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ACOUSTICS BACKSCATTER MEASUREMENT OF LARGE MICROPLASTICS IN CONTROLLED CONDITIONS USING A SINGLE BEAM ECHOSOUNDER

PENGUKURAN *ACOUSTICS BACKSCATTER LARGE MICROPLASTICS* DALAM KONDISI TERKONTROL DENGAN *ECHOSOUNDER* SOROT TUNGGAL

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ABSTRACT

Microplastics are particles ≤ 5 mm in size that result from the physical and chemical degradation of polymer-based materials. These particles are ubiquitously distributed in aquatic environments and pose significant threats to aquatic organisms. Currently, microplastic detection predominantly relies on water-sample analyses at a particular point, a method that is inherently limited in spatial coverage. Hydroacoustic techniques offer a promising alternative for detecting microplastics within the water column over larger areas. This study aims to assess the detection of large microplastics (1–5 mm) using a single-beam echosounder (SBES), specifically the Simrad EK-15, under laboratory-controlled conditions. Data validation was performed by comparing acoustic measurements with water-sample analyses using correlation and regression methods. The results reveal high model suitability with coefficients of determination exceeding 0.8 ($R^2 > 0.8$) and strong linear correlations ($r > 0.8$) between the two datasets. Furthermore, the average volume backscattering coefficient (s_v) for large microplastics at depths corresponding to 1.5, 1, and 0.5 m were 9.025E-05, 5.403E-05, and 6.850E-05 m^2/m^3, respectively, while the mean volume backscattering strength (SV) values were -40.445 dB, -42.674 dB, and -41.643 dB at these depths. These findings underscore the efficacy of the SBES in detecting microplastics sized 1–5 mm within the water column and suggest that hydroacoustic methods can serve as a viable approach for expanding microplastic monitoring capabilities.

Keywords: controlled, microplastics, single beam echosounder, underwater acoustic volume backscattering coefficient (s_v)

ABSTRAK

Mikroplastik merupakan partikel berukuran ≤ 5 mm yang terbentuk dari degradasi fisik maupun kimia objek berbahan dasar polimer. Partikel ini tersebar luas di perairan dan menimbulkan ancaman serius bagi organisma akuatik. Saat ini, pendeteksian mikroplastik terutama dilakukan melalui pengujian sampel air di titik tertentu, yang memiliki keterbatasan dalam cakupan area spasial. Metode hidroakustik menawarkan potensi untuk mendeteksi mikroplastik di kolom air dengan pencakupan yang lebih luas. Penelitian ini bertujuan untuk menganalisis pendeteksian mikroplastik berukuran 1–5 mm menggunakan *single beam echosounder* (SBES) Simrad EK-15 dalam kondisi terkontrol. Validasi data dilakukan melalui analisis korelasi dan regresi antara data akustik dan hasil pengukuran sampel air. Hasil penelitian menunjukkan kesesuaian model regresi yang tinggi ($R^2 > 0{,}8$) dengan kekuatan hubungan yang kuat ($r > 0{,}8$). Rata-rata nilai *volume backscattering coefficient* (s_v) untuk mikroplastik berukuran besar pada titik 1,5; 1; dan 0,5 m masing-masing adalah 9,025E-05, 5,403E-05, 6,850E-05 m^2/m^3, sedangkan rata-rata nilai *volume backscattering strength* (SV) adalah -40,445 dB, -42,674 dB, dan -41,643 dB pada titik-titik tersebut. Temuan ini mengindikasikan bahwa SBES Simrad EK-15 efektif mendeteksi mikroplastik berukuran 1–5 mm di kolom air dan dapat digunakan sebagai alternatif dalam memperluas cakupan monitoring mikroplastik.

Kata kunci: koefisien hambur balik volume akustik (s_v), mikroplastik, *single beam echosounder*, terkontrol

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INTRODUCTION

Plastics entering the marine environment consist of various polymer types with different densities and, over time, undergo degradation due to ultraviolet (UV) radiation, oxidation, biodegradation, and other mechanical disturbances that fragment them into smaller particles known as microplastics (Cui *et al.* 2022). Globally, microplastics are defined as particles with a maximum size of 5 mm and are categorized as large (1–5 mm), medium (330–1,000 µm), and small (1–330 µm) (Frias and Nash 2019; Gago *et al.* 2019; GESAMP 2019). In aquatic environments, microplastics often bind with toxic chemicals, and aquatic organisms that accumulate these particles act as vectors for spreading hazardous substances through the food chain (Pereao *et al.* 2020). Current detection and quantification methods rely mainly on conventional approaches, involving discrete water sampling and laboratory analysis using spectroscopic and microscopic techniques such as Raman and Fourier Transform Infrared Spectroscopy (Cunningham and Sigwart 2019; Cui *et al.* 2022; Omeyer *et al.* 2022). To enhance monitoring across wider and more complex marine areas, data harmonization and standardized characterization of polymer types and particle sizes are essential (Vriend *et al.* 2021; Arifin *et al.* 2023). In this regard, remote sensing of aquatic environments using underwater acoustic methods (hydroacoustics) offers a promising alternative for detecting plastics at greater depths, especially since conventional sampling remains labor-intensive (van Emmerik and Schwarz 2020).

Hydroacoustic methods have been widely employed to measure the acoustic properties of mesoplastics (particles ≥ 5 mm) in a fluid medium based on their polymer type. Additionally, detection and measurement of plastics in aquatic environments have been performed using scientific echosounders operating at mid-to-high frequencies (e.g., CHIRP Sonar, ARIS Sonar, SIMRAD EK80, ADCP) to cover larger areas, particularly for macroplastics (Broere *et al.* 2021; Flores *et al.* 2022; Boon *et al.* 2023), while controlled experiments on large microplastics have been conducted using the Acoustic Zooplankton Fish Profiler (AZFP) (Marko and Topham 2015).

Given that microplastics share physical characteristics (i.e., size and shape) with suspended sediments (Waldschläger *et al.* 2022), sedimentological approaches, such as the methods developed for measuring suspended sediment concentrations (Thorne *et al.* 1993), can be adopted to hydroacoustic experiments for detecting and quantifying microplastic concentrations in the water column. For instance, experiments measuring the volume backscattering coefficient (s_v) and backscattering cross-section (σ_{bs}) of large microplastics have been conducted with a determined concentration of polystyrene (PS) polymer granules under controlled conditions (Marko and Topham 2015). Although acoustic instruments have demonstrated the capability to detect suspended particles, including macroplastics and large microplastics, further advancements in acoustic signal processing are needed to extend these techniques through the application of general sonar equations. Therefore, this study examines the detection of large microplastics (1–5 mm) in the water column using a single-beam echosounder under controlled conditions to assess the applicability of sedimentological approaches to sonar analysis.

METHODS

Research setting

The experiment, conducted from June to November 2024, at the Laboratory of Underwater Acoustics and Marine Instrumentation, IPB University (for instrument calibration, acoustic measurements, and data analysis), and at the Freshwater Fisheries Laboratory Sumberpasir, Universitas Brawijaya (for microplastic extraction and observation). The experimental setup was adapted from previous studies, with Moate and Thorne (2009) providing the framework for probability density function (PDF) calculations, sample modeling, and homogenization. Marko and Topham (2015) guided sample type and size, and the D20 Committee (2017) served as the ASTM grading standard reference. The main instrument used was a Simrad EK-15 single-beam echosounder (200 kHz), selected for its resolution in detecting small suspended particles such as microplastics. Technical specifications are presented in Table 1, and supporting instruments and materials are summarized in Table 2.

Microplastic samples were obtained from a certified plastic pellet manufacturer to ensure consistent particle size and composition, specifically polystyrene pellets of approximately ±5 mm (Figure 1). The pellets were ground into 1–5 mm particles and sieved using a 1 mm stainless steel mesh following Bordós *et al.* (2021), while particles passing the sieve were treated as homogeneous with a uniform 1 mm size, as suggested by Moate and Thorne (2009).

To reduce water surface tension, samples were agitated in a dishwashing detergent solution (Oladejo 2017), and the test water was pre-treated to remove organic and suspended contaminants. Representative microplastic particles after pretreatment are shown in Figure 2.

Sphere ball calibration

Acoustic instrument calibration was performed prior to the measurements using a tungsten carbide (WC) sphere (Ø 38.1 mm) as the standard target (Foote 1982). The sphere was suspended at approximately 1.5 m below the water surface, while the Simrad EK-15 transducer was set in an upward-looking position. The measured target strength (TS) was -38.84 dB at 200 kHz (Figure 3), which is consistent with the manufacturer's specification of -39.1 dB (Demer *et al.* 2015). Similar results were also reported by Ma'mun *et al.* (2013) (-39.9 dB), Setiawan *et al.* (2020) (-39.86 dB), and Dwinovantyo *et al.* (2023) (-39.69 dB). These findings confirm that the Simrad EK-15 was properly calibrated before data acquisition.

Table 1. Specifications of the Simrad EK-15 single-beam echosounder (SBES) instrument (SIMRAD 2014).

Specification	Simrad EK-15 SBES
Operational frequency	200 kHz
Ping rate	Up to 40 Hz
Transceiver data rate	1.6 Mbps
Transducer type	Single beam
Transducer beamwidth	28 degrees
Pulse duration	80 to 1,240 µs
Raw data output	Raw data (EK60 format)

Table 2. Secondary instruments and materials used in this study.

Category	Items	Description
Field equipment	Digital thermometer, pH meter, 2-L water sampler, glass bottles (330 and 250 mL), plankton net (20 µm mesh)	Field sampling and in situ measurements
Calibration equipment	Tungsten Carbide (WC) sphere ball (Ø 38.1 mm)	Standard target for acoustic calibration
Laboratory apparatus	Vacuum pump, Memmert U-15 oven, Petri dish (Ø 60 mm), analytical balance (0.01 mg), sieves (1 mm), beaker, forceps, tweezers	Sample preparation, drying, and separation
Supplementary tools	Grinder (28,000 RPM), hand mixer (Miyako HM-620), microscope (Olympus CX23 + OptiLab Camera), air purifier (HEPA filter), gloves	Contamination control and microscopic observation
Materials	S-Pak filters (0.45 µm, Ø 47 mm, Millipore HAWG047S6), deionized water, aluminum foil, PS pellets (TRINSEO STYRON™ 666H), grafting tape	Filtration, standards, and analysis

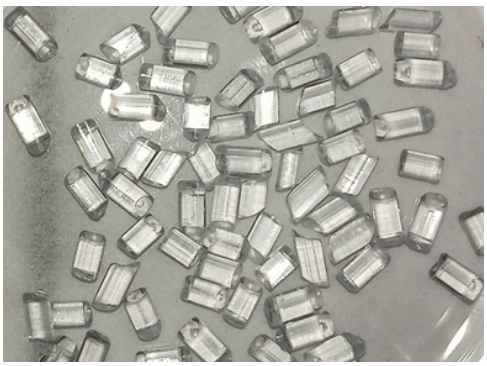


Figure 1. Polystyrene pellets (± 5 mm) manufactured for use as microplastic samples in this study.

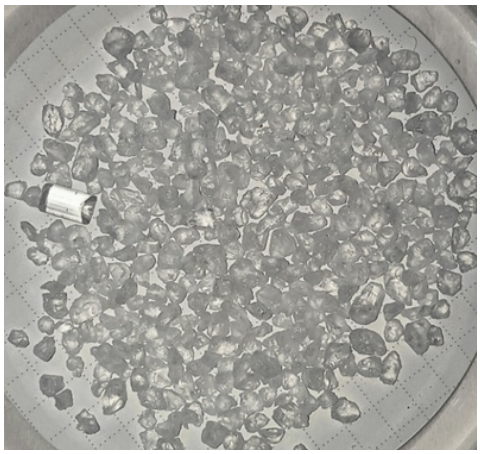


Figure 2. Representative microplastic particles (1 mm, polystyrene) obtained after grinding and sieving, used in the experimental trials.

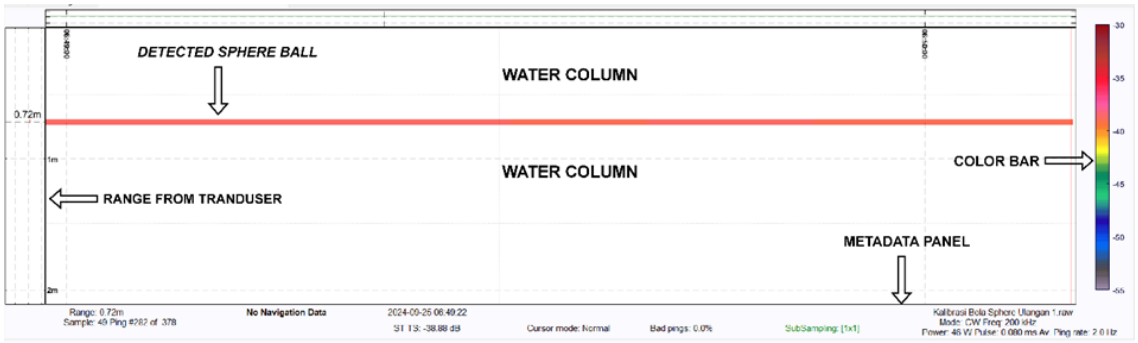


Figure 3. Echogram target strength ball sphere on ESP3 display.

Acoustic data acquisition

The experimental set-up of the acoustic data acquisition system (Figure 4) was performed using a Simrad EK-15 Single Beam Echosounder (SBES) operating at 200 kHz, with a 2.0 Hz ping rate and 80 µs pulse duration. The transducer was mounted at the bottom of the tank in an upward-looking (0°) position to detect particle concentrations. Under controlled conditions, 2,500 g of microplastic samples (2.90×10^5 mg/L) were introduced for three replicates, with sampling conducted 40–60 s afterward at three depth layers relative to the transducer (Table 3). Water quality parameters were maintained within experimental thresholds, with pH 6.5–8.7 and temperature 26.3–27.6 °C, measured using a pH meter and digital thermometer.

Data processing and analysis

Raw acoustic data were extracted and processed using the ESP3 version 1.5.2 software (Ladroit *et al.* 2020), developed by the Fisheries Monitoring and Acoustics Team at the National Institute of Water and Atmospheric Research (NIWA). The data processing workflow (Figure 5) included calibration and noise filtering, which resulted in validated volume backscattering coefficient (s_v) values (O'Driscoll *et al.* 2018; Della Penna *et al.* 2022; Perelman *et al.* 2023). These procedures ensure that the echo integration data are both clean and accurately calibrated. The validated s_v values were subsequently used to estimate microplastic concentration through an inverse problem approach, with adjustments based on the suspended particle estimation method proposed by Thorne and Hurther (2014), as applied to the sonar equation by Vergne *et al.* (2020):

$$V_m^2 = \frac{16\pi}{3}\frac{\Re^2 s_v}{\Psi^2 r^2} e^{-4r(\alpha_w+\alpha_s)}$$

In this equation, V_m^2 represents the quadratic mean of the received voltage signal (volts^2) over multiple pings, $\Re$ is the instrument calibration constant, s_v denotes the volume backscattering coefficient ($m^2 \cdot m^{-3}$), r refers to the range from the transducer (m), Ψ is a near-field correction factor, a_w corresponds

to the attenuation caused by water viscosity (dB·m^{-1}), and α_s represents the attenuation due to suspended particles. Fundamentally, the value of s_v depends on both the type and the quantity of scatterers present in the medium. This parameter can be further defined through mathematical formulations presented by Hay (1991), Medwin and Clay (1998), and Bjørnø (2017). The adaptation of these equations was performed based on the acoustic signal processing results obtained using the ESP3 V1.5.2 software, while also incorporating modifications of the sonar equation model as adopted by Guerrero *et al.* (2016) and Guerrero and Di Federico (2018):

$$s_v = \frac{3}{16\pi}\left(\frac{f(a)}{\sqrt{a\rho_{ps}}}\right)^2 M$$

In this context, a denotes the particle radius (m), ρ_{ps} is the density of polystyrene particles (kg·m^{-3}), M represents the mass concentration of suspended particles (kg·m^{-3}), and *f(a)* denotes the backscattering form function for particles of radius a. The backscattering cross-section (σ_{bs}) for water-sample data was determined by modeling the acoustic scattering properties of the particles. This modeling was undertaken to derive the backscatter form function (*f*) based on the equation proposed by Thorne and Meral (2008):

$$f(a) = \frac{x^2\left(1 - 0.35e^{([x-1.5]/0.7)^2}\right)\left(1 + 0.5e^{([x-1.8]/2.2)^2}\right)}{1 + 0.9x^2}$$

The parameter (x) is computed using the formula $x = 2\pi aF/c$, where (*a*) represents the particle radius (m), (*F*) is the instrument's frequency (Hz), and (*c*) is the speed of sound in water (m/s). This modeling assumes a homogeneous particle size distribution with a diameter of 1 mm, as a result of the grading process using a stainless steel sieve (Moate and Thorne 2009). Water samples were extracted gravimetrically to validate acoustic-derived s_v, and microplastic concentration (denoted as M_{ps}) was estimated using the following equation:

$$M_{ps} = \frac{16\pi\, s_v}{3K^2}$$

Acoustic data were filtered by time and depth (Lurton *et al.* 2015), with outliers detected using the MADs method (Mellenbergh 2019). Interpolation ensured comparability between acoustic and water-sample data. Validation employed Pearson correlation and robust bi-square linear regression (Becker and Sandwell 2008; De Winter *et al.* 2016; Pitarch and Brando 2025), with correlation strength (*r*) categorized as weak ($r \leq 0.4$), moderate ($0.4 < r < 0.8$), and strong ($r \geq 0.8$) (Bahna 2009).

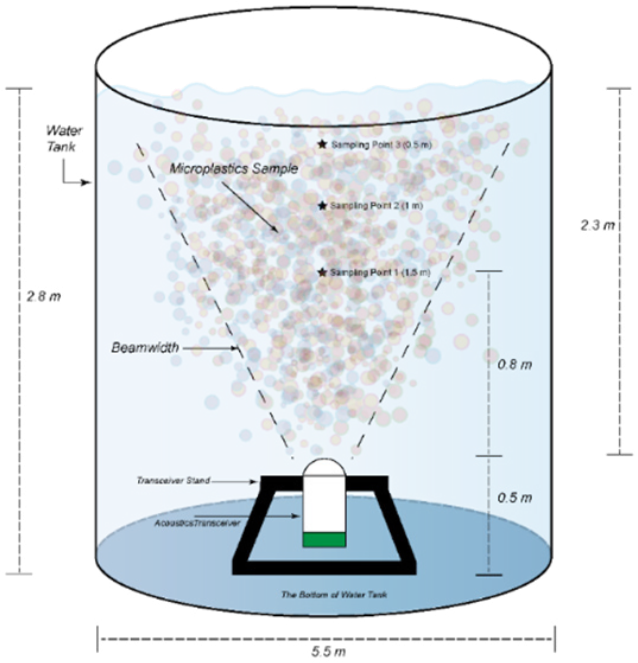


Figure 4. Visualization of acoustic data acquisition in a water tank illustrating the experimental set-up of a single-beam echosounder system.

Table 3. Depth layers and their corresponding distance ranges from the transducer.

Location	Depth (m)	Range from Transducer (m)
D1.5	1.5	0.80–1.05
D1.0	1.0	1.14–1.54
D0.5	0.5	1.65–2.04

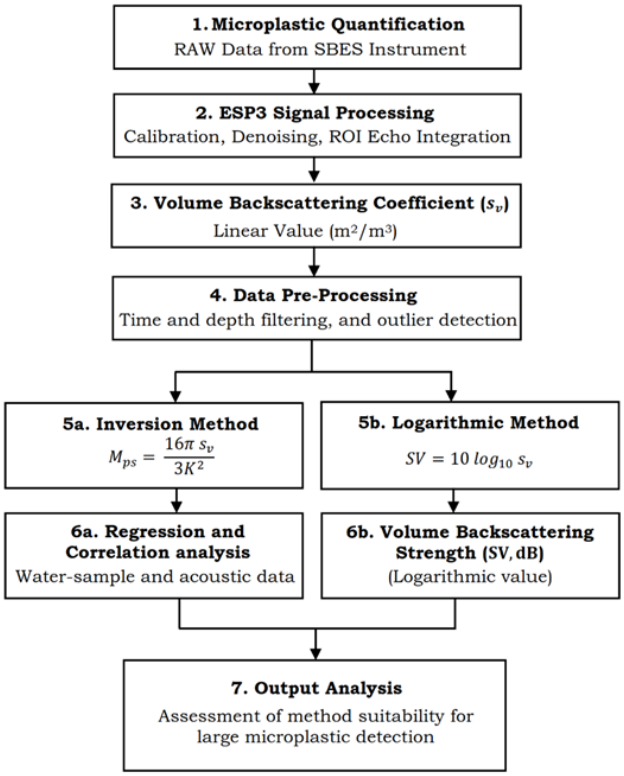


Figure 5. Acoustic signal processing workflow for microplastic detection and quantification.

RESULTS AND DISCUSSION

Backscatter and concentration measurement result

The acoustic measurements using the Simrad EK-15 successfully detected large microplastics (MPs) under control conditions. The denoised echogram (Figure 6) shows a gradual decrease in echo intensity from D1.5 to D0.5, indicating particle settling influenced by water movement, consistent with Elagami *et al.* (2022), who found that larger MPs (100–1,000 µm) have shorter residence times than smaller ones, and Dittmar *et al.* (2024), who reported that settling velocity increases with particle diameter following Stokes' Law.

The distribution of the volume backscattering coefficient (s_v) values (Figures 7 and 8) revealed a linear depth-dependent variation corresponding to microplastic stratification and concentration changes, with acoustic and water-sample data showing consistent patterns. Notably, the s_v values exhibit a progressively narrower range as the sampling area decreases or as measurements approach the water surface.

Using the inverse problem approach, microplastic concentration was estimated based on variables including s_v, SV, f, ρ_{ps}, and particle size (a). The highest concentration occurred at D1.5 (1.5 m depth) and decreased toward D0.5 (0.5 m), confirming vertical stratification (Figure 8). Volume backscattering strength (SV) (Figure 9) was more stable than s_v but showed similar depth-dependent trends. This distribution pattern indicates that both the acoustic and water-sample extraction methods are capable of capturing microplastic samples.

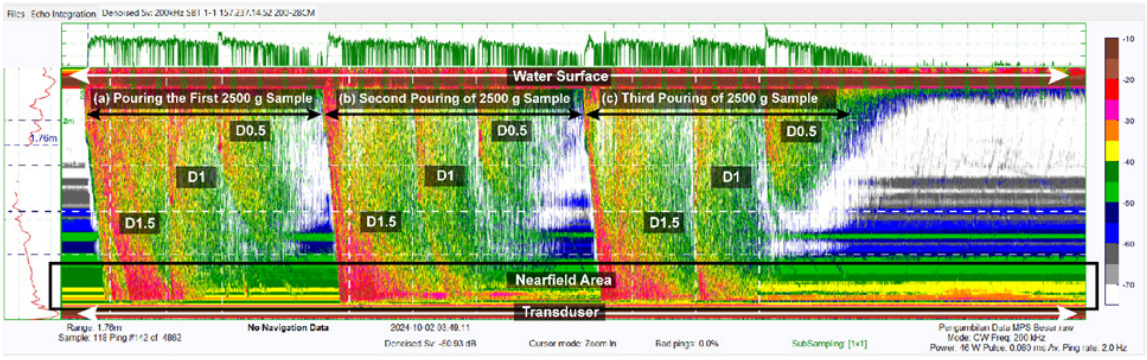


Figure 6. Example of an echogram of acoustic experiments in the water tank.

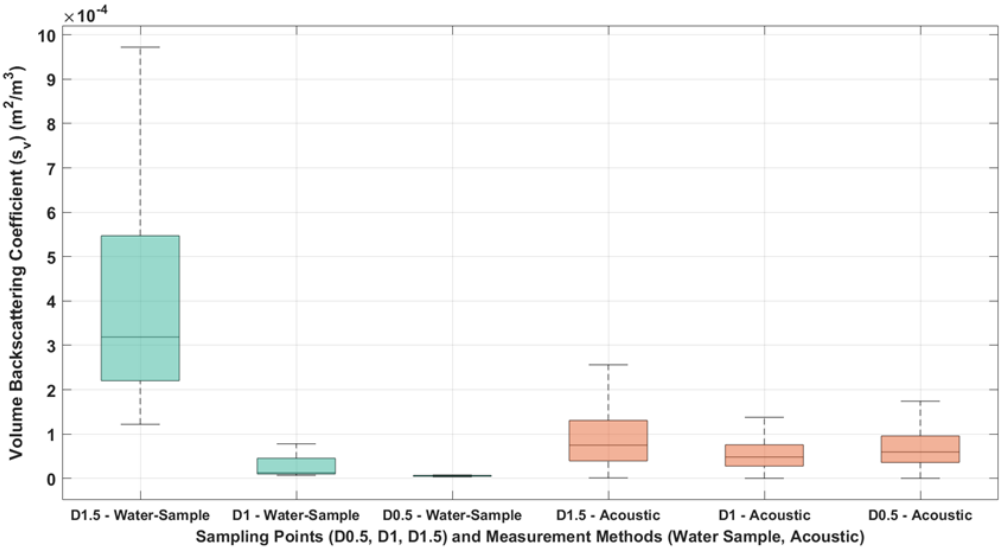


Figure 7. Distribution of volume backscattering coefficient (s_v) values of the large MPs water sample and acoustics at 3 data collection points.

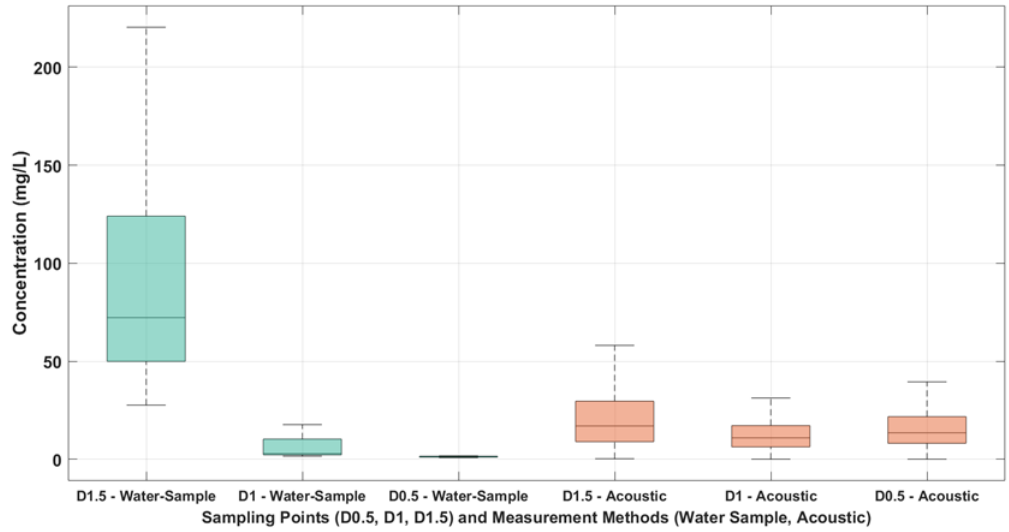


Figure 8. Distribution of water sample and acoustic large MPs concentration values at 3 data collection points.

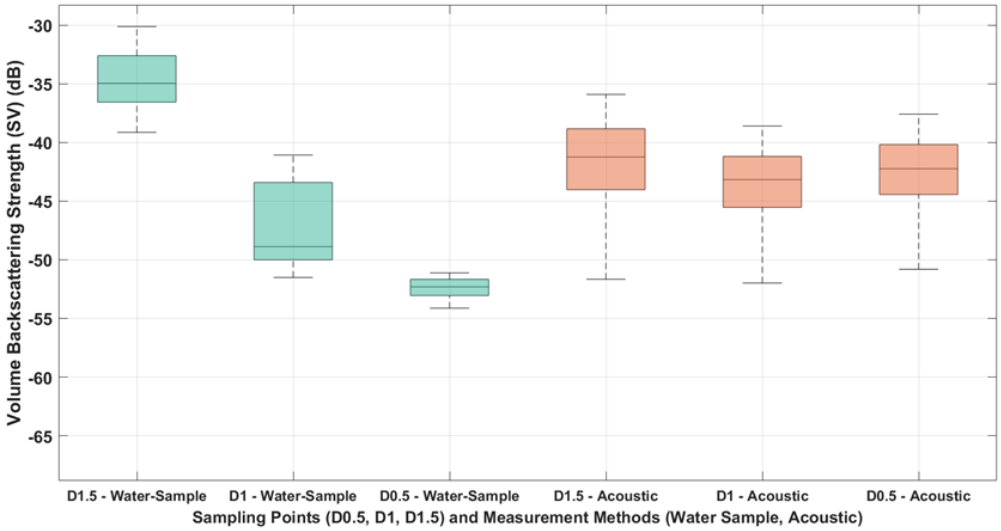


Figure 9. Distribution of volume backscattering strength (SV) values of large water samples and acoustic MPs at 3 data collection points.

Water-sample data indicate that microplastic concentration decreases toward the water surface, suggesting that most particles settle rapidly to the tank bottom while only a few remain in the upper layer (Table 4). At a depth of 0.5 m, the concentration was recorded at ≤1.7 mg/L. Acoustic measurements corroborate these findings, with the highest values of the volume backscattering coefficient (s_v) and volume backscattering strength (SV) were observed at 1.5 m depth, decreased at 0.5 m, and were lowest at 1 m (Table 5). The 1 m depth appears to be a critical zone, as waves and flow during sampling tend to resuspend previously settled particles, thus impacting the data.

Table 4. Validation data of microplastic concentration from water-sample extraction, P1–P3, indicate replicate extractions from the same sampling point (mg/L).

Sampling Point	Sample Pouring Replicates (mg/L)		
	P1	P2	P3
D1.5	85.675	27.575	220.375
D1	1.6	2.925	17.675
D0.5	0.875	1.75	0.95

Table 5. Descriptive statistics of acoustic backscattering parameters at different depth layers.

Acoustics Variable	Sampling Point	Min	Max	Mean	Median	Std. Dev
Volume Backscattering Strength (dB)	D1.5	-59.578	-35.912	-40.445	-41.246	± 2.706
	D1	-66.870	-38.607	-42.674	-43.170	± 2.396
	D0.5	-66.992	-37.591	-41.643	-42.244	±3.439
Volume Backscattering Coefficient (m^2/m^3)	D1.5	1.102E-06	2.563E-04	9.025E-05	7.507E-05	6.215E-05
	D1	2.056E-07	1.378E-04	5.403E-05	4.819E-05	3.222E-05
	D0.5	1.999E-07	1.742E-04	6.850E-05	5.964E-05	4.170E-05
Estimated Concentration (mg/L)	D1.5	0.250	58.102	20.458	17.015	14.088
	D1	0.047	31.239	12.247	10.924	7.303
	D0.5	0.045	39.477	15.526	13.519	9.451

Correlation and regression of water-sample and acoustic data

Based on Figure 10, the correlation between the acoustic volume backscattering coefficient (s_v) and water-sample-measured microplastic concentrations exhibits a very strong relationship across all depths (r > 0.9). Although the correlation coefficient is high, the coefficient of determination (R^2) from the regression model fluctuated; it was 0.9801 at the D1.5, decreased to 0.9328 at the D1, and then increased to 0.9641 at the D0.5. This variation, particularly the change observed at the D1, suggests that fluctuations in microplastic concentrations contribute to the overall variability in the data, possibly due to the stirring process during sample collection.

Although the coefficient of determination (R^2) indicates a good fit of the regression model to the data, a deeper interpretation of the underlying physical processes is achievable by examining the slope values. The observed slope was 1.160E-06 at point D1.5, increased to 6.122E-06 at point D1, and subsequently surged to 1.510E-04 at point D0.5. Notably, the slope pattern between the *volume backscattering coefficient* (s_v) and the microplastic concentration measured in the water sample is consistent with the relationship observed between the s_v values derived from both acoustic and water-sample data, as well as between the concentrations measured by these two methods. These results indicate that microplastic particle diffusion, induced by stirring during sample collection, contributes to data anomalies at point D1. In contrast, at point D0.5, which is closer to the water surface, diffusion occurs in conjunction with a stronger scattering effect due to shorter acoustic path lengths and reduced microplastic concentration. Despite these anomalies, the consistently high R^2 values (R^2 > 0.9) and strong correlation coefficients (r > 0.9) confirm that the overall regression model reliably describes the linear acoustic response to variations in microplastic concentration.

Ermoshkin *et al.* (2022) explain that variations in the acoustic backscattering spectrum are influenced by the complexity of the physical environment, while Zhang *et al.* (2021) highlight that sample physical characteristics and instrument sensitivity can also introduce error. In this study, the elevated near-surface value at depth D0.5 cannot be attributed to large microplastic particles (1–5 mm), since these tend to sink more rapidly, and as the last sampling point, this layer is expected to contain very few or no such particles. Instead, the elevated response is most plausibly explained by bubble interference, which can enhance acoustic backscatter even when scatterer abundance is low. This mechanism is consistent with the slope fluctuations observed in the regression model and the pronounced increase at D0.5. Vergne *et al.* (2020) noted that bubbles may dominate backscatter in near-surface waters, a view supported by Fernández *et al.* (2021), who reported that very low scatterer concentrations allow noise to dominate and artificially amplify the acoustic signal, thereby leading to an overestimation of the response relative to the actual particle concentration.

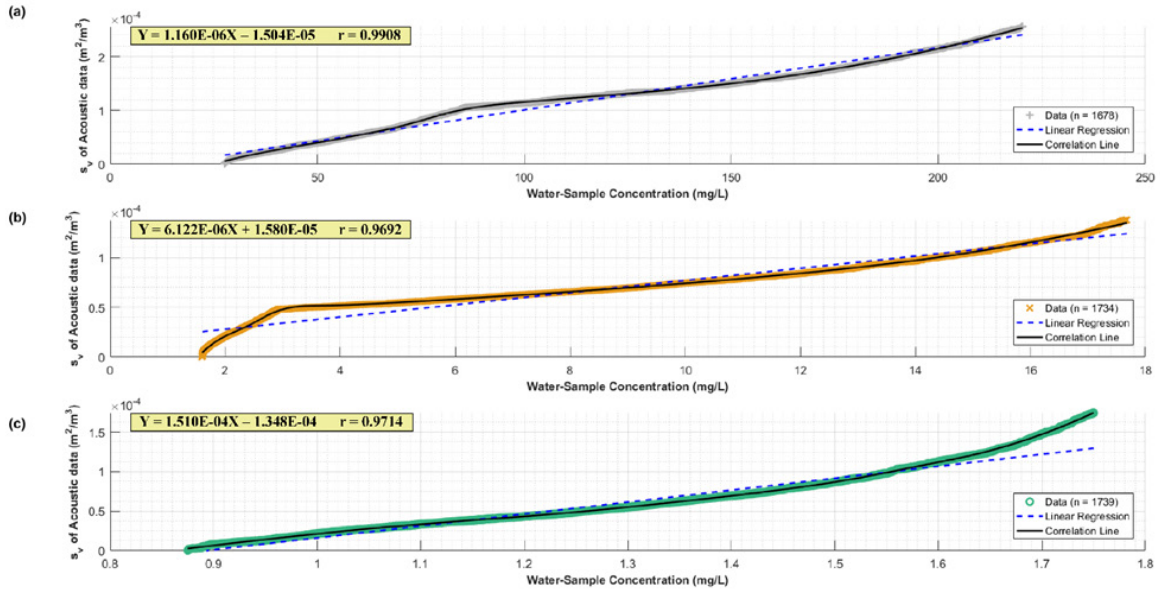


Figure 10. Regression and correlation results between water-sample MPs concentration values (x-axis) and acoustic s_v (y-axis) at 3 different depth points, namely (a) point D1.5; (b) point D1; (c) point D0.5. The results show a very strong linear correlation.

Further analysis evaluated the model fit between the volume backscattering strength (SV in dB) and the log10 of microplastic concentration. The transformation of data into decibels, significantly influenced by differences in measurement units, results in a slope that adjusts according to the data type. This observation is consistent with Iida *et al.* (1996), who stated that *SV* is proportional to object density, such that the regression slope in the decibel scale is ten times that of the corresponding linear slope. Additionally, the variability in slope values is attributable to the heterogeneity in the backscattering cross-section of the scatterers, arising from the diversity in particle shape and size.

Overall, the logarithmic transformation into decibel units yields a more interpretable model for capturing the exponential acoustic response to microplastic concentration. At point D1.5, the slope indicates a relatively high response; an increase of 1 mg/L in microplastic concentration results in a 13.09-fold rise, followed by a marked decrease of approximately 50% to a 6.45-fold increase at point D1. In contrast, at point D0.5, which is near the surface, the slope escalates dramatically to 33.76-fold (Figure 11). This anomalous behavior in slope values suggests that uneven particle distribution and resuspension effects due to stirring play a significant role; particles that initially settle are resuspended non-homogeneously during sampling. Moreover, the comparatively lower R^2 value at D1.5 is attributed to higher data variability resulting from elevated microplastic concentrations and the vertical alignment of the sample relative to the transducer.

Fielding *et al.* (2004) reported that acoustic instruments operating at 153 kHz can detect zooplankton approximately 1 mm in size, implying an *x* value greater than 0.3. Similarly, Marko and Topham (2015) demonstrated that even at 125 kHz, such instruments are capable of detecting polystyrene (PS) particles as small as 0.38 mm. Thus, although particles in the Rayleigh scattering regime (with *x* values below a specific threshold) are theoretically more challenging to detect, but in practice, the high concentration of particles in the water column enables reliable signal capture. Given the predominant influence of particle concentration, the estimated s_v values and corresponding microplastic concentration derived from acoustic data using a 200 kHz single beam echosounder remain both methodologically and theoretically acceptable.

The study's findings indicate that microplastic concentration estimates based on acoustic data tend to be significantly higher, often considerably exceeding those obtained from water samples. This overestimation is consistent with previous research and can be attributed to: (1) temporal differences between water sampling and acoustic data acquisition, which create time intervals leading to discrepancies in the detected concentration distributions, and (2) noise from microbubbles combined with non-uniform particle distribution resulting from stirring and subsequent turbulence.

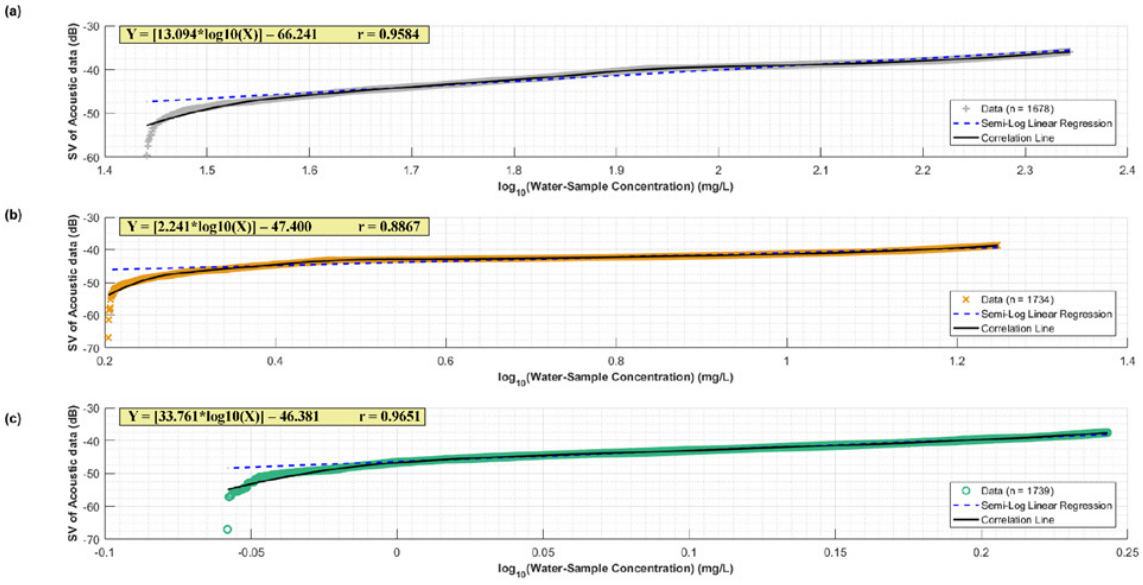


Figure 11. Regression and correlation results between water-sample MPs concentration values (x-axis) and acoustic *SV* (y-axis) at 3 different depth points, namely (a) point D1.5; (b) point D1; (c) point D0.5. The results show a very strong linear correlation.

CONCLUSION

Based on the experimental results, the use of a Simrad EK-15 SBES combined with a suspended sediment estimation equation adapted through a sedimentological approach to sonar equations demonstrated effectiveness for detecting and estimating microplastic concentrations within the water column. The resulting regression model exhibited a high level of fit ($R^2 > 0.8$) between the acoustic measurements and water-sample-determined microplastic concentrations. Further analysis revealed that the primary factor influencing the detection of large microplastics is the particle concentration present in the water column. In addition, irregular variations and a slight tendency for overestimation of concentrations may have occurred, although these did not substantially affect the overall strong relationship observed.

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