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Detecting Shallow Water Submarine Cables with Single Beam Echosounder in Tidung Island

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Abstract

Detecting submarine cables in tropical shallow waters remains challenging due to environmental complexity and the similarity of backscatter signatures to other seafloor objects. This study characterizes the acoustic backscatter response of two types of submarine cables concrete-armored and non-armored in the waters of Tidung Island using a SIMRAD EK-15 and a Furuno FCV-628 echosounder operating at 200 kHz. Data processing was conducted to derive Volume Backscattering Strength (SVc) and Surface Scattering Strength (SS). Measurements of the concrete-armored cable using the Furuno system produced SVc values of −6.701 dB and −5.055 dB, and SS values of −11.855 dB and −9.510 dB, indicating high reflectivity due to the impedance contrast between concrete and seawater. In contrast, measurements of the non-armored cable using the SIMRAD system yielded SVc values of −11.547 dB and −12.600 dB and SS values of −14.612 dB and −15.665 dB, reflecting weaker and more variable returns caused by direct exposure of the cable structure to sediments and hydrodynamic forces. The consistent differences between the two cable types demonstrate that each structure exhibits a distinctive acoustic signature that can be used as a discriminating parameter for mapping. This study provides important empirical evidence by presenting direct acoustic backscatter characterization of submarine cables in Indonesia and demonstrates that commercial echosounders can reliably support infrastructure inspection in shallow-water environments.

Keywords: Single-beam echosounder, submarine cable detection, acoustic backscatter, shallow-water acoustics, Tidung Island, underwater infrastructure monitoring.

1. Introduction

Detection and mapping of underwater objects are essential components in the maintenance of marine infrastructure such as communication cables, gas pipelines, and subsea energy networks. One commonly used approach for identifying these objects is the acoustic method, which operates by transmitting sound waves through seawater to the seabed and analyzing their reflections or backscattered signals [1], [2]. Technologies such as Side Scan Sonar (SSS), Multibeam Echosounder (MBES), and Single Beam Echosounder (SBES) are widely utilized because they can produce high-resolution seafloor imagery and efficiently cover large survey areas in a relatively short time (Prayetno & Ulinnuha, 2020; Testolin et al., 2022).

The characteristics of acoustic reflections are strongly governed by the physical properties of the seafloor, including sediment type, surface roughness, and the presence of biota or man-made structures (Feng et al., 2024). A study by (Yan et al., 2021) demonstrated that backscatter information derived from Side Scan Sonar can be employed to delineate seafloor boundaries and detect small objects using a deep-learning–based 1D-UNet approach. Similarly, (Du et al., 2023) reinforced these findings by developing an automatic detection model for subsea pipelines using high-resolution sonar imagery. Collectively, these studies highlight that acoustic methods can be optimized to identify targets on the seafloor based on their distinct backscattering responses.

In Indonesia, related investigations have also been conducted. For example, (Santosa et al., 2024) analyzed acoustic backscatter data collected in Yos Sudarso Bay using Side Scan Sonar to classify seafloor sediment types, while (Hamuna et al., 2025) employed an echosounder to quantify backscattering responses in Papua waters. These studies demonstrate that variations in acoustic backscatter can be utilized to distinguish objects with differing physical properties, including the potential identification of seabed structures such as submarine cables.

The waters surrounding Tidung Island in the Seribu Islands are characterized by complex environmental conditions, including shallow topography, mixed sediments consisting of sand and mud, and biological coverage such as seagrass and coral. This heterogeneity poses specific challenges for submarine cable detection, as the acoustic reflections produced by the cable often resemble those generated by benthic biota or hard substrates on the seafloor (Weijia et al., 2022). Consequently, sonar interpretation in such environments may lead to uncertainties in accurately determining the cable's location.

The central issue addressed in this study concerns how to reliably detect and map the trajectory of submarine cables while distinguishing them from other seafloor features. Inaccurate cable detection can compromise installation safety, maintenance operations, and vessel navigation (Feng et al., 2024). To mitigate these risks, it is essential to identify the distinctive acoustic backscattering characteristics of submarine cables so that they can serve as discriminating parameters in sonar imagery. This approach aligns with findings from (Smith et al., 2023), which demonstrated that the relationship between backscatter intensity and geotechnical sediment properties can be used to classify seafloor surfaces. These insights provide a strong foundation for employing acoustic backscatter measurements as an effective solution for detecting submarine cables in dynamic environments such as the waters around Tidung Island.

Accordingly, this study focuses on characterizing the acoustic backscattering signatures of submarine cables in the waters of Tidung Island as a means to enhance the reliability of underwater object detection and mapping. The analysis is expected to provide distinct identification parameters and support the advancement of more accurate acoustic survey techniques for shallow tropical waters in Indonesia.

2. Method

The survey was conducted in the waters of Tidung Island (Figure 1) using an acoustic sounding approach. Acoustic data were collected over a 10-minute period employing two single-beam echosounder systems: the SIMRAD EK-15 and the Furuno FCV-628.

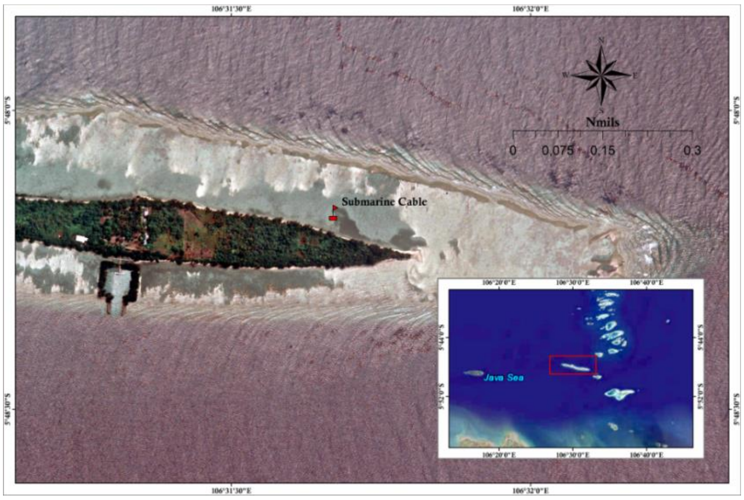
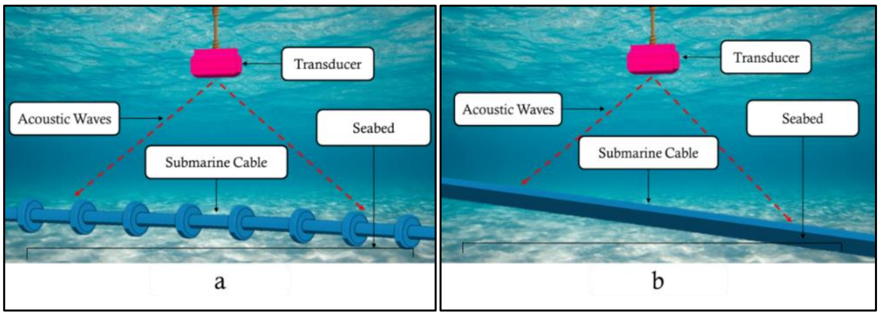


Figure 1. Research Location

Acoustic backscatter data of the submarine cables were collected using two instruments, the SIMRAD EK-15 and the Furuno FCV-628, both operating at a frequency of 200 kHz. The Simrad unit was deployed in shallow waters at a depth of approximately 1.5 meters, where the observed cable lacked a concrete protective layer (Figure 2a). In contrast, the Furuno system was mounted on the starboard side of the vessel at a similar depth, and the detected cable at this site was encased in a concrete covering (Figure 2b). Each instrument was used to conduct two measurement runs.



(a) Furuno FCV-628 (b) SIMRAD EK-15
Figure 2. Illustration of Submarine Cable Measurement

The Volume Backscattering Strength (SVc) values obtained from the submarine cable measurements using the SIMRAD EK-15 were processed with Echoview software. The backscattering outputs from the instrument were then analyzed to derive the Surface Backscattering Strength (SS). Following the approach described in (Johannesson & Mitson, 1983), the SVc calculation was performed using the following equation:

$$SV_c = 10\log\frac{I_r \text{ in units for volume at a distance of } 1\ m}{I_i} \quad (1)$$

The SS value was obtained using the formula presented in (Manik, 2016), as follows:

$$SS(dB) = 10\log\left(\frac{c\tau}{2}\right) + Sv_c \quad (2)$$

Where :
SS : Surface Scattering Strength (dB)
c : Sound Speed (m/s)
τ : Pulse Length
SV_c : Volume Back Scattering Strength From Submarine Cable

The acoustic data acquired from the FURUNO FCV-688 were processed following the procedures outlined in (Manik et al., 2020), through the following steps:

$$TS = EL - KTR + 40\log R + 2\alpha R - 120 \quad (3)$$

$$SV = EL - KTR + 20\log R - 10\log\left(\Psi\left(\frac{c\tau}{2}\right)\right) - 120 \quad (4)$$

$$KTR = EL + 40\log R + 2\alpha R - 120 - TS \quad (5)$$

Where :
EL : Echo Level ($\text{dB}_{\mu v}$)
KTR : Factor of Transmit and Received (dB_{v})
R : Water Depth (m)
α : Absorption Coefficient (dB/km)
Ψ : Equivalent Beam Width
c : Sound Speed (m/s)
τ : Pulse Width

In this study, bandpass filtering, Automatic Gain Control (AGC), and deconvolution were applied to enhance the quality of the recorded acoustic signals and to improve the detectability of submarine cable targets. Bandpass filtering was employed to suppress low-frequency noise and high-frequency interference outside the operational bandwidth of the echosounders, thereby preserving the dominant frequency content associated with cable backscatter. AGC was applied to compensate for signal attenuation with range and to normalize amplitude variations caused by water depth and spreading loss, which is particularly important in shallow-water environments characterized by strong bottom reflections.

To further improve signal clarity, deconvolution was implemented to reduce pulse-length effects and to enhance vertical resolution, enabling clearer discrimination between seabed echoes and submarine cable responses. While predictive deconvolution is effective in attenuating reverberation under relatively homogeneous seabed conditions, alternative approaches such as sparse-spike deconvolution may provide advantages in environments with complex seabed textures or heterogeneous sediment composition. Accordingly, future studies may explore a comparative assessment of these processing techniques to optimize signal-processing strategies for different seafloor types and environmental settings.

Beyond signal-processing considerations, the environmental characteristics of the waters surrounding Tidung Island also play an important role in shaping the recorded acoustic backscatter responses. The study area is classified as shallow tropical waters, where acoustic measurements are influenced by dynamic tidal conditions, local currents, and variations in seabed sediment composition, including sand, fine silt, and biogenic materials. Tidal fluctuations can modify water-column depth and alter the incident angles of acoustic signals, thereby affecting signal propagation paths and target insonification (Miron-Morin et al., 2021).

Furthermore, seabed sediment properties exert a strong control on acoustic reflectivity and attenuation, which may contribute to the observed differences in backscattering strength between concrete-armored and non-armored submarine cables (Alajuri et al., 2021; Pujiyati et al., 2019; Sari & Manik, 2022). Although these environmental conditions are briefly addressed in this study, establishing a clearer linkage between environmental factors and the resulting acoustic responses would enhance the interpretation of the backscatter data and strengthen the overall robustness of the analysis. The stages of data acquisition and processing are summarized in Figure 3.

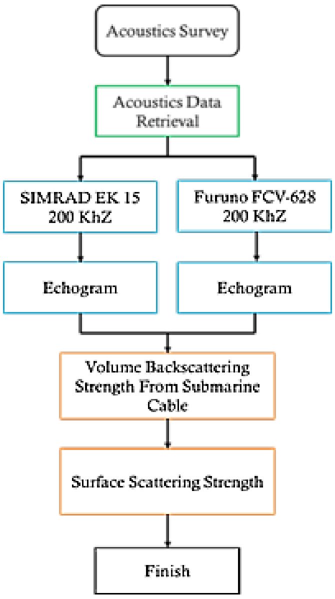


Figure 3. Data Acquisition and Processing Stages

3. Result and Discussion

Based on the hydroacoustic survey conducted in the waters around Tidung Island, two primary types of submarine cables were identified using a single-beam echosounder: cables encased in concrete protection and cables without concrete shielding. These cable types exhibit distinct physical and acoustic characteristics, closely associated with their installation methods and the environmental conditions of tropical shallow-water settings. Both measurements were conducted over seabed conditions dominated by sand mixed with coral fragments, which is typical of shallow reef influenced coastal environments and contributes to the observed acoustic backscatter responses.

Figure 4. Submarine Cables With Concrete Armoring

The concrete-coated cable has a diameter of approximately 30–40 cm and operates at 20 kV, in accordance with the provisions of KEPMEN KKP No. 14 of 2021. The concrete layer functions as a mechanical shield against external pressure, abrasion, and displacement caused by ocean currents. Field observations indicate that measurements were conducted along the central section of the conduit, where the cable surface appeared relatively uniform (Figure 4). According to (Zheng et al., 2022), protective layers such as concrete or other heavy structures are applied to enhance the burial depth protection index, a parameter used to assess the degree of physical security provided to submarine cables from potential seabed disturbances. Such protection is particularly critical in shallow-water environments where ship anchors, fishing gear, or strong currents may impose substantial mechanical stress on the cable. Beyond its mechanical role, the concrete material also influences acoustic backscatter behaviour due to differences in acoustic impedance between concrete, seawater, and seafloor sediments. This impedance contrast alters the echo response detected by the echosounder and must be accounted for in acoustic data analysis (Kartal et al., 2022).

Figure 5. Submarine Cables Without Concrete Armoring

In contrast to the previously described type, the cable without concrete protection (Figure 5) has a diameter of approximately 20 cm, making it smaller and visibly exposed on the seafloor. Field observations indicate that this cable was likely originally encased in concrete, but the protective layer has detached due to strong currents and dynamic seabed conditions. This situation reflects a higher structural vulnerability to abrasion, cable displacement, and external disturbances. As noted by (Yu et al., 2023), submarine cables without physical protection face an increased risk of material degradation and reduced transmission performance due to direct exposure to the corrosive marine environment. Furthermore, the absence of a protective layer generally results in higher acoustic backscatter values, as the conductive metallic components inside the cable are directly exposed to seawater and surrounding sediments (Hamuna et al., 2025). This condition also has implications for operational safety and the long-term reliability of marine energy transmission systems. A study by (Velásquez & Lara, 2020) reported that cables lacking adequate protection or burial exhibit up to twice the failure risk compared to those shielded by concrete structures or trenched into the seabed. The acoustic backscattering characteristics of concrete-coated cables measured using the Furuno device are as follows:

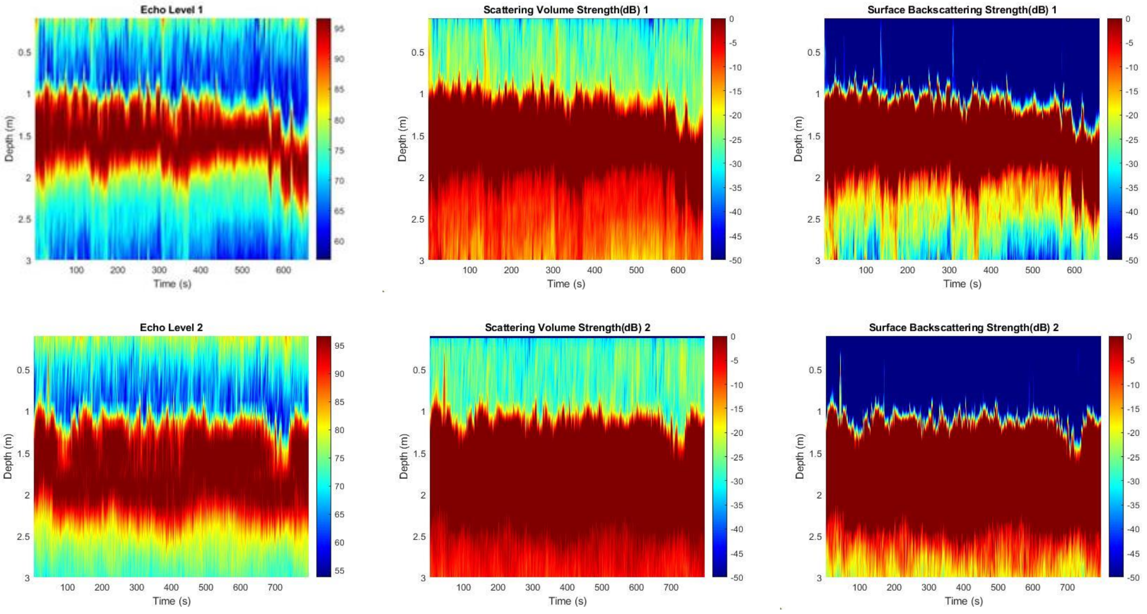


Figure 6. Echo Level, SVc, and SS Values of Submarine Cables

The acoustic backscatter measurements of the concrete-armored submarine cable obtained using the Furuno FCV-628 echosounder at 200 kHz show Scattering Volume Strength (Sv) values of −6.701 dB and −5.055 dB, indicating the presence of strong and distinctive volumetric scatterers associated with high-impedance solid structures such as concrete and metallic elements within the cable (Bae & Kim, 2024; Palermino et al., 2023). The relatively high Sv at this frequency suggests that the region surrounding the cable not only produces surface reflections but also generates localized volumetric scattering caused by small cavities, gaps, or irregularities within the concrete layer (Menandro et al., 2025). Meanwhile, the Surface Scattering Strength (Ss) values of −11.855 dB and −9.510 dB are consistent with the reflective behavior of hard interfaces characterized by sharp acoustic-impedance contrasts between concrete and seawater (Roche et al., 2025b; Trzcinska et al., 2021). The 1–2 dB variation between repeated measurements can be attributed to changes in incidence angle, transducer range, surface-water conditions, and instrument sensitivity (Levine et al., 2025; Zhu et al., 2024).

At 200 kHz, the short acoustic wavelength makes the echo response highly sensitive to micro-scale surface features on the concrete, and theoretical models based on the Kirchhoff approximation and DWBA are commonly applied to interpret scattering patterns from rigid targets (Song et al., 2024; Tang et al., 2023). Given the strong and relatively stable Sv and Ss values, these measurements indicate that the cable structure exhibits high reflectivity, and the combined use of multiband techniques and visual verification is recommended to enhance the accuracy of submarine-cable condition assessments (Idrissi et al., 2025; Paap et al., 2025). Rigorous instrument calibration and comprehensive documentation of measurement metadata remain fundamental components for ensuring reliable quantitative interpretation (Clare et al., 2024; Drapp & Mildner, 2025).

Although the calculation of Volume Backscattering Strength (SVc) and Surface Scattering Strength (SS) is well established, the measured values may be influenced by several sources of uncertainty. Minor variations in transducer positioning, such as changes in tilt angle or immersion depth, can affect insonification geometry and backscatter intensity, particularly in very shallow waters (Guruh et al., 2023; Roche et al., 2025a). In addition, signal noise, vessel motion, and short-term environmental variability may introduce fluctuations in the recorded echo levels.

Environmental parameters such as temperature and salinity also influence sound speed and absorption coefficients, which in turn affect SVc and SS estimations. While constant sound speed values were assumed in this study, small deviations from actual in situ conditions may contribute to uncertainty in the derived backscatter values. Incorporating uncertainty analysis or sensitivity testing in future studies would improve the robustness of quantitative backscatter interpretation and facilitate comparison across different survey conditions. The measurement results of the submarine cable obtained using the SIMRAD EK-15 at 200 kHz are as follows:

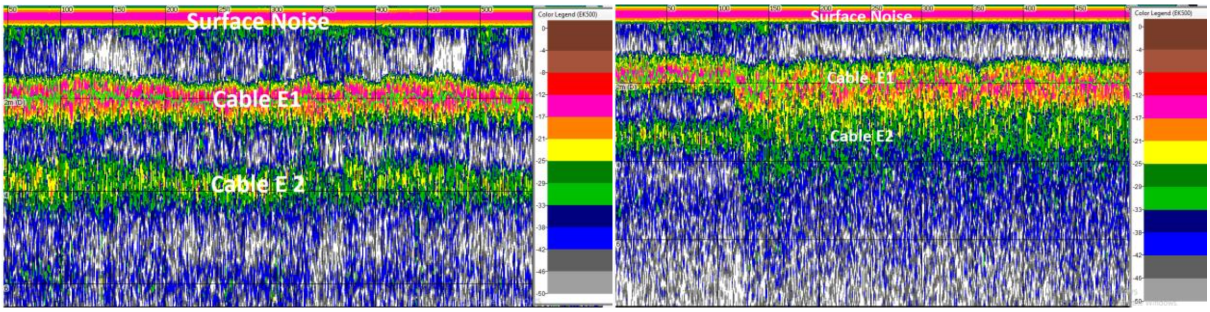


Figure 7. Acoustic Backscatter from Submarine Cables (SIMRAD EK-15)

The acoustic backscatter measurements obtained using the SIMRAD EK-15 at 200 kHz for the submarine cable without concrete protection revealed two consistent echoes, namely the primary echo (E1) and the secondary echo (E2), in both recordings. The primary echo appears stronger because it represents the direct reflection from the cable's core structure, which exhibits a high acoustic-impedance contrast relative to the water column. In contrast, the secondary echo shows lower intensity, resulting from multiple-scattering processes such as internal reflections within the cable layers, double reflections between the cable and the seabed, and variations in the acoustic incidence angle (Chen et al., 2021; Choi et al., 2021; Hamuna et al., 2024; Jung et al., 2022).

The first measurement yielded an SVC value of −11.547 dB and an SS value of −14.612 dB, while the second measurement showed a slight decrease, with SVC at −12.600 dB and SS at −15.665 dB. The difference of approximately 1 dB remains within the expected range of natural variation, which may arise from changes in aspect angle, transducer motion dynamics, and elevated surface noise typical of high-frequency echosounders (Dahl et al., 2020). The absence of a concrete mattress increases the sensitivity of echo amplitude to orientation changes and hydrodynamic conditions, as protective structures typically enlarge the reflective surface area and enhance backscatter intensity (Cheng et al., 2021).

The observed echo patterns also align with theoretical models of cylindrical-object backscattering at 200 kHz, where cable geometry, diameter, and material composition strongly influence acoustic responses, producing a prominent primary echo accompanied by weaker secondary returns (Taweesintananon et al., 2021). Both measurements therefore demonstrate clear and stable cable detection, with minor inter-measurement variations that can be fully explained by underwater-acoustic principles and instrument-operation characteristics (Simrad, 2012).

The higher acoustic backscatter observed from concrete armored submarine cables compared to non-armored cables is primarily attributed to differences in acoustic impedance between the cable materials, seawater, and surrounding sediments. Concrete exhibits a substantially higher impedance contrast, producing stronger reflections at the cable water interface, whereas non armored cables with polymer based insulation generate weaker and more variable returns. In addition, cable sediment interaction influences the recorded response, as concrete armored cables tend to remain exposed or only partially embedded, while non armored cables are more prone to sediment contact or partial burial, leading to increased signal attenuation. From an operational perspective, these findings indicate that single beam echosounder-based backscatter analysis can be applied to practical submarine cable inspection in shallow coastal environments. Although this study was conducted in the waters of Tidung Island, the underlying acoustic mechanisms are not site specific and are expected to be applicable to similar cable types elsewhere; however, for buried cables or installations in deeper waters, reduced detectability due to sediment and water column effects may require site specific calibration or complementary acoustic methods.

Table 1. SVc and SS Value From Submarine Cables

Repitition	SIMRAD EK-15 (Cables Without Concrete Armoring)		Furuno FCV-628 (Cables With Concrete Armoring)	
	SVc (dB)	SSc (dB)	SVc (dB)	SSc (dB)
1	-11.547	-14.612	-6.701	-11.855
2	-12.600	-15.665	-5.055	-9.510
Δ(dB)	-1.053	-1.053	-1.696	-2.354

The table above shows that the differences in acoustic detection between the two measurement repetitions are primarily influenced by several physical factors commonly encountered during submarine cable inspections. Variations in the acoustic incidence angle relative to the cable play a major role, as cylindrical targets exhibit highly orientation-dependent backscattering behavior (Trzcinska et al., 2021). In addition, the internal structure of the cable such as insulating layers, metallic conductors, and protective sheaths can generate multipath reflections that affect the strength of both the primary and secondary echoes (Ha et al., 2023).

Environmental conditions, including currents, turbulence, and water-column variability, further contribute to signal instability and thus produce differences between measurements. Additional factors, such as partial burial of the cable in sediments, variations in seabed roughness, and sediment heterogeneity, may attenuate or disperse acoustic energy, leading to the backscatter variability observed in both instruments (Vincent, 2024).

Although this study focuses on the use of single-beam echosounders (SIMRAD EK-15 and Furuno FCV-628), it is important to position their performance relative to other commonly used acoustic systems such as side-scan sonar (SSS) and multibeam echosounders (MBES). Compared to SSS and MBES, single-beam echosounders provide lower spatial coverage and resolution; however, they offer faster data acquisition, simpler processing workflows, and significantly lower operational costs, making them well suited for rapid and targeted inspection of submarine cables in shallow coastal waters. While MBES and SSS are advantageous for detailed seabed imaging and wide-area mapping, their deployment typically requires more complex calibration procedures, longer processing times, and higher logistical costs. In contrast, the results of this study demonstrate that single-beam backscatter analysis remains effective for detecting exposed submarine cables when supported by appropriate signal processing techniques. Unlike sediment and benthic habitat studies that primarily address distributed backscatter patterns, submarine cable detection poses unique challenges due to the linear geometry and small cross-sectional size of the target, emphasizing the need for targeted signal processing strategies such as optimized filtering and gain control. From an operational perspective, this approach is particularly suitable for routine cable monitoring, maintenance planning, and preliminary risk assessment along known cable routes in shallow coastal environments. Nevertheless, its application to large-scale surveys may be constrained by survey duration, environmental variability, and limited spatial coverage. Future work may therefore focus on enhancing detection sensitivity through advanced signal processing and multi-frequency approaches, extending applicability to deeper waters, and integrating single-beam echosounder systems with autonomous underwater vehicles (AUVs) or robotic platforms to improve survey efficiency and operational scalability.

4. Conclusion

This study demonstrates that the acoustic backscattering characteristics of submarine cables in the waters around Tidung Island can be clearly distinguished through quantitative analysis using the SIMRAD EK-15 and Furuno FCV-628 echosounders operating at 200 kHz. The two cable types those with concrete protection and those without exhibit consistently different SVc and SS values, reflecting the influence of material composition, physical structure, and acoustic interactions within tropical shallow-water environments. These findings confirm that the acoustic responses of submarine cables follow identifiable patterns that can serve as diagnostic indicators to improve detection accuracy and mapping reliability.

In contrast to previous studies that have primarily focused on sediments, biota, or subsea pipelines, this research provides a new contribution by presenting direct, calibrated mapping of the acoustic signatures of submarine cables based on in situ measurements. The dual-instrument approach used here proved effective in producing stable and replicable data, thus expanding the potential use of commercial echosounders for marine infrastructure inspections. Overall, the results enhance the understanding of backscattering behavior from high-impedance cylindrical objects and open opportunities for developing more precise acoustic survey methods to support submarine-cable management in Indonesia's coastal regions.

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