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Acoustic Characterization of Fish and Seabed Using Underwater Acoustic Technology in Seribu Island Indonesia

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Abstract

Remote sensing technique using underwater acoustics are one of the most cost-effective methods of resource detection and mapping, particularly in the coastal zone. We measured the acoustic backscatter using single beam echosounder from water column target and sea bottom. The increasing of fish size is followed by target strength value. For sea bottom, the highest acoustic backscattering was sand followed by silt and clay. This was caused by the acoustic impedance difference and also the presence of the organisms in sediment. By this study, classification and characterization of underwater target such as fish and seabed using acoustic technology was possible.

Keywords: Acoustic; Sensing; Backscatter; Target; Seabed; Mapping

Introduction

Underwater acoustic technologies are one of the most cost-effective methods of resource detection and mapping. The use of acoustic techniques in seabed mapping and monitoring has proven to be a useful tool in marine resource management. Underwater acoustic as a remote sensing tool are recognized as one of the most effective tools available to detect, map and characterize the seafloor [1]. Depth measurement or bathymetry gives the relief of the seafloor and acoustic backscattering value can relate to study the morphology and composition of the seabed. Bathymetry maps produced from acoustic instrument is well developed, but the processing and analysis of acoustic backscatter data has not yet reached its full potential. Hence, the need for enhanced techniques of acoustic backscattering strength analysis was evident. The primary objective of this study was to examine and develop new methodologies for using acoustic backscattering data for fish, sea bottom and benthic habitat.

Methodology

Underwater acoustic technology used in this research is CruzPro single-beam echosounders. The acoustic transducer transmits one single vertical beam towards the seafloor for determining the water depth. A transmission of acoustic wave travels through water by displacement of water particles. Seawater has low acoustic impedance which results in a low resistance to the propagation of the acoustic wave. A part of the incident wave is reflected in symmetrical direction, a part is scattered in all directions, and another part penetrates to the seabed. The scattering of the acoustic energy back towards the sonar is called backscatter. This backscattered energy is received by the transducer echosounder and used for depth or bathymetry and echo strength measurements [2].

Acoustic data acquisition

Data acquisition at Seribu Island Indonesia was conducted on 7-9 June 2014 (Figure 1). The three-frequencies (50, 120, and 200 kHz) of CruzPro single beam transducer were acquired over substrates ranging from clayey silt to sand in the Seribu Island of Jakarta, using a hull-mounted normal-incidence underwater acoustics instrument. The beam width of the echosounder transducer for 50, 120, and 200 kHz is 20°, 15° and 9°, respectively, with respective pulse lengths of 0.85, 0.75, and 0.5 ms. The raw analog output on the receiver circuit board was tapped and connected to a 12-bit A/D converter with a sampling frequency of 1 MHz. The echoes were stored together with the information of the echosounder adjustments and ship position obtained from the GPS system.

The recorded echo data were converted from binary to ASCII format. The shape of the sea bottom echo envelope is generally influenced by various factors including natural variability of the underwater target, seafloor, transducer motion, and due to electrical noise of echosounder [3]. Echo alignment and echo averaging were performed to obtain good averaged echo envelopes.

Fish, zooplankton, and oceanography sampling

Fish and zooplankton sampling were conducted in order to verify the type of each species and relate to acoustic backscatter value. Data collections are simultaneously with acoustic transmission. Fish species data were collected using underwater camera, zooplankton sample were obtained using plankton net. Sample plankton were treated for further analysis in laboratory. Ocean temperature and salinity were collected using CTD instrument.

Sediment sampling

Sediment data were collected using a Van Veen grab, covering an area of 0.04 m^2 and penetration of 10 cm. About 50 g of sediment were taken from each grab sample to carry out the textural analyses using a 4.0 cm diameter core tube. The sediment was repeatedly washed in distilled water until all the chloride ions detectable with 5% silver nitrate were removed. These samples were treated with 10% sodium hexametaphosphate. The acquired sediment samples were processed to wet sieving using a 62 μm sieve to separate the sand from the mud

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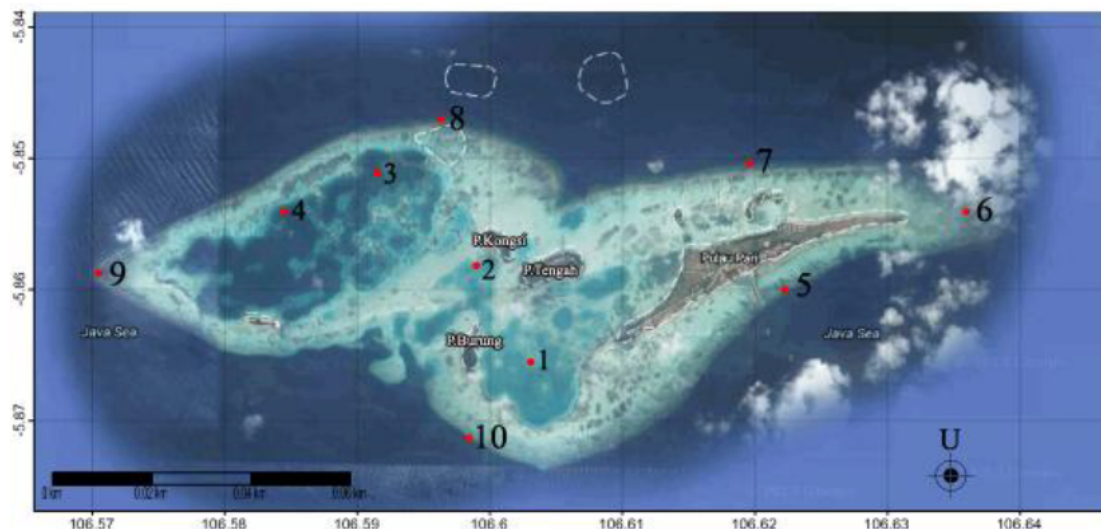
Figure 1: Ocean data acquisition in Pari Island. Acoustic track performed around the island with (●) are sampling points for plankton, diving, biota, coral reef, underwater vegetation, temperature and salinity.

No	Parameters	Value
1	Source Level: SL = 20 log (V_{TX})+TVR	220 dB
2	Directivity Index: DI_T=DI_R	30 dB
3	Transmit Voltage Response: TVR	170 dB
4	Open Circuit Voltage Response: OCVR	-178 dB
5	Detection Threshold: DT	-71 dB (V_{RX} = ± 3 mV rms)
6	Ambient Noise Level: NL	30 dB
7	Gain	60 dB (variable from 20 dB to 60 dB)
8	Absorption coefficient: α	0.0457 dB/m
9	Operating frequency: f	200 kHz

Table 1: Acoustic parameter for measuring detection range.

fraction. The size distribution of the sand fraction was determined using a dry sieving method [4].

Benthos sampling

The sediment samples for benthos identification were washed through a 0.5 mm mesh sieve, and all organisms retained on the sieve were collected and preserved in 15% seawater formalin. Benthos samples were washed through 0.5 mm mesh in running water in the laboratory to clear adhering sediments. All organisms were sorted into major groups, preserved in 90% alcohol for further identification and counted group-wise. The average number of organisms from the samples was then converted to number per m^2 (no. m^2). Biomass was determined by using the wet weight method. The obtained biomass was converted to gm^2 (wet weight). The species identification was based on manual book.

Result and Discussions

Use of underwater acoustic instrument as a primary tool to explore oceans has many advantages compared to conventional biological sampling, such as trawls and nets. First, underwater sound propagates at about 1500 m/s and can travel a much larger distance, making it possible to sample a much larger volume in a relatively shorter period of time. Secondly, acoustic measurements are remote, less invasive, and non-extractive. Thirdly, it can provide higher spatial resolution in both horizontal and vertical (or range for down-looking echosounders)

directions [2]. Fisheries acoustics is the use of sound to measure the distribution and abundance of fish and other aquatic organisms. To gain a high quality of acoustic data, calibration was performed as shown in Table 1. Figure 2 shows the measurement method for detection range of acoustics instrument.

Figure 3 shows the target strength (TS) of zooplankton. The distribution of TS is ranged from -110 to -70 dB. Fish school distribution is ranged from -85 to -60 dB shown in Figures 4 and 5.

Figure 6 shows the Target Strength histogram of underwater target. This figure shows that target strength distribution is -70.0 dB to -47.0 dB. Figure 7 shows the relationship between fish size and acoustic target strength. By this figure, the increasing of fish size is followed by the increasing of target strength value.

Table 2 shows the acoustic density of detected target using Sonar. Number of single echo detector (SED) is shown in the second row, followed by volume density and area density. This table show the acoustic density is highest at 3433 target /ha and the lowest density at 28146 target/ha.

Figure 8 shows the hardness (red line) and roughness (blue line) of the sea bottom. The hardness of sea bottom is depending on acoustic impedance value, while roughness is depend on bottom surface morphology. From ping 1 until 100, the roughness is higher than hardness and from ping 100 until 200; the hardness is higher than roughness. Table 3 shows the ground truth data for seabed.
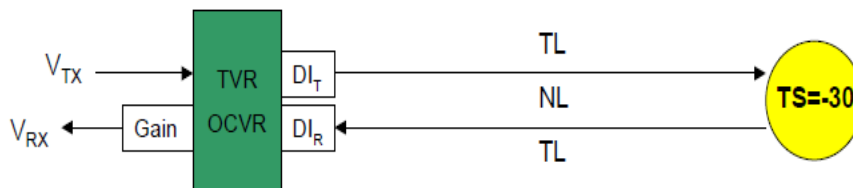
Figure 2: Measuring detection range of acoustic instrument.
Detection threshold (DT) was computed using the equation below:

$DT = SL - 2 TL + TS + DI_T + DI_R - NL + OCVR$

$2 TL \leq SL - DT + TS + DI_T + DI_R - NL + OCVR$

$2 TL \leq 220 + 70 - 30 + 30 + 30 - 30 - 178 = 122$

$20 \log R + \alpha R \leq 55 \quad R \leq 180\ m$

Where R is maximum detection range of acoustic instrument, SL is Source Level, TL is Transmission Loss, TS is Target Strength, DIT, DIR is directivity index for transmitting and receiving, respectively, NL is Noise Level; OCVR is open circuit voltage response. For data processing, the acoustic files contain run length packed and coded voltage samples.
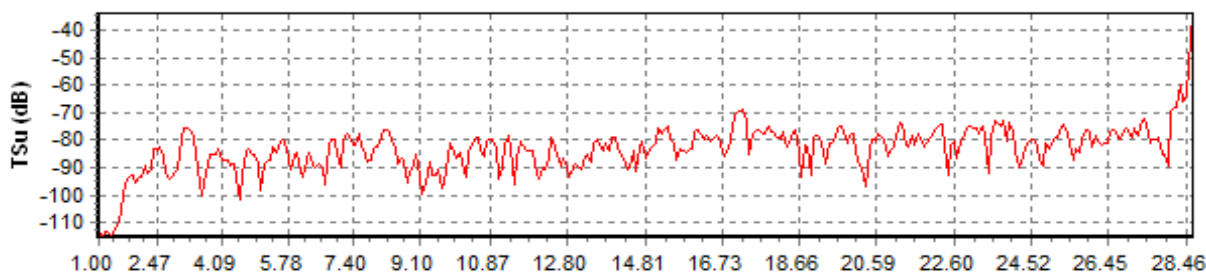

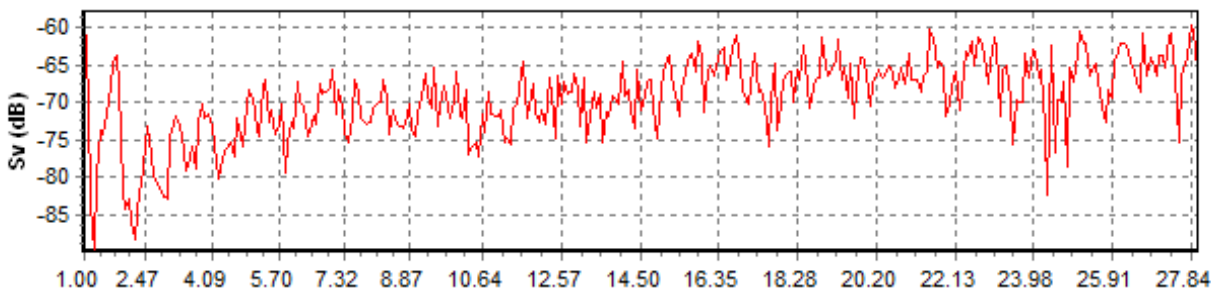**Figure 3:** Acoustic target strength (TS) of zooplankton.

Figure 4: Acoustic volume backscattering strength (SV) of fish schools.
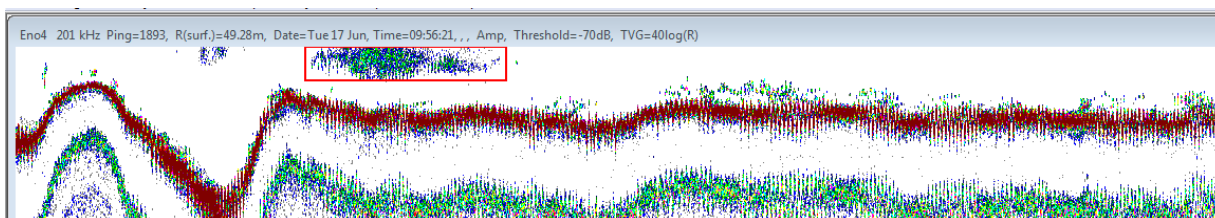

Figure 5: Acoustic image of underwater target and seabed profile.

Acoustic backscattering by the seafloor had long been studied in order to either predict the performance of instrument systems or to use sound to quantitatively detect and map the seafloor. The scattering is influenced by the roughness of the interfaces between the water and bottom and sub bottom layers as well as inhomogeneities [5-9]. There are both continuously varying inhomogeneities and discrete ones. Rocks, shells, and gas pockets are among the discrete inhomogeneities.

In this section, we measured backscatter strengths using underwater acoustic instrument with weight percentage of the sediment fraction and the number density of benthic macro-fauna present in the sea bottom. The establishment of traditional statistical techniques for the understanding of spatial and temporal dependence of benthic habitat on the acoustic backscatter has been proposed in the past [10].
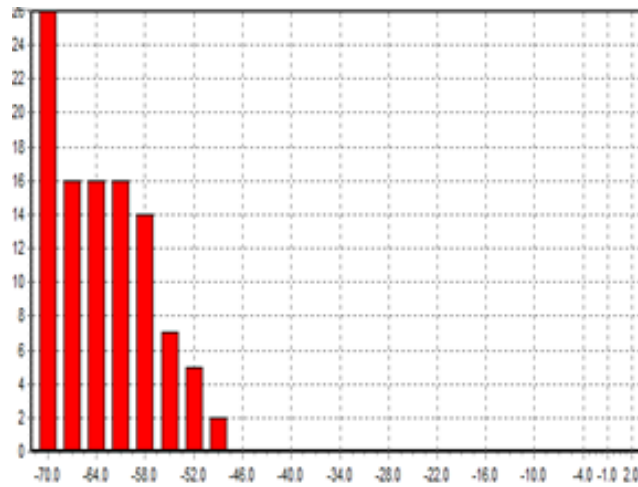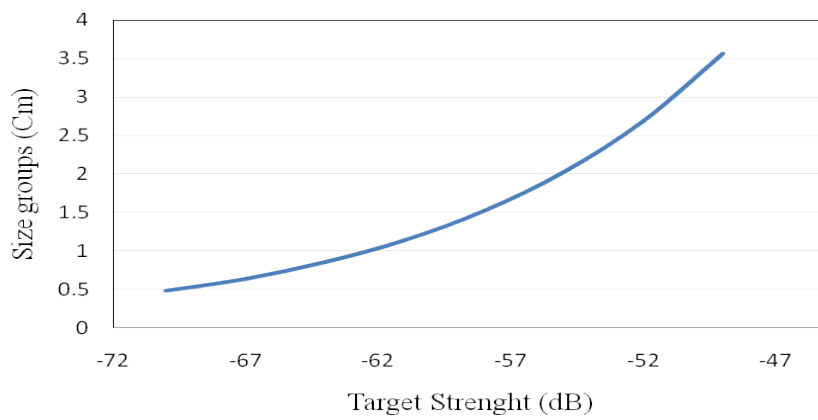
Figure 6: Histogram of Acoustic Target Strength.

Figure 7: Acoustic target strength and fish size.

Size group (TS dB)	-70.0- 43.0	-70.0- -67.0	-67.0- -64.0	-64.0 - -61.0	-61.0- -58.0	-58.0- -55.0	-55.0- -52.0	-52.0- -49.0	-49.0- -46.0	-46.0- -43.0
SED number	56	5	4	12	13	4	4	8	3	3
Volume Density SED (/1000m³)	28	3	3	6	3	3	4	2	2	2
Volume Density Total (/1000m³)	235	19	24	52	57	15	15	33	10	10
Area density SED (/ha)	2896	255	333	689	752	189	189	239	125	125
Area density total (/ha)	28146	2889	2583	4884	5608	3150	1150	2016	2433	3433

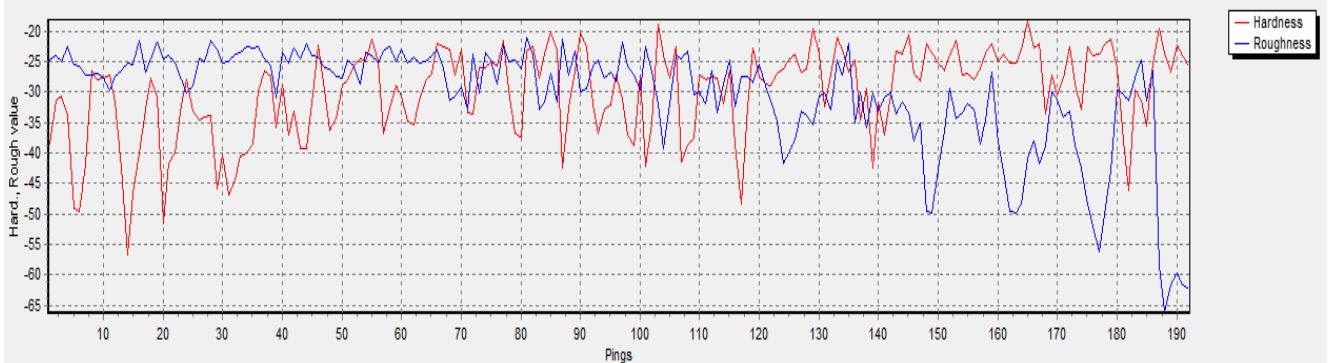**Table 2:** Acoustic density in the study area.

Figure 8: Hardness and roughness of sea bottom.

Station No.	Water Depth (m)	Laboratory measured of Grain size	Sand (%)	Silt (%)	Clay (%)	Sediment type
1	20	2-4 µm	0.75	20.98	78.27	Clay
2	25	4-63 µm	0.55	75.85	23.60	Silt
3	18	4-63 µm	0.65	75.90	23.45	Silt
4	32	1.5 mm	55.45	32.40	12.15	Silty sand
5	34	60 µm	0.18	75.53	24.29	Clayey silt
6	15	4-63 µm	0.95	79.08	19.97	Silt
7	18	63 µm - 2 mm	89.13	8.87	2.00	Sand
8	22	1.8 mm	73.65	22.45	3.90	Silty sand
9	24	1.9 mm	55.85	38.54	5.61	Silty sand
10	25	1.5 mm	80.75	15.01	4.24	Sand

Table 3: Summary of the ground-truth data with the percentage composition of each sediment type.
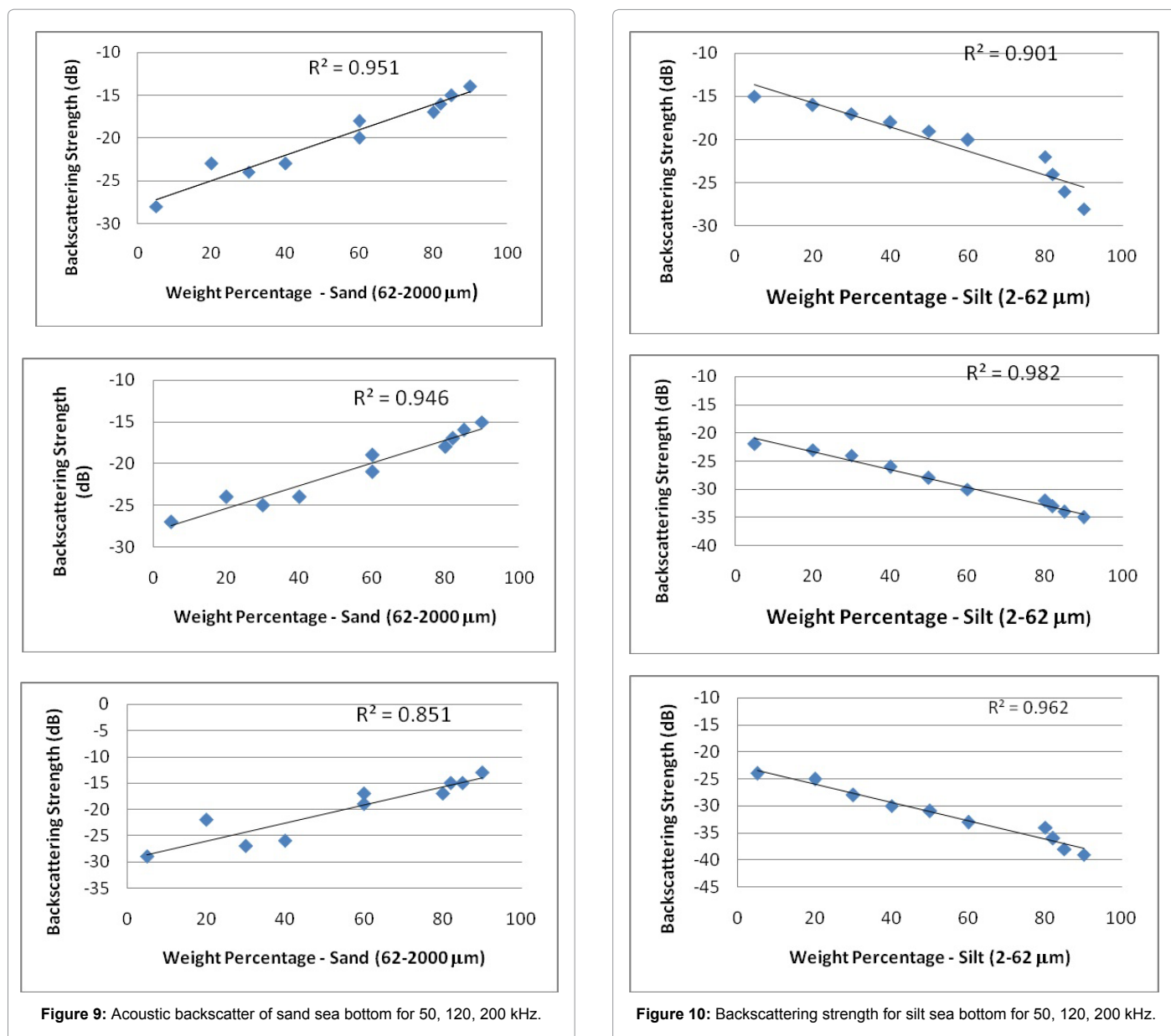

Figure 9: Acoustic backscatter of sand sea bottom for 50, 120, 200 kHz.

Figure 10: Backscattering strength for silt sea bottom for 50, 120, 200 kHz.

The percentage distribution of sediment compositions based on Shepard's classification [11] shows the presence of four seafloor sediment types: clayey-silt, silt, silty-sand and sand with varied levels of mixing of three textural grades of sand, silt, and clay. Sediment texture was relatively coarse in the deeper depths (20-35 m). Fine-grained sediment was located at the shallow depth region (15-25 m). Silty-sand and sand sediments will be referred to as coarse sediments; and clayey-silt and silt, and clay sediments will be referred to as fine sediments.

Backscatter strength data for three frequencies were compared with weight percentage of the individual grain size classes namely, sand, silt, and clay. The correlation coefficient R^2 between bottom backscattering strength and grain size classes is shown in Figures 9-11. For three frequencies, the backscattering strength is directly correlated with coarse fractions (sand within the range 62-2000 mm) and inversely correlated with finer fractions namely silt (2-62 mm) and clay (62 mm). The relationship between backscattering strength and the weight percentage of the sand fraction is shown in Figure 9. As the percentage of the sand fraction increases, the backscattering strength also increases linearly. The relationship between backscatter strength and the weight percentage of the silt and clay is expressed in Figures 10 and 11, and shows that the backscattering strength decreases with increasing weight percentage of both silt and clay fraction.

Sound wave interaction with the seabed depends partly on the impedance contrast between two layers. Acoustic impedance is a medium characteristic equal to the product of the density and sound speed. Large acoustic impedance contrast between water and rocky seabed with a considerable smooth surface means that the seabed surface behaves as perfect reflector. The value of acoustic impedance at softer sediments, mismatch is much less which means that larger energy will be able to penetrate to sub bottom layer. The signal encounters a different material and a portion of the acoustic energy is reflected and recorded by the system. The percentage of the acoustic energy reflected at each layer surface is a function of the relative densities, sound speeds, bottom material type, and the angle of incidence at the two layers.

Several studies have compared backscatter responses to ground-truth sediment data in order to assess the ability of different acoustic technologies to classify seafloor types [7,12-16]. The backscatter strength from a muddy seafloor has been shown to be inversely linearly related to the percentage content of silt and clay [17,18]. Fine sediments generally exhibit low backscatter strength due to low density and sound velocity [15,19]. However, the spatial variability of backscatter intensity along the seafloor characterized by coarse sediments has been shown to be mainly driven by the weight percent of coarse grains (sand) [10,20]. Coarse sediments are more likely to result in higher backscatter intensity due to scattering from coarse particles, lower porosity, higher density and sound velocity, and greater roughness of the water- sediment interface. The results of this study agree with those of Anderson in that backscatter strength and the proportion of the coarse fraction in sediments are strongly related [21,22]. In this study, a linear relationship between weight percentage of sand and backscatter intensity is also evident.

The present study for fine sea bottom, indicates an inverse linear relationship between percentage content of silt and clay. This findings were agreed with a previous study [23,24]. Benthic macro fauna present in the seafloor can affect backscatter in several ways. Hard-bodied fauna may individually be a discrete scatterer [25]. The benthic organism can influence seafloor roughness, and density or sound speed in the sediment are fluctuated. Benthic organism will contribute to acoustic backscattering by the seafloor. These animals can influence dominate the volume and seafloor reverberations [8,26]. The acoustic energy can penetrate into the sand sediment and scattered depends on the sizes of these buried inhomogeneities. For higher backscattering strength in coarse sediment where the benthic organism such as hard body organisms dominate. This is not a frequency related issue, as the single beam acoustic measurements are at 50, 120, and 200 kHz. At high frequencies acoustic, the backscattering from the seabed can generally be attributed to two contributing factors. Part of the energy

is scattered by the interface relief and by bottom roughness. The other part of the energy penetrates to the sand and muddy sediment were reflected back by volume heterogeneities [2,21,22].

The number density of both hard and soft body organisms were compared with weight percentage of the individual grain size classes. Species groups analyzed by location is depicted in Table 4. The correlation coefficient R^2, which assesses the animal-sediment relationship, is shown in Figures 12 and 13.

The number density of hard body organism is directly correlated with coarse fractions and inversely correlated with finer fractions namely silt and clay bottom. The relationship between number density of hard body organism and the weight percentage of the sand fraction is shown in Figure 12. As the percentage of the sand fraction increases, the number density of hard body organism also increases linearly. Meanwhile, for fine region the number density of hardbody organism decreases with increasing weight percentage of both silt
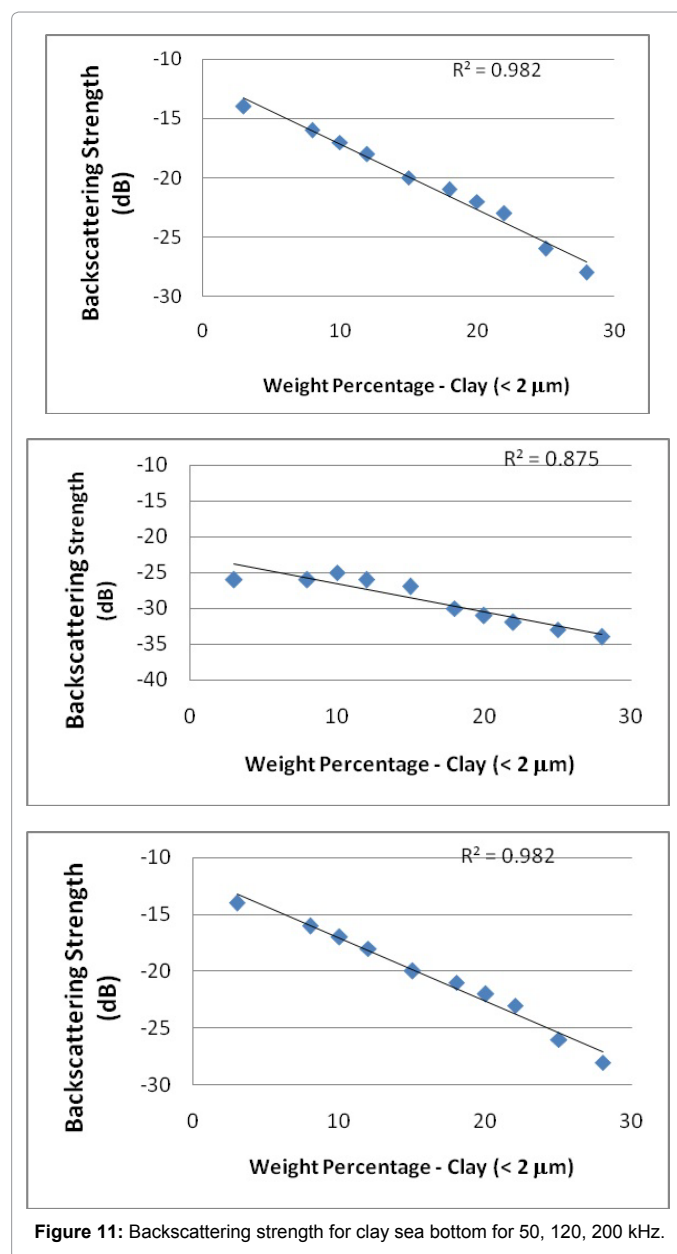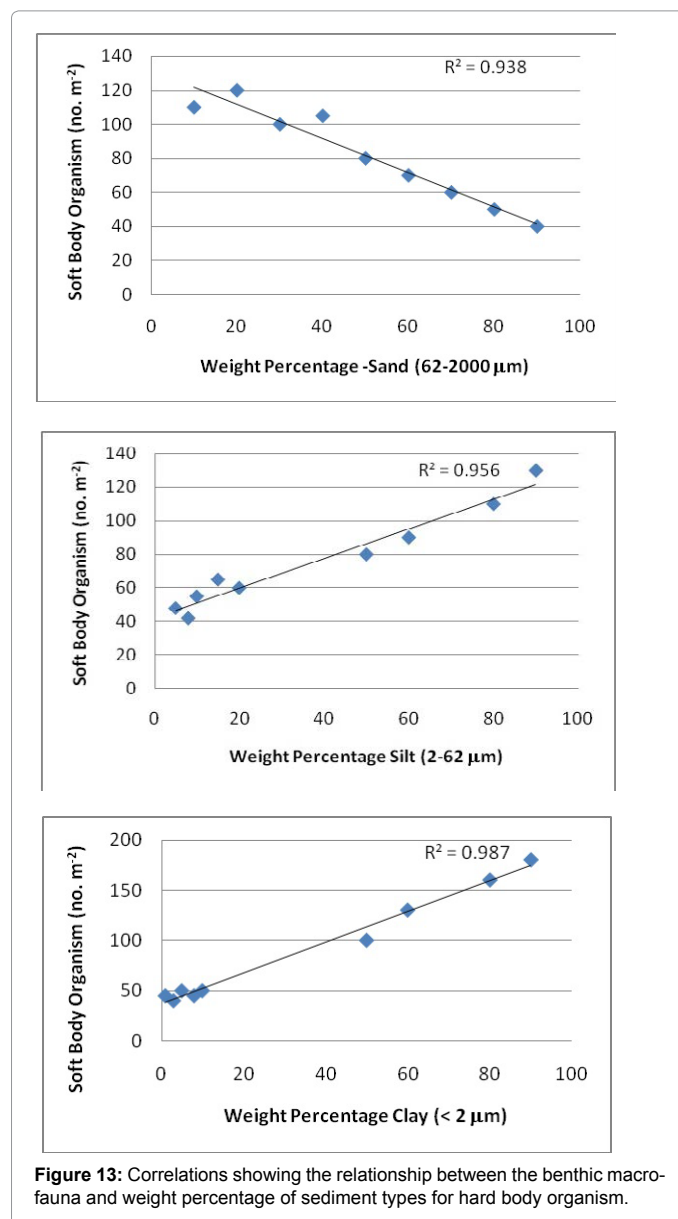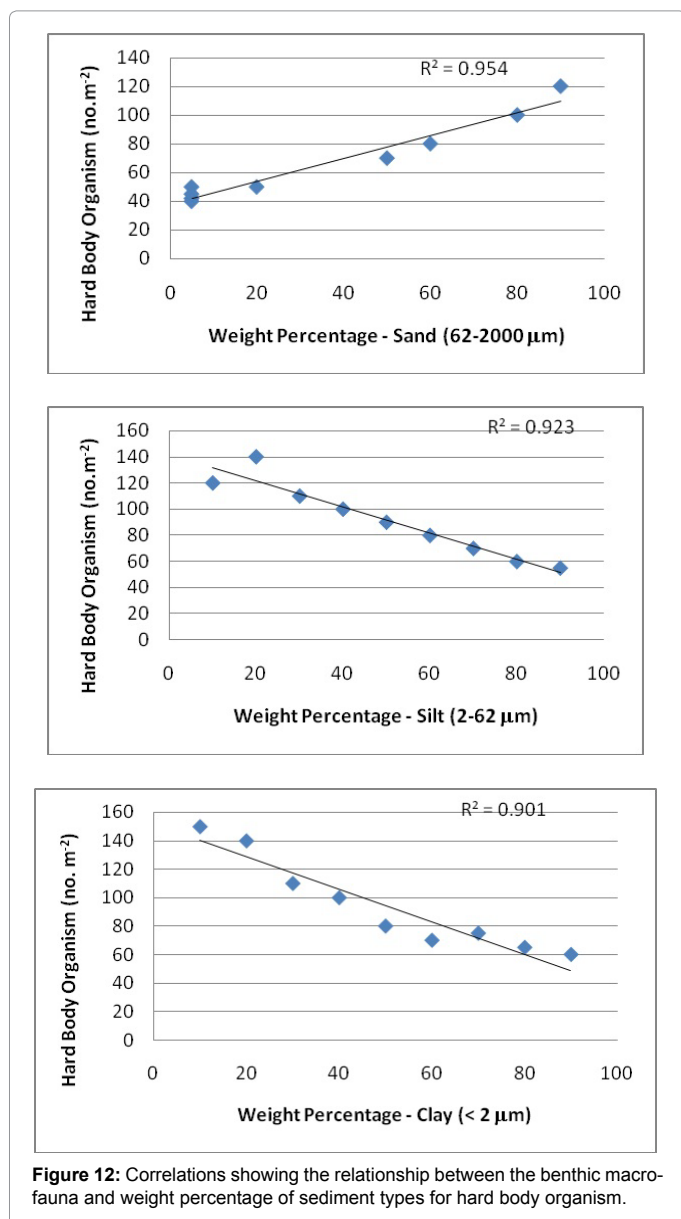

Figure 11: Backscattering strength for clay sea bottom for 50, 120, 200 kHz.

Location	Species Group						Density (number)
	Crustacea	Echinodermata	Mollusca	Polychaeta	Bivalvia	Gastropoda	
1	10	15	22	18	16	9	90
2	3	18	43	163	187	201	615
3	5	21	49	89	102	204	470
4	28	182	80	132	194	253	869
5	8	165	179	198	203	302	1055
6	12	198	152	203	246	198	1009
7	23	43	167	235	287	378	1133
8	15	46	98	327	23	14	523
9	18	126	23	213	312	341	1033
10	12	187	123	213	224	225	984

Table 4: Species groups analyzed by location.

Figure 12: Correlations showing the relationship between the benthic macro-fauna and weight percentage of sediment types for hard body organism.

Figure 13: Correlations showing the relationship between the benthic macro-fauna and weight percentage of sediment types for hard body organism.

and clay fraction (Figure 13). Conversely, the number density of soft body organism is directly correlated with both silt and clay fraction sand inversely correlated with coarse fractions. The correlations show that there could be many factors in combination that influence the distribution of benthic organism. There were five groups of benthic organism found like crustacean, echinodermata, mollusca, polychaeta, bivalvia, and gastropoda. Hardbody organism such as bivalves and gastropods, while the soft body such as crustacean, echinodermata,
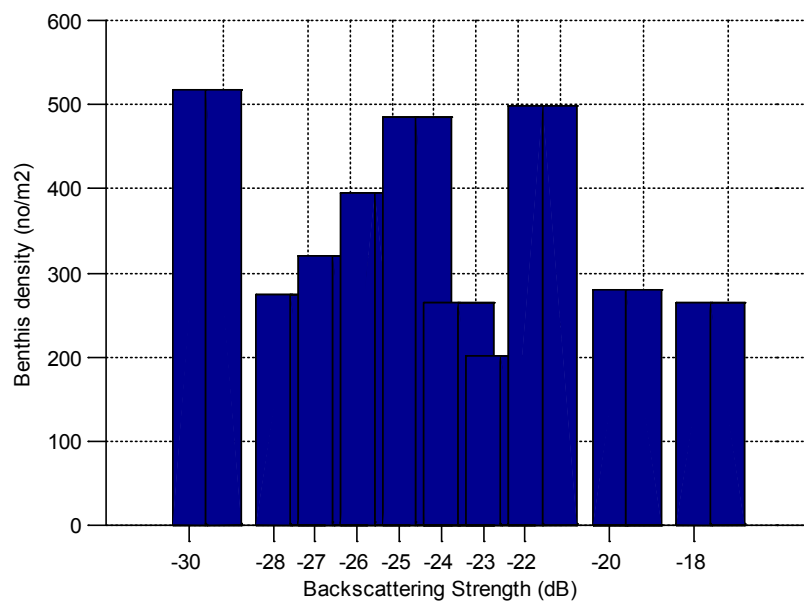
Figure 14: Relation backscattering strength and benthic density.

mollusca, and polychaeta. Jackson et al. and Jumars et al. have reported that fine-sediment such as clayey regions are not a favorable substratum for filter feeders [10,20]. Bloom et al and Bax et al had suggested that the sand bottom where the filter feeders dominate, reflects the more pronounced under water current activity and brings more potential food to filter feeding organisms than would weaker currents [27,28]. Conversely, fine sediment reflects the environment with feeble currents, which allow the fine particles to settle, so that only a small amount of organic matter in suspension is available as food for filter feeders, which in turn prevents them from inhabiting such environment and providing an adequate source of nutrition for deposit feeders only [29]. Relation of backscattering strength of sea bottom and benthic habitat is shown in Figure 14. From this figure, the value of backscatter was fluctuated in the presence of benthic organism. There have been very few controlled experiments involving acoustic backscattering by the seafloor in regions where there is a significant presence of benthic organism. Two such studies were published by Jackson et al. and Stanic et al. [10,30]. In the Jackson et al. study, the acoustic scattering by the seafloor was measured as a function of grazing angle, acoustic frequency, and seafloor type. One of the seafloor types involved a bottom material that consisted of very fine sand with a dense covering of live shellfish [8]. The scattering by the bed that contained the shellfish was elevated relative to the section of seafloor that contained sandy silt and no shellfish, indicating that the shellfish played a significant role in the scattering. In the studies by Stanic et al. the studies were focused entirely on a region where the seafloor was covered with shells and the acoustic scattering was measured as a function of grazing angle and acoustic frequency. Characterization of the shells was made possible through the use of samples collected at the site [30]. In the future, the knowledge on macrobenthic diversity is necessary to identify priority areas for conservation and manage human activities in such coastal zones using underwater acoustic method.

Conclusions

Remote sensing using underwater acoustic technology is useful for detection and quantification of marine fish and seabed characterization.

From the sea bottom profile of the region, the depth of the neighboring sea of Seribu Islands particularly in Pari Island and Pramuka Island ranged approximately 15-55 m. Coral reefs in these areas were deep-rooted in the muddy bottom. The number of marine biota such as fish and zooplankton were measured using underwater acoustic effectively. We found the increasing of fish size is followed by the increasing of Target Strength.

The roughness and hardness were measured to characterize the sea bottom. The interrelationship between backscatter, grain size, and benthic macro-fauna abundance were demonstrated based on the acoustic data from three frequencies (50, 120, and 200 kHz) of single beam acoustic in conjunction with the sediment grain size and benthic macro-fauna information. The sediment textural properties and benthic macro-fauna information were collected using a grab for ground truth data. The findings of this study show that the different seabed types of the Pramuka Island of Jakarta can be mapped using a combination of data, including acoustic backscatter strength, biomass analysis, target strength, zooplankton, and ground-truth sediment information. The acoustic backscattering data presented here provide information about the sediment type and also give information about the occupancy of the organisms present in the seafloor. It can be deduced that a given location is suitable for occupancy by a given type of organism.

Acknowledgment

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