usually digitised around areas of an image that are known to represent a particular biotope from direct observation. However, field samples in the sublittoral are mostly point data and the training sites are created by drawing a (circular) buffer zone around the points (or lines if the sample is a video tow, dredge, etc.). The buffer must be large enough to capture sufficient acoustic data to complete the next stage successfully, but not so large that data are wrongly attributed to the biotope.
- (2) *Developing acoustic signatures for the biotope classes.* Supervised classification calculates, for each biotope class, an 'n' dimensional probability distribution based on the mean and standard deviation of each variable (E1, E2, depth, etc) from 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. However, the actual probability values for each biotope are also accessible and can be used in their own right (if these are significantly above or below what might be expected by chance).

Classification of track data

A distinction needs to be drawn between the use of interpolation for generating (1) continuous coverages and (2) digital raster images. If a decision is taken not to create a continuous coverage, digital images can still be created through interpolation so that image processing software can be applied to track data. The most straightforward way is to interpolate and classify in the usual manner, but to blank out and eliminate those parts of the image away from the tracks. Alternatively, if nearest neighbour or a large weighting to nearest real data is used combined with a very small search radius, then interpolation will simply reproduce the tracks as raster images with the pixels in the inter-track spaces having zero values. The latter method will create very large files because of the small grid size used even though the great majority of the pixels will contain zero values. The classification algorithms (unsupervised or supervised) are applied to these 'track images' to create a classified track image.

Bathymetric models

In addition to the above products, the construction of 3-D bathymetric models is very useful for visualising the topography of the survey area and, if biotope maps are draped over the model, the relationship between bathymetry, topographic features and biotope distribution. These models can be created in the image processing packages and also in *Surfer*TM and *Vertical Mapper*TM. Some extra precautions need to be taken with the bathymetric data for successful modelling. The model is very susceptible to spurious depth records and the raw data must be rigorously filtered. Points along the high and low water isobaths should also be digitised, given a nominal height value and incorporated into the model. Interpolation procedures may need to be specifically tailored to the creation of the model in that more averaging of the data may be required to smooth the model than is the case for image processing (i.e. weaker distance weighting coupled with a larger search radius).

Accuracy testing

Field log

A log must be maintained with details of the equipment set-up, the parameters which are used, any changes made during the survey, and the performance of the survey equipment. Although data logging systems allow 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 record:

- (1) Details of equipment and power sources used and their position on the survey boat. Draft of the transducer and height of the GPS antennae.
- (2) Settings selected on the echo-sounder (power and depth settings).
- (3) Geodetic parameters, namely the co-ordinate system, its units and the datum set in the GPS (e.g. OSGB36; UTM zone 30; latitude/longitude in decimal degrees with WGS84).
- (4) Position and time of any changes to the equipment settings, interruptions of power supply or GPS signal, problems encountered with equipment and remedial action taken.
- (5) Sea conditions.
- (6) 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.

Analysis of field samples

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 biotope classes for the purposes of data analysis (see above discussion on classification). The reader should refer to the relevant procedural guideline to ensure that the appropriate measures are taken to minimise misclassification.

Data analysis

There are many ways that performance of the biotope mapping process can be assessed and the following questions form useful points for consideration:

- How internally consistent are the biotope maps with the ground samples used for classification?
- How well do maps predict biotopes as assessed against an external ground sample data set?
- How dependent is performance on survey design, particularly survey intensity? Where (in terms of confusion between biotopes and location within survey area) is uncertainty most acute?
- How consistent is the interpretation of different AGDS data sets for the same area?

An *error matrix* (from cross-tabulation between the classified biotope map and the field sample data) is a standard tool for assessing the performance of a map. Cross-tabulation is straightforward for digital images using GIS/image processing software (e.g. IDRISI™ or ERDAS™). Pixels in the buffer zone around the field samples are coded by biotope class and this image is overlain on the acoustic map (classified to the same codes). The pixels from each image are compared in a matrix and accuracy can be expressed as percent match, or other indices can be used (e.g. Kappa and Tau) that give probability of a match over and above chance. A similar cross-tabulation process can also be used to measure the similarity between two interpreted maps of the same area for comparing the results from repeat surveys.

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. 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 unsatisfactory since the subgroups will probably have too few samples per class and will not represent the whole survey area evenly (as intended by the surveyors). Thus, unless a separate field sampling exercise is planned specifically to test a map, it is probably advisable to use internal accuracy and regard the values as a measure of the relative performance of the survey. 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.

Error matrices are also useful in pointing out the extent of confusion between biotopes with similar acoustic signatures, which are also often very similar in terms of their habitat and biota.

Quality Control procedures

AGDS surveys are complex and involve a range of other sampling systems covered by other procedural guidelines. No universal approach can be adopted since the methodology will depend upon survey aims, the nature and extent of the survey area and the funds and time available. A well thought out project brief given to surveyors is essential.

Nevertheless, for any one area the adherence to the guidelines set out in the above sections will ensure that the data gathered will be of a high standard given the survey conditions. It is important to keep a record of the progress of the survey through planning, fieldwork (see 'Field log' above) and data analysis. This includes:

- the steps taken to ensure consistency of AGDS data during the survey
- all details of set-up conditions (equipment, GPS reference system);
- a record of data editing procedures adopted and proportion of data rejected. (NB: all raw data files must be archived in an unmodified format);
- data exploration and, in particular, justification for interpolation (e.g. variogram analysis);
- track plots and field sample locations for accurate re-location;
- the parameters used for interpolation;
- the parameters used to create digital images (e.g. min/max co-ordinates, value used for a *contrast stretch*);
- all measures adopted for classification accuracy assessment;
- all cartographic conventions: include details of source of coastline, projection and datum used, scale, date of survey, surveyors and data analysts.

If repeat surveys are to be compared, then they should follow the previous survey as closely as possible. Although the outcome of interpretation should be similar for different AGDS since analyses are independent and should stand alone, in practice the powers of discrimination will vary between systems and this will influence the final biotope map. It is desirable, therefore, that the same system (ideally the same instrument) should be used for repeat surveys.

Data products

The final products of the AGDS survey are maps of the most likely distribution of biotopes (and/or habitats). The raster output from classification procedures should be converted into vector maps for cartographic presentation and export to the required GIS format. Maps can give the impression of being definitive when in fact they are only predictions based on the best available information and using justifiable analytical procedures. The final maps should be underpinned by other information (graphical and tabular) which gives clear indications as to their accuracy and the confidence with which the maps can be used. These supplementary products should be:

- (1) Track plots of the edited data. The individual data points can be colour coded according to selected acoustic characteristics (e.g., E1 or E2, E1/E2 boxes, clustered division of Q-space). Track plots of bathymetry are also useful.
- (2) Contoured bathymetric maps.
- (3) Raster maps of E1 and E2, Q1,2 and 3.
- (4) Positions of all field samples coded to biotope.
- (5) Error matrices.

Electronic copies of these maps should be available in a GIS linked to the underlying data in spreadsheet or database.

Cost and time

The speed with which a given area is surveyed will depend upon tracking intensity, itself dependent upon biotope heterogeneity and complexity of the shoreline. Time must be allowed for setting up equipment and problems arising as well as poor weather. It is unlikely that any survey will require less than 5 working days. The following are estimated costs for a week's field survey:

<i>Stage</i>	<i>Time</i>	<i>Cost</i>
<i>Project management</i>		
Personnel (incl. travel)	2 days	£700
<i>Field survey</i>		
Equipment hire	7 days	£600
Vessel hire*	5 days	£2500
Travel/vehicle hire	7 days	£250
T & S for 2 surveyors	7 days	£500
Personnel	7 days	£3500
Field consumables		£200
<i>Analysis</i>		
Preparation of AGDS data	5 days	£1250
Analysis of field samples**	3 days	£750
Classification (interpretation)	5 days	£1250
Preparation of maps	3 days	£750
Preparation of report	5 days	£1250
<i>Total</i>		<i>£12,800</i>

* For hire of a small craft. Costs will be much higher for larger survey vessels.

** Based on video samples. Other sampling involving specialist identification and sediment granulometric analysis will incur supplementary costs.

Health and safety

Appropriate safety equipment for boat work must be used, particularly life jackets and/or lifelines during sampling operations where the risk of falling overboard is higher. Consideration must be given to any risks posed by the use of electrical equipment in wet environments.

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