Hydroacoustic Assessment of Zooplankton Abundance in Southeastern Pari Island Waters, Jakarta Bay

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Abstract

Hydroacoustic techniques provide a swift, non-intrusive approach to quantifying pelagic organisms; however, their application for zooplankton evaluations within Indonesian coastal waters remains underexplored. This investigation assesses the efficacy of a 200 kHz single-beam echosounder (SIMRAD EK15) for estimating zooplankton density and vertical distribution in the coastal marine environment surrounding Southeast Pari Island, Jakarta Bay. Acoustic information was amassed during a two-day survey conducted in June 2025 across 14 designated stations ranging from nearshore to offshore, augmented by vertical plankton-net collections and in situ measurements of temperature, salinity, density, and sound velocity. Volume backscattering strength (SV) was analyzed utilizing Echoview 4.0 and compared against laboratory-derived zooplankton density. Zooplankton density varied from 208.33 to 828.61 ind/L, with generally elevated figures observed at offshore stations, implying increased biological productivity. A total of 9,934 individuals representing 45 genera and 9 orders were identified, predominantly comprising copepods (including nauplii and Calanoida), yielding a Shannon-Wiener index of 2.40, a Simpson index of 0.80, and an evenness index of 0.63, indicative of a diverse and relatively equilibrated community. Acoustic findings illustrated distinct scattering layers and heightened SV values primarily within the upper 0-30 m of the water column, suggesting pronounced vertical structuring of zooplankton in relation to water column stratification. The correlation between mean SV and zooplankton density was found to be positive yet weak (log-transformed regression y = 6.3911log(x)-80.671, R^2=0.1497), indicating that species composition, size structure, and sampling discrepancies influence the acoustic response. Collectively, the findings of this study elucidate that single-beam hydroacoustics serve as an effective tool for delineating zooplankton spatial-vertical patterns, while the integration with traditional net sampling methodologies significantly enhances the monitoring of coastal ecosystems.

Keywords: backscattering strength, hydroacoustics, Jakarta Bay, Pari Island, zooplankton abundance.

INTRODUCTION

Jakarta Bay, encompassing the Thousand Islands archipelago, constitutes a multifaceted coastal ecosystem that accommodates coral reefs, mangroves, and seagrass meadows; however, it is progressively subjected to anthropogenic influences (Nugraha *et al.,* 2020). The degradation of habitats has been documented surrounding Southeast Pari Island, manifested through recurrent phytoplankton blooms, diminished macrozoobenthos diversity, and a decline in water quality in relation to marine biotic standards (Hartati *et al.,* 2015). Terrestrial inputs and riverine discharges augment the concentrations of dissolved inorganic nitrogen in proximity to estuaries, thereby enhancing nutrient availability and altering coastal trophic dynamics (Zhang *et al.,* 2013). Elevated anthropogenic ammonium inputs can further catalyze primary production and facilitate phytoplankton proliferation in coastal aquatic environments (Dugdale *et al.,* 2007). Within shallow coastal zones, these terrestrial-derived inputs also elevate levels of total suspended solids, organic detritus, and microbubbles, which can introduce substantial background backscatter, amplify ambient noise, and complicate the analysis of biological signatures at elevated acoustic frequencies such as 200 kHz (Richards and Leighton, 2000).

Zooplankton play a pivotal role within marine food webs, serving as both primary and secondary consumers that facilitate the transfer of energy from phytoplankton to fish larvae and subsequent higher trophic levels (Somoue *et al.,* 2005; Gilman, 2014). Due to their sensitivity to fluctuations in environmental parameters, zooplankton are extensively acknowledged as effective bioindicators of aquatic quality and trophic dynamics (Goswami, 2004). In coastal ecosystems such as Southeast Pari Island, the spatial and temporal dynamics of zooplankton abundance are predominantly influenced by an array of physical, chemical, and biological determinants, encompassing temperature, salinity, and nutrient-enhanced primary productivity (Harris *et al.,* 2000).

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Zooplankton communities frequently demonstrate significant horizontal heterogeneity and fine-scale vertical stratification, with concentrated layers often established in proximity to abrupt physical transitions such as pycnoclines (Longhurst, 2007). Traditional net-based methodologies, which depend on the utilization of plankton nets and subsequent microscopic analyses, yield comprehensive taxonomic insights but are characterized by their labor-intensive nature and constraints regarding spatial and vertical representation (Efendi and Imran, 2016). Given that these techniques amalgamate the water column over extensive depth ranges and towing trajectories, they may inadvertently obscure or underestimate the presence of thin scattering layers and localized aggregations of zooplankton (Greene *et al.,* 1998).

Hydroacoustic methodologies provide a supplementary framework by facilitating swift, non-intrusive, real-time delineation of pelagic organisms located within the aquatic column (Manik and Mamun, 2009; Manik 2015). Pertaining to zooplankton, high-frequency echosounders possess the capability to quantify volume backscattering strength (SV), serving as an indirect indicator of collective abundance or biomass when underpinned by suitable target strength (TS) assumptions (Aisyah *et al.,* 2015; Pieper, 2013). Empirical applications within Indonesian marine environments have evidenced that the amalgamation of acoustic data with net sampling techniques can yield estimations of planktonic abundance and facilitate the characterization of their spatial dispersion (Hasan *et al.,* 2021). Nevertheless, the precise conversion of aggregate SV into definitive zooplankton abundance necessitates the implementation of robust scattering models, such as fluid-like or Distorted Wave Born Approximation (DWBA) paradigms, that accurately align with the morphological characteristics and size distribution of indigenous species (Manik 2015; Chu and Ye, 1998), in addition to multi-frequency measurements to differentiate fluid-like zooplankton from micronekton and abiotic scatterers. These stipulations present formidable challenges in shallow, turbid coastal ecosystems, wherein single-frequency, single-beam configurations are inherently constrained in their capacity to effectively segregate taxonomic groups or size categories within heterogeneous pelagic scattering layers (Greene *et al.,* 1998; Richards and Leighton, 2000).

Despite the promising prospects, hydroacoustic methodologies for the assessment of zooplankton within the aquatic environments surrounding Southeast Pari Island have yet to undergo thorough evaluation, particularly concerning the correlation between calibrated single-frequency SV and net-derived zooplankton abundance in a shallow tropical coastal context. Considering that a 200 kHz single-beam echosounder is unable to distinctly differentiate zooplankton from diminutive micronekton or suspended particulate matter, its utility in such ecosystems is anticipated to be predominantly qualitative, focusing on the delineation of pelagic vertical stratification as opposed to accurate biomass quantification. Consequently, this investigation employs a 200 kHz single-beam echosounder in conjunction with plankton-net sampling and in situ oceanographic measurements to (i) delineate the vertical and nearshore-offshore distribution of pelagic scattering layers in the vicinity of Southeast Pari Island and (ii) assess the relationship between calibrated SV and traditional estimates of zooplankton abundance, while explicitly recognizing the intrinsic limitations associated with single-frequency acoustics in relation to quantitative assessments of zooplankton biomass.

MATERIALS AND METHODS

The study was executed within the pelagic zones of Southeast Pari Island, which is a component of the Thousand Islands archipelago situated in Jakarta Bay, Indonesia, geographically positioned approximately between 106°25′-106°40′ E and 05°24′-05°45′ S (Warsa and Purnawati, 2017). Fourteen static sampling sites were systematically allocated along a nearshore-offshore continuum to reflect shallow coastal marine environments affected by island dynamics, as well as comparatively deeper offshore waters subject to more expansive marine conditions (Yuliana and Mutmainnah, 2017). This cross-shelf configuration was meticulously devised to document the transition from turbid, land-influenced shelf waters to more transparent, pelagic waters, thereby establishing a reference framework for evaluating the impacts of modifications in hydrographic structure and suspended particulates on pelagic scattering. The coordinates of the sampling stations were acquired via GPS, visualized in Google Earth, and subsequently imported into ArcGIS to create bathymetric and navigational maps, as well as to plan the acoustic trajectory surrounding Southeast Pari Island (Figure 1).

At each sampling station, vertical profiles of temperature, salinity, density, and sound velocity were systematically collected utilizing a Conductivity-Temperature-Depth (CTD) profiler, which was deployed from the water's surface to the seabed, in accordance with established hydroacoustic survey methodologies (MacLennan and Simmonds, 1992). CTD casts were executed prior to the commencement of acoustic and zooplankton sampling in order to delineate the physical stratification of the water column and to elucidate the gradients present from nearshore to offshore environments. The resultant data pertaining to temperature, salinity, and sound speed were employed to compute the acoustic absorption coefficient necessary for backscatter analysis, adhering to the Francois-Garrison (1982) equation for the propagation of high-frequency sound in seawater.

$$\alpha(f,T,S,P,pH) = A_1(T,S,pH)P_1\frac{f_1f^2}{{f_1}^2+f^2} + A_2(T,S)P_2\frac{f_2f^2}{{f_2}^2+f^2} + A_3(T,S,P)P_3f^2$$

with: α = in dB/km; *f*= Frequency (kHz); f_1, f_2 = relaxation frequency (kHz) for boric acid and magnesium sulfate; A_1, A_2, A_3 = coefficients that depend on temperature T, salinity S, pressure/depth P, and pH; P_1, P_2, P_3 = nondimensional pressure correction factors.

conceptually, the first term (A_1, P_1) with represents absorption by boric acid; the second term (A_2, P_2) with represents absorption by magnesium sulfate; the third term (A_3, P_3) with represents absorption by pure water, which becomes dominant at very high frequencies.

Hydroacoustic data were acquired utilizing a SIMRAD EK15 single-beam echosounder affixed to the research vessel, in accordance with prior implementations of high-frequency acoustics for the examination of plankton in shallow marine ecosystems (Hasan *et al*., 2021). The apparatus operated at a frequency of 200 kHz, with a pulse duration of 0.32 ms, a transmit power of 46.1 W, a two-way beam angle of -8.7°, and a sound velocity established at 1541.39 m/s, as delineated in Table 1. At each of the fourteen sampling stations, stationary recordings lasting approximately 30 minutes were performed to acquire time series data of volume backscattering strength (SV) from the surface to the local seabed.

Prior to the survey, the echosounder underwent calibration in shallow water utilizing a 35 mm copper sphere, adhering to established standard-sphere calibration protocols for fisheries acoustics (Forber *et al*., 1980; Solikin and Manik, 2015). The calibration echogram exhibited a stable and well-defined echo from the sphere at a constant depth; the measured target strength at 200 kHz was -46.80 dB, in comparison to a theoretical value of -45.96 dB for the 35 mm sphere. The resultant discrepancy of -0.84 dB was employed as a calibration correction factor for all subsequent SV data, thereby ensuring that the current study aligns with published target strength standards for 35-40 mm metallic spheres and maintains internal consistency across the Methods, Results, and instrument specification table.

Zooplankton were collected at each designated site employing a plankton net characterized by a diameter of 30 cm and a mesh size of 200 µm, a configuration that is conventionally utilized for coastal zooplankton investigations in Indonesia (Efendi and Imran, 2016). Vertical tows were executed for a duration of 10 minutes commencing from approximately 2 m beneath the surface (or from near the seabed in shallower locations) while the vessel maintained a stationary position, and the contents of the cod-end were subsequently transferred into 250 mL containers labeled with the respective station numbers. The samples were preserved utilizing Lugol's solution and subsequently conveyed to the laboratory, where zooplankton were identified under a microscope using a Sedgewick-Rafter counting cell and quantified to ascertain abundance in individuals per litre (ind/L) and to characterize community composition (Harris *et al*., 2000).

Table 1. SIMRAD EK15 Specifications and Parameter Measurements

Parameter	Value
Temperature	29,68 °C
Sound velocity	1541,39 m/s
Frequency	200 kHz
Pulse Duration	0,320 ms
Power	46,1 W
Minor-axis Beam Width	28,00°
Major-axis Beam Width	28,00°
Two-way Beam Angle	-8,70
Transducer Gain	13,90 dB
Target Strength (TS) calibration result	-46,8 dB

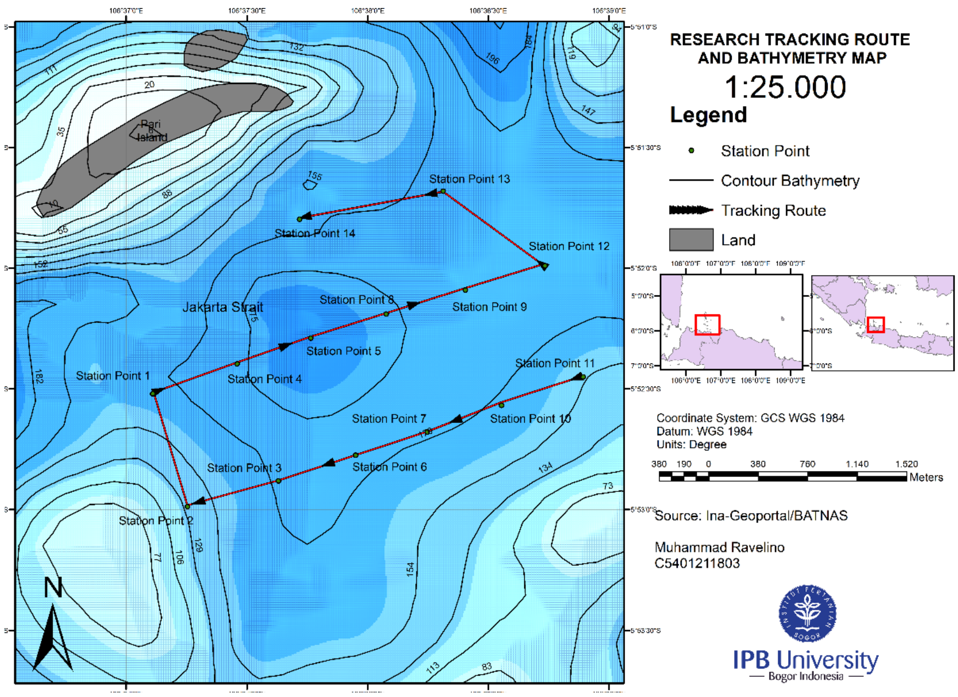


Figure 1. Bathymetric Map and Route of Acoustic Pathway

The 200 µm mesh effectively captures mesozooplankton while permitting smaller microzooplankton to escape, thereby engendering an inherent sampling discrepancy in relation to the 200 kHz acoustic measurements, which are attuned to a distinct target-size spectrum encompassing larger mesozooplankton, micronekton, and macro-aggregates. This limitation is meticulously acknowledged when analyzing the correlation between SV and net-based zooplankton abundance.

Hydroacoustic data analysis adhered to well-established methodologies associated with single-beam echosounders, wherein the instrument transmits brief acoustic pulses and captures echoes reflected by various targets within the aquatic column, thereby enabling the inference of their vertical distribution and relative acoustic density from the received returns (MacLennan and Simmonds, 1992; Prihantoro *et al*., 2022). The raw EK15 data underwent processing in Echoview 4.0 utilizing calibrated parameters. Background noise and surface-bubble interference were mitigated through the application of built-in noise-reduction algorithms, alongside the manual elimination of transient spikes. Subsequently, the water column was segmented into 1 m depth bins and 5-10 s time intervals to calculate the mean SV (dB re 1/m) for each depth-time cell within the 0-55 m depth range, exclusively utilizing pings acquired while the vessel remained stationary at each sampling station. Depth-integrated, calibrated SV values for the 0-55 m range were exported for each station and utilized as variables in regression analyses against zooplankton abundance.

In conceptual terms, target strength (TS) and volume backscattering strength (SV) were delineated in accordance with conventional acoustic theory (MacLennan, 2002; Medwin and Clay, 1998; Wiebe *et al*., 1990), with the pertinent equations for TS and SV as functions of organism size and numerical density being derived from existing literature. Nonetheless, in practical application, species-specific TS models and sophisticated scattering formulations such as the Distorted Wave Born Approximation (DWBA; Chu and Ye, 1998) were not employed, and calibrated SV was utilized merely as a relative indicator of pelagic backscatter instead of being transformed into absolute zooplankton biomass. Rather, the focus was directed towards qualitative patterns of pelagic stratification and an exploratory log-transformed regression analysis between mean depth-integrated SV and net-derived zooplankton abundance. Previous high-frequency acoustic studies have demonstrated the potential of such systems for extracting both biological and physical information from zooplankton layers and highlighted the value of DWBA-type models for quantitative interpretation (Manik, 2015).

Zooplankton abundance (ind/L) was determined employing a sweep-count Sedgewick-Rafter Cell (SRC) methodology as per APHA (2005), while the relative composition and community structure were assessed utilizing standard indices. Relative abundance at the species level was calculated employing the formula proposed by Fachrul (2007), and diversity, evenness, and dominance were characterized using the Shannon-Wiener index, evenness index, and Simpson dominance index, respectively (Basmi, 1998; Harris *et al*., 2000). The corresponding mathematical expressions elucidate the derivation and interpretation of these indices in terms of diversity levels, evenness, and dominance structure.

RESULTS AND DISCUSSIONS

Prior to the commencement of the survey, the SIMRAD EK15 single-beam echosounder underwent calibration in shallow aquatic environments utilizing a 35 mm metallic sphere in accordance with established sphere protocols for fisheries acoustics (Forber *et al*., 1980; Solikin and Manik, 2015). The resultant calibration echogram exhibited a stable and distinctly defined echo corresponding to the sphere at a predetermined depth, thereby signifying that the instrument functioned with reliability throughout the entirety of the survey. The target strength recorded at a frequency of 200 kHz was measured at -46.80 dB, in contrast to a theoretical value of -45.96 dB for the 35 mm sphere, resulting in a differential of -0.84 dB which was subsequently implemented as a calibration correction factor for all ensuing SV data (Fig. 2, Fig. 3, Table 2, and Fig. 4). This methodological configuration situates the present investigation in alignment with the established target strength (TS) standards for 35-40 mm metallic spheres and guarantees internal consistency between the instrument settings and the calibrated backscatter metrics.

Table 2. Results of SIMRAD EK15 and CTD calibration based on its parameter

Parameter	Value
Sea Depth	3,1 m
Transducer Depth	1,3 m
Sphere Ball Depth	2,1 m
Sphere Ball Diameter	35 mm
Sphere Ball Target Strength	-46,8 dB
Temperature	29,68 ^{o}C
Salinity	31,75 psu
Sound Velocity	1541.39 m/s.

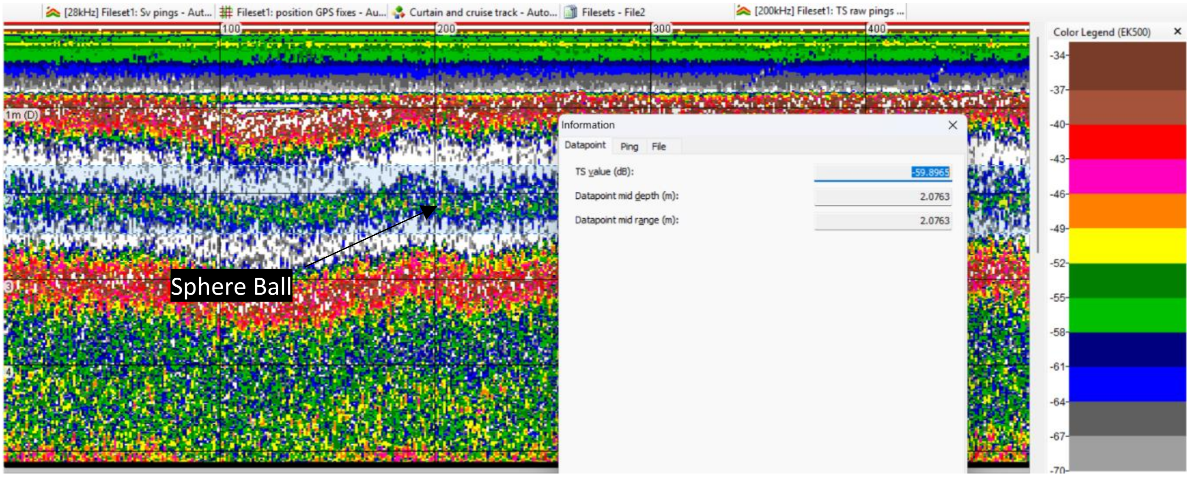


Figure 2. An echogram depicting raw Target Strength (TS) pings from the SIMRAD EK15 calibration conducted with a tungsten ball.

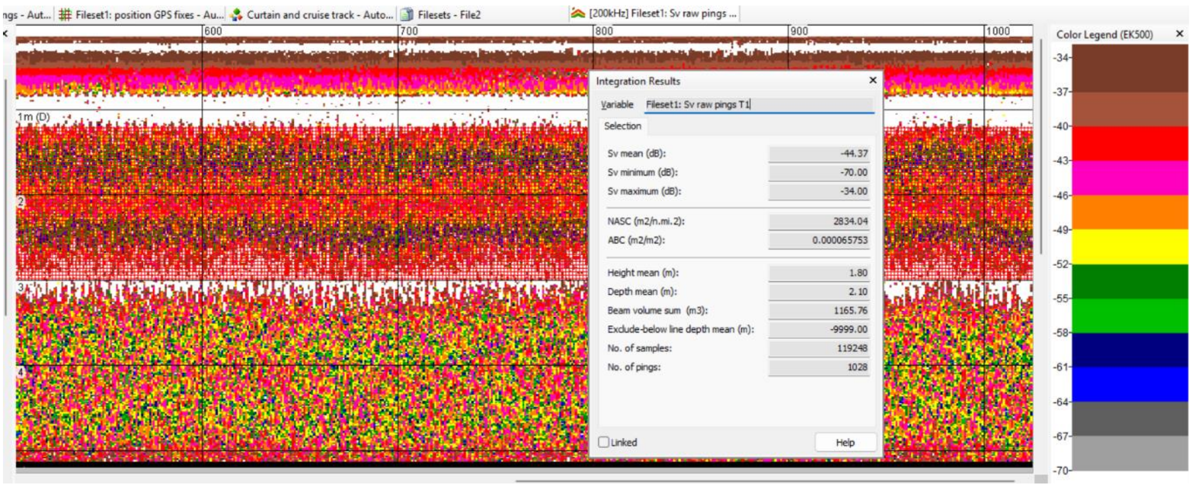


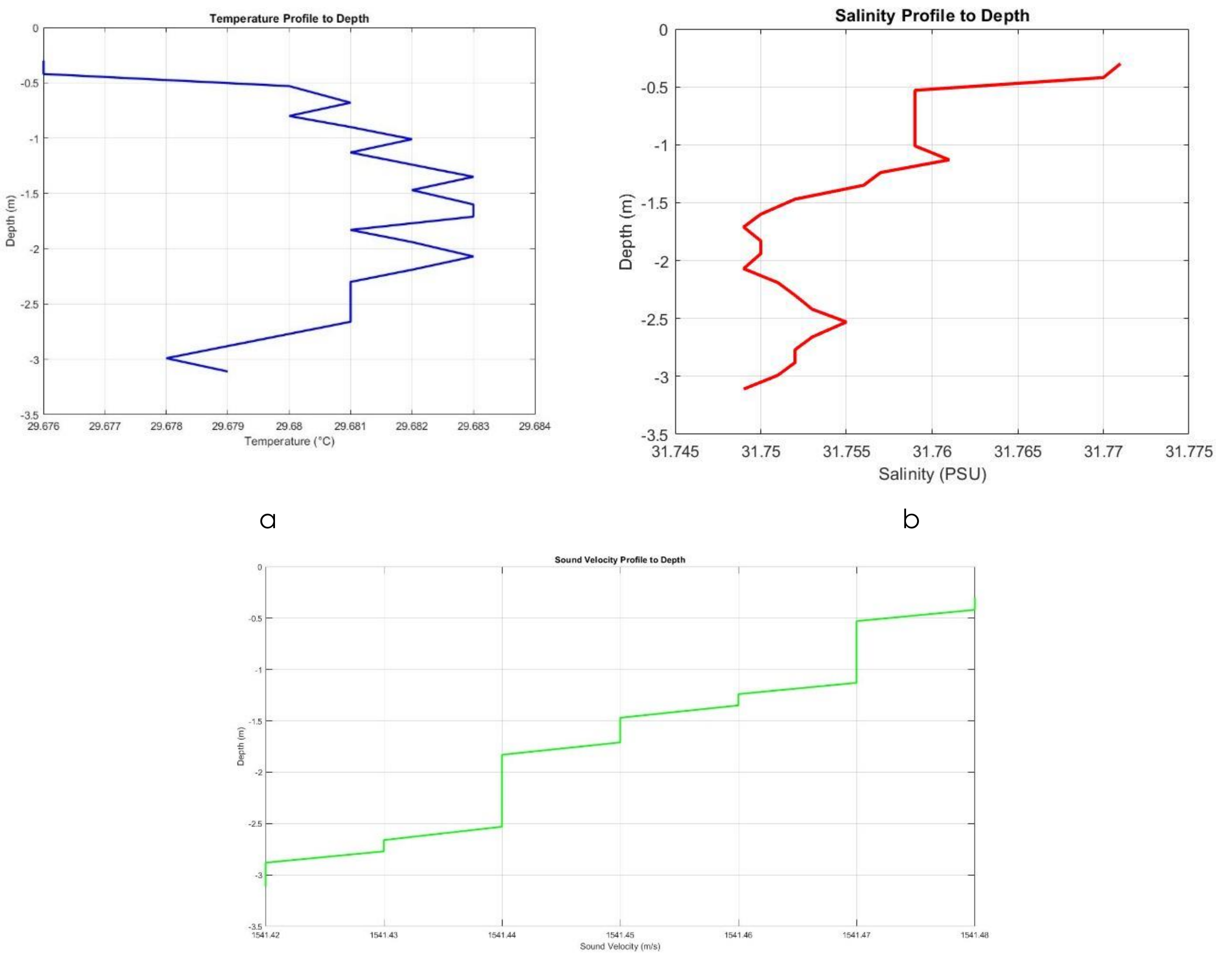
Figure 3. Echogram depicting raw SV strength pings from the SIMRAD EK 15 calibration conducted with a tungsten ball.

Concurrent CTD casts at the calibration station produced stable profiles of temperature, salinity, and sound velocity (Fig. 4), confirming that the physical sensors operated within expected tolerances. These hydrographic measurements provide the background physical framework required to interpret spatial variations in sound propagation and backscatter in the study area.

Surface water temperatures observed in Southeast Pari Island exhibited a range from 29.50 to 30.15 °C, with a calculated mean of 29.88 °C, values that are consistent with prior research conducted in Jakarta Bay and the Thousand Islands, where elevated, moderately saline temperatures foster significant planktonic productivity (Yuliana and Mutmainnah, 2017). The analysis of vertical temperature profiles indicated the presence of relatively uniform warm surface layers extending to approximately 10 meters, beneath which a gradual temperature decline established a thermocline between depths of approximately 10 and 30 meters (Fig. 5). This phenomenon of thermal stratification is characteristic of shallow tropical coastal environments and has the potential to impede vertical mixing, consequently affecting nutrient availability within the euphotic zone and the vertical distribution of zooplankton (Harris *et al*., 2000).

Salinity profiles demonstrated marginally less saline surface waters overlaying more saline deeper strata, resulting in a diminutive halocline that predominantly coincided with the thermocline (Fig. 6). The concomitant increase in density with depth, as depicted by vertical density profiles, delineated a distinct pycnocline that segregates a thoroughly mixed surface layer from a more stable deeper water mass (Fig. 7). Pycnoclines function as physical and biological interfaces where particles, phytoplankton, and zooplankton may aggregate, thereby establishing preferred feeding and refuge habitats (Matthews and Ohman, 2023). Although the horizontal gradients in temperature, salinity, and density along the nearshore-offshore transect were relatively modest, the existence of a subtle yet persistent pycnocline within the upper 30-40 m aligns with conditions that promote the development of pelagic scattering layers.

The sound speed profiles derived from the CTD data closely, follow the combined patterns of temperature and salinity, with values ranging from approximately 1537 to 1543 m/s and only small vertical variations within the water column (Figure 8). The modest sound velocity gradient indicates that acoustic ray bending is limited over the sampled depth range, supporting the assumption of near-vertical sound propagation used in processing the SIMRAD EK15 data and enhancing confidence in the interpretation of zooplankton backscatter (MacLennan and Simmonds, 1992). Overall, the vertical structures of temperature, salinity, density, and sound velocity depicted in these profiles provide an essential physical context for interpreting the observed scattering layers and zooplankton distributions.



a b

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Figure 4. Vertical profiles of the (a) temperature, (b) salinity, and (c) sound velocity at the calibration station.

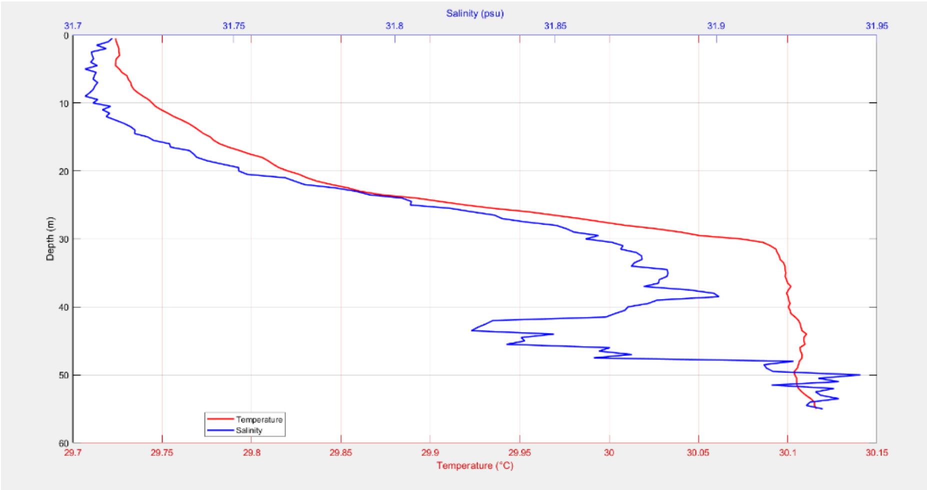


Figure 2. Vertical profile of temperature and salinity at the sampling station (Station 1 - Station 14).

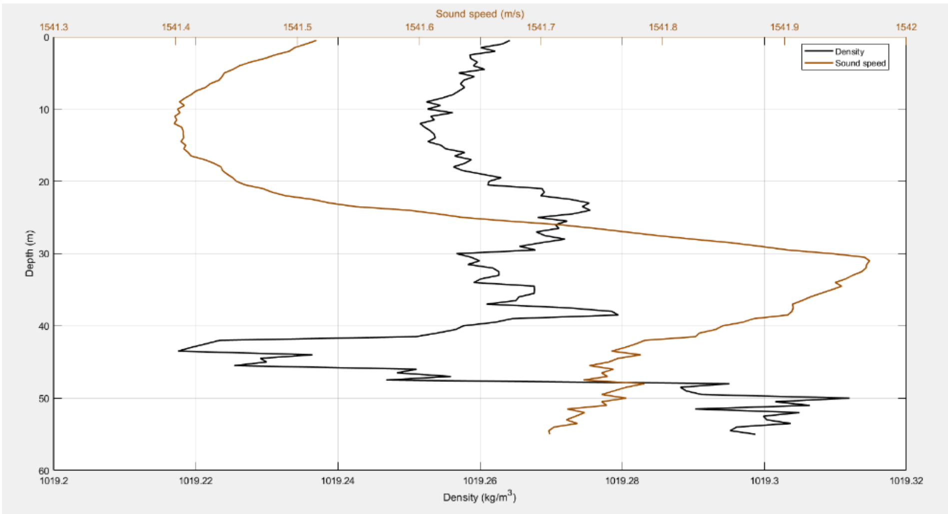


Figure 6. Vertical profile of the sound velocity at the sampling station (Station 1 - Station 14)

Sound speed profiles obtained from the Conductivity Temperature Depth (CTD) data exhibited a strong correlation with the observed patterns of temperature and salinity, with recorded values ranging from approximately 1537 to 1543 m/s and exhibiting minimal vertical variability throughout the water column (Fig. 6). The constrained sound-speed gradient suggests that the bending of acoustic rays is negligible across the sampled depth range, thereby reinforcing the presumption of nearly vertical propagation applied during the processing of the EK15 data and augmenting the reliability of the interpretation of calibrated standard volume (SV) (MacLennan and Simmonds, 1992). Collectively, these hydrographic features furnish critical context for elucidating the vertical distribution of acoustic backscatter and zooplankton.

Calibrated echograms obtained from the fourteen designated stations illustrated significant scattering layers distributed throughout the aquatic column, with the majority of backscatter predominantly localized within the upper 0-30 meters (Figure 7). Within these layers, the depth-integrated SV values typically fluctuated between approximately -75 and -71 dB, forming uninterrupted undulating bands as well as discrete dense patches along the transect. These principal scattering strata frequently aligned with, or were situated marginally below, the thermocline-pycnocline

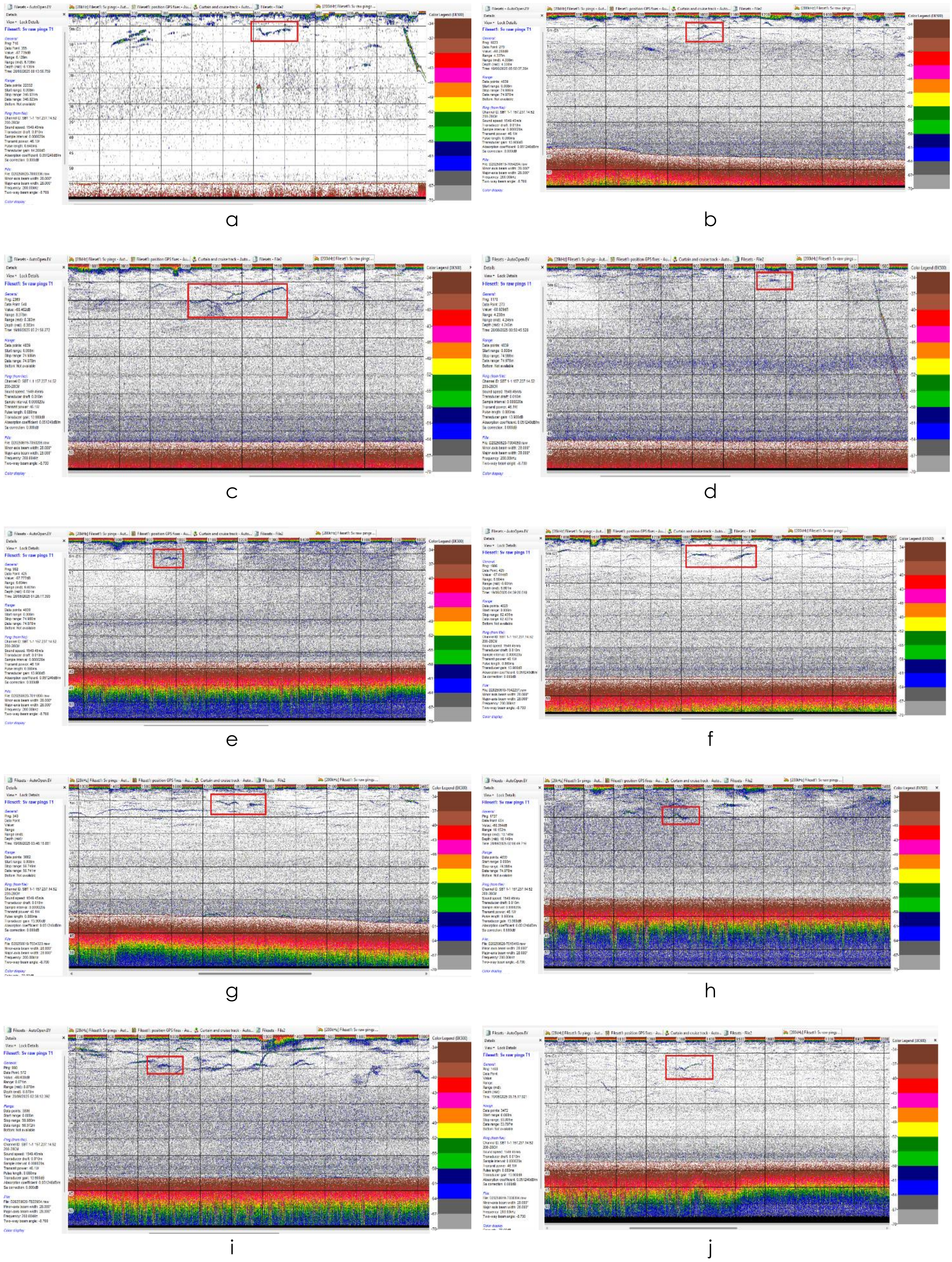


Figure 7. Layers of zooplankton sound scattering in the echogram of Pari Island: (a) station 1 - (n) station 14

interface delineated in the CTD profiles, while backscatter generally exhibited a decline below depths of 30-40 meters, with exceptions noted at certain stations (e.g., Station 13) where secondary maxima observed between 35 and 50 meters correlated with pronounced density gradients (Figure 8). Comparable applications of ADCP backscatter have delineated zooplankton distributions across 0–300 m depth and linked enhanced scattering layers to specific hydrographic structures and currents, such as the Equatorial Undercurrent in West Sumatra waters (Bakhtiar *et al.,* 2024).

Net sample analyses indicated that zooplankton assemblages were predominantly characterized by copepod nauplii and various other diminutive copepods (Table 3). These organisms typically exhibit body lengths ranging from approximately 100 to 400 µm, situating them firmly within the Rayleigh scattering regime at a frequency of 200 kHz, where the associated acoustic wavelength is roughly 7.7 mm. Within this scattering regime, individual backscattering cross-sections are markedly diminutive, and the corresponding target strengths frequently fall below -95 dB, rendering the observed net abundances (maximum 828.61 ind/L) inadequate, in isolation, to yield bulk SV values as elevated as -71 dB. As a result, the coherent acoustic layers discerned in the echograms are more accurately construed as mixed pelagic scattering layers predominantly influenced by larger mesozooplankton, micronekton, or small pelagic fish larvae, entities that often exhibit greater acoustic impedance contrasts and, in numerous instances, possess gas-filled swim bladders rather than being attributable to the microscopic nauplii that predominate in the net counts.

The vertical variability of SV therefore reflects the combined influence of physical structure and the behaviour of a broader pelagic community. Elevated SV in the upper layer is likely associated with enhanced densities and/or larger mean scattering cross-sections of pelagic organisms in warm, well-lit surface waters where phytoplankton food is abundant, while deeper peaks suggest that some taxa preferentially occupy or migrate into cooler, more stable strata near the pycnocline (Jones and Xie, 1994; Aisyah *et al*., 2015; Matthews and Ohman, 2023). Similar diel vertical migration patterns and vertically structured scattering layers have been demonstrated using ADCP backscatter in Indonesian waters, emphasizing the role of zooplankton in forming persistent sound-scattering layers (Dwinovantyo *et al.,* 2019). In this framework, the 200 kHz single-beam echosounder is best viewed as delineating qualitative patterns of pelagic stratification and micronekton distribution, with zooplankton contributing only a portion of the total backscatter. This interpretation reconciles the apparent mismatch between high SV and the dominance of very small organisms in the nets, and underscores the need to account explicitly for size-dependent scattering physics when inferring species composition from single-frequency echograms.

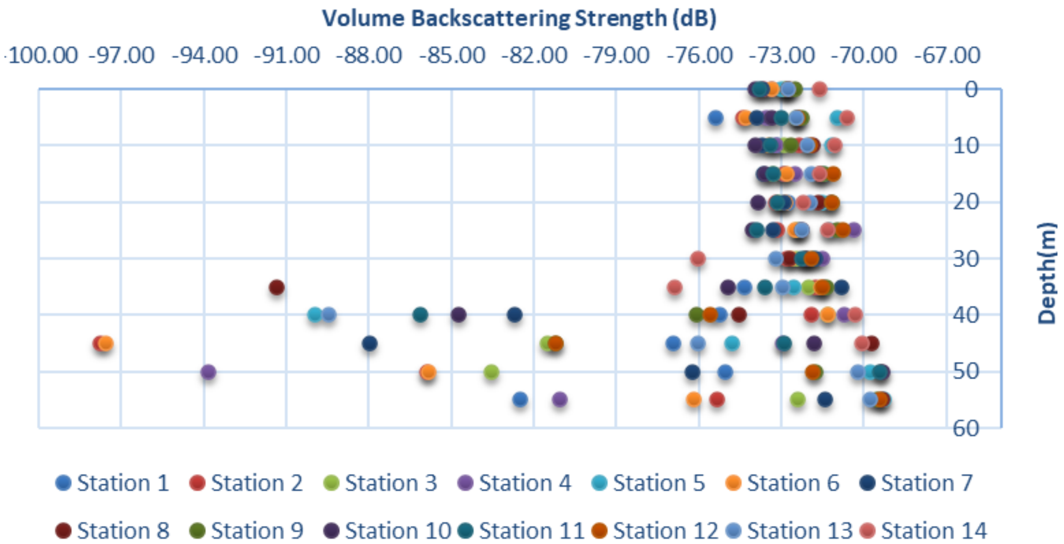


Figure 8. Vertical distribution of the backscattering strength (SV) of zooplankton with depth

The abundance of zooplankton, ascertained through plankton-net sampling, exhibited significant spatial heterogeneity across the 14 designated stations (Fig. 9), with values ranging from 208.33 ind/L at Station 2 to 828.61 ind/L at Station 7. The offshore and semi-offshore stations typically demonstrated greater densities compared to nearshore stations, suggesting that zooplankton biomass is inclined to accumulate in deeper marine environments along the outer survey arc, rather than within the shallow coastal zone immediately adjacent to the island. This observed phenomenon aligns with antecedent research indicating that hydrodynamic circulation, stratification, and nutrient availability can engender offshore retention zones where zooplankton aggregate under optimal feeding conditions (Harris *et al*., 2000).

Laboratory identification indicated a taxonomically diverse assemblage consisting of 9 orders and 45 genera, with a cumulative total of 9,934 individuals enumerated (Table 3). The order Calanoida predominated within the community, accounting for 71.70% of the total individuals and encompassing genera such as Paracalanus, Acartia, and Calanus, whereas other significant groups comprised Cladocera (9.27%), Harpacticoida (7.26%), Cyclopoida (5.83%), and Amphipoda (5.19) (Figure 10). The considerable predominance of calanoid copepods and their nauplii is consistent with their recognized function as pivotal herbivores and trophic intermediaries facilitating energy transfer from phytoplankton to fish larvae and higher trophic level predators (Paffenhöfer *et al*., 1982). Illustrative specimens of the dominant copepod taxa are depicted in Figure 11.

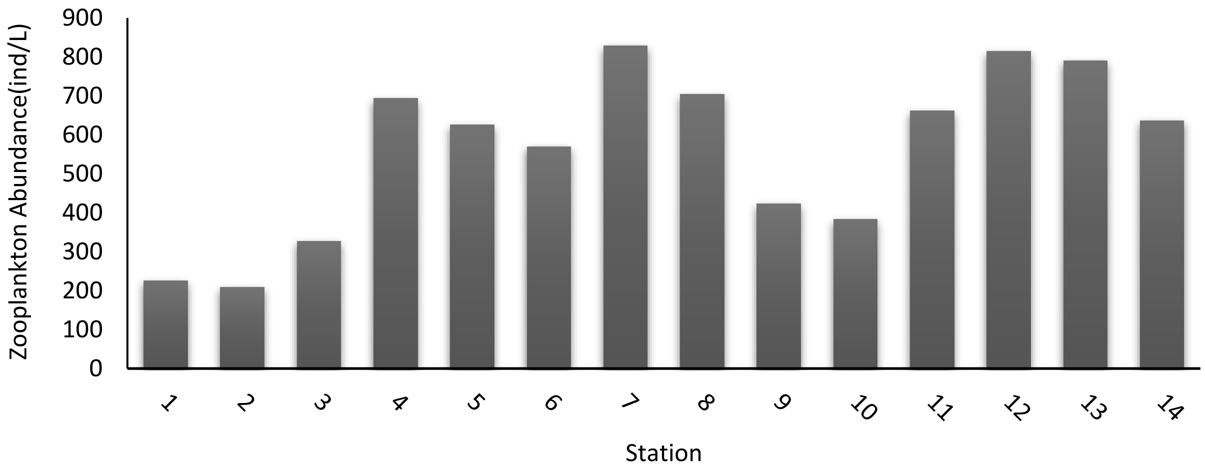


Figure 9. Zooplankton abundance at each sampling station

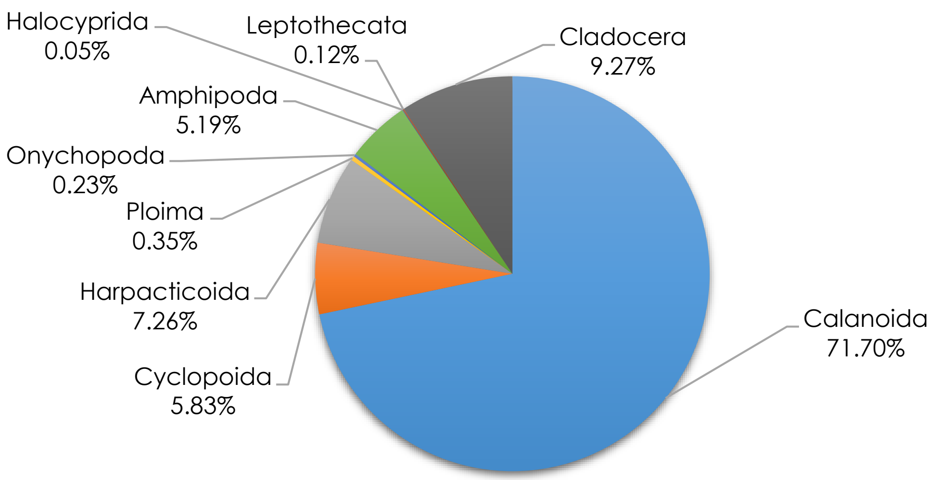
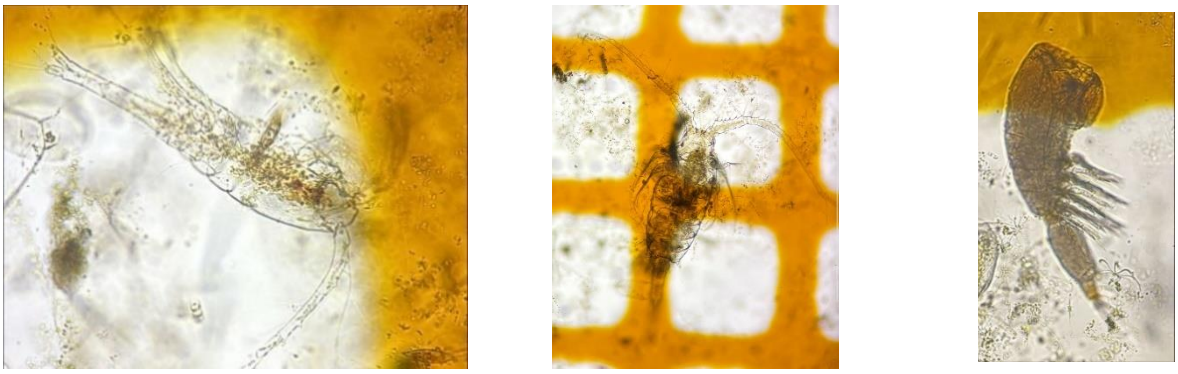


Figure 10. Percentage of zooplankton abundance by order

Table 3. Individual abundance of zooplankton by order and genus

Order	Genus	Number of patients	Order	Genus	Number of patients
Calanoida	*Acartia sp.*	828		*Corycaeus sp.*	101
	Aetideus sp.	189		*Lubbockia sp.*	26
	Calanus sp.	622		*Paroithona sp.*	189
	Calocanus sp.	40		*Oithona sp.*	253
	Candacia sp.	27	Cyclopoida	*Oncaea sp.*	3
	Centropages sp	41		*Sapphirina sp.*	7
	Diaptomus sp.	158		*Clytemnestra sp.*	165
	Eucalanus sp.	9		*Euterpina sp.*	61
	Euchaeta sp.	30		*Macrosetella sp.*	34
	Gaetanus sp.	48	Harpacticoida	*Microsetella sp.*	461
	Haloptilus sp.	50		*Branchionus sp.*	5
	Heterohabdus sp.	2	Ploima	*Keratella sp.*	28
	Metridia sp.	10		*Synchaeta sp.*	2
	Naplius sp.	4104	Onychopoda	*Podon sp.*	23
	Paracalanus sp.	32		*Phronima sp.*	4
	Pareuchaeta sp.	100		*Phronimopsis sp.*	114
	Pleuromamma sp.	134	Amphipoda	*Scina sp.*	218
	Pontellina sp.	1		*Vibilia sp.*	180
	Pontelopsis sp.	1	Halocyprida	*Conchoecia sp.*	5
	Pseudocalamus sp.	221	Leptothecata	*Eutonina sp.*	12
	Pseudodiaptomus sp.	262		*Daphnia sp.*	914
	Scolecithricella sp.	4	Cladocera	*Evadne sp.*	7
	Scolecithrix sp.	209		Total	9934



a b c

Figure 11. Samples of individual zooplankton species identified by microscope in the laboratory: (a) *Oithona simplex*, (b) *Pleuromamma gracilis*, and (c) *Oncaea mediterranea*

Life-history analysis revealed that holoplanktonic entities predominantly characterized the assemblage, while meroplankton constituted a lesser proportion of the overall abundance (Fig. 12). This dominance of holoplankton implies that the examined community predominantly represents resident pelagic taxa as opposed to ephemeral larval contributions, thereby strengthening the interpretation of a sustained standing stock within the aquatic environment of Southeast Pari Island. The presence of taxa such as Daphnia sp. in certain samples further suggests the impact of estuarine or low-salinity influences, which aligns with the coastal context and terrestrial runoff into Jakarta Bay (Zhang *et al*., 2013).

The diversity metrics produced a Shannon-Wiener index H' = 2.40, a Simpson index (1 - D) = 0.80, and an evenness index E = 0.63 (refer to Table 4). H' values that range from 1 to 3 suggest a moderate to high level of diversity, indicating that the zooplankton community exhibits a degree of complexity and stability, rather than being predominantly influenced by a singular opportunistic species (Basmi, 1998). A Simpson index approaching 0.8 and an evenness index exceeding 0.6 signify minimal dominance and a relatively equitable distribution of individuals across taxa, conditions frequently correlated with coastal ecosystems where environmental stress is not excessively harsh (Margalef, 1956). Concurrently, the numerical dominance of nauplii and diminutive calanoids underscores the sampling discrepancy concerning the 200 kHz acoustic data: while the net effectively captures mesozooplankton and small larval stages down to the 200 µm mesh size, the echosounder demonstrates heightened sensitivity to larger mesozooplankton, micronekton, and macro-aggregates that may not be adequately represented in the net samples. Therefore, the scattering layers discerned in echograms ought to be construed as heterogeneous pelagic scatterers rather than a direct one-to-one correlation with the zooplankton size classes quantified in the laboratory.

The correlation between acoustic backscatter and zooplankton abundance derived from net collections was assessed through the regression of mean depth-integrated SV at each sampling location against the log-transformed zooplankton abundance obtained from plankton-net samples (Fig. 13). The resultant model, $y = 6.3911log(x) - 80.671$, produced a coefficient of determination R^2= 0.1497, signifying a positive albeit weak association, wherein approximately 15% of the variability in SV can be accounted for by fluctuations in numerical density (Table 5). Sampling stations characterized by extremely high or low zooplankton abundance exhibited deviations from the regression line, resulting in a dispersed arrangement of data points surrounding the fitted relationship.

Table 4. Zooplankton abundance dominance index and its categorization

Index	Value	Category
Shannon (H')	2.40	High diversity
Simpson (1-D)	0.80	High diversity, but low dominance
Evenness (E)	0.63	Nearly even distribution (moderate)

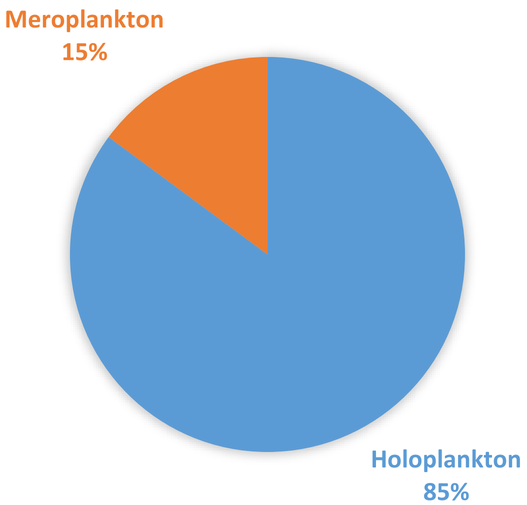


Figure 12. Zooplankton abundance percentage based on life cycle

Table 5. Station-wise zooplankton abundance (linear and logarithmic) and mean volume backscattering strength (SV) were used in the SV abundance correlation analysis.

Station	Zooplankton Abundance (ind/L)	Abundance of Zooplankton (Logarithmic)	Average SV(dB)
1	225.62	2.35	-74.63
2	208.33	2.32	-76.26
3	326.25	2.51	-74.19
4	693.39	2.84	-74.65
5	625.78	2.80	-73.14
6	569.96	2.76	-76.20
7	828.61	2.92	-75.17
8	703.61	2.85	-73.30
9	422.95	2.63	-72.76
10	382.86	2.58	-74.15
11	661.16	2.82	-74.08
12	814.46	2.91	-72.64
13	790.09	2.90	-73.76
14	636.01	2.80	-72.18

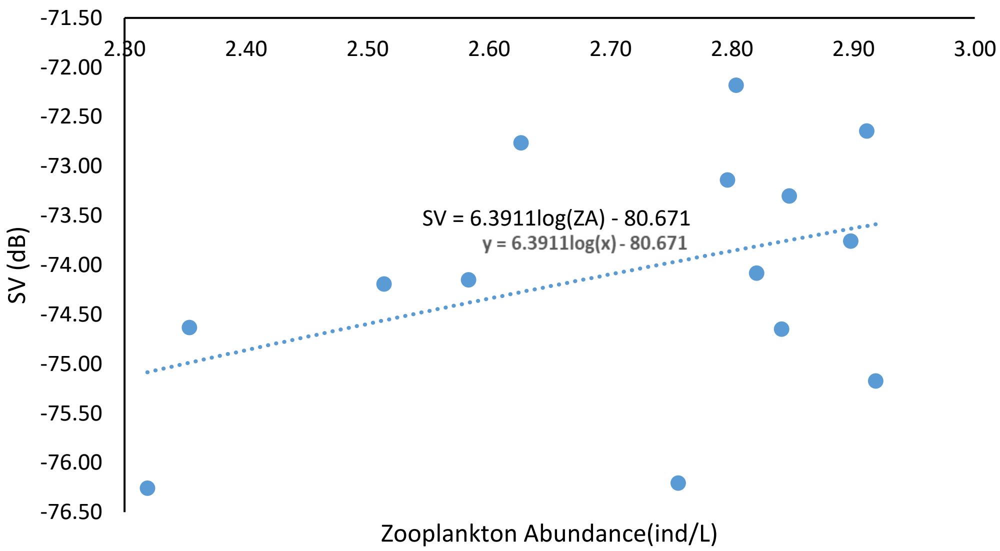


Figure 13. Correlation analysis of SV zooplankton with zooplankton abundance

This tenuous correlation is not surprising for heterogeneous zooplankton assemblages and signifies both biological and methodological sources of variability. From a biological perspective, the community consists of multiple taxa and developmental stages exhibiting diverse sizes, morphologies, and material properties, each linked to unique target strengths; consequently, equivalent numerical abundance does not directly equate to analogous volume backscattering strength (Aisyah *et al*., 2015). Furthermore, fine-scale spatial heterogeneity and transient vertical movements, including diel vertical migration, have the potential to modify local zooplankton concentrations during the 30-minute acoustic recordings and discrete net hauls, thus diminishing the station-by-station correlation between SV and abundance (Forward and Cohen, 2010).

Methodologically, hydroacoustic assessments amalgamate echoes across an extensive aquatic volume and depth spectrum, whilst plankton nets capture a more confined vertical trajectory and may either underrepresent or overrepresent concentrated layers contingent upon the depth and timing of the haul (Hasan *et al*., 2021). Furthermore, all measurements undertaken in this investigation were performed at a singular frequency (200 kHz), thereby constraining the capacity to differentiate zooplankton from other diminutive scatterers including micronekton, suspended particulate matter, organic detritus, and microbubbles, in addition to obstructing the utilization of frequency-differencing methodologies for the segregation of taxonomic or size classifications (Jones and Xie, 1994; Chu and Ye, 1998). In the absence of multi-frequency observations and species-specific target strength models, the Sv signal cannot be unequivocally delineated into biological constituents that correspond with the zooplankton fractions retained by the net.

Consequently, the regression analysis delineated herein ought to be construed as a preliminary investigation elucidating a tenuous aggregate correlation between bulk pelagic backscatter and net-derived zooplankton abundance, rather than as a definitive quantitative framework for estimating absolute zooplankton densities via single-frequency acoustics. As with ADCP-based assessments of zooplankton vertical migration, our single-beam 200 kHz observations are best interpreted as qualitative indicators of mixed pelagic scattering layers rather than as precise biomass estimates (Dwinovantyo *et al.,* 2019). Nevertheless, the overarching positive trajectory insinuates that calibrated SV may function as a qualitative metric for relative density gradients, while underscoring the imperative for multi-frequency data, enhanced sampling synchrony, and sophisticated scattering models to attain more dependable quantitative abundance estimations in forthcoming research endeavors (Oh *et al*., 2013; Hasan *et al*., 2021).

The integrated acoustic and net observations suggest that the upper 0-30 m surrounding Southeast Pari Island is distinguished by enduring pelagic stratification and mixed scattering layers, rather than solely the presence of zooplankton. The alignment of scattering layers with the thermocline-pycnocline indicates that density gradients function as physical traps, facilitating the accumulation of pelagic organisms, a finding that is consistent with observations from other coastal ecosystems where pycnoclines coincide with subsurface chlorophyll maxima and act as preferred zones for feeding and refuge (Chen *et al*., 2022; Cowles *et al*., 1984; Matthews and Ohman, 2023).

Net samples revealed a numerical predominance of nauplii and small copepods, indicating elevated secondary production within this coastal ecosystem. However, their diminutive body size places them within the Rayleigh scattering regime at 200 kHz, where individual target strengths are exceedingly low and, given their observed abundances, cannot adequately account for bulk SV values approaching −71 dB. This observation suggests that the most pronounced backscatter layers are predominantly composed of larger mesozooplankton, micronekton, and fish larvae, with small zooplankton contributing only a fraction of the acoustic signal. Such size-dependent scattering dynamics help to explain the apparent discrepancy between elevated SV and the predominance of microscopic organisms in the net samples. This interpretation is consistent with previous high-frequency zooplankton acoustics, which have shown that scattering levels are highly sensitive to organism orientation and size (Manik, 2015).

The correlation between mean SV and zooplankton abundance exhibits a positive yet feeble relationship ($R^2 \approx 0.15$), signifying that single-frequency backscatter predominantly reflects relative density gradients and is significantly shaped by taxonomic composition, size structure, and fine-scale patchiness. Transient vertical movements, diel behavioral patterns, and small-scale heterogeneity may decouple the 30-minute acoustic integrations from the discrete net hauls, thereby further diminishing the station-by-station correspondence between SV and abundance (Forward and Cohen, 2010; Hasan *et al*., 2021).

From a methodological perspective, the application of a singular 200 kHz frequency constrains the capacity to differentiate zooplankton from other scatterers such as micronekton, suspended sediments, organic detritus, and microbubbles, and inhibits the utilization of frequency-difference and advanced scattering methodologies (Jones and Xie, 1994; Chu and Ye, 1998). Consequently, single-frequency SV ought not to be regarded as a dependable quantitative proxy for zooplankton biomass in the absence of multifrequency or optical constraints. Research employing multifrequency techniques has illustrated that the integration of multiple frequencies (e.g., 38-200 kHz) significantly enhances density estimations for euphausiids and copepods (Oh *et al*., 2013), underscoring the advantages of multifrequency systems for quantitative assessments of zooplankton. Furthermore, The need to constrain backscatter to specific MVBS ranges to isolate zooplankton echoes from other scatterers has also been demonstrated for ADCP data in West Sumatra waters, underscoring the importance of careful signal processing and noise correction (Bakhtiar *et al.,* 2024).

Despite these limitations, the current findings affirm that 200 kHz single-beam hydroacoustics remains an advantageous instrument for quantitatively delineating the vertical and horizontal structure of mixed pelagic layers in shallow tropical coastal waters when utilized in conjunction with net sampling. Echograms provide prompt, high-resolution insights into the depth range, relative intensity, and continuity of scattering layers, along with their association with hydrographic structures. Subsequent investigations should incorporate multifrequency acoustic arrays, flow-metered nets, and optical or imaging systems to enhance target classification, improve resolution of size structure, and transition from qualitative descriptions of layering to more robust quantitative estimations of zooplankton abundance and ecosystem dynamics.

CONCLUSSION

This study demonstrates that integrating calibrated single-beam hydroacoustics, CTD observations, and plankton-net sampling is effective for characterizing the spatial and vertical organization of pelagic communities in the coastal waters of Southeast Pari Island. The findings indicate that water-column stratification plays an important role in structuring pelagic scattering layers and influencing zooplankton distribution. However, the weak relationship between acoustic backscatter and zooplankton abundance confirms that 200 kHz single-frequency acoustics alone cannot provide reliable quantitative estimates of zooplankton abundance or biomass in these mixed-scatterer coastal environments. Therefore, single-frequency hydroacoustics should be applied primarily for detecting and quantifying pelagic aggregations within their hydrographic context. To improve quantitative assessments of zooplankton dynamics, future studies should employ multifrequency acoustic systems, species- or size-specific target strength models, and complementary biological sampling techniques targeting the same organisms detected acoustically.

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