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Hydroacoustic Analysis of Pelagic Fish Aggregation Around Fish Aggregating Devices (FADs) in Maluku Sea

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Abstract

The Maluku Sea is a body of water with considerable potential in terms of the fisheries sector. Several fish aggregations are located in the Maluku Sea that are being checked using a Simrad EK-15 single beam echosounder with a frequency of 200 kHz using the hydroacoustic method to record fish echoes. The hydroacoustic method provides information in the form of echoes from fish groups or fish volume. The backscattering strength (SV) is distributed around the fish aggregating device. This study aims to detect the presence of pelagic fish using hydroacoustic technology in the form of backscatter values and to analyze the relationship between pelagic fish SV and temperature, salinity, and currents around fish aggregating devices in the Maluku Sea. Fish aggregating devices in the Maluku Sea are dominated by small pelagic fish with fish aggregating device constructions reaching 70 meters below the water surface, there are buoys tied with floating ropes and artificial attractors such as palm fronds and weights. The temperature profile is around 29.73 – 26.85 °C, salinity ranges from 34.4 to 34.9 PSU, and the current speed is 0.2 meters per second. The distribution of fish SV values in the three fish aggregating devices was at a depth of 5 to 20 meters with SV values ranging from -46.53 to -52.91 dB, indicating that the fish aggregating devices greatly influenced the distribution of pelagic fish that tend to gather and follow the presence of attractors in the fish aggregating devices.

Keywords: Fish Aggregating Devices, Hydroacoustics, Maluku Sea, Pelagic Fish

1. Introduction

Fish Aggregating Devices (FADs) are fishing devices used to attract fish to gather in one place, thereby increasing fishing efficiency (Fuatkait, 2025). They have long been known to fishermen and come in two types: shallow sea and deep sea FADs (Yusfiandayani, 2020). Wudianto et al. (2019) also stated that FADs placed in the sea play a role in creating new habitats for fish and other marine life, so that FADs can function as places of refuge, breeding, feeding, and can increase the number of fish in certain waters. The placement of fish aggregating devices in WPPNRI is also stipulated in Regulation of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia Number 36 of 2023, which regulates that the distance between fish aggregating devices in fishing grounds must be at least 10 nautical miles. With the established policy, it is hoped that fish aggregating devices can become an efficient fisheries management tool in preserving pelagic fish resources and ecosystem health to achieve sustainable fishing activities.

Alheit et al. (2018) state that coastal communities around the world, especially in developing countries, derive much of their welfare from and depend on pelagic fish resources. Pelagic fish are organisms that have the characteristic of schooling in their feeding activities in the

open sea, especially in the surface layer. Pelagic fish have a habit of feeding at sunrise and sunset, therefore small pelagic fish are generally positively phototactic, meaning they tend to be attracted to and approach light (Kainama et al., 2019). The abundance of pelagic fish tends to be sensitive to the environment, as some fish species are affected by changes in ecological conditions influenced by environmental changes or a water area. Several factors identified as influencing environmental change in the study by Sari et al. (2022) are sea surface temperature, wind speed, rainfall, ocean currents, and humidity. Therefore, pelagic fish move dynamically and naturally choose water areas with suitable habitats so that they can support the ecological life of pelagic fish optimally (Pratama et al., 2022).

The fisheries potential in the Maluku Sea is quite high with diverse marine biodiversity, making it one of the considerations in improving national economic development (Siahainenia et al., 2017). Several types of pelagic fish that are dominant and have economic importance in the Maluku Sea are based on research by Suman et al. (2018), are skipjack tuna (*Katsuwonus pelamis*), tuna (*Thunnus* sp.), tongkol (*Euthynnus* sp.), mackerel (*Rastrelliger* sp.), layang (*Decapterus* sp.), and julung-julung (*Hemirhamphus* sp.). The Maluku Sea is geographically located in the eastern part of Indonesia, between the islands of Sulawesi and Halmahera. These waters are part of the entrance to the global ocean water mass pathway from the Pacific Ocean to the Indian Ocean, commonly known as the Indonesian Throughflow (Arlindo) with an average depth of around 4,000 m and a maximum depth of more than 6,000 m (Sprintall et al., 2019). Differences in water mass input due to ITF and supported by monsoon wind patterns that vary between seasons can affect water conditions in terms of the high and low productivity of fish resources. Other characteristics of the waters that fulfill the habitat of a group of fish and serve as indicators of potential fishing areas are temperature, salinity, and currents.

Accurate data on fish resources around fish aggregating devices (FADs) is crucial for sustainable fisheries management (Capello et al., 2023). With limited capacity, the utilization of fishery resources, especially pelagic fish, is renewable. This requires the availability of fisheries data that can produce information on fish attraction to fish aggregating devices, both oceanographic parameters in the Maluku Sea and the construction of fish aggregating devices in a water area. The method used in this study to determine the distribution of fish resources in a water area is the hydroacoustic method. The hydroacoustic method is a method that uses acoustic instruments in the form of transducers with the working principle of converting pulses with a certain frequency to produce sound waves that will propagate through the water medium and hit objects or targets, then reflect the echo from the target back to the transducer (Pujiyati et al., 2020). The detected objects are the distribution of pelagic fish schools that scatter back echoes called Volume Backscattering Strength (SV), which are groups of single targets that form aggregations rather than individuals, known as schooling fish.

This study focuses on analyzing the distribution of pelagic fish around the Maluku Sea FADs. It aims to detect pelagic fish schooling using hydroacoustic technology that can provide information on pelagic fish resources in the form of backscatter values and analyse the relationship between pelagic fish SV and oceanographic parameters, namely temperature, salinity, and currents around the Maluku Sea FADs. Thus, this study is expected to assist in providing data on the distribution of pelagic fish around the Maluku Sea FADs to relevant policy makers, so that it can be further conveyed to stakeholders such as fishermen and the community in assisting efforts to manage and utilize fish resources in the Maluku Sea in a sustainable manner.

2. Materials and Methods

2.1. Time and Location of The Study

Data acquisition was conducted at three points in the Maluku Sea with depths reaching 100 meters and observations were made from morning to night. Data collection was carried out on January 8, 11, and 14, 2016, by researchers from the National Research and Innovation Agency (BRIN). **Figure 1** shows a map of the data collection locations in the Maluku Sea.

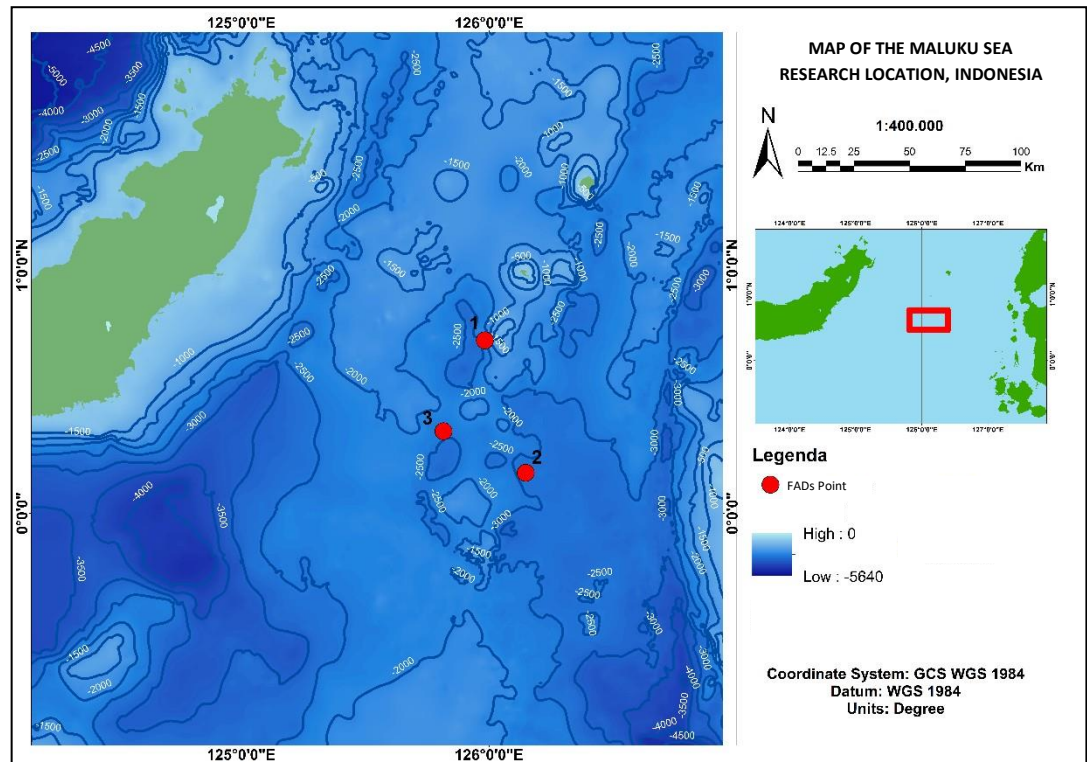


Figure 1. Location of the study area in the Maluku Sea, eastern Indonesia, showing the positions of the three anchored Fish Aggregating Devices (FADs) used for hydroacoustic observations (red circles labelled 1–3). The bathymetric background and contour lines represent seafloor depth (m), while the inset map indicates the geographical location of the study area within Indonesia.

2.2. Tools and Materials

The tools used in this study was a SIMRAD EK-15 Single Beam Echosounder with a frequency of 200 kHz and a laptop with ESP3 1.50.0, ArcGIS, ODV, SPSS, and Microsoft Office software installed. The materials used were raw data from acoustic acquisition received by acoustic instruments in *.raw file format in the form of echograms and supporting data on the characteristics of the Maluku Sea based on oceanographic parameters downloaded from the Marine Copernicus website. Hydroacoustic observations were conducted around three anchored Fish Aggregating Devices (FADs) owned by local fishermen, consisting of a floating platform, natural attractors (coconut, areca, or nipa palm fronds), rope, and an anchoring system.

2.3. Data Acquisition

The collection of oceanographic parameters such as temperature and salinity on the surface of the Maluku Sea was conducted in situ and used in the calibration process. Meanwhile, data on temperature, salinity, and currents based on vertical conditions at depths of 5–70 meters were downloaded from the Marine Copernicus website from the three fishing grounds studied in this research. Acoustic data collection was conducted over three consecutive days, with one Fish Aggregating Device (FAD) surveyed per day.

Acoustic data acquisition was carried out using a SIMRAD EK-15 single beam echosounder instrument with a frequency of 200 kHz. The transducer was placed 1 m from the bottom of the surface to avoid noise, and then the transducer transmitted sound waves that were propagated into the water column until they hit the target. Thus, the detected object or target will produce a sound wave scattering value that will be reflected and received back by the transducer.

2.4. Data Processing

The raw data from the acoustic survey was then processed using ESP3 software set to the calibration tool by entering the values Gain 15.81 dB, Sa -0.57 dB, and EQA -5.10. while in the environment section, the values of temperature 28 °C, salinity 35 psu, and depth 3 m were entered to adjust the top strand of the fish aggregating device attractor to eliminate surface noise originating from the near field transducer. Next, filtering was performed by entering the threshold value range for fish based on the research by Manik and Nurkomala (2016), namely -34 dB to -60 dB, assisted by the polygon digitization feature to detect the SV value of each group of fish visualized in **Figure 2**.

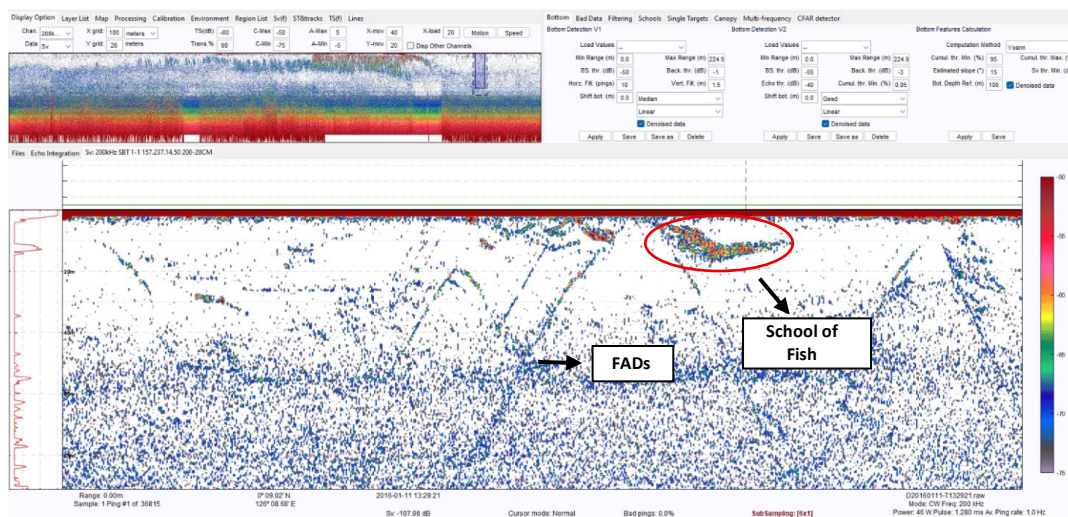


Figure 2. Visualization of echogram results from acoustic sounding. This indicates the presence of fish aggregating devices, and the red circles indicate schools of fish that have been digitized to determine their SV values.

Each digitization of a fish school on the echogram will display the integrated selection of the average SV value. The SV values of the fish obtained are then further analyzed using the equation by MacLennan and Simmonds (2005):

$$Sv = 10^{\left(\frac{SV}{10}\right)} \quad (1)$$

$$\overline{Sv} = \frac{\sum Sv}{n} \quad (2)$$

$$\overline{SV} = 10 \log \overline{Sv} \quad (3)$$

Notes, SV = Volume Backscattering Strength; Sv = Volume Backscattering Strength Coefficient; n = Amount of data.

2.5. Data Analysis

The acoustic fisheries data obtained in linear SV format was then visualized horizontally using ArcGIS 10.8 software. Oceanographic parameters that have been sorted and converted from *.nc to *.txt, including temperature, salinity, and current data for the Maluku Sea, were then processed using ODV software to visualize the vertical distribution (temperature and salinity) and horizontal distribution (current data).

This study used a statistical approach to determine the relationship between fish SV values and oceanographic parameters, namely using multiple linear regression analysis, which is a regression model to measure the extent of the influence between several independent variables and the dependent variable (Sari and Wardani 2015). Priyatno (2022) states that multiple linear regression analysis is complemented by a significance test using a T-test to determine the effect of independent variables (oceanographic parameters) on the dependent

variable (fish SV values) and an F-test to test the overall validity of the regression model. This analysis produces a coefficient of determination (R^2) that can show and assess the extent to which the independent variables in the model can explain the relationship or influence on fish SV values around the fish aggregating device.

3. Results and Discussion

3.1. Characteristic and Construction of Fish Aggregating Devices (FADs)

Three anchored Fish Aggregating Devices (FADs) owned and operated by local fishermen were used as observation sites in this study. The FADs were deployed in offshore waters of the Maluku Sea, particularly within the Indonesian Throughflow (ITF/Arlindo) pathway, and were installed in deep-water environments with mooring systems extending approximately 200 m below the sea surface. Each FAD consisted of four main components: a floating structure, attractors, mooring ropes, and anchoring weights (**Figure 3**). The floating structure was in the form of a guard-house platform assembled above the sea surface, functioning as both a buoyancy unit and an operational platform for fishermen. Natural attractors made of coconut, nipa, and areca palm fronds were suspended beneath the floating structure to enhance fish aggregation (Zudaire et al., 2023). The attractors were connected using nylon ropes, while the anchoring system consisted of concrete sinkers positioned on the seabed to maintain the stability of the FADs under prevailing oceanographic conditions. Similar construction designs have been widely adopted in Indonesian offshore fisheries because they provide shelter, orientation cues, and feeding opportunities for pelagic fish assemblages (Wudianto et al., 2019).

It should be noted that detailed engineering specifications, including the exact number of attractors, spacing between attractors, and anchor weights, were not available during the survey because the FADs were privately owned and had been deployed by local fishermen prior to the research activities. Therefore, only the main structural components, construction materials, and general configuration of the FADs could be documented through direct field observations. Despite these limitations, the investigated FADs are representative of the traditional anchored FAD systems commonly used throughout eastern Indonesian waters to support pelagic fisheries.

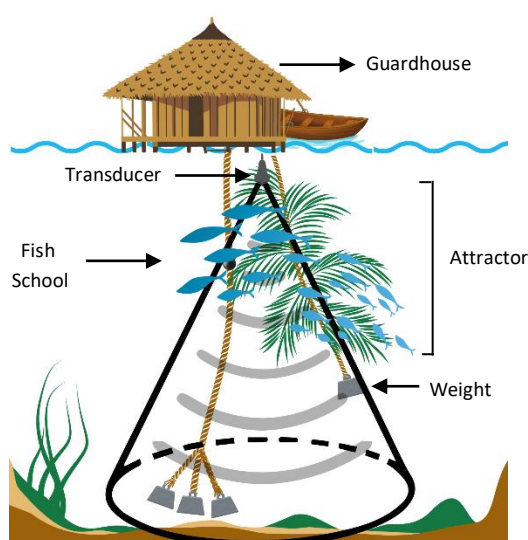


Figure 3. Schematic illustration of the anchored Fish Aggregating Device (FAD) used in this study, consisting of a floating platform (guardhouse), natural attractors, mooring ropes, concrete sinkers, and a hydroacoustic transducer. The illustration shows the general configuration of the FAD and the position of fish schools aggregated around the attractors during hydroacoustic observations.

3.2. Characteristics of The Waters at The Research Site

The Maluku sea area included in WPP-RI 715 has a high potential for large and small pelagic fish resources. The distribution of fish around fish aggregating devices (FADs) is influenced by several oceanographic parameters such as temperature, salinity, and currents that help spread plankton as the main food source for fish (Pratama et al., 2022; Riadi et al., 2024). These waters are part of the Indonesian Throughflow (Arlindo), which carries water from the Pacific Ocean to the Indian Ocean. This current also influences changes in water layers and upwelling phenomena in accordance with the shape of the seabed and seasonal changes (Atmadipoera et al., 2016; Atmadipoera and Hasanah 2018). Analysis of the distribution at three points shows stratification in the water column to a depth of 70 meters (**Figure 4**). Water temperatures range from 29.73 to 26.85 °C, forming a mixed layer at the top (0–20 meters) and a transition layer towards the thermocline at the bottom (20–70 meters). Water salinity was relatively stable, ranging from 34.4 to 34.9 PSU, which was influenced by western monsoon conditions (Tangke et al., 2016; Patty et al., 2020). However, pressure from human activities such as overfishing and irregular use of fish aggregating devices could reduce the number of pelagic fish. To maintain the sustainability of fish resources in WPP 715, ecosystem-based management is needed by regulating the use of fish aggregating devices, limiting fishing times, and establishing conservation areas (Taib et al., 2018).

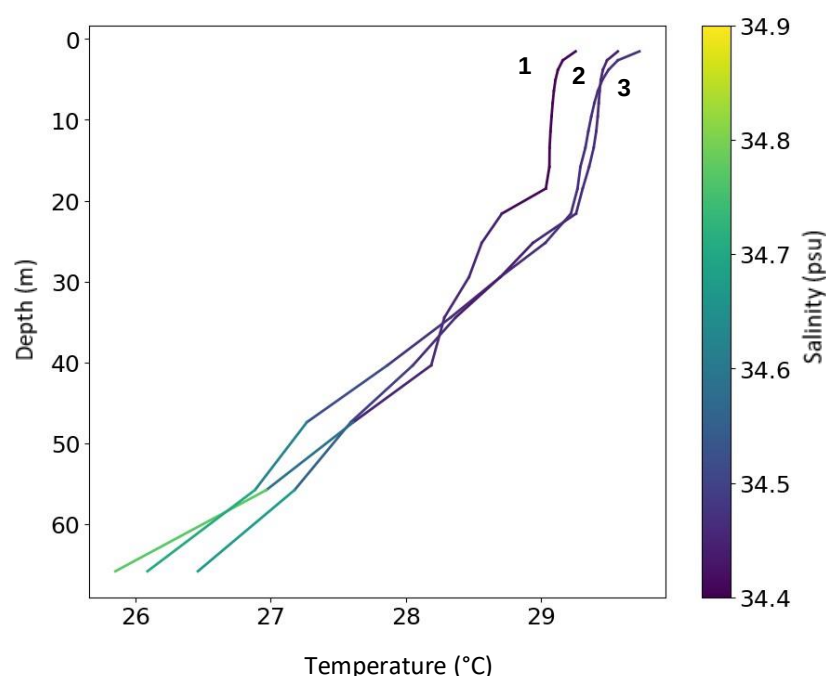


Figure 4. Profile of vertical distribution of temperature and salinity in the Maluku Sea. There are three vertical lines indicating each depth of the fish aggregating device studied.

The currents visualized in **Figure 5** around the Maluku Sea FADs in January flowed from the southeast to the southwest at a speed of 0 to 0.4 m/s (average 0.2 m/s). These currents were influenced by the west monsoon winds (Daruwedho et al., 2016). In addition, the dynamics of Arlindo and the upwelling phenomenon increase nutrient supply, water mixing, and primary productivity, thereby potentially affecting the distribution of pelagic fish (Noor et al., 2024; Sulistiyono and Samiaji, 2024).

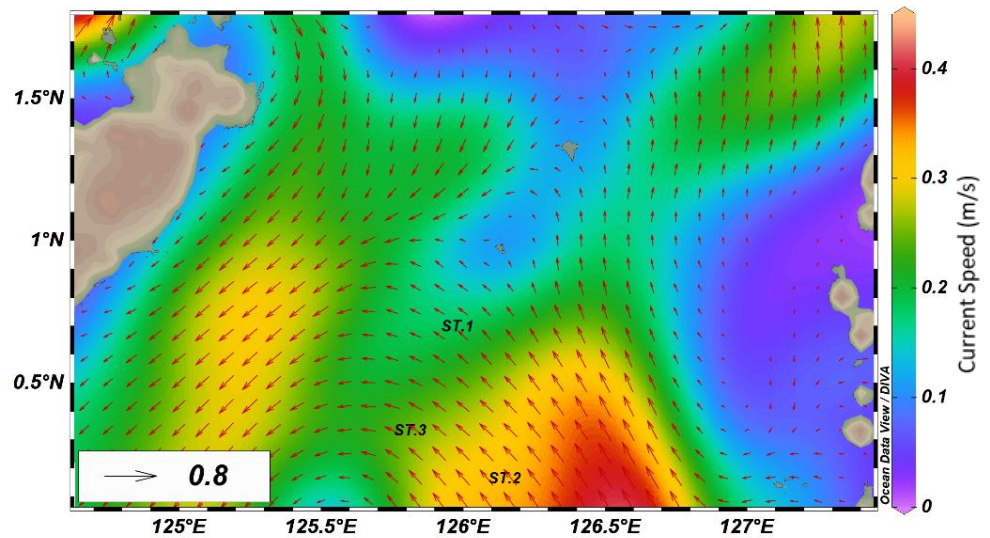


Figure 5. Spatial distribution of surface current velocity around the three Fish Aggregating Devices (FADs) in the Maluku Sea during the observation period. The color scale represents current velocity (m s^{-1}), while the arrows indicate the direction of current flow, showing the hydrodynamic conditions surrounding each FAD location.

3.3. Horizontal Distribution of Pelagic Fish SV Values

SV values moved dynamically around three fish aggregating devices (FADs) in the Maluku Sea, indicating the movement of fish and FADs due to ocean currents (**Figure 6**). Floating FADs can be pulled by currents, causing the fish gathered around them to move and tend to gather at the rear of the FAD in the direction of the current. Analysis of SV distribution shows differences in pelagic fish density among the various fish aggregating devices. Fish aggregating device 2 has a higher and more even density compared to fish aggregating devices 1 and 3, which show more uneven distribution. The presence of periphyton and the location of the fish aggregating devices in the Arlindo channel, which carries nutrient-rich water, also encourages the growth of organisms, the availability of plankton, and the productivity of the waters as a food source for pelagic fish (Ridhoni et al., 2018; Yuliardi et al., 2022). From an ecological and fisheries perspective, fish aggregating devices serve as shelters, feeding grounds, and places for fish to interact. In addition, fish aggregating devices can also be a good tool for sustainable fisheries management if managed using an ecosystem-based approach (Yusfiandayani, 2020).

The distribution of pelagic fish SV values at FADs 1 ranged from -59.48 to -43.67 dB and was dominant at depths of 5–25 m. At FADs 2, the range was -56.18 to -38.12 dB with a main concentration at 5–25 m to a depth of 55 m. while FADs 3 ranged from -59.99 to -38.12 dB and was more dominant at depths of 30–55 m, which generally showed a decrease in fish density with increasing depth. This vertical distribution pattern is influenced by oceanographic factors, light availability, and water productivity related to Arlindo dynamics, upwelling, and chlorophyll-a concentration as an indicator of water fertility (Ma'mun et al., 2018; Uneputty et al., 2022; Pesoth et al., 2024).

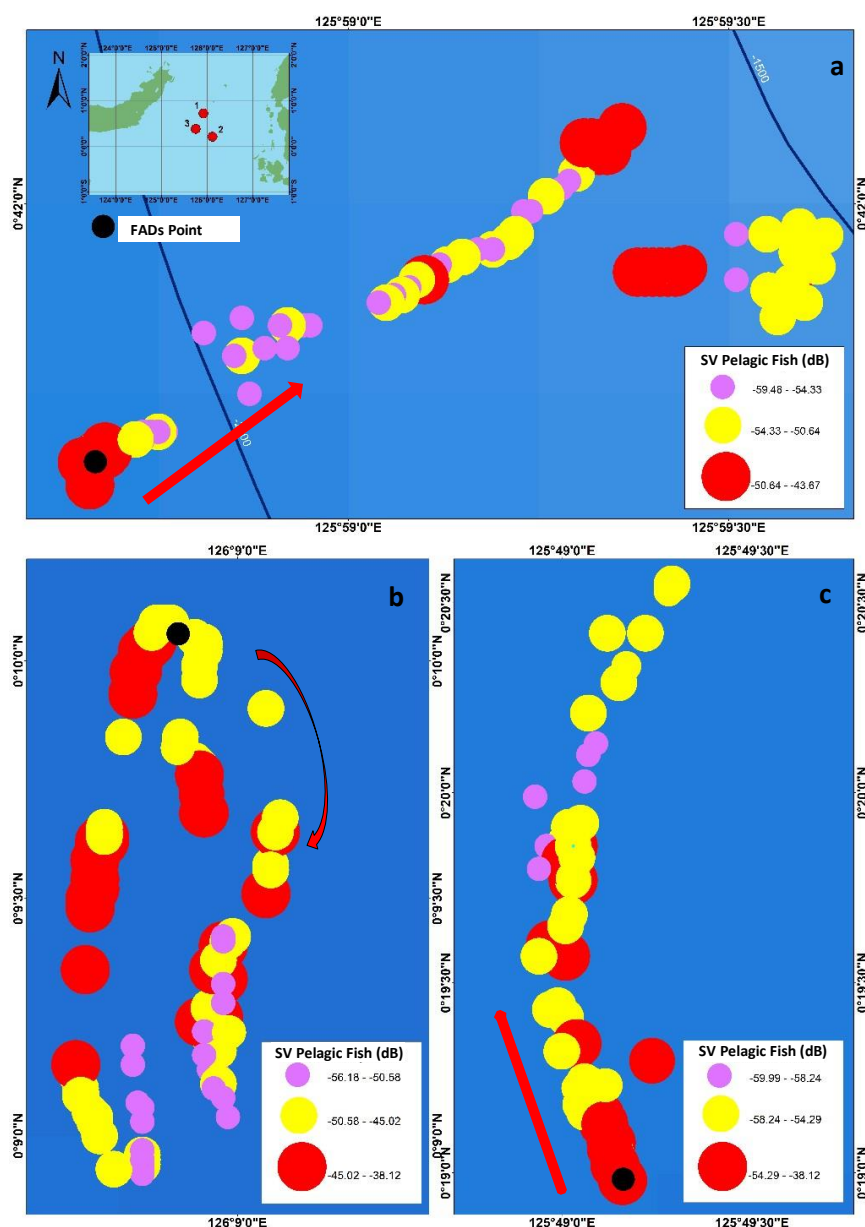


Figure 6. Horizontal distribution of pelagic fish SV in (a) FADs 1, (b) FADs 2, and (c) FADs 3 in the Maluku Sea. The coloured dots indicate the range of pelagic fish SV values: purple (low), yellow (medium), and red (high).

3.4. Frequency of Occurrence of SV Values for Pelagic Fish

The frequency distribution of pelagic fish SV values in the three fish aggregating devices shows differences in density and how fish gather. Fish aggregating device 2 has the highest average SV of -48.21 dB, indicating a higher density of fish. Meanwhile, Fish Aggregation Device 1 with a value of -52.87 dB and Fish Aggregation Device 3 with -55.87 dB show a more concentrated pattern of fish grouping in a certain range, indicating that the fish gather quite densely (**Figure 7**). The difference in these characteristics is most likely due to the age of the fish aggregating devices, where newer ones are usually inhabited by smaller fish, while older ones tend to attract larger fish (Alfian et al., 2023).

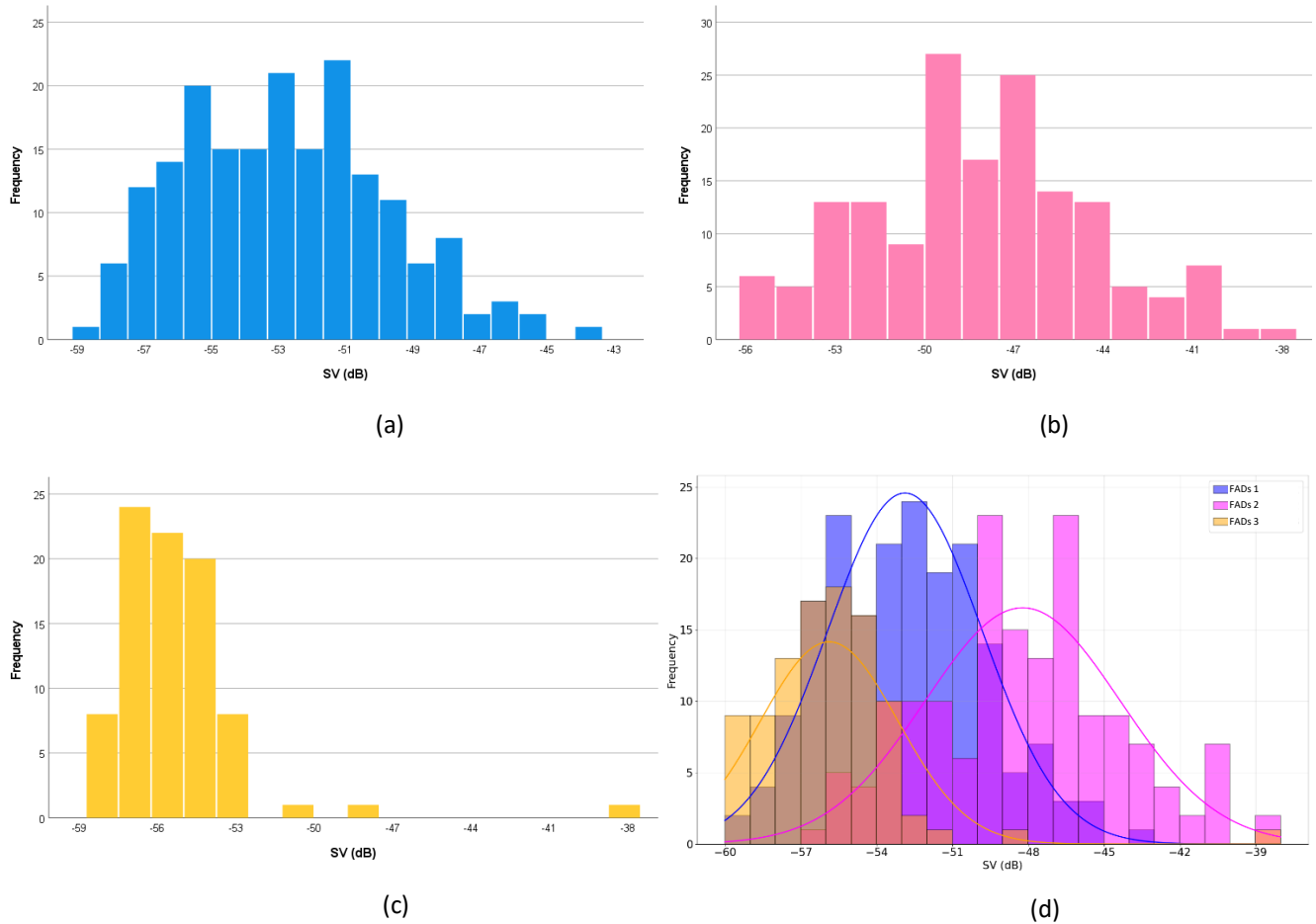


Figure 7. Frequency distribution of pelagic fish volume backscattering strength (SV) values at (a) FAD 1, (b) FAD 2, (c) FAD 3, and (d) the combined distribution of all FADs. The histograms show the variation in SV values at each FAD, while the overlaid density curves in panel (d) facilitate comparison of the distribution patterns among the three observation sites.

3.5. Relationship between the SV Value of Pelagic Fish and Environmental Parameters

The results of multiple linear regression show that location R2 has the best and statistically significant model (Adjusted $R^2 = 0.94$; Sig. = 0.009), where temperature is the most influential variable compared to salinity and current. Meanwhile, locations R1 (Adjusted $R^2 = 0.75$; Sig. = 0.22) and R3 (Adjusted $R^2 = 0.61$; Sig. = 0.99) are not significant, so the relationship between variables at these two locations is relatively weak. This difference is most likely due to the west monsoon and changes in attractors at FADs 2, which proved to be more effective in attracting fish, in line with research showing that the installation period of fish aggregating devices affects the number of fish in the surrounding area (Wuaten et al., 2023).

Table 1. Results of the multiple linear regression analysis between pelagic fish volume backscattering strength (SV) and the oceanographic parameters at each Fish Aggregating Device (FAD) location. The table presents the adjusted coefficient of determination (Adjusted R^2), F-statistic, significance level (Sig.), and the regression equation, indicating that the strongest and statistically significant relationship was observed at location R2.

Location	Adj. R^2	F	Sig.	Regression Equation
R1	0.75	2.09	0.22	$Y = 6.33E-05 - 2.1E-06X_1 + 4.34E-08X_2 + 1.73E-05X_3$
R2	0.94	12.9	0.009	$Y = 9.94E-06X_1 + 2.55E-06X_2 - 8.9E-05X_3$
R3	0.61	0.99	0.47	$Y = 6.69E-06 - 3.1E-07X_1 + 1.83E-07X_2 - 4.2E-07X_3$

4. Conclusions

Hydroacoustic observations successfully characterized the distribution of pelagic fish aggregations around the anchored Fish Aggregating Devices (FADs) in the Maluku Sea. Pelagic fish were predominantly concentrated in the upper water column at depths of 5–25 m, with SV values ranging from –59.99 to –38.12 dB, indicating that the FADs functioned as aggregation centers that influenced both the horizontal and vertical distribution of fish. The observed distribution patterns varied among FAD locations, reflecting differences in local environmental conditions and fish aggregation density. Multiple linear regression analysis further showed that oceanographic parameters influenced pelagic fish distribution, with temperature being the most influential variable and a statistically significant relationship detected at one observation site (Adjusted $R^2 = 0.94$). These findings demonstrate that hydroacoustic methods provide an effective approach for assessing pelagic fish distribution around FADs and offer valuable scientific information to support sustainable fisheries management in the Maluku Sea.

Conflicts of Interest

There are no conflicts to declare.

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AI Writing Statement

In preparing this manuscript, the authors utilized ChatGPT (OpenAI) to assist with language refinement and stylistic enhancement. Following the use of this tool, the author carefully reviewed and revised the content as necessary and assume full responsibility for the final version of the publication.

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