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Measurement and analysis of acoustic backscattering strength for characteristics of seafloor sediment in Indian Ocean WPP 572-573

Fauziyah[1], Priatna A[2], Prakoso W F[1], Hidayat T[2], Surbakti H[1] and Nurjuliasti E[1]

[1] Marine Science Study Programme, Sriwijaya University, Indonesia
[2] Marine Fisheries Research Agency (MFRA), Ministry of Marine Affairs and Fisheries - Republic of Indonesia

E-mail: siti_fauziyah@yahoo.com

Abstract. Understanding and predicting the acoustic backscattering from seafloor substrates was essential to support the management and development of coastal area as well as offshore. The aims of this study were to quantify the acoustic backscattering strength from the seafloor substrates,classify the types of seafloor substrates, as well as correlation between the seafloor substrates and the value of surface backscattering strength (SS). The data collection was done in April to June 2016 in the Indian Ocean WPP 572-573 using hydroacoustic instrument SIMRAD EK60 with operating frequency of 38 kHz. Substrate sampling was used for data validation using Van Veen Grab. The results showed that the SS value for the type of sand substrate (-8.05 dB to -5.25 dB), silty sand (-8.15 dB to -7.03 dB), sandy silt (-11.30 dB to -11.35 dB), silt clayey (-14.71 dB to -12.17 dB) and clay substrate -23.55 dB. Between the SS value and the sand percentage had a very strong positive correlation, and a very strong negative correlation between the surface backscattering strength and the clay percentage. In contrast, a poor negative correlation was also found between the SS value and the silt percentage.

1. Introduction

Indian Ocean is a part of Fisheries Management Area WPP-572 and 573.These waters have a lot of potential for marine resource development. In order to support the management and development is required a comprehensive data and information both related to fish resources and its environment. This is important because Indonesian waters have multispecies fish resources and each region has different environmental characteristics [8]

One of important environmental factors is the data and information about condition and distribution of substrate type on the seabed. The information of seabed substrate is very important because in addition to the seabed substrate useful as a habitat, feeding ground, and nursery ground to the most aquatic organism, seabed substrate also has a complex composition ranging from a small substrate to a rock. In relation to coastal management, data and information about the substrate type is also useful for coastal infrastructure building planning, even did not close the possibility to be used in high seas.

Mapping of bottom sediments in marine is commonly based on sonar data and backscatter analysis [3] (e.g., multibeam, splitbeam and side scan), calibrated using sediment samples.

In the hydroacoustic method, the characteristics of the bottom substrate of the waters can be determined by assessing the characteristics of seabed backscattering because seabed have the characteristics of reflecting and scattering sound waves. According to [16], the hydroacoustic method is a technology that utilizes the echo principle that can detect targets in the aquatic columns such as plankton, larvae, fish, and bottom waters.

Research on substrate type of seabed by hydroacoustic method has been studied in various countries, [19] analyzed the relationship between *backscattering strength* measurement on seabed and geotechnical parameters, [20] classified the seabed using the data of backscatter from multibeam echosounder, [9] examined the effect of the relationship of backscattering values on the composition of sediment particles in New Jersey, while [11] focused on sound propagation at low frequencies for sediment characteristics in Kinneret Lake.

Research on substrate type of seabed using hydroacoustic technology has been done in Indonesia were [17] assessed the effect of grain size, roughness, and hardness of seabed on backscattering value of hydroacoustic detection, [5] mapped and classified the sediment with side scan sonar instruments, [2] reviewed the relationships of backscattering on seabed substrate (E1 and E2) to the distribution of demersal fish (Sv fishes), [1] classified the bottom sediment used mosaic data of backscatter, and [13] reviewed the measurement and analysis of acoustic backscattering to classify the seabed and its relation to makrozoobentos.

This study aims to determine the value of acoustic backscattering strength on seabed, classify the substrate of seabed, and the correlation between substrate type on seabed and the value of surface backscattering strength. The value of acoustic backscattering strength consists the value of volume backscattering strength (VS) and surface backscattering strength (SS).The value of VS consists of the value E1 and E2. Roughness was measured from the integral of the portion of the first echo that occurs after the returns from the initial incident angles (the initial returns contained strong, undesirable amplitude contributions from bottom reverberations). Hardness was defined as the integral of the second echo. The ratio of roughness (E1 for first echo) to hardness (E2 for second echo), hereafter referred to as E1:E2, was also used for bottom-sediment typing as an alternative to using plots of E1 versus E2 to identify clusters related to sediment type [6]. While SS is the backscattering strength on seabed surface [13].

2. Materials and methods

2.1 Study site

All data reported in this article were collected by the Marine Fisheries Research Agency (MFRA), Ministry of Marine Affairs and Fisheries - Republic of Indonesia, Its concerning in characteristics of fisheries biology, resource habitat, and potentialof production in WPP 572 and 573 on year 2016. The acoustic sounding and substrate sampling in the Western Waters of Sumatra (WPP 572) and Southern waters of Java (WPP 573). The sounding data has been processed in Fisheries Acoustic Laboratory, Marine Fisheries Research Agency (MFRA). The following is the location of the seabed sediment sampling as a research station (Fig 1) as well as the coordinates of the position of the research station (Table 1).

Table 1. The position of seabed sediment sampling

Station	Name of Area	Position	
		Latitude	Longitude
1	Waters of West Aceh	$5^0$11'59.7552" N	$95^0$09'22.9861" E
2	Waters of West Aceh	$4^0$27'07.4663" N	$95^0$38'25.4590" E
3	West Waters of North Sumatera	$1^0$25'10.6940" N	$98^0$34'59.4182" E
4	Waters of West Padang	$0^0$02'39.3903" N	$99^0$10'54.0540" E
5	Waters of West Bengkulu	$3^0$36'16.3079" S	$101^0$57'04.7124" E
6	Waters of West Bengkulu	$4^0$15'15.4038" S	$102^0$30'26.6433" E
7	South Waters of West Java	$7^0$50'43.1578" S	$108^0$20'54.2493" E
8	South Waters of West Java	$7^0$48'39.3109" S	$108^0$51'56.8118" E
9	South Waters of Cilacap	$7^0$50'52.6898" S	$109^0$40'50.2393" E

Station	Name of Area	Position	
		Latitude	Longitude
10	South Waters of Cilacap	$8^0$13'32.2574" S	$110^0$52'51.0958" E
11	South Waters of Cilacap	$8^0$03'59.3028" S	$110^0$16'56.5956" E
12	South Waters of Cilacap	$7^0$51'54.7429" S	$109^0$16'05.2106" E
13	South Waters of West Java	$7^0$46'29.4480" S	$108^0$38'03.4670" E

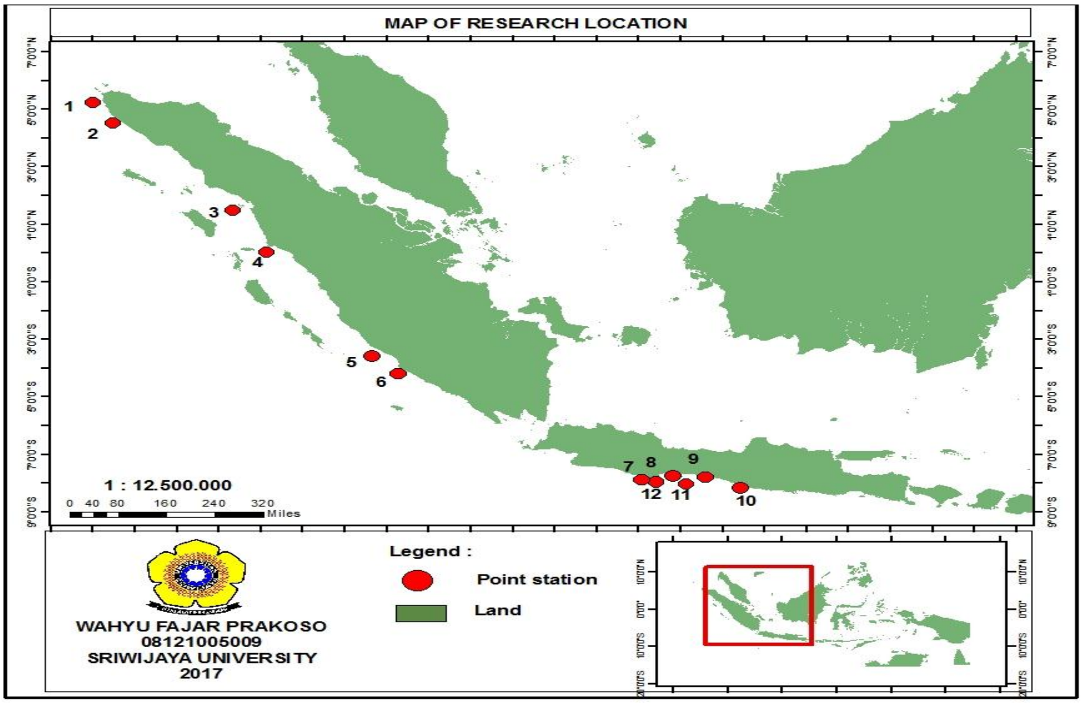


Figure 1. map of research location sediment sampling station

2.2. Acoustic data

Acoustics data is collected using a scientific split beam echosounder system SIMRAD EK 60 frequency 38 kHz, research vessel Baruna Jaya IV. The acoustic data was recorded using an ER60 software that will record and integrate all detected targets in a single file. Recording is performed about 10-20 minutes before sampling the substrate at each observation station.

Sediment samples were collected at 13 locations using a Van veen grab (dimensions 60 cm x 30 cm). Samples of substrate then analyzed by its physical properties, that is substrate texture in Soil Physics Laboratory, Land Research Institute, Ministry of Agriculture, Bogor-Indonesia. Texture of the substrate used as in situ data as well as comparable data from the results of acoustic measurement data. Substrate texture analysis was done by wet screen method of stratified. Substrate texture analysis was divided into 3 fractions i.e. sand fraction (0.05 - 2.00 mm), silt (0.05- 0.002 mm), and clay (> 0.002 mm). Classification of substrate types using Shepard triangle classification. The diagram is constructed with corners consisting of sand-silt-clay.

2.3. Acoustic data processing

The acoustic data were post-processed using Echoview 4.0 software to obtain water depths and backscatter measurements of bottom roughness (tail of first echo) and hardness (second echo). The first reflected data (E1) was processed using a minimum threshold of -50.00 dB (decibel) and a maximum of 0 dB. The second reflected data (E2) was processed using a minimum threshold of -70.00

dB and maximum threshold of0 dB (Pujiyati, 2008). Elementary Sampling Distance Unit(ESDU) was 100 ping. The integration thickness of E1 and E2 was 0.30 m.

According to [11]), the value of acoustic surface backscattering strength (SS) obtained using ring surface scattering model (RSS Model). The RSS Model show a relationship between the raw (or not averaged) SV value of the bottom echo (S_{VB}), and the raw bottom backscattering strength (S_S), as;

$$S_s = \frac{S_{VB}\, \psi(c\,\tau/2)}{\phi} \tag{1}$$

where ϕ and ψ are the equivalent beam angle for surface and volume scattering, respectively, c is the sound speed, and τ is the pulse width. At the peak of the bottom echo, we have:

$$\phi = \phi_0 \cong \psi \tag{2}$$

where ϕ_0 is the asymptotic value of the equivalent beam angle for surface scattering. Introducing Eq. (2) into Eq. (3) gives

$$S_s = (c\,\tau/2)\, S_{VB} \tag{3}$$

An application of this formula for all S_{VB} yields a convenient measure called ″instantaneous″ SS. The SS value was obtained by using a logarithmic equation, as:

$$SS = 10 log(c\,\tau/2) + S_{VB} \tag{4}$$

2.4. Calibration Data

The data calibration is collected to establish relationships between acoustic data and bottom sediment type. The sample sites that encompassed a range of roughness and hardness combinations.

The relation of SS parameter with sediment type was annalized by best fit model approach to linear regression model, logarithmic regression and polynomial regression. Best fit modelwas chosen based on the highest coefficient of determination (R2). The coefficient of determination shows how much percentage of independent variable (sediment type) can explain the non-free (surface backscattering strength).

Scatter and trendline chart types in Microsoft Excel 2007 software were used to determine the best fit relationship model between each type of sediment with SS value. Based on the regression model graph can be known the direction and magnitude of the correlation between the independent variables (percentage of substrate type) and the dependent variable (the value of surface backscattering strength).

3. Result

3.1. Seabed substrate

The result of physical survey analysis to the seabed substrate on 13 stations shows that the average of sand fraction has percentage of 40.07%, the silt fraction has a percentage of 36.23% while the clay fraction has a percentage of 23.69% of the total sediment percentage (Table 2 and Fig 2). The highest sand fraction composition is found at stations 4 and 6 respectively of 90% with a depth of 37.82 m and 35.25 m. The highest silt fraction was found in station 13 with a composition of 65% at 48.38 m depth while the highest clay fraction composition was found at station 1 of 93% at 50.62 m depth.

Table 2. Percentage of substrate fraction at research location based on physical survey

Station	Depth (m)	Fraction (%)			Substrate Type
		Sand (%)	Silt (%)	Clay (%)	
1	50.62	2	5	**93**	Clay
2	33.74	22	62	16	Sandy Silt
3	50.72	46	37	17	Silty Sand
4	37.82	**90**	8	2	Sand
5	18.65	16	63	21	Clayey-Silt
6	35.25	**90**	3	7	Sand
7	44.20	58	32	10	Silty-Sand
8	61.28	11	56	33	Clayey-Silt
9	49.93	39	42	19	Sandy Silt
10	65.86	52	30	18	Silty Sand
11	58.44	85	6	9	Sand
12	54.38	6	62	32	Clayey-Silt
13	48.38	4	**65**	31	Clayey-Silt
Average		40.07	36.23	23.69	

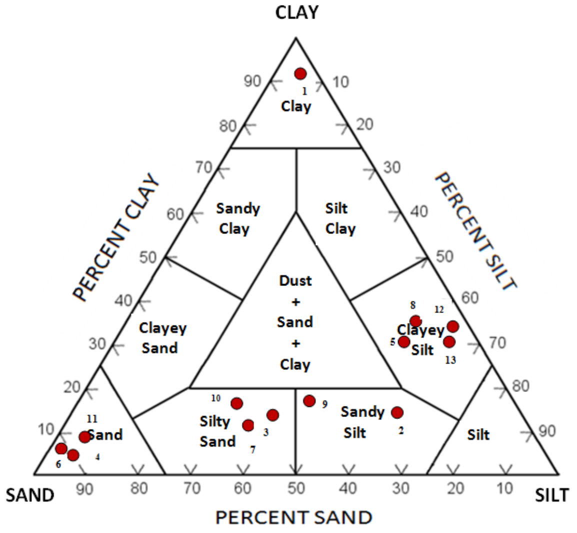


Figure 2. Classification of substrate fraction using Shepard triangle system

3.2. Bottom surface backscattering strength (SS)

The value of backscattering volume (SV) obtained as in Table 3 show the values of E1 (roughness) and E2 (hardness). The type of sand substrate has an E1 value ranging from -16.16 dB to -12.57 dB and E2 ranges from -56.89 dB to -44.05 dB. The type of silty sand has an E1 value ranging from -16.55dB to -15.29 dB and E2 value ranges from -60.72 dB to - 56.79 dB, sandy silt substrate type has an E1 value ranging from -19.40 dB to -18.49 dB and E2 -61.72 dB to -59.76 dB, Type silt -22.82 dB to -18.97 dB and E2 -67.89 dB to -46.21 dB and Clay substrate ranges between less than or less than -36.24 dB and E2 -58.94 dB.The obtained E1 and E2 values show that the sand fraction has a greater roughness and hardness value than the clay fraction and silt fraction. As mentioned on [17] and [15].

Table 3. The value of bottom backscattering strength.

Station	SV		SS (dB)	Substrate Type	WPP RI
	E1 (dB)	E2 (dB)			
1	-36.24	-58.94	-23.55	Clay	572
2	-18.49	-61.72	-11.35	Sandy silt	572
3	-15.88	-57.33	-7.93	Silty sand	572
4	-16.16	-44.05	-8.05	Sand	572
5	-18.97	-46.21	-12.53	Clayey-Silt	572
6	-13.58	-56.61	-6.13	Sand	572
7	-16.55	-56.79	-8.15	Silty sand	573
8	-21.46	-67.89	-14.48	Clayey-Silt	573
9	-19.40	-59.76	-11.30	Sandy silt	573
10	-15.29	-60.72	-7.03	Silty sand	573
11	-12.57	-56.89	-5.25	Sand	573
12	-22.82	-65.35	-14.71	Clayey-Silt	573
13	-19.52	-65.78	-12.17	Clayey-Silt	573
Ratio	1	3.3			

The bottom surface backscattering strength (SS) is a development model to figure the value of surface backscattering strength on the bottom. The SS value was obtained by using a logarithmic equation that connects the backscattering volume (SV) of the bottom, the sound speed (c), and the pulse width (τ). The value of SS is not directly proportional to the SV (E1 and E2) values. This is because the place of observation station has a long distance and difference characteristics among environmental conditions such as oceanographic factors such as temperature, salinity, the sound speed and also the bottom material characteristic will affect the difference in backscattering strength values [14]. Table 3 shows SS value for sand substrate ranging from -8.05 dB to -5.25 dB. Substrate type of silty sand ranging from -8.15 dB to -7.03 dB. Substrate type of sandy silt ranging from -11.30 dB to -11.35 dB. Substrate type of Clayey-Silt ranging from -14.71 dB to -12.17 dB as well as SS Value for clay substrate -23.55 dB.

SS influenced by the particle size of the substrate fraction (Fig 3). Graph of SS value will increase when the composition of clay fraction is very dominant while the graph of SS value will decrease if the composition of sediment at the station has the dominant sand fraction. The substrate of sandy silt has a higher SS value compared with Clayey-Silt substate. This is due to the influence of sand fraction which contributes a stronger reflection value than clay fraction.Based on the SS value pattern obtained in the study illustrates that the smaller and smoother the grain size of the sediment the acoustic backscattering strength value will be weaker and if the larger and harder grain size of the sediment the acoustic backscattering strength value will be stronger. As mentioned on [7], [17] and [1] that the value of backscattering strength is strongly influenced by the size of the grains of sediment.

3.3. The type of bottom substrate based on echogram display

The bottom substrates detected can be distinguished qualitatively based on the color spectrum of the echogram layer (Fig 4). Echogram display taken on each type of substrate obtained in this study as an example.The echogram on the substrate of sand, silty sand, sandy silt and Clayey-Silt has a pulse length 512 µs while clay substrate are1024 µs.

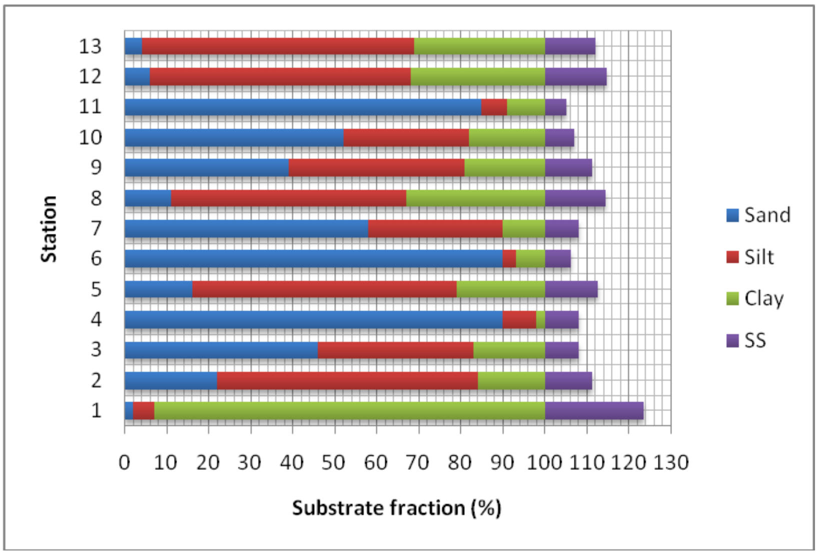
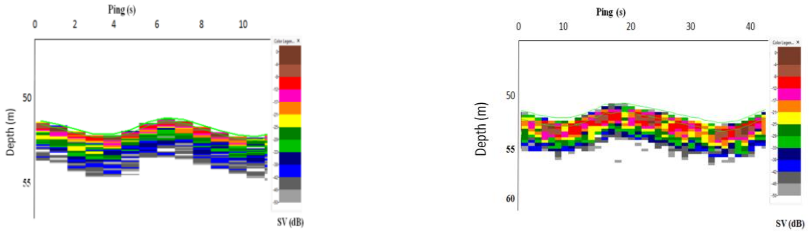
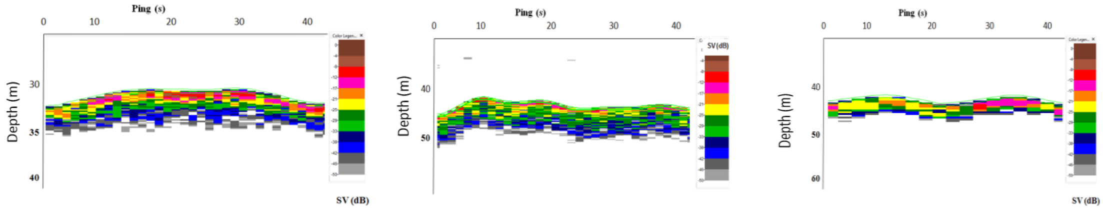


Figure 3. Graph of substrate fraction ratio with SS value.



(a). Sand (b). Silty sand



(c). Sandy silt (d). Clayey-Silt (e). Clay

Figure 4. Echogram display on the type of bottom substrate

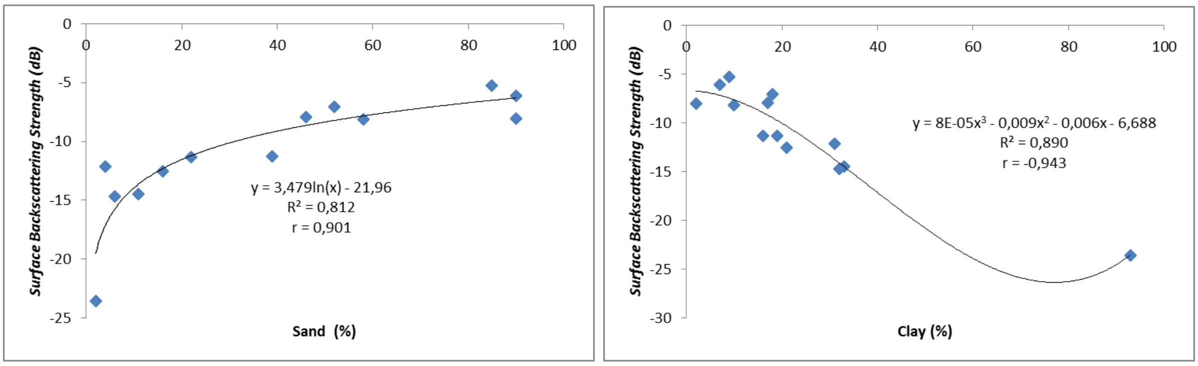
4. Discussion

The composition of the grain size of the sediment will be smaller with the increasing depth of the water (Table 2). This is in accordance with the value of backscattering volume (SV) obtained as in Table 3 show that the values of E1 (roughness) and E2 (hardness) are influenced by substrate type and substrate particles. The obtained E1 and E2 values show that the sand fraction has a greater roughness and hardness value than the clay fraction and silt fraction.

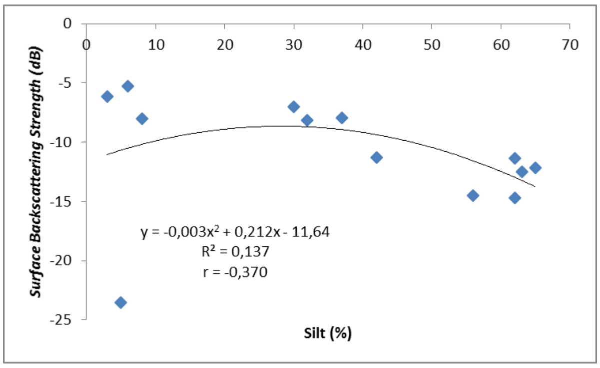
The E1:E2 ratio provided the clearest information on sediment type (Table 3), showing distinct hydroacoustic sediment types. The sediments containing coarser fractions (sand, silt, clay) exceed an E1:E2 ratio of 2.00 [21]. Hence, there was information on where coarse and hard sediments occur, but there was a zone of overlap where all sediment classes were represented. The overlap was the main challenge to this case study and demonstrates that acoustic-based hardness and roughness measurements may have limited function.

Meanwhile, SS represents the return value of the bottom surface of the waters which is the derived equation of SV. Sand has a grain size larger than silt and clay [15] so the sand is able to provide the strongest reflection according to the SS equation using SVmax. The roughness, hardness and substrate size of the substrate greatly affect the baseline SS value of the water [17], [1].

Figure 5 indicates the existence of two types of best fit models used, namely 1) logarithmic model for regression between sand and SS, and 2) polynomial model for regression between silt and SS as well as regression between clay and SS. Logarithmic model between sand fraction with SS value has R square value equal to 0,812. This shows that the sand fraction influences the SS value by 81.2% (significant) and another 18.8% is influenced by other factors outside this study. Similarly, between clay fraction and SS value having R square value of 0.890, it means that the clay fraction has an effect of 89% (significant) to SS value and the rest (11%) is influenced by other factors outside this research. Conversely, between the silt fraction and the SS value has R square value of 0.137, meaning that the silt fraction only affects 13.7% (not significant) to the SS value and 86.3% is influenced by other factors outside this study. Based on R square value, it can be concluded that the fraction of sand and clay significantly influence the value of surface backscattering strength and vice versa silt effect is not significant.



(a). Logarithmic Equation of Sand-SS (b). Polynomial Equation of Clay-SS



(c). Polynomial Equation of Silt-SS

Figure 5. Regression graph relation of bottom surface backscattering strength (SS) to sediment fraction

Based on the value of the correlation coefficient (r) obtained as shown in Figure 5, it can be classified how strong the relationship (correlation) between each type of sediment (substrate) with the value of SS. Refers to the criteria of [18], the correlation of sand and clay faction to SS value is included in very strong category (0,8 ≤ r ≤ 1). Conversely, the correlation of the silt fraction to the SS value is included in the low category (0,20 ≤ r ≤ 0,39). Based on the tendency of regression graph it can be seen that the sand fraction has a positive correlation (the greater % of sand fraction the greater the value of SS), otherwise fraction fraction of clay and silt have negative correlation. These results are in line with the results of the study of [4] which states that statistically, the sediment of sand and calcium carbonate reservoir has a significant correlation to 210 kHz backscatter signal. This shows that SS values have a strong correlation with subtratic type of bottom waters [10], [12].

Clay fraction has the smallest particle size compared to the sand and silt fraction so it has a high porosity and has little air [15]. It affects the energy of the reflected sound waves so that sound waves will be more absorbed into the bottom substrate of the water and lose much of the energy that is re-emitted to the tranducer.The silt fraction value has a low correlation of all sediment fractions with r value of 0.37. The silt fraction obtained in this study is suspected to spread and mix with sand and clay fractions. It can be seen that from13 substrate sampling stations there is no dominant silt fraction as in stations 4 and 6 for sand and station 1 for clay fractions.

5. Conclusion

The results showed backscattering strength (SS) values for the type of sand substrate -8.05 dB to -5.25 dB, Silty sand -8.15 dB to -7.03 dB, Sandy silt -11.30 dB to -11.35 dB, Clayey-Silt -14.71 dB to -12.17 DB and clay substrate -23.55 dB. The sand fraction has a strong positive correlation with the surface backscattering value, the clay fraction has a very strong negative correlation with the surface backscattering value, whereas the silt fraction has a weak negative correlation with the surface backscattering strength value.

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