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Seabed habitat mapping techniques: an overview of the performance of various systems

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Abstract

Seabed mapping has become vital for effective management of marine resources. An important role in moving towards ecosystem based management is played by the defining and understanding of the relationships among marine habitat characteristics, species distribution and human activities. Mapping seabed characteristics by means of remote acoustic sensing, using seabed seismic profiling, sidescan sonar, or echo-sounder based classification systems, is becoming of increasing importance. This paper gives a brief overview of existing marine habitat mapping technologies and their recent developments. In single-beam echo-sounders, using multiple frequencies will be useful in classifying the seabed. It must be observed that the resolution of a sidescan sonar with narrower along-track beam width and higher range sampling rates will be better than a multi-beam echo-sounder, although the specifications of the newer systems are much improved. Airborne LIDAR bathymetry is very useful for shallow water seabed mapping, particularly in challenging rocky areas vulnerable for ship-based mapping operations. Seabed maps are essential in any case for siting of bottom mounted energy devices. The utmost care should be taken at all stages of the classification process, such as input data, control of interfering factors, seabed acoustic attributes, classification methods and ground-truth observations. The results of seabed mapping depend mostly on instrument stability, settings, algorithms adopted, environmental factors and survey methods. It is essential that seabed maps undergo frequent updation and improvement over time due to technological advances.

Keywords: Seabed habitat mapping; Acoustic techniques; Remote sensing.

Introduction

Mapping marine benthic habitats is now widely acknowledged as a critical step for effective and informed management of marine resources (KOSTYLEV *et al.,* 2001). Habitat mapping combines information from sample data with full coverage of physical proxy factors that are known to discriminate between habitats. The latter can be obtained either directly from some form of remote sensing (e.g. bathymetry from acoustic techniques) or derived from physical models (e.g. wave energy from wave height and bathymetry). To address the need for habitat maps that cover significant areas of the seafloor in an efficient way, the scientific community has developed an approach that combines acoustic (sonar) mapping of a larger area of the seafloor with ground-truthing and biological surveys of selected sites by visual observations and sampling. The inferential stage, combining widespread coverage of remotely-sensed information and very limited coverage ground-truth information, has profound consequences for the success of the habitat mapping process, and the quality of the final habitat map (MESH, 2008). Seabed mapping becomes essential for the effective management of the marine environment and the ever increasing exploitation of marine resources.

From the existing literature, it is well known that no universal definition for the process of 'benthic habitat mapping' exists. One reason why a definition has not been forthcoming is the remarkably wide variety of instrumentation and survey techniques that have evolved for characterizing the seafloor (KENNY *et al.,* 2003; SOLAN *et al.,* 2003; DIAZ *et al.,* 2004). With the development of seabed-mapping technologies (KENNY *et al.,* 2003) came the possibility of generating benthic habitat maps that would be useful for assessing the state of living resources in a similar manner to that which has been applied to delineating wetlands or sub-tidal mineral resources. The key to successful application, however, lies in the translation of basic physical data on bottom substrate and characteristics into meaningful representations of benthic habitat quality. The concept of habitat quality incorporates aspects of the physical substrate as they pertain to specified organisms. Extending these primarily substrate defining acoustic techniques to include aspects of the biology is a logical progression since most work on benthic ecology, at least to some degree, has been directed at detailing organism–sediment/substrate interactions and relationships (RHOADS, 1974; GRAY, 1974). Recent high-resolution algorithmic mapping efforts of local features are showing great potential for use in smaller scale management and research investigations (DIAZ, 1999; DARTNELL, 2000; WHITMIRE, 2003). This has led many investigators interested in benthic habitat mapping to equate benthic habitats with bottom sediment or substrate type (DIAZ *et al.,* 2004).

Field surveys involving ship time are notoriously costly. Whilst continuous acoustic surveys provide good value in terms of their data richness and spatial coverage when compared to point sample surveys (e.g. trawls, dredges, grabs), there is scope to improve survey methods and provide value-added data (MACKINSON *et al.,* 2004). In the last decade, acoustic seabed classification has established itself as a standard tool in seafloor surveying and underwater remote sensing. Mapping seabed characteristics by means of remote acoustic sensing, using seabed seismic profiling, sidescan sonar, or echo-sounder-based classification systems, is becoming increasingly important (WIENBERG & BARTHOLOMÄ, 2005). Despite the range and volume of habitat mapping programmes being undertaken, there is only limited internationally-agreed guidance available on the techniques which should be used (ICES, 2007).

It was recognized that each technique (e.g. satellite imagery, sidescan, video, grabs) offers a different view of the marine environment, and that their integration into a single (hierarchical) classification would prove a challenge (ICES, 2006). The objective of this paper is to give a brief overview of existing marine habitat mapping technologies and their recent developments. This paper also deals with essentials of seabed mapping in the context of deployment of wave and tidal energy devices and avoiding conflicts between the various interests of the marine environment.

Single-beam echo-sounders (SBES)

Single-beam echo-sounders (also known as acoustic ground-discrimination systems) are used to obtain a variety of information about the reflective characteristics of the seabed. They send a pulse of sound at a particular frequency (usually within 30–200 kHz) that reflects from the seabed, creating an echo which is picked up by the transducer (KENNY *et al.,* 2003). More recently acoustic ground-discrimination systems (AGDS) have been developed to detect the acoustic-reflectance properties of the seabed. Indeed, the nature of bottom echoes is influenced not only by basic sediment grain-size parameters, sediment sorting, microtopography, sediment density and porosity, but also by the presence, concentration and type of benthic fauna and flora (TSEMAHMAN & COLLINS, 1997; COLLINS & GALLOWAY, 1998; BORNHOLD *et al.,* 1999; HAMILTON *et al.,* 1999; KLOSER *et al.,* 2001; ANDERSON *et al.,* 2002; HUTIN *et al.,* 2005). RoxAnn™ (CHIVERS *et al.,* 1990) and QTC VIEW™ (COLLINS *et al.,* 1996) are two widely used AGDSs to extract shape, energy or both features contained in the bottom acoustic signals. The main characteristics of the most commonly used AGDSs were broadly discussed in KENNY *et al.* (2003).

RoxAnn™, which has been frequently used for environmental studies off the United Kingdom (FOSTER-SMITH & GILLILAND, 1997), uses echo-integration methodology to derive values for an electronically gated tail part of the first return echo (E1) and the whole of the first multiple return echo (E2). While E2 is primarily a function of gross reflectivity of the sediment (hardness), E1 is influenced by small- to meso-scale backscatter and is used to describe bottom roughness. By plotting E1 against E2, various acoustically different seabed types can be discriminated (CHIVERS *et al.,* 1990; HEALD & PACE, 1996; KENNY *et al.,* 2003). Canadian Quester Tangent Corporation's seabed classification system, the QTC View/Impact is one of the newer powerful instruments in the field of seabed studies. It records the first return signal of the transmitted pulse of a single-beam echo-sounder, and processes the data in a geographic information system. The shape of the return wave signal reflects a number of seabed characteristics such as sediment composition, seabed roughness and biological components, which can be used to classify and map seabed types (WIENBERG and BARTHOLOMÄ, 2005). Several studies using the single-beam acoustic seabed classification system QTC VIEW™ Series IV have revealed its ability to distinguish various bottom types and associate them with distinct acoustic properties (HAMILTON *et al.,* 1999; PRESTON, 2001; ANDERSON *et al.,* 2002; FREITAS *et al.,* 2005 & FREITAS *et al.,* 2006). These studies showed that the acoustic response may depend on the surface roughness, sediment grain size, the presence/absence of shell debris and some infaunal species, texture properties of the sediment and sediment porosity, while being independent of depth. However, the acoustic system QTC VIEW™ Series IV is limited to survey depths ranging from

15 to 500 m. Although most studies would not use this type of equipment to exploit deeper areas, its use in waters shallower than 15 m is in much more demand, due to the portability of the whole system and its ability to be deployed from very small boats. For such situations, the QTC VIEW™ Series V was developed, enabling seabed classification in less than 1 m of water and to depths over 2000 m. Moreover, in comparison with the Series IV, Series V has the capability of full echo-length data logging and real-time echo trace viewer, thus providing adequate quality assurance during data acquisition (FREITAS *et al.,* 2008).

From the earlier studies, it has been shown that RoxAnn™ performance is highly dependent on ship speed (HAMILTON *et al.,* 1999). In contrast, QTC VIEW™ systems examine the shape characteristics of the first echo and uses a series of algorithms to translate this into an array of 166 descriptive variables (COLLINS *et al.,* 1996), which are then reduced through principal component analysis (PCA) to three Q-values, Q_1, Q_2, and Q_3 (COLLINS and McCONNAUGHEY, 1998). These three Q-values are plotted in three-dimensional Q-space and then run through a cluster analysis to distinguish acoustically distinct bottom types. The QTC VIEW™ classification accuracy has been shown to be greatly affected by bottom slopes exceeding approximately 5–8° (VON SZALAY and McCONNAUGHEY, 2002). According to HAMILTON *et al.,* (1999), QTC VIEW™ appears to be the more consistent and reliable of the two systems.

The performance of the recently introduced acoustic system QTC VIEW™ Series V was analysed by FREITAS *et al.,* (2008) and used to identify seabed habitats in a shallow water system located in the inner basin of the Bay of Cadiz, SW Spain. The inner basin is shallower than 5 m except for the navigation channels, and is characterized by turbid water and an extensive bottom coverage of a mixture of macroalgae and phanerogams (RUEDA & SALAS, 2003). Two different echo-sounder frequencies, 50 kHz and 200 kHz, were used in the surveys and their results were compared. The acoustic data obtained at the two different frequencies were individually submitted to manual clustering and a final solution consisting of three acoustic classes was reached for both datasets. Only the geographical distribution of the acoustic classes obtained with 50 kHz echo-sounder frequency was coincident with the spatial distribution of the superficial sediment groups (silty medium sand, very silty fine sand and mud), identified through multivariate analysis of the grain-size data of ground-truth sediment samples. The results obtained with the 200 kHz echo-sounder frequency did not match the sedimentary gradients obtained for the area surveyed and could not even obtain the separation of muddy and sandy areas due to suspended sediments (FREITAS *et al.,* 2008). Compared with traditional physical sampling, acoustic tools permit rapid, broad-scale, and non-intrusive sampling of the seabed. Some systems register and display the full echo waveform envelope upon which the classification procedure operates. However, the outcome of AGDS classification should be assessed based on comparisons with ground-truth sampling.

Multi-beam echo-sounders (MBES)

Multi-beam bathymetry sonar employs many simultaneous beams of sound to cover a large fan-shaped area of the ocean floor rather than the small area of seafloor covered by echo-sounders. Multi-beam systems can have a large number of transducers, arranged in precise geometrical patterns, sending out a swath of sound that will cover a distance either side of the vessel that is equal to about twice the water depth. The data acquired by multi-beam systems are much more complex than single-beam surveys. Multi-beam systems will produce high-resolution bathymetry data throughout the survey area. Since they acquire dense sounding data both along the ship's track and between the track lines, they can provide 100% coverage of the seafloor. Marine vessels also use this technology to avoid danger areas, to find fishing grounds and for precise seabed mapping. There are different versions of MBES available for seabed mapping. Table 1 shows some general characteristics of different MBES systems. From the table, it is understood that old versions such as EM 2000, EM 3001 and EM 3002 are useful only for shallower depths ranging from a few metres to 300m; whereas the latest versions such as EM 122, EM 302 and EM 710 can be applied up to 11000m, 7000 and 2000m respectively. A similarly higher swath width can be achieved through the newer versions when compared to older versions.

A typical high resolution set-up would be a 1.5° beam width in 30m of water providing a 0.8m diameter nadir footprint (KENNY *et al.,* 2003). Relative performance of some of the older and newer versions of MBES are presented in Table 2. The recent version EM 710 system generates 256 beams/400 soundings per ping for 0.5 and 1° systems and 128 beams/200 soundings for a 2° system,whereas other recent systems, EM 122 and EM 302, have up to 288 beams/432 soundings per swath with pointing angles automatically adjusted according to achievable coverage. In multiping mode, 2 swaths are generated per ping cycle with up to 864 soundings. These systems are also equipped with a function that reduces the transmission power in order to avoid injury to marine mammals that are close by (KONGSBERG, 2008). RESON's SeaBat 8000 series represented the first pioneering wideband MBES. The SeaBat 8000 series features true delay beam form-

Table 1
Characteristics of some multi-beam echo-sounders.

Type	Frequency in kHz	Simultaneous beams up to	Depth range (m)	Achievable swath width	Accuracy	Manufacturer
EM 2000	200	111	1 - 300	7 x Depth or 300m	NA	Kongberg
EM 3001	300	NA	0.5 - 200	10 x Depth or 200m	NA	Kongberg
EM 3002	300	NA	0.5 - 200	10 x Depth or 200m	High	Kongberg
EM 122	12	288	20 – 11,000	30,000m	High	Kongberg
EM 302	30	288	10 – 7000	5.5 x Depth or 8 km	High	Kongberg
EM 710	70 - 100	256	3 - 2000	5.5 x Depth or 2500m	NA	Kongberg
GeoSwath Plus	125, 250 & 500	NA	0.5 - 200	12 x Depth or 780m	NA	Kongberg
Sonic 2024	200 – 400	256	200	400m	NA	R2Sonic LLC
SeaBat 8125	455	240	0.5 - 120	400m	High	RESON

NA – Details not available

Table 2
Relative performance of previous and recent versions of multi-beam echo-sounders.

Specifications	Previous version EM 2000		EM 3001		EM 3002		New version EM 122	EM 302	EM 710	Sonic 2024
	120° version	150° version	Single sonar head	Dual sonar head	Single sonar head	Dual sonar head				
Angular coverage	120°	150°	130°	200°	130°	200°	NA	NA	140°	130°
Beam spacing	Equiangular or equidistant		Equiangular		Equiangular or equidistant		Equiangular or equidistant	Equiangular or equidistant	Equiangular or equidistant	NA
Depth resolution	1 cm		1 cm		1 cm		1 cm	1 cm	1 cm	NA
Pulse length (μs)	200		150		150		NA	NA	NA	10 μs – 1ms
Range sampling rate (kHz)	11		14		14		NA	NA	NA	NA
No. of soundings per ping	111	111	160	320	254	508	864	864	800	NA
Pitch stabilisation	NA	NA	Yes	Yes	Yes	Yes	± 10°	± 10°	± 10°	NA
Roll stabilisation	NA	NA	Yes	Yes	Yes	Yes	± 15°	± 15°	± 15°	NA
Swath profiles/ping	NA	NA	NA	NA	NA	NA	1 or 2	1 or 2	NA	NA
Pulse forms	NA	NA	NA	NA	NA	NA	CW and FM chirp	CW and FM chirp	CW and FM chirp	CW

NA- Details not available

ing and dynamic focusing capabilities. The range of SeaBat 8000 echo-sounders and imaging sonar systems are being used with success in dredging projects, rivers, harbor inspection surveys, oil field engineering, oceanographic research projects, environmental studies, mine detection, obstacle avoidance and numerous other submarine applications.The SeaBat 8125 is the first wide-sector, wide-band, focused multibeam sonar ever to be deployed. Utilizing 240 dynamically focused receive beams, the system measures a 120° swath across the seafloor, detects the bottom, and delivers the measured ranges at a depth resolution of 6mm. The backscatter intensity image is displayed in real time on the sonar display. The SeaBat 8125 can be mounted on a survey vessel or deployed on an ROV at depths down to 1500m (RESON, 2006).

Sidescan Sonar (SSS)

The sidescan sonar is a predominant tool for imaging the seafloor because of its good object detection and seafloor character discrimination when deployed with the transducers mounted on a tow fish close to the seafloor. SSS technology will provide high resolution, almost photographic quality imagery of the seafloor. SSS data are some of the best available for marine habitat mapping on both regional and local scales. The utility of SSS data is largely a function of system frequency, where low frequency systems have low spatial resolution and tend to penetrate the bottom, reducing their effectiveness for surficial mapping. High frequency systems in contrast have high utility for surface mapping and qualitative delineation of sediment types.

The 'Compressed High Intensity Radar Pulse' (CHIRP) techniques and synthetic aperture sonars (SAS) provide high-resolution sonar images at a greater range (McHUGH, 2000). These systems emit more energy by generating longer-duration and wide-bandwidth pulses, with the resolution of the sonar depending on the bandwidth and not the pulse length, as is the case with traditional SSS. By constantly changing its frequency over time, the chirped transmission can be thought of as having a unique acoustic signature. Thus, if two pulses overlap because the targets are closer than the range resolution, the known frequency versus time information can be used to tell them apart. The advanced digital CHIRP acoustic techniques employed by StarFish SSS can offer a better range resolution. The GeoAcoustics Dual Frequency SSS-Multiplexer will offer flexibility and high quality results up to 1000 m depth operating at 114 and 410 kHz. This system can perform high resolution direct digital sampling and dynamic range (24 bit), with simultaneous dual frequency operation. Other versions, Sportscan and SHD700SS are useful at shallower depths. Performance characteristics of some of the advanced versions of EdgeTech SSS are presented in Table 3. From Table 3, it is evident that there are versions available to capture the seabed from 1000 m to 6000 m. Most of the recent versions of SSS are operating in CHIRP mode with digital technology.

Modern high (dual) frequency digital SSS devices offer high-resolution images of the seabed on which objects of the order of tens of cm may be detected at a range of up to 100m either side of the tow fish (total swath width 200 m). A major advantage is that under optimal conditions, SSS can generate an almost photo-realistic picture of the seabed. Once several swaths have been mosaiced, geological and sedimentological features are easily recognisable and their interpretation provides a valuable qualita-

Table 3
Performance characteristics of some advanced EdgeTech Sidescan Sonars.

Version	4100		4200MP				2400DSS	
Frequency (kHz)	100	500	300	600	100	400	120	410
Horizontal beam width(°)	1.2	0.5	0.28	0.26	0.64	0.3	0.9	0.6
Vertical beam width(°)	-	-	-	-	-	-	70	70
Depth rating (m)	1000	1000	300	300	2000	2000	6000	6000
Maximum operating range	500m swath	200m swath	230m/ side	120m/ side	500m/ side	150m/ side	800m	300m

tive insight into the dynamics of the seabed. SSS does not normally produce bathymetric data, but does provide information on sediment texture, topography, and sea grass meadows, and the low-grazing angle of the beam makes it ideal for object detection (KENNY *et al.,* 2003).

In addition to the above systems, MS992 SSS is a simultaneous dual frequency system available with 120/330 kHz and 120/675 kHz and ROV mountable with a depth rating of 1000m. Similarly, KLEIN 3000 digital SSS system with simultaneous operating frequency of 100/500 kHz with a horizontal beam of 1° and 0.2° at 100 and 500 kHz respectively and a vertical beam of 40°, is a versatile system easily adapted to ROVs and Towfish. This system has a standard depth rating of 1500m with options to 3km and 6km. The sidescan sonar does not measure calibrated backscatter strength however, only amplitudes with an unknown absolute level compensated by a 20/30/40 logR TVG. The sidescan sonar data may be slant range corrected, but only presuming a flat bottom and cannot thus be correctly scaled when taking into account variation in bottom slope. The sidescan sonar is usually towed close to the bottom and most data is collected at low incidence angles for shadow detection purposes. In contrast, the majority of multibeam data is collected at higher incidence angles for classification purposes.

Remote Sensing

Due to a lack of accurate baseline habitat maps in the Wider Caribbean region, WABNITZ *et al.,* (2008) wanted to generate high resolution remote sensing data. The main goal of their study was to achieve Landsat based large-scale seagrass mapping with limited ground truth data and acceptable accuracies. They used a combination of methods such as geomorphological segmentation, contextual editing and supervised classifications. Accuracies reported spanned a broad range of values between 46 and 88% but were comparable with those from previous Landsat based seagrass mapping efforts. Consistently higher values could have been achieved had images with high spectral and/or spatial resolution been used to map seagrass extent (MUMBY & EDWARDS, 2002; HOCHBERG & ATKINSON, 2003). However, data availability and costs justify the use of Landsat images in the study by WABNITZ *et al.,* (2008), rather than IKONOS and Quickbird imageries.

Airborne LIDAR (light detection and ranging) bathymetry is a relatively new technique for shallow water mapping, having become well established in the past decade. Significant advantages are rapid and efficient data collection and elimination of the safety issues associated with mapping shallow, rocky areas from small boats. Significant limitations are imposed by water turbidity, which affects the depth of light penetration into the water; whitewater on the sea surface, which can cause false or degraded surface returns as well as scattering signal energy; and weather and safety considerations for the operation of small aircraft (REYNOLDS *et al.,* 2008).

Seabed mapping for Marine Spatial Planning

Marine habitat maps provide useful information which might be helpful in spatial allocations for future uses. It will help to avoid conflicts among the various interests invested in marine resources. There are many demands placed on the marine environment; in addition to the current demands placed on them by fishing and the extraction of oil, gas and aggregates (gravel extraction), there are increasing pressures from things such as offshore wind-farms and leisure activities. Already marine species are in decline as a consequence of activities such as bottom trawling and dredging. Seabed habitat maps provide vital information to help us obtain a balance between these demands and conservation (MESH, 2008). In the context of marine renewable energy exploitation, these maps will play a pivotal role in identifying the locations for the deployment of wave and tidal energy devices and to avoid potential sites of nature conservation. Multibeam bathymetry data provides detailed topography of the seabed and water depths. Areas of potential tidal resources may be overlain with other interests or sectoral uses which might occupy the same locations or area of sea and/or form a conspicuous constraint to deploying tidal energy devices. Conflict between tidal energy and other special interests would be avoided by the detailed seabed maps (GUBBAY *et al.,* 2006). Seabed maps are very useful in key understanding of seabed materials and processes for the appropriate siting of bottom mounted energy devices.

Discussion

Habitat valuation is an essential tool for tracking changes in habitat quality and in adjudicating environmental mitigation. All current methods for estimating habitat values of coastal marine sites rely heavily on the opinion of experts or on data variables that can readily be manipulated to influence the outcome. As a result, unbiased quantitative comparisons between the values of different marine habitats are generally unavailable (BOND *et al.,* 1999). Seabed mapping is critical to improving the understanding of ecosystem dynamics and relationships between habitats and biota. In the absence of detailed seabed information, decision makers often feel handicapped in making decisions about the effects of different activities on marine habitats.

Many field surveys typically utilize several acoustic tools. A number of features have contributed to the good reputation earned by the SBES approach, namely its non-intrusive properties, the ability to cover large areas with almost continuous sampling rates, the discrimination of a variety of soft sediment types and bottom features and their lower cost compared to side-scan sonar or multi-beam systems. In SBES, using multiple frequencies will be useful in classifying the seabed. Even though lower frequencies penetrate deeper, multiple frequencies will help identify even small structures. Currently two or more frequencies have been combined for SBES to improve seabed classification (KLOSER *et al.,* 2002; FÖSA *et al.,* 2005). Combining multiple frequency SBES with single frequency MBES may be a cost-effective approach. Similarly combination of data from SBES and MBES could yield desirable results in seabed classification. Performance of different acoustic systems on different features is presented in Table 4.

Sidescan sonar and/or multi-beam echosounder can be used to develop a composite picture of roughness/hardness and bathymetric profile and a single beam echosounder for detailed ground discrimination (MACKINSON *et al.,* 2004). For multibeams which use sectorized transmission (in most current Kongsberg systems), the beam defocusing is applied in the central sector(s) in shallow waters which will imply that the near field will be shortened and the drop-off in pressure level will start earlier. For curved transducers the near field limit and the pressure level will remain fairly constant across the whole angular coverage angle. Sonars may be transmitting horizontally and with a sound speed profile where the sound speed lessens towards the surface, then spreading will be cylindrical even in the far-field due to ducting, causing a sound channel at the surface. For multibeam echo-sounders this is usually not the case, except for tilted systems such as with the dual head EM 3002 (HAMMERSTAD, 2005). In benthic marine habitat studies,

Table 4
Performance of acoustic systems on different features.

Feature	System	Performance
Spatial coverage	SBES	Due to narrow swath with no angular resolution typically sampled across-track, large areas of seabed remain unsampled between track lines
	MBES	Fine-scale and continuous coverage enables significant classification in seabed mapping
	SSS	Increase in coverage but are restricted to off-axis roughness component. Relied on visual interpretations rather than image processing
	SBES+MBES +SSS	Combination of these systems provides opportunity to map and classify features from the scale of boulders (< 1 sq. m) to banks (>10000 sq. m) and shelves (>100,000 sq. m)
Spatial scales	SBES	Adjacent pings are normalized into a single observation to a scale of about 100 sq. m.
	MBES	Accurate geo-referenced locations at scale 0.25 sq. m
	SSS	Accurate geo-referenced locations at scale 1 – 2 sq. m
Calibration difficulty	SBES	Low
	MBES & SSS	High
Frequency	SBES	Combination of two or more frequencies in the range of 10 – 300 kHz will improve seabed classification for mapping
	SBES & MBES	Combining multiple frequency SBES with single frequency MBES will provide better classification results

Note: SBES – Single beam echo sounders; MBES – Multi beam echo sounders; SSS – Side scan sonar however, surveying the distribution of different species and biological assemblages is the problem rather than the solution. Instead, seafloor depth, morphology, and substrate characteristics form the framework for classifying the seafloor into regions of distinct benthic habitats.

To compensate for the shortcomings of high-resolution acoustics, equipment such as sidescan sonar (BROWN *et al.,* 2002) or multi-beam systems (KOSTYLEV *et al.,* 2003) become more appropriate for complete coverage of a site. These systems provide a more precise mapping of the seafloor topography by using multiple beams. A major advantage of MBES over sidescan sonar is that MBES generate quantitative bathymetric data that are much more amenable to classification and image processing but the narrow beam width means MBES is less useful for detection of small objects (BRISSETTE & CLARKE, 1999). However, the distance between the instrument and the seafloor affects spatial resolution for all systems. A combined application of sidescan sonar and QTC View/Impact would be highly effective in characterizing the seabed sedimentologically and morphologically. Due to the smaller footprint, the QTC seabed classification is based solely on the nature of the primary return signal, whereas the backscatter of the sidescan sonar is influenced by both seabed roughness and morphology. Moreover, sidescan sonar provides a better spatial resolution of hard and smooth surfaces (WIENBERG & BARTHOLOMÄ, 2005).

Perhaps the most important consequence of the habitat mapping process is the fact that habitat maps are not purely a statement of observational data: they predict habitat distribution based on the best available information and, ideally, should be derived from well developed models linking physical factors to biological data (MESH, 2008). However, classifying sidescan data to define bottom types remains elusive, as the backscatter intensities are not unique and are dependent on system gainsetting, bottom topography, sea-state, and other factors (LANIER *et al.,* 2007). The emergence of remotely sensed acoustic technologies coupled with ground-truthed information with geo-referenced towed camera systems enables scientists to survey larger area of seabed and to produce high resolution maps of topography, subsurface structures and seabed habitats. Therefore, bringing together remotely-sensed data and ground-truth data is fundamental to the habitat mapping processes.

Acoustic seabed classification is both less expensive and less time consuming, and also provides higher spatial and temporal resolution than conventional methods such as *in situ* sampling of bottom sediments or underwater video-recording (BLONDEL, 2003; KENNY *et al.,* 2003). There are sampling issues: how representative is a ground-truth sampling programme of the whole area? The remote sampling techniques will have their limitations: how successful is discrimination between habitats for different techniques and deployment strategies? Since only a small proportion of an area of the sea floor will be sampled, there is uncertainty about inferred habitat distribution: how accurately does a map predict actual distribution? (MESH, 2008). In this context it is very evident that ground-truth sampling plays a pivotal role in seabed mapping. Therefore it is essential to formulate the procedural strategies to carry out ground-truth sampling so that seabed mapping will be an ideal representation of the seabed. Finally it must be observed that the resolution of a SSS with narrower along-track beam width and higher range sampling rates will be better than a MBES, although the specifications of the newer systems are much improved. However, the logged data of these systems are not such that they allow the post-processing to absolute levels, resolution or correct geographical scaling. As far as remote sensing applications are concerned, airborne LIDAR bathymetry is very useful for shallow water seabed mapping, particularly in challenging rocky areas vulnerable for ship-based mapping operations.

Summary and remarks

Research and management both require, at the very least, a basic level of seafloor data such as accurate bathymetry and textural or sediment distribution maps, as well as habitat maps. Thematic maps that depict the distribution and abundance of seafloor types will enhance the capability to apply spatially explicit actions in the marine environment. Only a small proportion of the sea floor can be directly observed or sampled and the complete coverage of habitats is inferred (predicted) from the association between the full coverage of physical habitat data and samples. When properly interpreted, physical habitat factors act as a proxy for the biological habitat data. As mentioned above, the quality of seabed maps will be enhanced based on adequate ground-truth sampling. The utmost care should be taken at all stages of the classification process, such as input data, control of interfering factors, seabed acoustic attributes, classification methods and ground-truth observations. The results of seabed mapping depend mostly on instrument stability, settings, algorithms adopted, environmental factors and survey methods; since seabed maps provide vital information it is necessary to consider carefully each of the factors mentioned above. Seabed maps require frequent updation and improvement by considering the recommendations of different international expert groups working on the subject areas.

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