MeshAtlantic

RECOMMENDED OPERATING GUIDELINES

Sidescan sonars

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Recommended Operating Guidelines for Sidescan Sonars

1 – Methodology

Acoustics is the most efficient and accurate means to investigate vast amounts of seabed area in a cost effective way.

Sidescan sonar is one of the acoustic remote sensing methods available to image the sea bottom, along with single-beam and multibeam echosounders. It is the tool of choice for high resolution seabed mapping studies where the primary aim is to locate bedforms on the seabed and to determine sea bed sediment properties from their backscatter signature as is often the case of habitat mapping in coastal areas.

Sidescan sonars allow coverage of large areas of the sea-bottom, typically ensonifying the seabed along swaths ranging from tens to hundreds of meters wide or more, to both sides of the ship's track. This large seabed coverage is obtained using transducers that generate two wide beams, one on each side (port and starboard).

Sidescan sonar equipments can operate at a wide range of frequencies (from about 1kHz to 1MHz) depending on the specific objectives they are used for. For benthic habitat mapping and monitoring, high frequencies (>50kHz) are usually used in order to capture surficial seabed features such as sediment type, presence of rocky outcrops, seabed forms (sandwaves, ripples, furrows, etc.) and epifauna facies, along with all other sort of structures standing out from the sea bottom.

Sidescan sonar systems are regarded as effective mapping tools when seabed data records and post-processing are coupled to positioning data from GPS receivers.

In general, when using sidescan sonar for seabed mapping, the main steps that should be taken into consideration include the following:

- <u>Definition of the sidescan sonar working characteristics required</u>. The system chosen should cope with the depth range of the study area and the seabed discrimination level required (see Annex 1);
- <u>Survey planning</u>. As vessel time availablity is often a scarce resource, setting up a detailed working plan before survey execution is crucial to maximise the field work undertaken. It is recommended that the design of transects should consider the geographic and depth extent of the study

area, seabed coverage ratio, overlap coverage desired, prioritary areas to survey, prevailing winds and currents, etc;

- Survey execution. This is the phase of data acquisition, encompassing all the study area and using the methodologies established in the pre-defined plan. The initial set up should anticipate the consequences to the survey outputs of every planned task change made during the cruise;
- Data processing. At this post acquisition stage, raw data processing and analysis is carried out through specific software, aiming to correct and clean the data used in the interpretation step. Common processing steps include slant range and beam angle correction, mosaicing and georeferencing of the image files. It also includes exporting processed data into other raster formats compatible with Geographical Information Systems (GIS) or any other spatial image analysis software;
- Interpretation. During this step, the detection and segmentation of image texture or intensity into interpreted seabed classes is undertaken. Visual identification of homogeneous seabed patches is carried out with eventual support of ground truth data (supervised process) and/or automated image segmentation software.

2 – Equipments

Sidescan systems are available from a number of manufacturers. These units vary in size, working and technical characteristics and acquisition configuration (towed or vessel mounted).

Typically, a sidescan sonar system consists of: (1) a topside displaying and recording unit; (2) an electro-mechanical reinforced cable to data transmission and towing; and (3) a subsurface streamlined transducer unit to transmit and receive the acoustic energy (Fig. 1). Table I of the Annex shows the technical equipment specifications for a group of both stand-alone and integrated sidescan sonars from a number of manufacturers.

Transducers consist of a group or array of acoustic units. They are used in two forms: mounted in a towfish towed by the vessel (just below the sea surface, such as the system depicted in Fig. 1, or deep towed) or, less frequently, attached to the vessel hull (mainly for larger systems).

Figure 1 - Main components of a typical surface-towed sidescan sonar system.

The transducer unit emits sound in two

downward directions symmetric about the vertical. The sound directionally and intensity is expressed by the beam shape (directivity pattern), which is a function of the shape and dimension of the transceiver arrays, as well as of the operating frequency. The angular dimensions of these beams are designed to be narrow along-track, to allow a high resolution and wide across-track to cover as much seabed range as possible. The swath width encompasses the ranges covered by both side beams (Fig. 2).

Each time a ping is produced, the side beams' configuration allows them to ensonify a thin bottom strip (footprint) perpendicular to the direction of the boat.

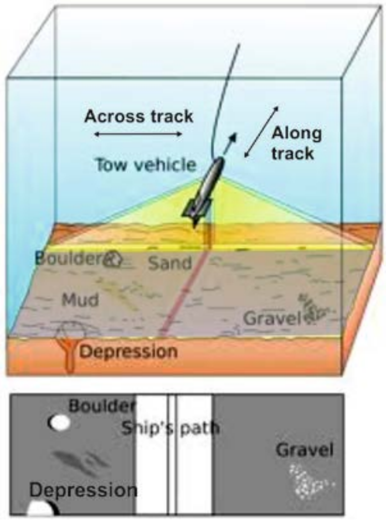

Figure 2 - Schematic view of sidescan sonar systems operation (http://oceanexplorer.noaa. gov/ gallery/technology/technology.html).

The system transmits successive short sound impulses ("pings") into the water in the form of wave signals and receives the energy backscattered from the sea bottom features with different seismic velocities, densities and texture, at the water-seabed interface and just below it, within the acoustic footprint (in all such systems, depending on their operating frequency, there is always some small penetration into the uppermost layers of the sediments; this is essentially negligible for high frequency systems but should be taken into account for lower frequency systems).

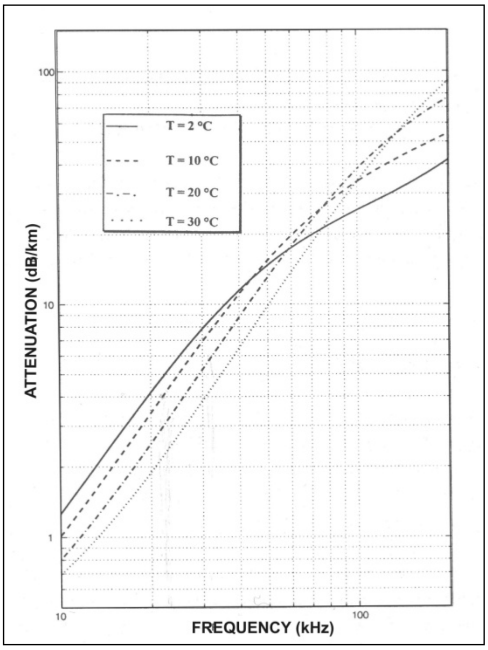

Figure 3 - Acoustic energy attenuation (dB.km^{-1}) with frequency variation for four seawater temperatures. Source (Diner and Marchand, 1995).

For each emitted pulse, a new footprint data is received in the transducer, produced by its interaction with the bottom. This information is displayed on the onboard screen as a new horizontal line on top of the image, moving down the older echoes to create a scroll effect. These lines when put together, build up an image of the seabed texture and characteristics in real time that are made available to operator for onboard interpretation and recording.

The sidescan sonar performance may be defined as the ability to detect seabed features of interest at a specific time rate. The discrimination of any particular system (resolution) is measured by its capability to separate closely spaced objects or, in other words, to detect discrete echoes returning from the distinct units or targets on the seafloor.

In this regard, the role of the frequency is a very important and limiting factor as it defines both the resolution and the maximum range achievable.

Backscattered signals are orders of magnitude lower than the signal transmitted because of the attenuation and other factors (Blondel, 2009). As the attenuation increases rapidly with the frequency (Fig. 3), lower frequencies permit energy to travel larger distances but provide lower resolution than higher frequencies. So, low frequencies (of the order of a few kHz, e.g. 5-12 kHz) can be used to survey large and deeper seabed areas covering large swaths with lower resolution in a given time, whereas high-frequency systems (a few hundreds of kHz) are more suited for detailed (higher resolution) surveying in shallower and smaller areas. There is a general trade off between coverage and resolution as frequencies vary.

Presently, dual frequency digital systems are available in the market which allows more survey flexibility; some systems can acquire and record both frequencies swaths independently and simultaneously. Using these systems, the operator may use the higher frequency to produce sharper images and narrow swath or use the lower frequencies to cover greater depths and obtain wider seabed coverage.

The system's signal frequency (*f*) and wavelength (*λ*) are the main operational parameters used to characterize the acoustic systems. They are related as:

$$\lambda = \frac{c}{f}$$

where *c* is the mean velocity of sound waves. Velocity of sound in water (acoustic propagation) depends on water temperature, salinity and pressure (Urick, 1987). For seawater, it ranges from 1450 to 1550 $m.s^{-1}$. The value 1500 $m.s^{-1}$ is usually taken as the average sound velocity in seawater.

Sidescan sonar systems can be characterized according to the operating frequency used (Table 1 and Annex I).

The quality or accuracy of the positional information linked to the collected survey data, especially the acoustic data, is of paramount importance. Presently, surveys rely heavily on georeferencing data obtained from the satellite Global Positioning System (GPS) receptors. GPS accuracy can be improved by using differential GPS (DGPS), which allows dynamic position accuracy of the order of 1-5 m.

Table 1 - Characterization of Sidescan Systems according to their operating frequency*.

Sidescan Sonar Type	Frequency (f)	Wavelength (λ)	Range
"Low"	5 kHz	30 cm	> 50 km
"Low"	10 kHz	15 cm	10 km
"Low"	25 kHz	6 cm	3 km
"Medium"	50 kHz	3 cm	1 km
"Medium"	100 kHz	1.5 cm	600 m
"Medium"	200 kHz	0.75 cm	300 m
"High"	500 kHz	3 mm	150 m
“High”	1 mHz	1.5 mm	50 m

* based on USGS (http://woodshole.er.usgs.gov/operations/sfmapping/sonar.htm; Long, 2007).

3 – System operation at sea

3.1 – Initial testing and planning

Before the sidescan survey begins, a series of integrity tests should be performed on the system before leaving port. At the dock, the towfish assembly should be lowered into the water to check that system seals are watertight and the mechanical deployment systems are functioning properly. The software system should be turned on to check the whole system circuitry. Rubbing the transducer zone on the towfish with a hand should induce some visual response on monitor screen. Remember to test that both port and starboard transducers are working properly.

Equipment manuals are always a good technical support to the system operators in difficult times. Copies should be taken on board and kept in a readily accessible place.

A plan with emergency actions to avoid hazards should also be discussed between the sonar operator and the helmsman in advance of the survey. The actions to consider depend on the working depths, seabed depth gradients, seabed type and the danger from obstacles. This is particularly critical for deep-towed systems. If a sharply rising ground or an obstacle is detected on the ship’s echo sounder, it may already be too late to raise the towfish by hauling in the tow cable, particularly if the cable paid out is too long. In this case, the quickest way to raise the towfish may be to increase the ship’s speed as quickly as possible. If, despite this manoeuvre, it still looks certain that the towfish will hit the obstacle or the sea bottom, an alternative is to slow down and, if possible, change the vessel’s course. This last attempt to avoid an impact with an obstacle will almost certainly drop the towfish onto the seabed, but may reduce the risk of losing the towfish.

In case the ship is stopped or manoeuvring to free an entangled towfish, beware of catching the tow cable in the propeller.

Another important issue for survey planning is to check the positional parameters that are selected in the GPS receptor, notably the geographic datum. Nowadays, the standard datum for positioning and navigation is the global WGS84 (World Geodetic Datum 1984).

3.2 – Surveying

An important aspect of the sidescan operation is the towfish deployment and recovery from the vessel. The deployment operations should be initiated at a distance from the start of the survey transects.

Usually, towfishes are deployed either from a crane or davit on the side of a vessel or more often from the stern. In small vessels with lighter systems their deployment is generally done by lowering the equipment into the water by hand; as concerns the larger and heavier models operating in larger vessels, these are handled mechanically using cranes or power blocks. For all systems safe handling procedures need to be considered when moving equipment on deck and transferring into the sea. While the towfish sinks through the water column, the umbilical is paid out sufficiently until the working depth is achieved.

The backscatter strength returned from the sea floor heavily depends on the nature and topography of the sea bottom, but also on the grazing angle of incidence, *i.e*. the acute angle between the line of sight to the sea bottom and the sea floor itself (Fig. 4). The towfish needs to be towed at relatively low fixed altitudes above the bottom to obtain adequate grazing angles, although at a height suitable not to compromise the desired swath coverage. As a rule of thumb, the towfish should work at a height above the seabed of 10 to 20% of the horizontal range setting.

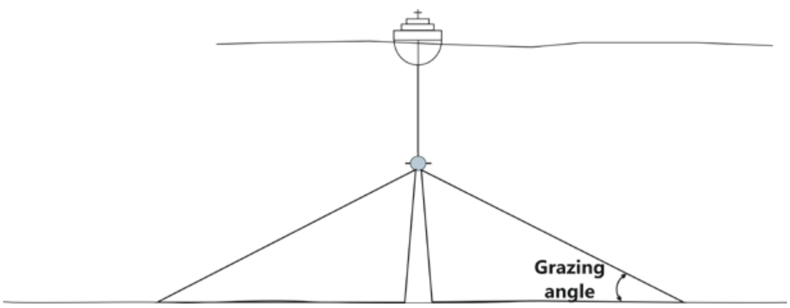

Figure 4 - Low grazing angles, up to a certain limit, improve the seabed imaging contrast, in particular for small scale roughness.

The advantage of this transducer positioning is to produce clear acoustic shadows in echograms from relatively small objects protruding from the seabed or from small scale morphology variations in bottom soft sediments. However, in sidescan sonar systems, the closer the sensor is to the seafloor, the narrower the useable swath coverage will be, thus making mapping large areas a long and costly task. This situation is especially true in shallow water surveying.

Other critical decisions are what ping rates to use in a particular area (thus controlling the swath width being used) and the main objectives of the study. Is the main aim of the study to map small scale features, or is it a just a large-scale regional survey? In the case of large-scale regional studies, one can use a setting that performs a large swath width to ensonify a larger area per time unit.

In general, the ship's speed while towing a sonar is normally low, usually bellow 5-6 knots (2.5-3.0 $m.s^{-1}$); however there are equipments available in the market that can stand working speeds up to 8 knots and more. Note that with the velocity increase, the strain on the data cable may become too great and the towfish unsteady, reducing data quality. It is also harder to keep the towfish on required depths at higher speeds. When working in deeper waters, fitting a high-aspect-ratio wing depressor to the towfish body can be a solution and this is offered by some manufacturers. Depressor devices can produce downward applied forces typically increasing the stable towfish working depth by 40-50% with the same cable length and reducing layback by the corresponding amount, although at expenses of a rise in strain on the cable. The advantages are that less cable on deck is needed leading to the use of less expensive cable handling systems and less signal attenuation is produced by the cable. A depressor also removes much of the towfish unwanted motion transmitted by the cable.

An important aspect of any sidescan sonar operation is establishing where the towfish is positioned behind the vessel (layback distance, d; Fig. 5), to predict accurately the horizontal position of the acquired data with reference to the GPS antenna (geopositioning).

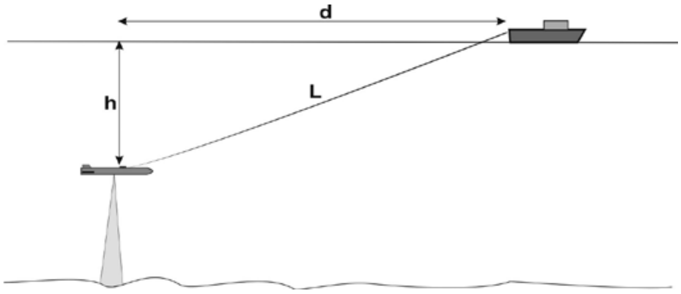

Figure 5 - Sonar working configuration using a layback distance d.

For single-unit systems in which case the only variable known is the length of cable paid out (L), the control over layback is difficult. Where there is a control on the sonar depth (h) such as a pressure sensor recording data, an estimate of layback (d) can be obtained using the following equation:

$$d = \sqrt{L^2 - h^2}$$

This does not take into account the catenary effect produced by hydrodynamic forces on the cable which lessens the layback. However, this only becomes a real problem for long cable deployments.

Likewise, estimates of layback can be made by performing a patch test where overlapping tracks in opposite directions are performed over a distinct seabed feature and the layback is adjusted during processing until the features on both tracks line up. Note that these estimates only work when the ship path is linear, to assure that the sonar lies back on the same path, and that the across-track displacements are not significant.

Accurate towfish positioning can also be obtained using acoustic ranging systems (Blondel, 2009) in which an acoustic link between the towfish and the survey vessel is established to calculate their relative distance, which is later integrated into the survey navigation data stream.

3.3 – Seabed coverage ratio

Often, the complete coverage of the seabed is the ultimate goal of an acoustic survey design, to enable the creation of full mosaics. In these cases, theoretically, parallel transects should be run to produce swath overlapping of, at least, 50%.

When complete coverage is not necessary to define seabed boundaries, consecutive swaths overlapping 20 to 30% can be adequate (Fig. 6). However, in some cases, transect spacing of at least 75% of the swath width can provide reasonable overlapping to compensate any loss of resolution at the outer range limits.

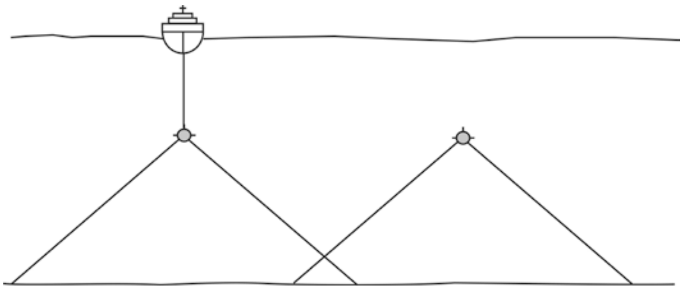

Figure 6 - Schematic of full coverage with swath overlapping.

A full coverage may not always be possible. Therefore, a grid approach may be adopted with lines parallel and at right angles to the principal physical *grain* of the seabed. Such *grain* could be due to channels, sand banks or rock outcrops (Kenny, Todd and Cooke, 2001). Line spacing of the grid should enable capture of the shape and nature of the principal features on the seabed and its global character. The spacing chosen should also allow the interpretation to be extrapolated between lines.

In some areas, a parallel corridor approach may be adopted rather than a square grid, for example where there are strong rectilinear currents and unidirectional swells and waves. Surveying across these would be difficult and uncomfortable and would also compromise the quality of the survey data.

The corridor approach is also useful in areas of sand waves where collecting survey data at right angles to the principal crest direction provides more relevant data on the nature of the seabed.

Poor weather conditions are one of the principal causes of distorted sonar imagery. High sea states and pitching survey boats will increase towfish motion and the quality of the acquired data quickly deteriorates. For this reason, often the survey set up will have to be made with reference to the local weather conditions so the vessel is running into and away from the prevailing sea or wind. The working conditions limits are specific to the vessel characteristics, but typically, larger vessels can operate in poorer sea and weather conditions.

Based on his experience, the sonar operator is able to anticipate the data quality limitations imposed by weather conditions and can design the survey/search plan accordingly.

3.4 – Resolution

The acoustic pulses in sidescan sonars are emitted at specific time rates and pulse lengths, T, (in milliseconds). A short pulse emission will produce a thinner spatial pulse length resulting in a higher resolution whilst a longer pulse would be less sensitive to the background noise resulting in improved range performance (Mitson, 1983).

The spatial resolution is the main limiting factor in a sidescan sonar performance and it is defined as the minimum distance between two detected objects that can be distinguished as separated entities in the sonar image. This resolution in any point of the ensonified area can be split in two perpendicular components: the across-track and the along-track resolutions.

The resolution in the along-track direction, Δ_{rx}, measures the resolution parallel to the line of travel. It will be strongly dependent on the horizontal beam width, θ_{hx}, and range, R, and can be expressed as:

$$\Delta_{rx} = \theta_{hx}.R$$

According to this expression, the along-track resolution of a sonar, working under the same operational conditions, degrades with distance to the transducer (Fig. 7). Therefore, two objects will be detected as separated entities if they are separated by a distance which is less than the spread of the sonar beam Δ_{rx} at that range.

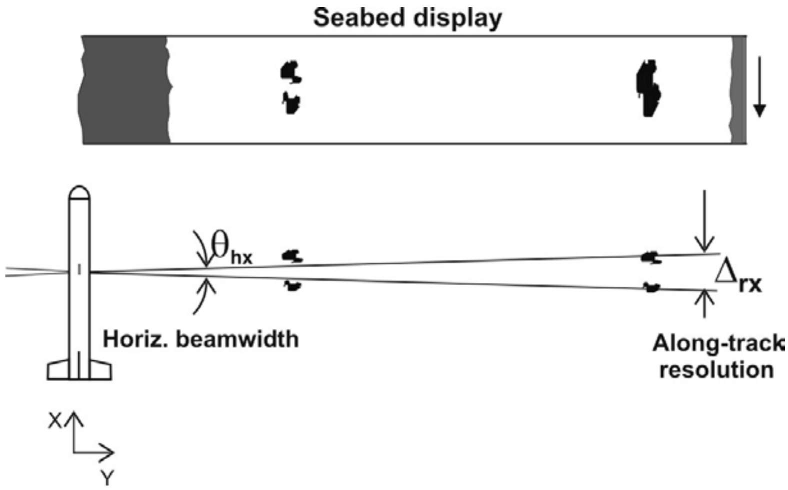

Figure 7- The along-track resolution of a sidescan sonar is dependent on the horizontal beamwidth and the slant range. The resolution improves at lower depths.

The across-track resolution Δ_{ry} (Fig. 8), is defined as the minimum distance between two objects perpendicular to the line of travel that can be distinguished as separated entities in the sonar image.

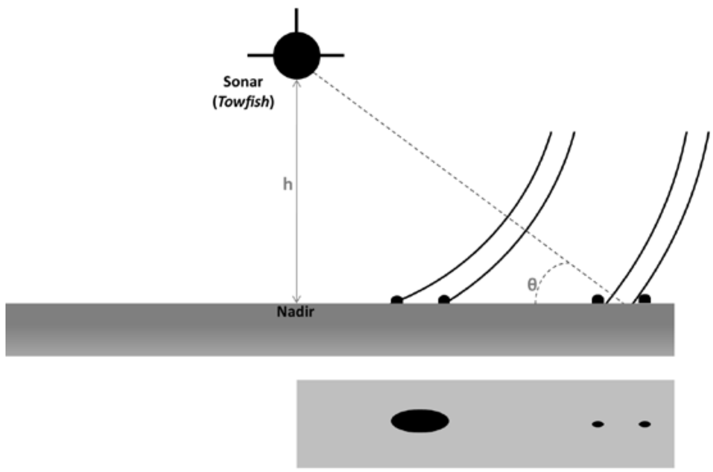

Figure 8- The across-track resolution of a sidescan sonar is dependent on the grazing angle θ and the pulse length T (after Mazel, 1985).

The pulse length, T, is the overriding operational parameter determining this resolution. As the acoustic wave direction is oblique to the seabed, this resolution can be expressed as:

$$\Delta_{ry} = \frac{T.c}{2}.\sec\theta$$

where θ is the grazing angle.

Additionally, to ensure full coverage in the swath area, no gaps between ensonified areas from two successive pings should exist (Blondel, 2009). This complete coverage condition depends on the transducer length, *L*, the vessel speed, *v*, and the ping rate, f_p. The ping rate can be calculated by the sound velocity in water, *c*, and the selected range, *R* (the theoretical sonar range resolution, across-track in the case of sidescan sonar):

$$f_p = \frac{c}{2 \cdot R}$$

For a given transducer length, *L*, a working ping rate (determined by the selected range), allows a complete coverage (without gaps) when a maximum vessel speed, v_{max}, is not exceeded:

$$V_{\max} = L \cdot f_p = \frac{L \cdot c}{2 \cdot R}$$

A short pulse will produce a thinner spatial pulse length, resulting in a higher spatial resolution, whilst a longer pulse will be less sensitive to the background noise, resulting in improved range performance. As a consequence, for greater seabed depths, ping rates must decrease to cope with longer range scales R involved. In such cases, the operator can be forced to slow down the tow speed to maintain total coverage along the swath.

4 – Recording Formats and Sidescan Sonar Data Processing

4.1 – Software and recording Formats

The interpretation of sonar remote sensing images has traditionally been performed mostly by visual inspection. Although, the analyst interpretation skills remain important, this task is always time-consuming and largely relies on the subjective experience of the interpreter. However, in recent years, image processing and quantitative interpretation have improved significantly with the appearance of computer-assisted tools.

Presently, sidescan sonar manufacturers offer dedicated software packages for data recording, processing and interpretation through dedicated packages. Additionally, third-party software, such as Triton Elics, Caris, Hypack, Swathview or Sonarwiz MAP/SonarWiz 5, also include packages for sidescan sonar real time data acquisition as well as a range of data processing and post-processing capabilities.

Additionally, most dedicated software allows data recording into exchangeable file formats, allowing migration of the data into other software packages for additional computed-assisted analysis, or exporting it into GIS programs or websites for mapping purposes. Amongst the various sidescan sonar file formats available, the open-source XTF ("Extended Triton Format"), developed by Triton Elics, allows saving different types of data into a single file.

4.2 – Data Processing

Although some processing, including composite mosaics, can be produced in real time while surveying, mainly for data quality control and preliminary onboard interpretation, final imagery and classification require post processing of the recorded raw data which may constitute a definite plus for image visualization.

This data processing can include analysis tools from a very wide variety of techniques available, depending on the specific objectives initially established. Composition or mosaicing of the swath imagery is produced at this stage.

The raw data processing can be split into several stages:

- Preparation of the raw sonar data for processing. This stage includes the removal of poor data sections, the smoothing of the navigation data and corrections for horizontal offsets of the towfish relative to the GPS-antenna, including the layback.
- Transformation of the raw data into usable images that will be radiometrically (includes beam angle compensation, grazing angle compensation and filtering) and geometrically (slant-range and sound speed corrections, and water column removal) correct representations of the seafloor (Fig. 9).
- Mosaicing, *i.e*. assembling geo-referenced sonar images from adjacent track lines to create a comprehensive global image of the seafloor surveyed.

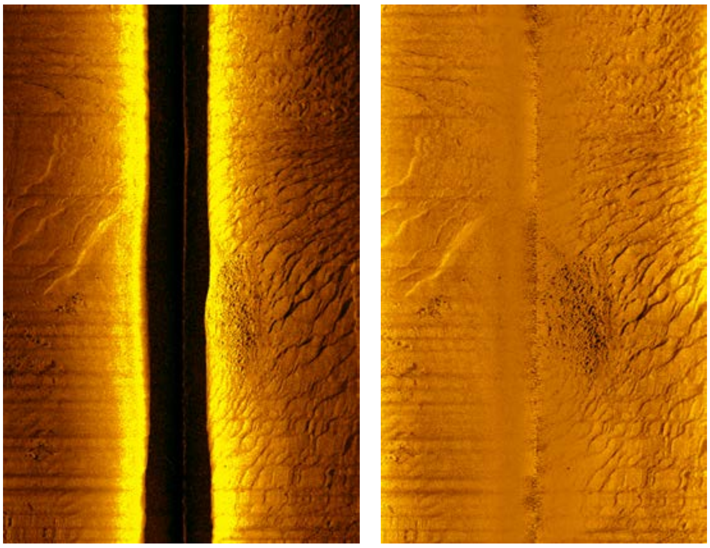

Figure 9- Example of a sidescan sonar profile before (left) and after (right) processing (from Pinheiro *et al*., 2011).

Sidescan sonars are susceptible to interferences from a wide number of sources. Some, though, are frequent and can be recognised in the data image. These errors are usually detected during the survey stage and are either runtime solved or annotated for the related image segments to be post processed.

Survey vessel noise is shown up as regularly spaced lines across the image (Fig. 10). Such noise is often due to energy sources on the survey vessel and commonly occurs when the sonar is close to the vessel. This noise interference will often be eliminated increasing the horizontal distance between the towfish and the vessel (Long, 2007).

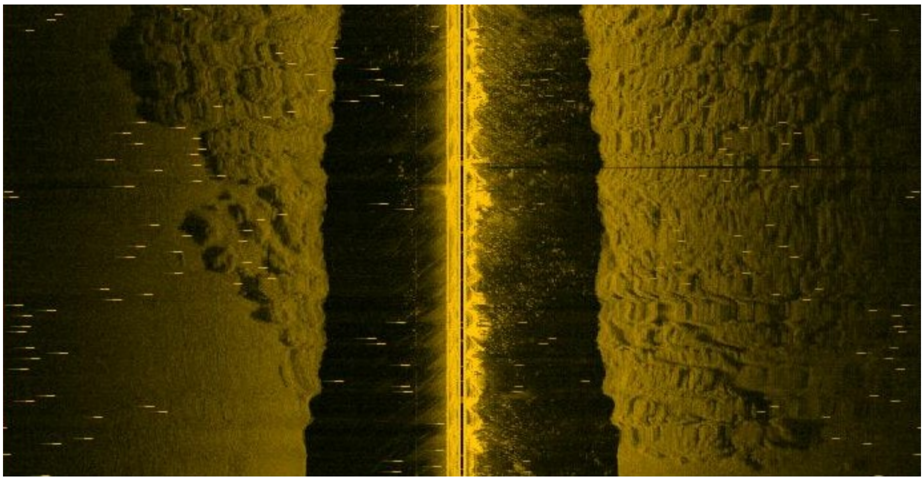

Figure 10 – Example of interference in the image produced by the vessel echo sounder.

Navigation drop-out of the signal will cause errors in the speed correction of the record. The distortions produced depend on the system used, but may be evidenced in the record by areas of no data or as interpolated bands (Fig. 11) (Long, 2007).

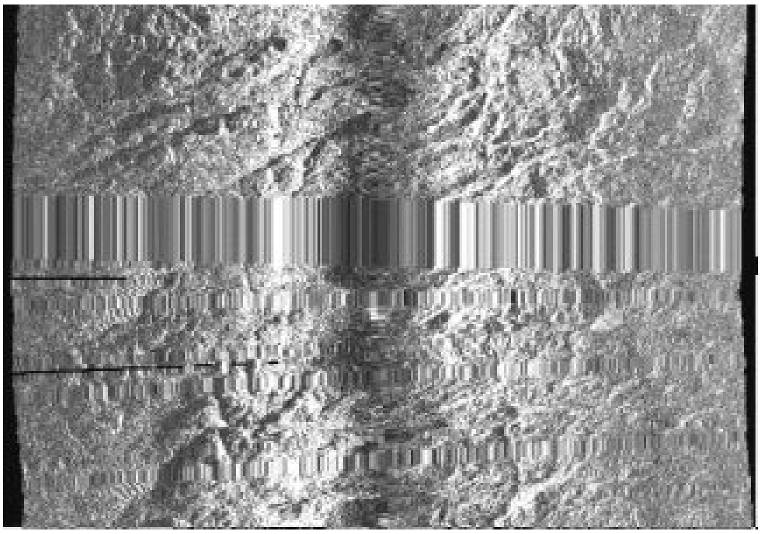

Figure 11 – Navigation drop-out of the signal (Davies et al. 2001).

Interference from sources, such as fish or marine mammals either as individuals or in schools, may occur if they are located within the ensonifyng towfish beam. Figure 12 illustrates the acoustic interference caused by a porpoise (Long, 2007).

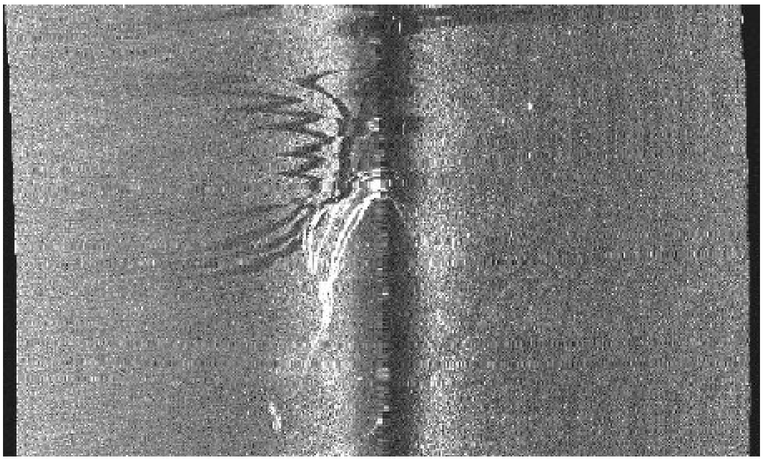

Figure 12- Interference caused by a porpoise. Individual fish or schools caught by the beam may cause disturbs in backscattering signal (Davies *et al.*, 2001).

Similarly, interference effects can come from bubble streams in the water column (figure 13) which cause strong local perturbations to the acoustics propagation. The detection of such features can be important for geological and habitat mapping purposes.

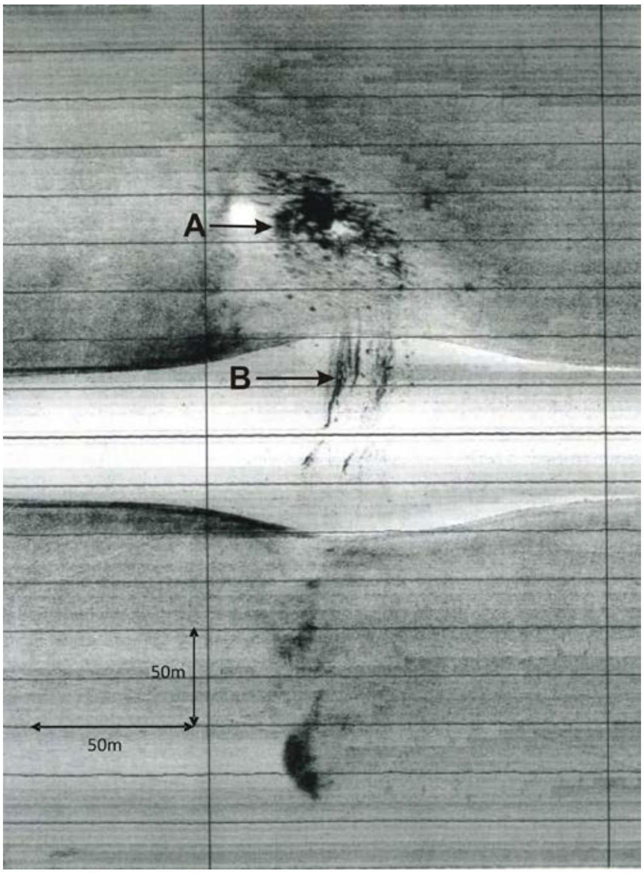

Figure 13 – Example of gas bubbles interference. This perturbation was registered as high backscatter marks (black) from: (A) seabed carbonates and gas bubbles close to seabed and from (B) plumes of mid-water gas bubbles (Source:British Geological Survey side-scan sonar line 91/03/22).

Figure 14 illustrates the negative effect of towfish heave in the acoustic image, caused by waves on the transducer stability. This effect can be visualized as dark banding across the sonograph (Long, 2007).

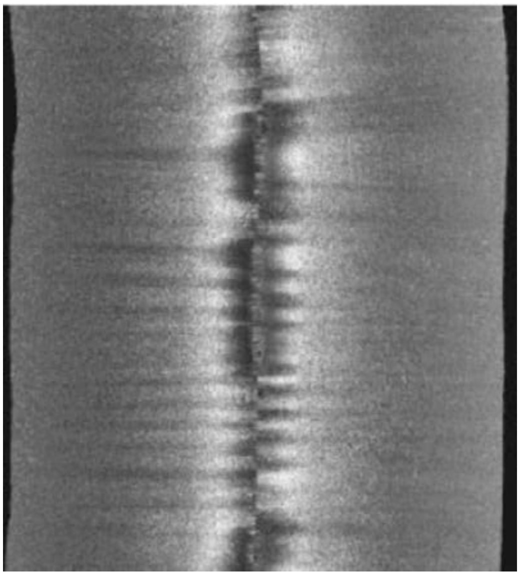

Figure 14 - Interference caused by heave on the towfish as a result of waves (Davies *et al*., 2001).

The processing methodologies which can be used at this stage are diverse and, to a great extent, are selected according to raw image quality and final objectives devised. Typical post-processing procedures include the computation of image statistics and histograms and the application of standard image processing techniques, to improve the image quality.

The processed digital images constitute the information delivered for the following seabed interpretation task. Interpretation is usually carried out by expert personnel using image analysis tools. For this purpose, third-party software such as ESRI ArcGIS, ERDAS Imagine, ENVI and ER Mapper can be used.

5 – Data interpretation

5.1 – Backscatter interpretation

The almost photo realistic acoustic images of the seabed often provided by the sidescan backscatter data, makes them suitable for the identification and interpretation of seabed features aiming at the classification of the benthic habitat. The digital images used in this final stage are those selected earlier during the post processing.

The use of sidescan imagery interpretation in the context of benthic habitat map is a very complex task. In general, image interpretation is an open subject of research and there is no definitely proven technique (Blondel, 2009).

Therefore, there is no unique methodology but a set of best practices that an analyst may use according to its experience, the seabed complexity, the amount and quality of data, available analysis tools and aimed objectives.

Sidescan sonar is a remote-sensing technique, therefore, rarely used alone for habitat mapping. To guide seabed interpretation it is advisable to correlate the found image backscatter patterns using ground truth or validation in situ data samples (supervised classification process).

Ground truth datasets are usually collected during the surveys or, in a lesser extent, may be formed by historical datasets obtained from diverse sources. To integrate all these separated strands of ancillary data with the processed sidescan images they can be combined in GIS software in order to spatially relate and query them during the process of identification and interpretation of seabed features.

Before using a set of criteria for interpretation it is important to take into account the details about the acquisition system, its settings used and the survey method and field work daily logs.

In sidescan data analysis it is important to bear in mind that the formed images or sonographs are artificial seabed views reconstructed from the backscatter of acoustic waves (Huff, 2008). Usually, harder areas, reflecting more energy (high backscatter), are shown in the sonographs as lighter tones, while softer areas that reflected less energy (low backscatter) are shown as darker tones. Very dark areas normally mean the absence of backscattered sound, indicating a shadow behind objects. These shadows, forming acoustic unsurveyed blind spots located behind high relief terrain or an object that stands out, are cast by low grazing angles of echoes and become larger at longer ranges. In these conditions, to obtain full coverage, the seabed must be ensonified in two opposite directions and the overlaps between subsequent swaths must be 100%.

Very dark shadows on the seafloor may be useful, since they allow estimating the height, h, of associated features standing out from the seafloor (Fig. 15). This can be estimated using the following equation (application of the Thales Theorem):

$$h = \frac{L.H}{R}$$

where H is the height of the sidescan sonar towfish above the seabed, L is the length of shadow cast by the target, and R is the distance through the water between the towfish and the end of the shadow cast by the object (Kenny, Todd and Cooke, 2001; Long, 2007).

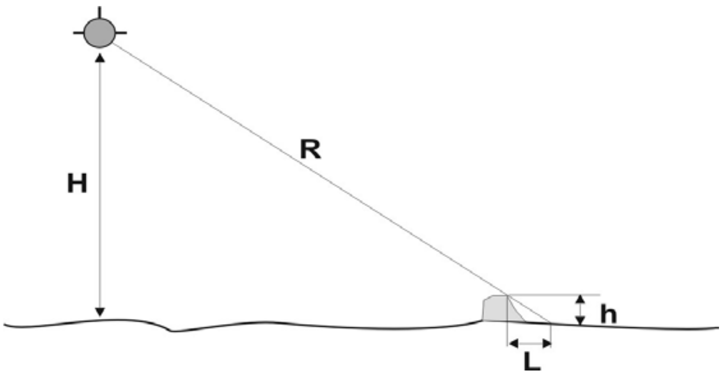

Figure 15 - Object height estimation from the shadow size recorded in a sonograph.

Sonar data interpretation can be significantly facilitated when draped on top of bathymetric data, in particular on top of high resolution bathymetry such as standard multibeam. One such example is shown in figure 16. The inclusion of the bathymetric information further allows distinguishing topographic effects from variations in geological character on the backscatter intensity. The same type of sediment, for example, will appear with much stronger backscatter if it is lying on a slope facing the sidescan sonar beam, than when it is lying on a horizontal seafloor or on a slope with the opposite dip – this can be mistaken for a change in type or grain size of sediment.

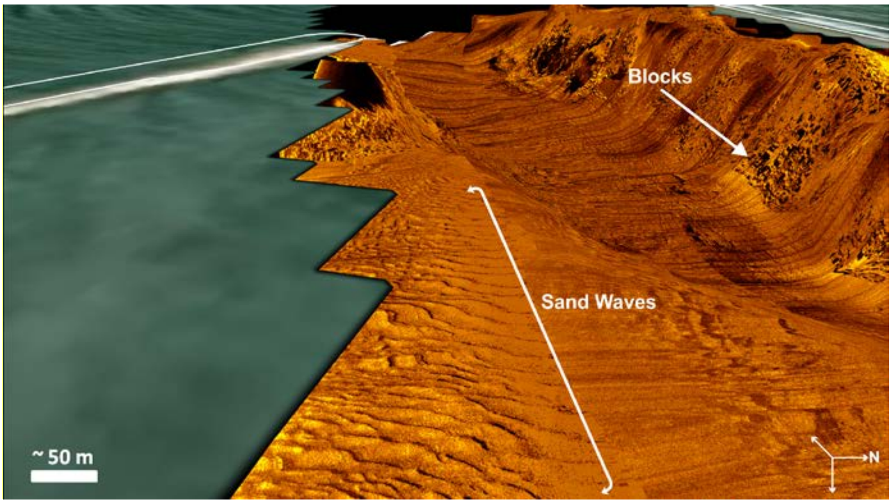

Figure 16 - Sidescan sonar mosaic projected on top of the bathymetry. From Pinheiro *et al*. (2011).

Classification techniques are basically *ad hoc* and judged on their performance (Blondel, 2009). Segmentation of acoustical imagery into discrete patches is usually carried out by visual analysis alone or complemented with semi-automated image segmentation algorithms. These often depend on the extent of ground truthing data available. This image partition is based on the delimitation of seabed areas with homogeneous acoustic texture or intensity. Published literature can provide a comprehensive broad view on the suitable automated methods, some already included in commercial sonar classification packages.

Geographically segmented images are not the final classification although patches of similar patterns share the same identification index according to a list defined by the analyst criteria.

The classification process organizes or clusters the seabed indices into habitat classes exhibiting similar relevant geological or biological features in the study area. In this process, segmentation results are usually validated by correlating image indices with ground truth datasets by means of multivariate analysis tools, to achieve a quantitative interpretation.

Some analysis steps involved in the classification process can be accomplished in a Geographic Information System (GIS) environment such as ArcGIS. In GIS we can uniformly georeference all dataset types and apply a wide range of tools to manage and explore spatial relationships among data layers.

Additionally, GIS is the most suitable environment not only to merge all datasets into a spatial database which can be easily upgraded and queried but also to aggregate the attributes layers along with metadata to produce the benthic habitat map of the study area.

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ANNEX – Sidescan Sonar Systems: Technical Characteristics

Table I – Sidescan technical survey (4 pages). Adopted from www.hydro-international.com/productsurvey/id30-Sidescan_Sonar,_NovemberDecember.html

Brand	C-MAX Ltd	C-MAX Ltd	DSME E&R Ltd.	EdgeTech	EdgeTech	EdgeTech
Name of product	CM2	CM2 DEEPTOW	SonarBeam S-150 Series	2200 Series for AUVs	4125	4200 Series
Year of first manufacture	2002	2010	2001	2005	2008	2004
Frequency operation (Single, dual, simultaneous dual)	Dual	dual	Single / Dual	Dual Simultaneous	dual	Dual Simultaneous
Towfish length x Diameter/Height (X width)(cm)	124cm	125cm	(90-136cm) x Ø(8.9-11.2cm)	N/A	112 x 9.5	125.6 x 11.4 x 20
Towfish weight (air) (kg)	18kg	42kg	12kg up to 32kg	N/A	20kg	48kg
Max. depth Rating (m)	2000m	2000m	300m	N/A	200m	2000m
Transducer Type and Material	PZT	PZT	Ceramic	Aluminum, Urethane, PZT	Alumium	Urethane and PZT
Fish height from seabed determination method	integral echo sounder	integral echo sounder	Altitude Sensor	Bottom track from sidescan echo	Bottom track on Sidescan echo	Bottom track on Sidescan Echo
Deployment methods	manual or winch	winch	Portable Manual Winch	N/A	Winch/A-frame	over the side by hand
Depression technique	optional wing	weight of towfish & cable	Wing	N/A	Optional keel weights and/or v-fin depressor wing	Optional v-fin depressor wing
Type of Cable supported	coax or twisted-pair	coax or twisted-pair	Polyurethane Sheathe tow cable / Armored Coaxial tow cable	N/A	Coaxial	Coaxial Kevlar or double-armored
Max length of cable (m)	3000m	6000m	350m	N/A	600m	Up to 6000m
Actual frequency (kHz)	325/780kHz or 100/325kHz	100/325kHz	Single Frequency: 100, 400, 900, 1250kHz/ Dual Frequency : 100/400, 400/900, 400/1250kHz	Frequency options include: 75/120, 75/410, 120/410, 230/540, 230/850, 600/1600 kHz.	Choice of 400/900 or 600/1600 kHz	Choice of 100/400 kHz
Pulse length (µs)	variable	variable	100kHz: 50~200µs / 400kHz: 25~150µs / 900kHz: 15~50µs / 1250kHz: 10~25µs	1000 to 20000 (FM Chirp)	600 to 4000 (FM Chirp)	1000 to 20000 (FM Chirp)
Source level (dB relative to µPa at 1m)			-	226 effective	226 effective	226 effective
Max. Range (m)	150m (300m swathe) or 500m (1km swathe)	500m (1km swathe)	500m	750m	150m	500m
Horizontal beam width (deg)	0.3º	0.3º	1.2º:100kHz/ 0.3º:400kHz /0.3º:900kHz/ 0.3º:1250kHz	0,2º	0,2º	0,2º
Vertical beam width (deg)	full below horizontal	full below horizontal	40º:100kHz / 40º:400kHz / 40º:900kHz / 30º:1250kHz	50º	50º	50º
Max. Horizontal Resolution (cm)	4cm	4cm	3cm (Range 100m)	0,6cm	0,5cm	1cm (900kHz) up to 8cm (100kHz)
Max. Operating speed (kt)	12kt	12kt	8kt	10kt	10kt	10kt
Max. Vertical Resolution (cm)	N/A	N/A	5~10cm	N/A	N/A	N/A
Applications	survey/search/inspection	survey/search/inspection	Survey, Inspection, Rescue, Seabed mapping	Cable/pipeline surveys, geological/geophysical surveys, route surveys	Search & recovery	shallow water surveys

Table I – Cont.

Brand	IXSEA	IXSEA	IXSEA	Humminbird	JW Fishers Mfg.
Name of product	ELICS 100-400	ELICS 400-1250	SHADOWS Mapping Sonar	Side imaging	SSS-100K/600K
Year of first manufacture	2008	2008	2006	2005	1991
Frequency operation (Single, dual, simultaneous dual)	Dual	Dual	Dual simultaneous	Dual (455kHz and 800kHz)	Dual
Towfish length x Diameter/Height (X width)(cm)	136 x 11.2	102.6 x 9.5	200 * 90 * 50 cm (L*W*H)	15x7.5x2.5 cm	140 x 11.4 cm
Towfish weight (air) (kg)	32	16	450 kg	350grams	25kg
Max. depth Rating (m)	300 m	100 m	300 m / (Deep Tow or AUV: consult us)	45 m	150 m
Transducer Type and Material	Ceramic	Ceramic	Piezo-electric ceramics	N/A	focused piezoceramic
Fish height from seabed determination method	Altimeter (acoustic) and/or software detection and editing. Pressure sensor included.	Altimeter (acoustic) and/or software detection and editing. Pressure sensor included.	Altimeter	N/A	First bottom return
Deployment methods	Winch (manual with slip ring)	Winch (manual with slip ring), Over-the-side Pole	A-Frame or Lifting Arm	Boat mounted	Towed, overside mounted
Depression technique	Wing	Wing		N/A	depressor wing
Type of Cable supported	Quad-connectors polyurethane or armoured	Polyurethane or armoured	Fiber optic	N/A	co-axial
Max length of cable (m)	300m	150m	1200m	N/A	300m
Actual frequency (kHz)	100kHz or 400kHz	400kHz or 1250kHz	100/300 khz	455kHz or 800kHz	100 and 600
Pulse length (µs)	100kHz: 50?s to 200?s 400kHz: 15?s to 100?s	400kHz : 15 to 100µs 1250kHz : 5 to 25µs	User selectable (chirp)		25 - 100
Source level (dB relative to µPa at 1m)	N.C.	N.C.	210 dB		222dB
Max. Range (m)	100kHz: 500m 400kHz: 150m	400kHz : 150m 1250kHz : 35m	300m	75m	600m and 75m
Horizontal beam width (deg)	1.2°(100kHz); 0.3° (400kHz)	0.3°	6º	N/A	1.0º and 1.0º
Vertical beam width (deg)	40°	40° (400kHz); 30° (1250kHz)	60º	N/A	40º and 40º
Max. Horizontal Resolution (cm)	3.75-15cm (100kHz); 1.12-7.5cm (400kHz)	400kHz : 1.12 to 7.5cm 1250kHz :0.37 to 1.87cm	15*15cm square pixel constant across and along track	N/A	6cm and 3cm
Max. Operating speed (kt)	8kt	N/A	N/A	N/A	3kt
Max. Vertical Resolution (cm)	N/A	N/A	N/A	N/A	N/A
Applications	Hydrography, Route Survey Geological / Geophysiscal Survey Habitat & Sediment Mapping Wreck Search	Harbour, Object Search & Recovery Search and Habitat Mapping	EEZ mapping, Hydrography, Habitat Mapping,Environmental, Archaeology		Search and Rescue, Law enforcement, underwater construction, dredging

Table I – Cont.

Brand	L-3 Klein Associates, Inc	L-3 Klein Associates, Inc	L-3 Klein Associates, Inc	Systems Engineering & Assessment Ltd	Teledyne Benthos
Name of product	System 3000 Digital Side Scan Sonar	System 3900 Dual-Frequency Side Scan Sonar	System 4000 Multi-Beam Side Scan Sonar	SWATHplus	1625 Combined Sidescan Sonar and Sub-bottom Profiler System
Year of first manufacture	2002	2007	2008	2006	+ 15 years
Frequency operation (Single, dual, simultaneous dual)	Dual simultaneous	Selectable - Dual	Single	Single	Dual Simultaneous 100/400kHz Chirp/CW and single low frequency Chirp/CW Sub-bottom
Towfish length x ameter/height (x width)(cm)	122 cm, 8.9 cm diameter	122 cm x Ø 8.9cm	137 cm x 5 in x 74 in	100 x 215 x 42 for H	71.9 cm high by 108.7 cm wide by 209.0 cm long
Towfish weight (air) (kg)	29kg	29kg	58kg without ballast	13kg(L) / 6kg(M) / 1kg(H)	154kg
Max. depth Rating (m)	1500 m standard	200 m	200 m	1000m	2000m max.depth
Transducer Type and Material	Single Beam - Pizeo Electro Ceramic Array	Single Beam - Pizeo Electro Ceramic Array	Multi-Beam Dynamically nge Focused Complex Pizeo ctro Ceramic Array	Interferometric. Ceramic or Composite dependent on frequency	Four 10-element transducer arrays
Fish height from seabed determination method	Altitude Algorithm	Altitude Algorithm	Altitude Algorithm	From Bathy, Vernier Phase Detection	First return of data
Deployment methods	Winch with coaxial	hand deployed, Kevlar reinforced lightweight cables & AUV platforms	One man deployable from aller boat in shallow water	Vessel or AUV mounted	Optional winch and vessel mounted handling system
Depression technique				N/A	Dead Weight Depressor
Type of Cable supported	Coaxial, Kevlar	Coaxial, Kevlar	Armored Coaxial, Kevlar	N/A	Light weight Kevlar and or Double armored steel cable
Max length of cable (m)	300m Ltwt. Coaxial cable	5000m armored coaxial	250m Ltwt. Coaxial cable	900m armored coaxial	N/A
Actual frequency (kHz)	100 kHz (132 kHz +/- 1% act.), 500 kHz (445 kHz, +/- 1% act.)	445 kHz and 900 kHz	455 kHz	117kHz(L)/234kHz(M)/ 468kHz(H)	Low Freq.: 100 to 120kHz band, High Freq.: 380 to 400kHz band, Sub-bottom: 2-7kHz
Pulse length (µs)	Tone Burst, operator select. from 25 to 400µsecs.	Tone burst, operator selectable from 8 to 100µsec.	50 to 200µsec. Operator ectable	34(L) / 34(M) / 8.5(H)	50 µs
Source level (dB relative to µPa at 1m)	234dB (132 kHz) - 242dB (445 kHz)	225dB (900 kHz)	249dB	224dB(L) / 220dB(M) / 222dB(H)	+225 dB
Max. Range (m)	600 meters @100 kHz	150 m@ 500 kHz	150 m @ 445 kHz	350m(L)/200m(M)/ 90m(H)	25 to 500m each channel
Horizontal beam width (deg)	0.7º @ 100 kHz, 0.21º @ 500 kHz	0.21° @ 900kHz, 0.21° @ 445kHz	Dynamically focused, 40° Vertical, Tilted 20° down	1.7º(L) / 1.1º(M) / 1.1º(H)	0.7°
Vertical beam width (deg)	40º	40º	40º	240º	65°
Max. Horizontal Resolution (cm)	2.5cm	7.5cm	(Along Track) 20cm @ 75m, 30cm @ 125 m (Across Track) determined by Select. pulse length (3.75 to 15cm)	5cm(L) / 2cm(M) / 1cm(M)	3.75 cm across-track resolution
Max. Operating speed (kt)	N/A	N/A	N/A	6kt	10kt Max. tow speed
Max. Vertical Resolution (cm)	N/A	N/A	N/A	5cm(L) / 2cm(M) / 1cm(M)	Sub-bottom:7.5cm typical, depends on pulse length setting
Applications	Shallow water Hydrographic Surveys	Geophysical Surveys	Nautical charting, Benthic Habitat mapping, dredging operations	Bathymetry mapping, Habitat survey, pipeline and cable route surveys	Geophysical Survey Work

Table I – Cont.

Brand	Teledyne Benthos	Teledyne Benthos	Teledyne Benthos	Tritech International
Name of product	C3D-LPM Sidescan Imaging with Bathymetry	C3D-SBP Sidescan Imaging with Bathymetry and Chirp Sub-bottom Sonar	Chirp-III Sub-bottom Sonar	StarFish 452F
Year of first manufacture	5 Years	6 Years	+20 Years	2010
Frequency operation (Single, dual, simultaneous dual)	Single 200kHz or 100kHz	Single 200kHz or 100kHz	Single and/or Dual	Single Chirped
Towfish length x diameter/height width)(cm)	17.5 cm OD, not including handles, by 100.0 cm long	71.9 cm high by 108.7 cm wide by 209.0 cm long	94 cm (TTV-172); 208.7 cm (TTV-292)	
Towfish weight (air) (kg)	19kg	168kg	34kg (TTV-172); 150kg (TTV-292)	0.4kg, approx.
Max. depth Rating (m)	surface vessel mounted	3000m max.depth	200m	50m
Transducer Type and Material	1-element transmit transducer - 6-element receive hydrophone, one port and one starboard	1element transmit transducer - 6-element receive hydrophone, one port and one starboard	A circular piston that is ½ wavelength in diameter at 4 KHz.	Monolithic Ceramic
Fish height from seabed determination method	First return of data(altimeter optional)	First return of data	First Return from downward facing Sub-bottom transducer	First Return Algorithm
Deployment methods	Surface vessel mounted via a standard low pressure 3-inch pipe flange	Optional winch and vessel mounted handling system	Optional winch and vessel mounted handling system	By hand,towed from boat
Depression technique	Not Applicable	Dead Weight Depressor	Dead Weight Depressor	Unique Body Design
Type of Cable supported	Kevlar deck cables	Light weight Kevlar and or Double armored steel cable	Light weight Kevlar and or Double armored steel	Polyurethane jacketed with internal Kevlar reinforcing (strain) member
Max length of cable (m)	200m max. of Kevlar, 5000m max.of double armored cable	200m max. of Kevlar, 10000m max of double armored cable	up to 200m of Kevlar, up to 1000m of double armored	20m , (50m) available)
Actual frequency (kHz)	200kHz standard frequency and optional 100kHz	200kHz standard frequency	Low Frequency: Sweeps in the 2 to 7 kHz band, High Frequency: Sweeps in the 10 to 20 kHz band	450kHz
Pulse length (µs)	0.125–3 msec in accordance with range	0.125–3 msec in accordance with range	Chirp transmit pulse length, user selectable from 5.0 to 60.0 sec	400msec
Source level (dB relative to µPa at 1m)	+224 dB	+224 dB	Low Frequency: 197 dB nominal, High Frequency: 205 dB	<210dB
Max. Range (m)	25–300m each side (200kHz), 25–600m each side (100kHz)	25–300m each side (200 kHz), 25–600 m each side (100kHz)	1 to 80m of sediment penetration, depending on sediment type	200m max. total (1m to 100m per channel)
Horizontal beam width (deg)	1°	1°	Low Frequency: Downward facing 100º, High Frequency: 30°: conical	0.8º nominal width
Vertical beam width (deg)	100°	100° vertical	100º Low Frequency:30°High Frequency: Conical downward.	60º nominal width
Max. Horizontal Resolution (cm)	Side Scan Across Track 4.5cm resolution, Bathymetry 5.5cm Across Track resolution	Side Scan Across Track Resolution 4.5cm, Bathymetry Across Track Resolution 5.5cm	Not Applicable	
Max. Operating speed (kt)	10kt Max.tow speed	10kt Max.tow speed	6kt Max.survey speed	
Max. Vertical Resolution (cm)	1.0cm	Bathymetry: 1.0cm, Sub-bottom: 7.5cm, depends on pulse length	Sub-bottom: 7.5cm typical, depends on pulse length setting	
Applications	Geophysical Survey Work	Geophysical Survey Work	Geophysical Survey Work	Geological surveys, environmental, reef monitoring.