



Marine Monitoring Handbook

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Contents

Preface	7
Acknowledgements	9
Contact points for further advice	9
Preamble	11
Development of the Marine Monitoring Handbook	11
Future progress of the Marine Monitoring Handbook	11
Section 1	
Background	
Malcolm Vincent and Jon Davies	13
Introduction	14
Legislative background for monitoring on SACs	15
The UK approach to SAC monitoring	16
The role of monitoring in judging favourable condition	17
Context of SAC monitoring within the Scheme of Management	22
Using data from existing monitoring programmes	23
Bibliography	25
Section 2	
Establishing monitoring programmes for marine features	
Jon Davies	27
Introduction	28
What do I need to measure?	28
What is the most appropriate method?	37
How do I ensure my monitoring programme will measure any change accurately?	40
Assessing the condition of a feature	51
A checklist of basic errors	53
Bibliography	54
Section 3	
Advice on establishing monitoring programmes for Annex I habitats	
Jon Davies	57
Introduction	60
Reefs	61
Estuaries	70
Sandbanks which are slightly covered by seawater all the time	79
Mudflats and sandflats not covered by seawater at low tide	87

Large shallow inlets and bays	94
Submerged or partly submerged sea caves	101
Lagoons	110

Section 4

Guidance for establishing monitoring programmes for some Annex II species

Jon Davies	119
Introduction	121
Grey seal <i>Halichoerus grypus</i>	122
Common seal <i>Phoca vitulina</i>	125
Bottlenose dolphin <i>Tursiops truncatus</i>	129

Section 5

Advice on selecting appropriate monitoring techniques

Jon Davies	133
Introduction	135
Monitoring spatial patterns	136
Monitoring biological composition	148
Future developments	161
Bibliography	161

Section 6

Procedural guidelines

Caroline Turnbull and Jon Davies	163
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Procedural Guideline No. 1-4

The application of sidescan sonar for seabed habitat mapping

Andrew J. Kenny,¹ Brian J. Todd² and Richard Cooke³

Background

The aim of this guideline is to highlight those aspects of sidescan sonar configuration and operation that must be considered to ensure good quality data are obtained in the field. The procedure assumes the surveyor has some experience of using sidescan sonar, particularly in respect of maintenance, testing and operation and that the terms used in this guidance note will be familiar. However, in the first instance, the authors wish to highlight an important distinction between the principal acoustic mapping systems, at a non-technical level.

Principal acoustic systems

In general, acoustic remote seabed mapping or sensing instruments may be classified into one of two types:

- broad beam swath systems (sidescan sonars); and
- narrow beam echo-sounders (AGDS).

The distinction between the two is very important as they look at the seabed in very different ways, and therefore the output requires very different interpretation. The broad beam swath systems may have single or multiple beams that exhibit the same beam geometry characteristics, i.e. the beam insonifies a wide swath of seabed due to its low grazing angle, but the beam is narrow in azimuth as shown in Figure 1. In order to achieve the low grazing angle the sonar has to be towed at a fixed altitude above the seabed and hence the sonar is not hull mounted. The advantage of this is that relatively large acoustic shadows are cast by relatively small objects protruding from the seabed (including changes in sediment composition such as gravel substrata). The acoustic geometry of the sonar footprint therefore makes the sidescan system most suitable for detecting small objects on the seabed and changes in bed roughness.

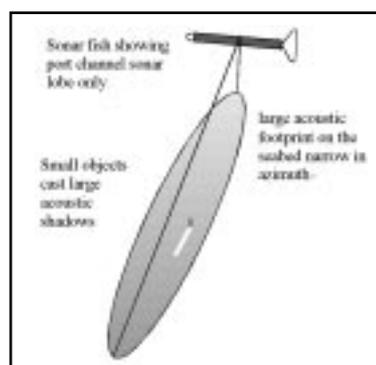


Figure 1 Schematic of sidescan sonar

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The echo-sounder system may again be a single or multi-beam unit which, by definition, will be hull mounted in order to measure changes in bed level. To achieve good object detection capability the beam geometry must be narrow (which is the opposite of the sidescan system) with the sonar having a high sample rate. A schematic showing the beam geometry of a typical echo-sounder such as an AGDS is shown in Figure 2. It should be noted that the actual sonar lobes have very complex shapes which are seldom exactly the same between soundings owing to the subtle changes in the properties of the water from one location to the next. The technical attributes of AGDS are provided elsewhere in this handbook. The remaining sections will focus on the use of sidescan sonar.

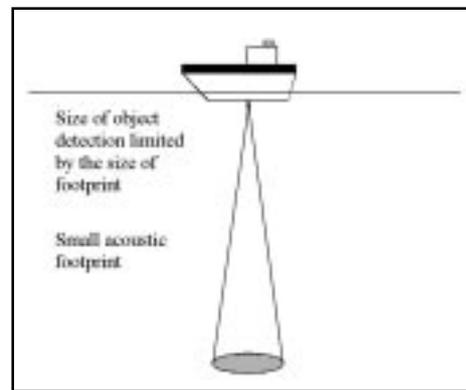


Figure 2 Schematic of an echo-sounder

Theory of sidescan sonar operation and purpose

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

Modern high (generally dual) frequency digital sidescan sonar devices offer very high resolution images of the seabed that can detect objects in the order of tens of centimetres at a range of up to 100m either side of the towfish (total swath width 200m), although the precise accuracy will depend on a number of factors. For example, the horizontal range between the transducer and the seabed is affected by the frequency of the signal and the grazing-angle of the signal to the bed which is itself determined by the altitude of the transducer above the sea floor. Some typical limits associated with sidescan sonar are as follows: operating at 117kHz under optimal seabed conditions and altitude above the bed, a range of 300m (600m swath) can be obtained and typically 150m at a frequency of 234kHz. Accuracy increases with decreasing range, for example, 0.1m accuracy is typically obtained with a range of 50m (100m swath) whereas 'only' 0.3m accuracy is obtained at a range of 150m. The sidescan sonar provides information on sediment texture, topography and bedforms, and the low grazing angle of the sidescan sonar beam over the seabed makes it ideal for object detection.

In general, there is a trade-off between the area which can be mapped in a given time and the resolution or detectability of seabed features within the mapped area. For example, a sidescan system operating at 500kHz can potentially detect features measured in decimetres, but this can only be achieved along a narrow swath of about 75m per channel and therefore the typical area which can be mapped in an hour is relatively small. By contrast, the systems which operate a lower frequencies of around 50kHz have much greater range and can be towed at faster speeds which allows a greater area of seabed to be mapped in a given time (Table 1).

Table 1 Object resolution versus range for two sidescan sonar systems

Range (m)	Spacing between soundings (m) @ 4knts	120kHz Sidescan 75° beam width	330kHz Sidescan 0.3° beam width
25	0.07	0.33m	0.13m
50	0.13	0.65m	0.26m
100	0.26	1.30m	0.52m
200	0.52	2.60m	1.00m
500	1.30	6.50m	n/a

Advantages

- Due to the relatively large swath produced by sidescan at lower frequencies it is possible to cover relatively large areas of the seabed in a relatively short period of time. For example, a system operating at 100kHz towed at a speed of 5 knots would allow about $3.5\text{km}^2/\text{h}^{-1}$ of seabed to be mapped at a resolution of about 1m (Kenny *et al.*, 2000).
- An almost photorealistic picture of the seabed can be generated as individual survey tracks are mosaiced together and like a photograph the raw acoustic data ‘speaks for itself’, which is why sidescan sonars are sometimes referred to as self-calibrating. For example, certain bedform features are instantly recognisable, such as sand ripples and rocky outcrops, before any ground truth samples are taken.
- The morphology of the features can be interpreted to reveal information on sediment transport pathways and the stability of the bed.
- The quality of the data are not affected by changes in the depth of water since the sonar fish is towed at a fixed height above the seabed at all times.

Disadvantages

- The grey-scale (or signal amplitude) between swaths covering the same area of seabed is often noticeably different, particularly when the orientation of the sonar to the target feature varies. The variation in signal amplitude for the same area or type of seabed causes problems when trying to classify the sonograph, since ground truth samples (grabs and underwater cameras) may reveal the seabed to be composed of different sediments such as muds or muddy sands, but the difference between these is not easily identifiable on the sonograph.
- Target location using sidescan is complicated by the need to know where the fish is relative to the navigation system antennae. This has been solved by using a transmitter on the sonar which allows its position to be fixed exactly; however, this is not at present common practice. The more common approach is to calculate a layback of the towfish when using short cables and an equation for this is provided in the QA/QC section below.
- Large amounts of data are typically generated, for example a 19km^2 survey generates about 500 megabytes of data in the form of *geotif* files (gridded at 0.2m), and at least 1 gigabyte of storage space should be available for each day of survey.
- The size of the data files also necessitates powerful computers. These have traditionally been (Unix) workstations, but increasingly dual-processor PCs are being used.

Equipment

Like any sonar system used from a vessel at sea, the more dedicated the system is (i.e. it is configured for use on a single survey vessel and is used for the same type of operation between surveys) then the better quality of data. Systems which are ‘off-the-shelf’ for use on any survey vessel will not provide the same quality of data. The two configurations have been described below:

Non-dedicated (off-the-shelf) configuration

The configuration of a typical sidescan sonar system is shown in Figure 3. It should be noted that with the advent of digital technology most sidescan sonar systems are now fully supported by proprietary

software which allows the user to fine-tune parameters such as the time-varied gain whilst at sea. The inclusion of a computer to run both the system set-up and data post-processing software is now commonplace.

The last few years have seen a move by manufacturers from analogue to digital towfish for better quality data. In simple terms, in an analogue towfish, the energy returning to the towfish is converted in to millivolts, which is transferred along the tow cable to the recording device that converts the millivolts in to a digital value. The tow cable has several wires running through it (multi-core) and the data can suffer from slight degradation. A digital towfish however, converts the millivolt readings to digital values, which are transferred along a single coaxial cable to the recording device. This results in less data degradation as the data are transferred along the cable from the towfish to the recording device.

A vessel should be used that is of suitable size for the survey area. For shallow water surveys, a vessel with shallow draft, adequate cover for electronic equipment and a suitable power source should be used. It should also be big enough to deploy a sidescan sonar safely. For deeper water surveys the draft of the vessel is not an issue, but there should be enough deck space to accommodate a sidescan sonar cable winch.

It is often good practice to have a thermal recorder and digital acquisition and processing system interfaced together during data collection as this provides data backup and aids online quality assurance and control. For low budget surveys where only an overview of the seabed is required, a survey undertaken with only a thermal recorder will be sufficient. However, if more detailed examination of individual targets or mosaicing of the data are required, for example for seabed classification, a digital acquisition and processing system should be used. Particularly in shallow water, sidescan sonar data are adversely affected by poor sea conditions. To obtain good quality data it is recommended that data are not collected when the sea conditions are worse than sea state 4.

Apart from the vessel crew, a sidescan sonar system can be operated by one person trained to operate the systems involved. It is essential that the operator can determine the quality of the sidescan sonar data being collected on board the vessel and can determine that the correct amount of data has been collected from the correct place and that the navigation system is functioning correctly.

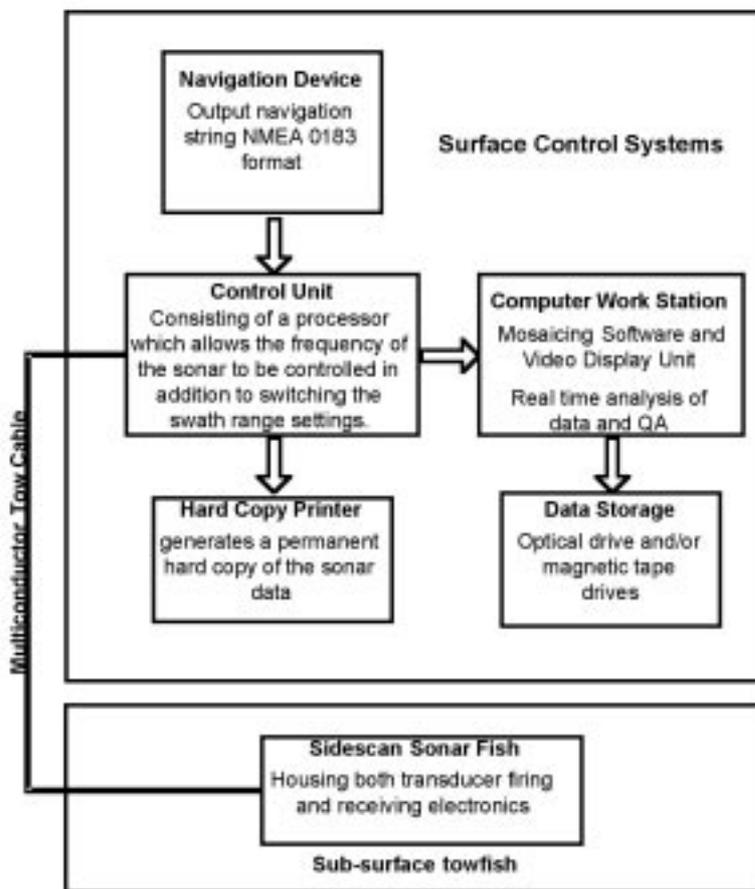


Figure 3 Schematic diagram showing the configuration of a typical (off-the-shelf) sidescan sonar system

Specific items of a typical system are:

- Digital dual frequency sidescan sonar fish: the most commonly used are manufactured by Simrad, Kline, GeoAcoustics, EG & G and DataSonics (Figure 4).
- Depressor for the sonar; this is most useful for soft tow cables which tend to be neutrally buoyant (Figure 4).
- For inshore survey work (water depths <50m) a soft tow cable is suitable; this avoids the need for sophisticated winch systems with high slip ring specifications.
- Sonar firing control unit which may be integral with the sonograph plotter/printer and data storage system.
- Configuration and testing software installed on an appropriate computer.
- Data viewing and mosaicing software also installed on the computer.
- Survey vessel with dGPS and navigation software (e.g. Sexton, Hypack) to accurately follow planned survey lines.

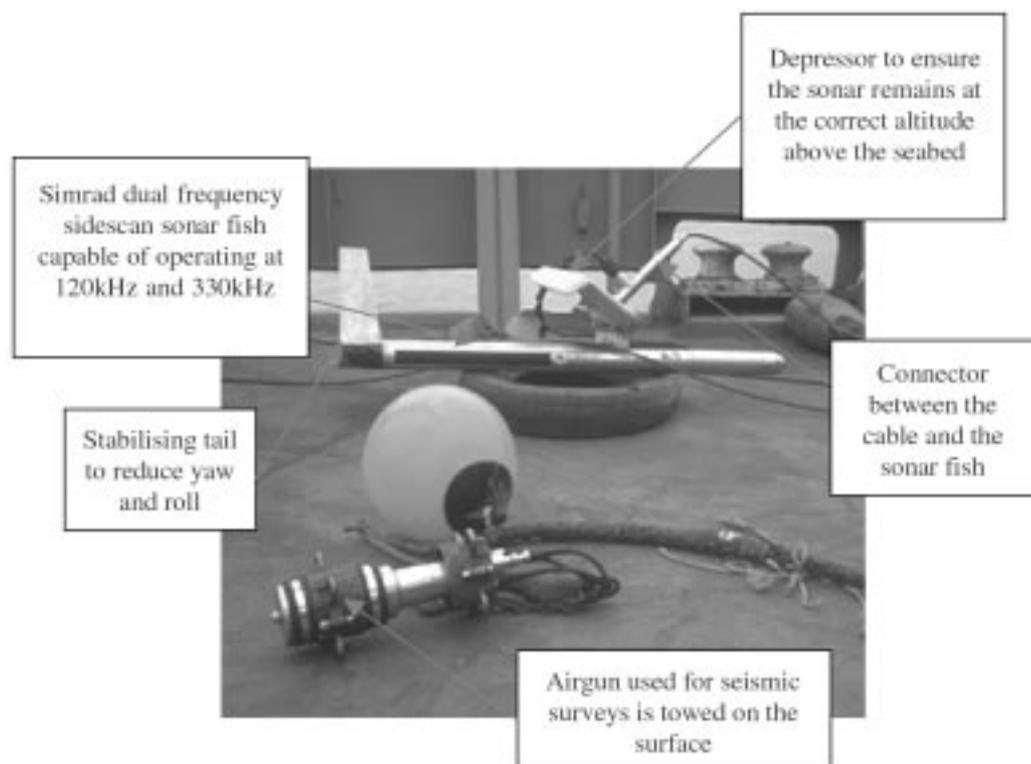


Figure 4 Typical (off-the-shelf) sidescan sonar

Dedicated configuration

There are a variety of sidescan sonar deployment geometries; the geometry described here is the neutrally-buoyant arrangement designed and used by the Geological Survey of Canada (Atlantic) for surveys on the continental shelf. As shown in Figure 5, a Simrad MS 992 dual-frequency sidescan sonar towfish is attached beneath a hydrodynamic buoyancy housing containing vinyl floats rated to a depth of 200m. A beacon mounted at the front of the plastic housing is the sidescan assembly component of the Trackpoint acoustic positioning system which provides range and bearing to the assembly from a transducer mounted beneath the ship's hull. This information is combined with depth data from the towfish by the shipboard navigation system, giving the latitude and longitude of the towfish. The sidescan towfish also transmits pitch and roll information. Accuracy in towfish position and attitude is necessary for correcting sidescan record distortion.

As illustrated in Figure 5, the neutrally-buoyant sidescan assembly is towed by an umbilical cable from the stern of the survey vessel. The umbilical cable is composed of two or more conductors and a Kevlar strength member, both housed in a double urethane waterproof sheath. From 10–20m from the sidescan assembly, a 120kg depressor towfish is attached to the armoured tow cable. This depressor tow-

fish acts to isolate the sidescan system from the surface motion of the survey vessel, thus reducing sidescan assembly instability. The buoyancy package is weighted to be slightly buoyant and bow up. This results in the sidescan assembly tracking above (and behind) the depressor towfish, which is the optimum position to avoid sidescan collision with the seabed and to negate ship heave transmitted along the tow cable. A large-diameter cable block suspended from the A-frame on the stern of the survey vessel guides the tow cable to the 20 hp winch. Usually, about 600–800m of cable is available for deployment.

Two options are available for recording the sidescan system output. As illustrated in Figure 6, both a hard copy and digital version of the data are recorded by the Geological Survey of Canada. Commonly, two 11" grey scale thermal recorders are utilized, one for the 120kHz record and one for the 330kHz record. Simultaneously, the four channels of the digitised sidescan signal (port and starboard 120kHz and 330kHz) are logged in SEG Y format, along with time, on digital Exabyte tape with a capacity of approximately 4 gigabytes. During post-cruise sidescan processing, the dGPS navigation data are merged with the sidescan data, based on time. Thus it is critical to synchronise the sidescan datalogger clock with the dGPS time and this is true of both dedicated and non-dedicated systems.

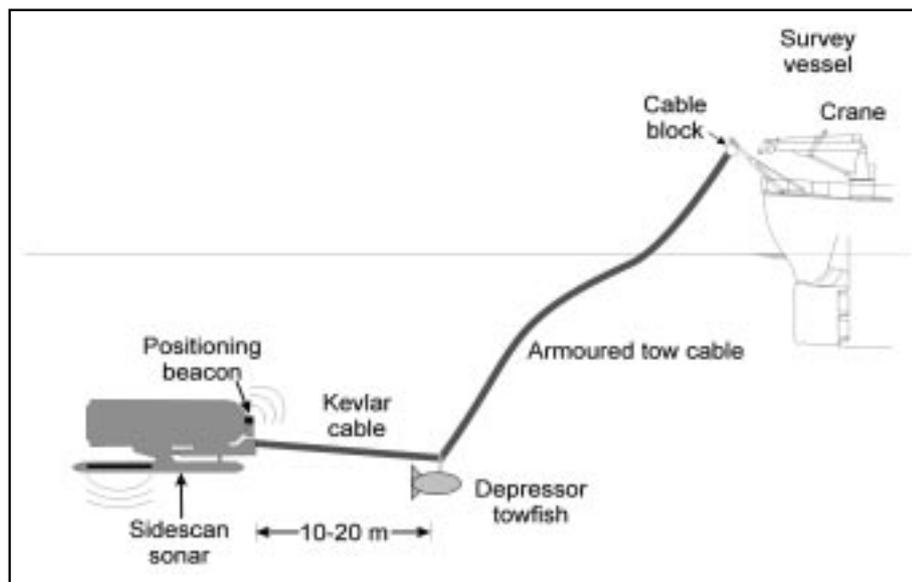


Figure 5 Deployment of a neutrally-buoyant dedicated sidescan sonar system

Operations at sea

Testing

Before sidescan deployment, a rub test is done to determine the integrity of the system. The sidescan system is turned on with the gain set to maximum. The transducers are lightly rubbed by hand until a dark line appears on the paper record and/or on the monitor screen. In this manner, the system circuitry is checked and confirms that the port and starboard sidescan transducers are functioning properly. Detergent is brushed on the transducer faces to improve acoustic coupling to the water. To test that system seals are watertight and that the mechanical deployment systems are functioning properly, the towfish assembly is lowered into the water while the survey vessel is secured at the dock. The system is turned on and the record is inspected.

In addition a series of tests should be undertaken to calibrate instruments and to check equipment settings and interfacing – this is particularly relevant for non-dedicated systems. These checks may include the following:

- compass calibration
- acoustic underwater positioning system calibration
- navigation system check and calibration
- sidescan sonar navigation check (survey a known point in opposite directions)
- trial runs over the survey area to adjust gain settings; when data are recorded on thermal paper gain changes should be kept to a minimum

System deployment

The dedicated systems tend to be more bulky than soft tow systems. In the case of the Canadian neutrally-buoyant sidescan the unit weighs about 85 kg in air, and deployment of this system from the stern of the survey vessel is a two-stage operation. A crane is used to swing the assembly over the stern (Figure 6). Once in the water, the Kevlar umbilical cable is paid out from the depressor towfish. The armoured tow cable passes from the sidescan winch through a large-diameter cable block suspended from the A-frame on the vessel's stern (Figure 6). This cable is used to hoist the depressor towfish from the deck, with the umbilical trailing over the rail, and deploy over the stern using the swinging A-frame. The system sinks slowly through the water column, so deployment is done at least a nautical mile from the start of the survey line. Retrieval of the sidescan system is the reverse of this process. Lifting loops attached to the umbilical enable the crane to hoist the system from the water.

For the soft tow system the towfish is gently lowered into the water by hand and the umbilical is paid out sufficiently to ensure that any drive-train noise is minimised and the altitude above the bed is suitable.

System tuning (fish stability, height, position)

Fish stability is of paramount importance in reducing or eliminating artefacts in sidescan sonar records (see QA/QC section). Each of the four forms of towfish instability (heave, roll, pitch and yaw) produces characteristic artefacts, or distortions, on the sidescan record which can sometimes be misinterpreted as real data. Stability of the neutrally-buoyant sidescan system is maintained even when the sea state is unsafe for the survey vessel. Sidescan systems which do not decouple fish and ship motion to the same extent as the neutrally-buoyant system will be adversely affected even at relatively low sea states and this tends to be a problem of the non-dedicated systems.

Survey design

The standard survey speed on most multiparameter surveys (i.e. sidescan, seismic, and other geophysical survey tools) is about 4 knots (7.4 km hr^{-1}). Note that 2.5 knots is the optimum survey speed for many high-resolution sidescan systems, providing an along-track horizontal resolution of 7cm. However, at this speed many survey vessels cannot maintain an accurate heading, and seabed coverage is slow, whereas the horizontal resolution at 4 knots is about 15cm. Enough cable is paid out to allow the sidescan towfish to fly at a height of between 10 and 20m off the seabed (generally 25% of the horizontal range setting). For benthic habitat mapping, short ranges are used (100m or less) which allow relatively small objects to be detected. For seabed reconnaissance, individual survey lines are collected over a broad area. In mosaic mode, a pattern of survey tracks is run at a specific line spacing. The line spacing is less than the swath width (i.e. twice the range) of the sonar so that range overlap occurs. This design ensures that the area of seabed being surveyed is completely insonified and that the loss of resolution at the outer limit of the range is compensated for. As a rule of thumb, in areas of relatively smooth seabed, a line spacing of between 75% and 50% of the swath width will provide the necessary overlap.

Record interpretation

A basic understanding of how the sidescan record is generated is essential in order to understand how to interpret the record.

Figure 6 summarises how the intensity of the returning echoes is influenced by the shape and density of the seabed (or objects). The returning echoes from one pulse are displayed on the recorder as one single line, with light and dark portions of that line representing strong or weak echoes relative to time. There are many variables which will affect the sonar data, such as waves, currents, temperature and salinity gradients, and some examples of how specific sonar interference is manifested in the record are given in the QA/QC section.

Whilst there are efforts to make sidescan sonar interpretation an objective semi-automated process, the interpretation remains very much a qualitative analysis. As indicated in Figure 4 there are two important attributes of the seabed that will affect the intensity of grey-scale in the sonograph:

- (1) The material properties of the substrata. This will determine the acoustic reflectivity of the seabed. For example, rock, cobbles and gravel are better reflectors than sand or mud and will therefore show up darker on the sonograph.
- (2) The shape of the seafloor (or topography). Up slopes facing the towfish are better reflectors than down slopes.

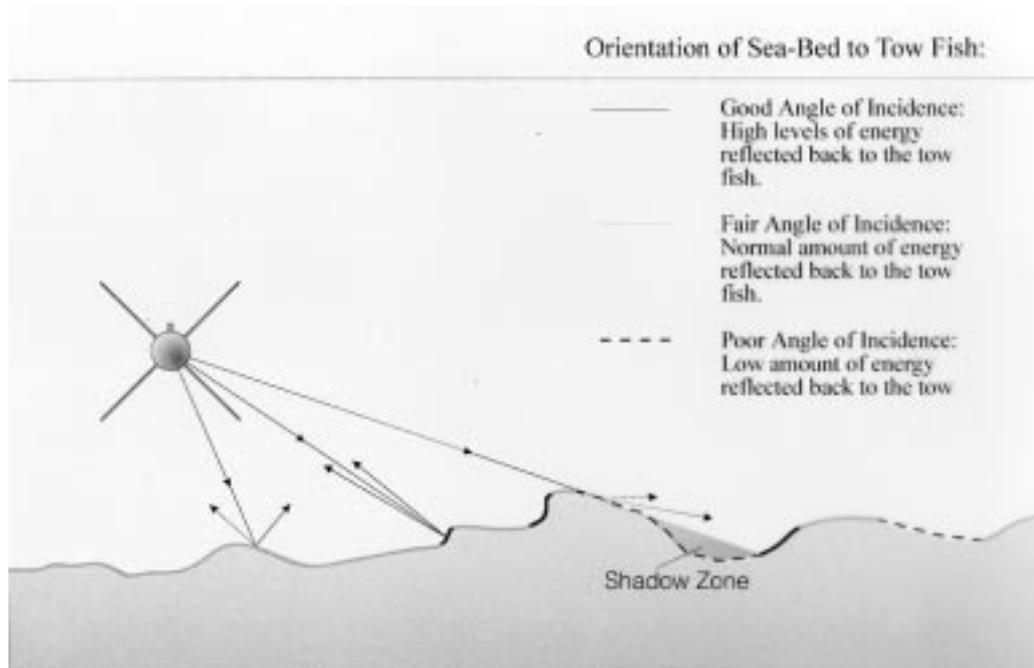


Figure 6 Schematic of sidescan return echoes

Since material reflectors and topographical reflectors often produce the same result on the sonograph it is up to the operator to interpret the image carefully in order to determine the actual composition of the seabed. Shadows are the single most important feature of sidescan sonographs since they provide the three-dimensional quality to the two-dimensional image. Shadows are therefore of extreme importance and the interpreter relies on their position, shape and intensity to accurately interpret most sonar records.

The height of objects on the bed can also be determined from the record. For example, using the following equation the height of a target can be calculated:

$$H_t = \frac{(L_s \times H_f)}{R}$$

Where H_t is the height of the target (m), L_s is the length of shadow cast by the target (m), H_f is the height of the fish above the seabed (m) and R is the distance (m) along the hypotenuse between the towfish and the end of the shadow cast by the object.

In general, for data collected with an analogue thermal recorder only, features of interest should be plotted on a trackplot for the survey. The same features identified from data collected on adjacent survey lines should be compared to check that position calculations are correct. Any other data that may enhance the interpretation, such as field notes, bathymetry data, seismic data, sediment distribution information and Admiralty Charts should also be collated and compared with the sidescan sonar information. From this a plan of seabed features and/or sediment distribution can be drawn.

Data collected digitally should be played back several times until the optimum settings for gain and bottom track threshold have been determined to create a good sidescan sonar mosaic. The data should then be mosaiced, ensuring that correct slant-range correction and layback calculations are applied. Any features of particular interest identified can be magnified and further enhanced if required. Most sidescan sonar processing software will allow other information to be overlaid to enhance the sidescan sonar images and mosaics. It should also allow for annotation of the processed data so that objects and sediment types can be labelled and mapped out.

QA/QC

Like any other type of acoustic system sidescan sonar is susceptible to interference from a number of sources, but with experience most of these can be recognised in the data. The sources of error to watch out for areas follows:

- Survey vessel drive train noise. This is less obvious than direct propeller noise and appears as faint regularly spaced dark lines in the record (Figure 7). The most common cause of this is when the sonar is too close to the vessel (typically <50m), and simply increasing the horizontal distance between the towfish and the vessel will often eliminate the noise.

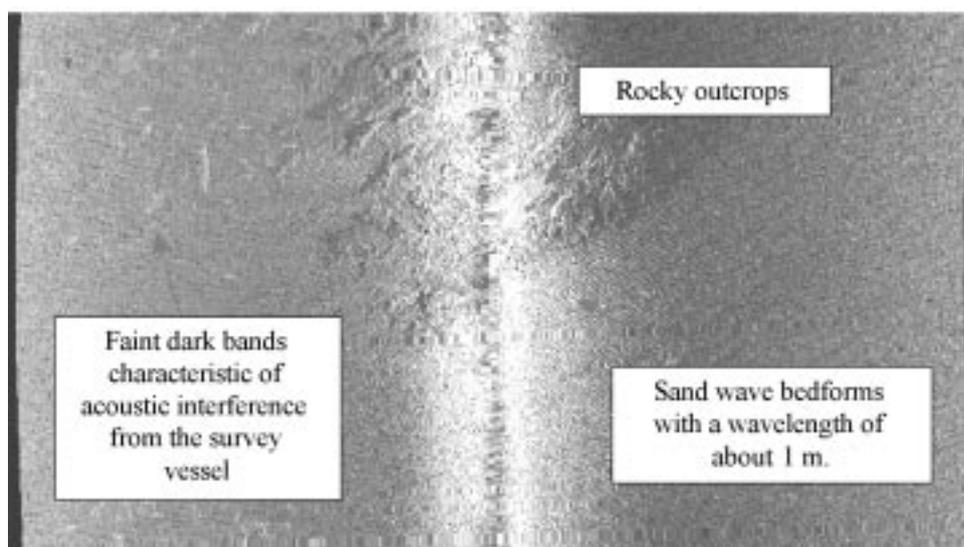


Figure 7 Surface vessel drive-noise

- Navigation drop-out of signal will give rise to errors in the speed correction of the record causing distortions. Depending on the system this may be evidenced by areas of no data in the record or as interpolated bands as shown in Figure 8.

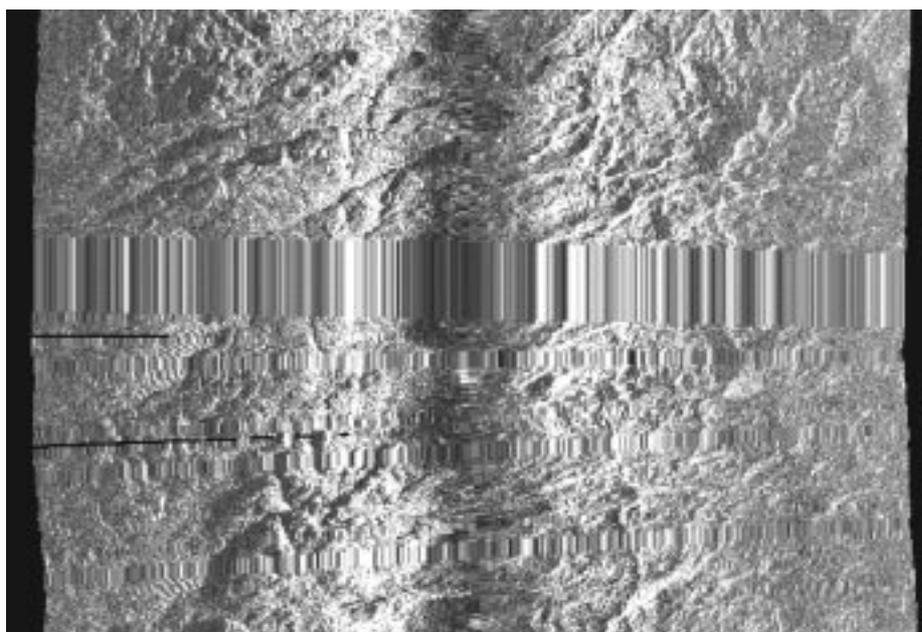


Figure 8 Navigation drop-out

- Interference may also be caused by schools of fish or a porpoise, as illustrated in Figure 9, which shows the body undulations travelling in the direction of the sonar.

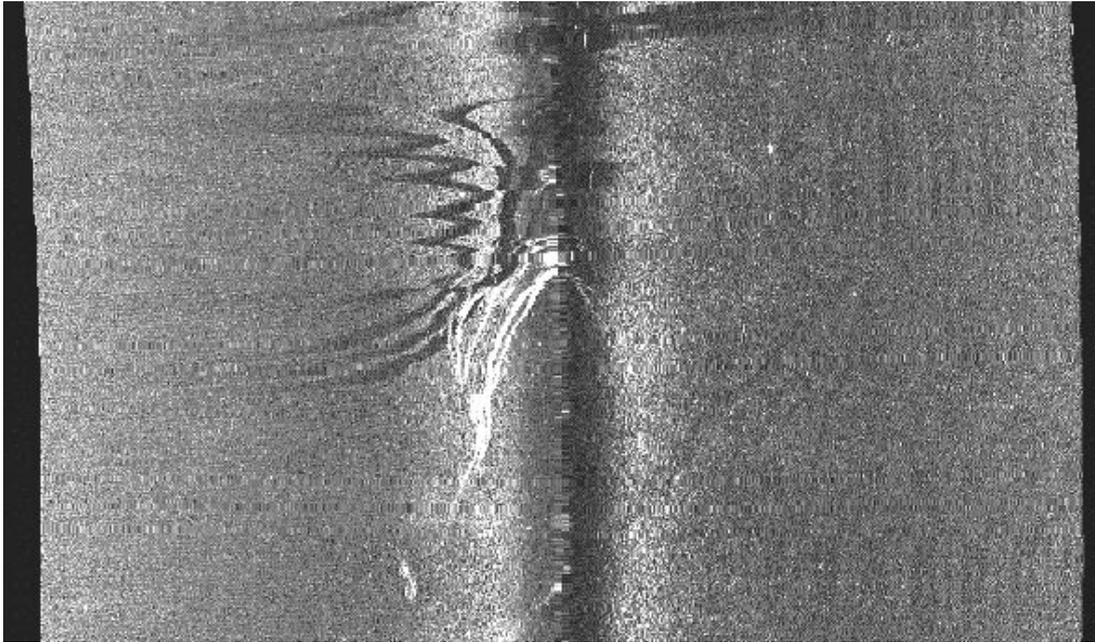


Figure 9 Interference caused by a porpoise

Other significant effects are caused by changes in seawater temperature and waves. In Figure 10, wave effects are evident as dark banding across the sonograph; note how the effect is more apparent towards the centre line of the record. Banding due to acoustic interference tends to be more evident towards the edge of the sonograph.

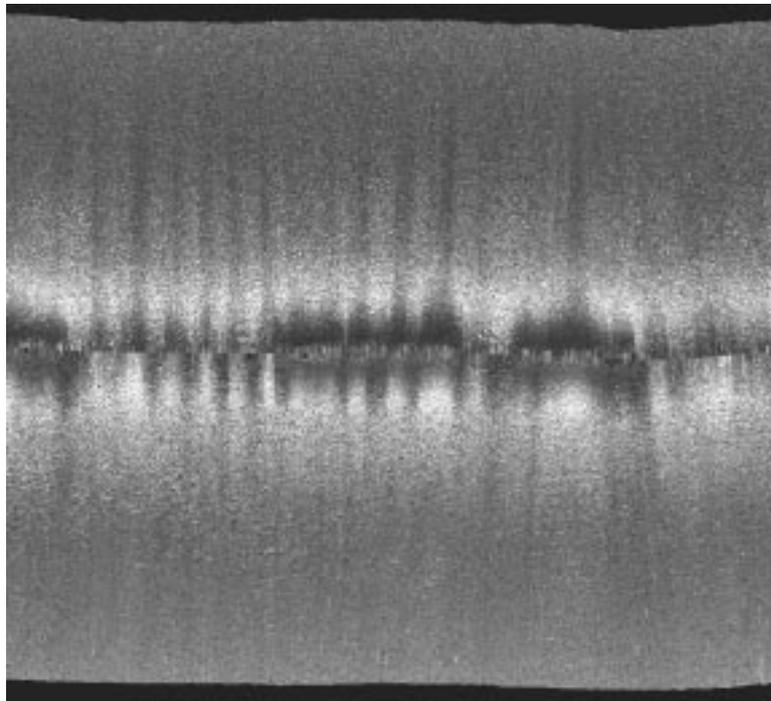


Figure 10 Interference caused by heave on the towfish as a result of waves

For soft tow systems an estimate of towfish layback should also be calculated using the following equation:

$$L = 2\sqrt{(C^2 - D_f^2)}$$

This does not take account of the catenary effect which lessens the lay back, but this becomes more of a problem for long cable deployments. In the equation, L is the layback, C is the amount of in-water cable and D_f the depth of the towfish.

Good quality survey and data processing logs should be maintained throughout a sidescan sonar survey. All equipment settings and offsets used on the survey vessel should be logged. The survey logs should also include information such as the time of start and finish of each survey line and the vessel heading, even though these data are normally logged in the navigation software. These logs will allow the navigation data to be cross-checked and enable the data processor to correctly process the data and quickly find any faults.

Data products

From thermal records a seabed feature and/or sediment distribution plan is typically produced. These should be annotated with information on the dimensions of targets such as sand waves. This may be augmented by images showing features of interest that have been scanned in to a computer and added to the plan(s).

Typical output from digitally collected data may include the following:

- mosaic of data annotated with features of interest, supplied as both a paper chart and in digital format correct for insertion into a GIS system (*GeoTiff* files)
- magnified and enhanced images of particular features of interest supplied both in paper and GIS compatible format
- plan of sediment type distribution supplied as a hard copy chart and in GIS compatible digital format.

Health and safety

The survey vessel must be seaworthy and suitable for the type of survey work to be undertaken. The crew should be suitably qualified and familiar with sidescan sonar survey operations.

All personnel on the vessel should be made aware of the vessel safety procedures and should be aware of the dangers involved in sidescan sonar surveys in particular. Apart from normal dangers involved in being at sea on a vessel the personnel should be aware of the following:

- The towfish may become snagged on underwater structures, endangering any person near the tow cable and perhaps endangering the vessel itself.
- Most sidescan sonar systems use 110 or 240 volts mains systems, which can be dangerous if misused, particularly when in close proximity to water.
- Care must be taken when deploying and recovering a towfish from the water and personnel involved in this procedure should wear the correct safety gear.
- Some parts of a sidescan sonar system are heavy.

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Sources of further information

Open Seas Instrumentation Incorporated: www.openseas.com

Theory of interferometric sonar: www.submetrix.so.uk

Handbook of seafloor sonar imagery: www.soc.soton.ac.uk/chd/bridge/research/interp.html

Multiparameter approach to nearshore seabed mapping: www.pgc.nrcan.gc.ca/marine/intro.htm

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