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Detection of bottom substrate type using single-beam echo sounder backscatter: a case study in the east coastal of **Banyuasin**

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Abstract. This research was aimed to identify substrates type in the east part of the Banyuasin coastal waters using quantitative backscatter data from single-beam echo-sounding. The SIMRAD EK-15 was used to classify the seafloor substrate types. The ground truth was required for calibrating the acoustic result. Wet sieving methods and Shepard's triangular diagram were used to analyze the ground truth samples. The acoustic data were filtered to extract the volume backscattering strength of bottom surface (SV) using Echoview 4.0. The data of bottom surface backscattering strength (SS) and SV were classified by using Hierarchical Cluster Method. Data of substrate type from the ground truth will be used as a guideline to classify the SS data to identify the substrate type based on the SS characteristic which associated with various types of the bottom substrate. The results showed the single beam capability in distinguishing the types of bottom substrate, namely clayed sand with the SS value ranges from -47.29 to -46.32 dB), silt + sand + clay with the SS value ranges from -51.00 to -48.54 dB), clayed silt with the SS value ranges from -53.47 to -52.24 dB), and silty clay with the SS value ranges from -56.89 to -55.94 dB.

Keywords: bottom surface backscattering, echo sounder, single beam, substrate

Introduction 1.

Information on a seafloor composition is very important for various fields of activity such as marine geology, marine biology, off-shore construction projects, coastal infrastructure building planning, environmental defense organizations, fishery management strategies and monitoring (Eleftherakis et al 2012, Costa et al 2013, de Pinho et al 2016, Montereale-Gavazzi et al 2018, Fauziyah et al 2018). In the terms of ecology, the seafloor is responsible for various processes that often affect the species spatial distribution and become the basis for interactions between ecosystems (Costa et al 2013) and used as

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the key indicators of 'Good Environmental Status' (Montereale-Gavazzi *et al* 2018). The substrate type of the seafloor in the Banyuasin coastal waters was one of the key factors for the shrimp abundance (Fauziyah *et al* 2019a) and the fish community stability (Fauziyah *et al* 2019b).

One method that the most cost-effective for detecting and mapping the coastal and marine resources was hydroacoustic (Manik 2015) and this method has become a standard tool for the seafloor mapping and classification around the world (Bartholomä 2006). An approach of acoustic remote sensing techniques for classifying the sediments commonly use equipments such as single beam echo sounder (Hamuna et al 2017, Amri-Simkooei et al 2011, Snellen et al 2011), split-beam sounder (Costa et al 2013, de Pinho et al 2016, Zakariya et al 2018), and multi-beam echo sounders (Eleftherakis et al 2012, Montereale-Gavazzi et al 2018, Harahap et al 2010). Whereas single beam echo sounder (SBES) acquires a single measurement per ping, the MBES (multi-beam echo sounders) can take up to 500 measurements per ping along a wide swath perpendicular to the direction of navigation. Despite the advantages of the MBES, the SBES is still extensively used. Methods that base the sediment classification on SBES measurements are consequently of high interest (Snellen et al 2011). The various advantages of SBES were: 1) low data volume and standardized procedures cause the data processing was more efficient; 2) the acquisition costs were comparatively low; 3) using multiple frequencies during one survey was very possible; 4) availability of water column backscatter and easy for processing; 5) on-axis calibration to scientist; 6) ready to use and comprehensive; and 7) relatively easy to be understood and operated (Anderson et al 2008).

The seafloor composition mapping is an ultimate goal of acoustical remote sensing techniques. Information about the seafloor composition was obtained from the shape and intensity of the received signal. Different types of sediments can be identified from changes in the form of the echo received from one of sediment to another (Amri-Simkooei *et al* 2011). Information about the sediment type can be produced from the combination of data of echo form changes and ground truth from different areas (Lied *et al* 2004). Direct estimation of target strength (TS) cannot be done because of the SBES system does not provide information on target location. Therefore when using the SBES system, the SS distribution must be estimated statistically (Manik *et al* 2014). Based on the approach of acoustic remote sensing techniques, this research is aimed to identify and classify substrates type using quantitative SBES backscatter in part coastal waters of Banyuasin.

2. Materials and methods

2.1. Study location

The study took place in the eastern part of the Banyuasin coastal waters (figure 1). A field survey was conducted on September 2017.

2.2. Acoustic sampling

Acoustic sampling was carried for 3 days using a mixed survey design consisting of parallel and series (figure 1). The total Elementary Sampling Distance Unit (ESDU) used was 13 ESDUs with a total distance of 24.05 nmi or 44.60 km and a distance of 1 ESDU of 1.85 nmi or 3.43 km.

Acoustic sampling was performed by means of SIMRAD EK-15 (a scientific single beam echo sounder) operating at 200 kHz. Acoustic data were recorded at a constant speed of 5 knots. To minimize the effect of noise in order to produce a good recording quality, the transducer was mounted on the center-right side of the ship at a depth of 1 meter below the seawater surface, specifically at the sediment sampling location, recording acoustic data was carried out for approximately 1 hour.



Figure 1. Study location and cruise track, scale 1:100,000 (\bullet = oceanography parameter sampling station, \blacksquare = land, \square = sea, O = sampling station, - = survey track).

2.3. Sediment sampling

Groundtruth information was required for calibrating the acoustic classification results. This information was collected from the sediment sampling undertaken at the track lines of acoustic survey. This line track was the principal test location to associate between the backscatter data and the seafloor substrate types.

The sediment samples were collected using Ekman Grab $(15 \times 15 \text{ cm})$ based on the stratified random sampling methods. In relation to the acoustic sampling, ground-truthing was carried out to identify the seafloor substrate types at 7 station points based on field conditions that allowed for sampling and closeness to the track lines of acoustic survey (figure 1). In order to verify the acoustic sampling results, the sediment sampling was attempted just below the transducer then the sample was put into a plastic bag, labeled and sealed (Hamuna *et al* 2017, Zakariya *et al* 2018). The sediment samples were taken to the laboratory and substrate texture will be used as in situ data and comparative data from the acoustic data (Fauziyah *et al* 2018, Hamuna *et al* 2017).

2.4. Sediment and acoustic data analysis

The wet sieving technique was used to determine the size grains of the sediment from the sediment samples that have been obtained (Haris *et al* 2018). Substrate texture analysis was based on Shepard's triangular diagram for samples containing silt, clay, and sand (Costa *et al* 2013, Fauziyah *et al* 2018, Ningsih *et al* 2013).

To extract the volume backscattering strength of bottom surface (SV), the acoustic data obtained at 200 kHz were filtered using Echoview 4.0. The SV data obtained consists of backscattering value from the first reflection (E1) and the second reflection (E2). In this study, the SV value used was the E1 value (Hamuna *et al* 2017). The E1 value was processed using the threshold range from -50.00 dB to 0 dB (Fauziyah et al 2018, Hamuna *et al* 2017, Pujiyati *et al* 2010). The Elementary Sampling Unit (ESU) used in the data processing to find out the SV value was 100 pings (Hamuna *et al* 2017). The integration thickness of the E1 value was 0.15 meters which were adjusted to the grap sampling (15×15 cm).

Data processing was done at the peak intensity value or the maximum value of the raw SV on each ping. This value was considered the SV value produced by the bottom substrate (Pujiyati *et al* 2010). This study also used the backscattering strength of bottom surface (SS) as the acoustic parameters of the bottom surface for further analysis.

Formulations that explain the relationship between the raw bottom backscattering strength (Ss) and the raw SV value of the bottom echo (S_{VB}) (Manik *et al* 2006, Manik 2011) as:

$$S_{VB} = \frac{Ss \Phi}{\Psi(\frac{c\tau}{2})} \tag{1}$$

where, S_{VB} = the raw SV value for the seafloor echo (not averaged)

- Ss = the raw backscattering strength for the seafloor
- Φ = instantaneous equivalent beam angle for surface scattering
- Ψ = equivalent beam angle for volume scattering
- c = sound speed (m/s)
- τ = the pulse width (ms).

At the seafloor echo peak, integration value $\Phi \cong \Psi$, therefore, equation becomes:

$$Ss = \left(\frac{c_1}{2}\right) S_{VB} \tag{2}$$

$$SS = 10log(\frac{c\tau}{2}) + S_{VB}$$
(3)

$$SS = 10 \log Ss \tag{4}$$

2.5. Clustering

This study used an unsupervised classification method namely class assignments were only based on the data distribution and then associated with ground-truthing. The hierarchical cluster method was utilized to identify any similarities between group of acoustic sampling sites based on the E1 and SS value. This result was displayed in the dendrogram.

2.6. Calibration

The classification system based on empirical relationships between acoustic parameters and the sediment properties needs to be calibrated. Calibration method consists of direct or indirect calibration methods (Penrose *et al* 2005). This study used an indirect method was that of applying the acoustic data classification base on the hierarchical cluster method, as well as using ground-truth to provide the meaning of the acoustic cluster. Based on the compatibility between the acoustic cluster and the sediment cluster, the substrate type can be determined. The stepwise multiple regression model was developed to examine relationships between the sediment fraction and SS value.

3. Results

3.1. Hydroacoustic

The spatial distribution of sedimentary properties and bathymetry in the sampling locations were identified from the results of hydroacoustic measurements. The sampling locations in Banyuasin coastal water were shallow with minimum depth of 2.8 m and maximum depth of 8 m (table 1). The E1 values ranged from -12,91 dB to -2.34 dB and the SS value ranged from -56.89 dB to -46.32 dB.

The first analysis was to use the backscattering value (E1 and SS) and apply the hierarchical cluster method to create the acoustic data classification (figure 2). The results identified four unique clusters of stations, i.e., Cluster A containing the stations 2, 4, 6, 13, Cluster B containing the stations 3, 5, 8, 8, Cluster C containing the stations 10, 11 and Cluster D containing the stations 1, 7, 12. The SS interval value for cluster A ranged between -47.29 dB and -46.32 dB, cluster B ranged between -51.00 dB and -48.54 dB, cluster C ranged between -53.47 dB and -52.24 dB, and cluster D ranged between -56.89 dB

and -55.94 dB. This clusters can reveal the substrate types. The results of classification cluster (figure 2) would be compared with the classification result of the seafloor substrate (figure 4).

Station	Depth (m)	E1 (dB)	SS (dB)	
1	3.50	-9.49	-53.47	
2	3.59	-2.99	-46.97	
3	5.67	-6.16	-50.14	
4	3.74	-2.51	-46.49	
5	5.17	-4.56	-48.54	
6	7.25	-2.34	-46.32	
7	2.80	-8.26	-52.24	
8	7.78	-5.25	-49.23	
9	8.00	-7.02	-51.00	
10	4.90	-11.96	-55.94	
11	3.90	-12.91	-56.89	
12	5.93	-8.52	-52.50	
13	4.30	-3.31	-47.29	

Table 1. Acoustic bottom backscattering strength from each acoustic sampling in Banyuasin coastal water.

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Rescaled Distance Cluster Combine
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Figure 2. Cluster analysis dendrogram of the acoustic data.

3.2. Substrate types based on ground truth

Based on the substrate compositions (figure 3), the classification method was used to generate a set of substrate classes typifying the ground truth area (figure 4). Using Shepard's triangular diagram, meaningful substrate type can now also be distinguished. Figure 4 shown that the substrate type in the ground truth area is divided into four clusters, i.e., silty clay (station 10, station 11), silt-sand-clay (station 8, station 9), clayed silt (station 7) and clayed sand (station 6, station 13).

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Figure 3. The Sediment percentage based on ground truth in Banyuasin Coastal Water, silt (blue), clay (orange), sand (grey).

3.3. Acoustic classification based on ground truth

The sediments consisted of four bottom substrate types: silty clay, silt-sand-clay, clayed silt, and clayed sand (figure 4). These results were used to describe each of the acoustic classes. The acoustic classes obtained by matching the ground truth classes have been analyzed, so that the SS value is obtained for each substrate type (table 2). The results show the interval value of SS for clayed sand ranged between -47.29 dB and -46.32 dB, the type of silt+sand+clay ranged between -51.00 dB and -48.54 dB, clayed silt ranged between -53.47dB and -52.24dB, as well as ranged between -56.89 dB and -55.94 dB for silty clay.



Figure 4. Shepard's triangular diagram of the sediment data.

The clayed sand substrate has the highest SS value among the silt+sand+clay, clayed silt, and silty clay. This result indicate that the sand percentage as a factor causing different value of the bottom surface backscatter strength. The multiple regression resulting from adding stepwise substrate fraction parameters in the model are given in table 3. The contribution of sand percentage to the model is significant (P < 0.05) and helps to explain 70% of the variance in SS value to sand percentage (adj. $R^2 = 0.70$). Conversely, the percentage of clay and silt does not have a contribution to the model. There was a positive correlation between the SS value and the sand percentage of bottom substrate.

Clustering Station		Substrate Tipe ²	
Acoustic data ¹	Sediment data ²	- Substrate Tipe	
Cluster A:	Cluster A:	Clayed sand	
Station: 6, 4, 2, 13	Station :6, 13		
SS: -47.29 to -46.32 dB			
Cluster B:	Cluster B:	Silt + sand + Clay	
Station: 5, 8, 3, 9	Station: 8, 9		
SS : -51.00 to -48.54 dB			
Cluster C:	Cluster C:	Clayed Silt	
Station: 7, 12, 1	Station: 7		
SS: -53.47 to -52.24dB			
Cluster D:	Cluster D:	Silty Clay	
Station: 10, 11	Station: 10, 11		
SS: -56.89 to -55.94 dB			
· Hierarchical Cluster Method			

 Table 2. The classification of the SS and substrate type in Banyuasin Coastal Water.

: Hierarchical Cluster Method

² : Shepard's triangular diagram

Dependent Variable	Intercept		β_i			
	(β_0)	Sand	Clay	Silt	Auj. K	
SS value	-56.2	0.17*	NS	NS	0.70	
* : Significant level p <	0.05; NS : N	lot Significant				

4. Discussion

This study found the SS values ranged from -55.94 to -47.29 dB. The high decibels shown coarse particles because the rough surface will reflect sound waves, while low decibels have shown a soft surface because some sound waves are being absorbed (Zakariya et al 2018).

In this study, the acoustic classification was generally in accordance with the sediment sampling. Acoustic class A was associated with the clayed sand, class B comprised combinations of sand, silt and sand, and class C associated with the clayed silt and class D associated with the silty clay. According to the stepwise multiple regression, the sand fraction is a key factor affecting the SS value. The higher the sand fraction, the higher the SS value. Thus, the most important influences on the acoustic classification (Ellingsen et al 2002, Collins and Lacroix 1997) were the seafloor roughness and the density difference between the water and the seafloor material. The grain size and porosity were the best descriptors of surface properties (Preston et al 1999).

There was a strong correlation between the SS values and the seafloor substrate type (Haris et al 2015, Kloser et al 2010) as well as a very strong positive correlation between the SS value and the sand percentage (Fauziyah et al 2018). The value of roughness, hardness, and grain size for the sand substrate greater than the substrate type of clayed sand and clay (Hamuna et al 2017, Ningsih et al 2013, Pujiyati et al 2010). The values of acoustic backscattering for the sand substrate also greater than clay and clayed sand (Hamuna et al 2017, Ningsih et al 2013, Pujiyati et al 2010). Based on Shepard's triangular diagram, the substrate type of clayed sand tend to have more the sand fraction than sandy clay, silty clay and clayed silt.

Echo sounders have to be calibrated in order to produce accurate estimates, and the simplest is to place a target with known acoustic size in the center of the beam and adjust the gain (Sathishkumar *et al* 2013). For accurate classification, the echoes should be influenced only by properties of the seabed. The bottom acoustic roughness and hardness would affect the echo shapes and energies (Penrose *et al* 2005). Acoustically, greater penetration into softer sediments weakens signal strength more than harder sediments and a smooth flat seafloor returns the incident ping with a form that is largely unchanged. Smoother sediment surfaces provide less backscattered energy from the beam outer parts than rougher sediment surfaces, at the same composition, a rougher surface is expected to have a lower peak and a longer tail (Penrose *et al* 2005, Hamilton 2001).

In reality, the situation is more complicated if suitable averaging techniques are not used because of the harder seafloor surfaces such as rock that tend to own greater roughness than others sediments, produce vary the return shape and energies that could own an average signal strength that identical with mud (Hamilton *et al* 1999). A very rough rocky bottom may show less echo reflection than muddy sediments, as well as losses in consequence of the roughness effect could produce sand with ripples, waves, holes and scour to appear on several acoustic measures that have the identical properties as mud (Penrose *et al* 2005, Hamilton 2001).

Some bottoms may have similar acoustic signatures but are not similar for their substrate type. This was due to differences in the specifications of acoustic instruments used, and differences in water conditions, such as salinity, depth, and temperature. Although the acoustic system provides useful information, its use requires the ground truth data of the seafloor which is classified by conventional techniques (Hamilton *et al* 1999).

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