Acoustic Detection and Quantification of Fish in Lancang Waters of Seribu Islands, Indonesia

Syahrul Purnawan[1,2], Henry M. Manik[3]*, Agustina Sartika Manik[2], La Elson[2], Myounghee Kang[4]

[1]Laboratory of Marine Acoustics, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[2] Marine Technology Study Program, Department of Marine Science and Technology, Faculty of Fisheries and Marine Sciences, IPB University, Bogor 16680, Indonesia
[3]Department of Marine Science and Technology, Faculty of Fisheries and Marine Sciences, IPB University Jl. Rasamala, Kampus IPB Darmaga Bogor 16680 Indonesia.
[4]Department of Maritime Police and Production System, Gyeongsang National University 501 Jinju-daero, Jinju-si, Gyeongsangnam-do, Republic of Korea
Email: henrymanik@apps.ipb.ac.id

Abstract

Sound propagates effectively through the water column, establishing hydroacoustic technology as a premier method for underwater exploration, including the mapping of aquatic ecological resources. While the fisheries sector is considered pivotal in aquatic resource studies, mapping fisheries remains challenging due to the distinct distribution patterns exhibited by fish within the water column, which are intricately linked to their habitat preferences. In this study, the hydroacoustic method was employed to analyze the distribution of fish in the waters surrounding Lancang Island, Seribu Islands, Jakarta. This analysis utilized the target strength (TS) value alongside oceanographic parameters. Acoustic data was collected using a 200 kHz single beam echosounder based on parallel transects encircling the waters of Lancang Island. CTD was utilized to collect oceanographic data to acquire temperature and salinity profiles within the water column. The acoustic data processing was conducted using the post-processing software SONAR 5-pro. The analysis was performed based on acoustic cells, obtained by dividing segments every 100 m horizontally and layers every 5 m vertically, thereby obtaining the Target Strength per cell (TSc) and volume backscattering strength (SV) values from each cell. The results showed that the highest average TSc value was found in the depth range of 26-31 m at -46.98 dB, and the highest SED biomass was also found in the same depth range at 26.6 kg.ha^{-1}. Based on the analysis of water temperature and salinity, it was found that these factors significantly influence the distribution of fish in the waters of Lancang Island (R-square= 0.1276 and P< 0.05). This finding also indicates the presence of other parameters affecting fish distribution in Lancang waters, with the type of substrate and habitat emerging as potential determining factors, notably in coral reef environments.

Keywords: *Lancang Island, fisheries acoustic, single beam, echo integration, TSc, Simrad EK15*

Introduction

Underwater acoustic technology has long been recognized as the most reliable method in underwater surveying and mapping applications (Hersey, 1969; Manik, 2014; Lee *et al.*, 2021). Underwater acoustic technology uses sound waves to detect and quantify objects in the water column. Currently, acoustic technology is widely used in fisheries surveys (Achmadi *et al.*, 2014; Manik *et al.*, 2018; Purnawan *et al.*, 2023), monitoring marine areas (Dwinovantyo *et al.*, 2017; Manik *et al.*, 2017), and conducting bathymetric surveys and seabed mapping (Manik *et al.*, 2006b; Manik *et al.*, 2006a; Manik, 2012). The application of acoustic technology in fisheries is also recognized for its non-invasive nature, which does not require the capture or killing of fish, making it an ideal method for estimating fish biomass (Simmonds and Maclennan, 2005).

Acoustic methods offer advantages in rapidly and accurately obtaining information on fish distribution and biomass in an area (Hilborn *et al.*, 2020; Peck *et al.*, 2021),. Estimating fish abundance quantitatively can be done with the development of echo integration and echo counting techniques (Thomas and Kirsch, 2000). Inferring quantitative information about target fish is an important requirement to obtain the target strength value as a signal of target fish (Simmonds and Maclennan, 2005). Fish biomass, on the other hand, is the total mass of fish in a given area, often expressed as the weight of fish per unit area. Acoustic technology can be used to estimate fish biomass by measuring the number and size of fish in a given area (Orduna *et al.*,

*) Corresponding author

https://ejournal.undip.ac.id/index.php/ijms
DOI: 10.14710/ik.ijms.29.2.181-190
Received : 18-03-2024
Accepted : 22-04-2024

2021). This information can then be used to calculate the total weight of fish in that area. Therefore, this method can be used to quantitatively estimate the number of fish under actual conditions (Laouar and Djemali, 2018).

Lancang Island is located in the Seribu Islands chain northwest of Jakarta City. It is inhabited by people predominantly engaged in fishing, relying on natural catches for their livelihoods. Like other small islands in the Seribu archipelago, Lancang Island is primarily composed of limestone-based reef plains. The soil type on Lancang Island is coral sand formed from the weathering of coral rocks, characterized by a bright, grayish-white, and loose texture (Elson *et al*., 2022). The waters surrounding Lancang Island are renowned for their hard coral reefs, playing a crucial ecological and economic role by sustaining diverse aquatic life at various life stages and contributing to high fish diversity (Purnomo and Ruswahyuni, 2009). Unfortunately, the ecological condition of these coral formations has been adversely affected by pressures originating from Java Island (Sachoemar 2008).

The waters surrounding Lancang Island harbor significant fisheries potential, with the presence of scad, sardine, and squid, supported by the surrounding coral reef ecosystem (Rivai *et al*., 2017). However, the fisheries potential related to the standing stock of fish in Lancang Island waters has not been previously explored. Thus, it is necessary to comprehensively assess fisheries potential using acoustic methods in this area. This study employed hydroacoustic methods, using a Simrad EK15 single-beam echosounder to assess fish distribution and estimate biomass in Lancang waters. Additionally, oceanographic parameters such as water temperature and salinity were examined to understand their relationship with fish distribution in the region. The findings of this study provide essential insights to support the sustainable use and conservation of natural resources in the Lancang Island area.

Materials and Methods

Acoustic data acquisition

Field data collection was conducted in January 2020. During the acoustic data recording, the vessel's speed was maintained at approximately 3 to 4 knots. Track data collection, including both acoustic data and CTD data, was carried out following the parallel transect around the waters of Lancang Island, as shown in Figure 1.

The acoustic survey instrument used for data acquisition was a single beam echosounder (SBES) Simrad EK-15. The SBES Simrad EK-15 is a portable scientific echosounder with a frequency of 200 kHz, a beam width of 26 degrees, and a maximum output power of 45 watts. The pulse length was set at 80 µs with a ping rate of 40 Hz. The speed of sound obtained based on the Mackenzie equation (Mackenzie, 1981) by entering the temperature and salinity values of the local waters was 1549 ms^{-1}. The transducer was attached to the starboard side of the ship using an iron pipeline and submerged in water at a depth of about 0.7 m from the sea surface. Prior to data collection, the Simrad EK-15 device was calibrated. The calibration process was conducted aboard a stationary boat near Lancang Island Harbor, during good weather and calm water conditions. This involved lowering a 35 mm tungsten sphere to a depth of around 2 m and adjusting the measured reflection value to the reference value. Once the instrument calibration process was completed, the Simrad EK-15 was then used for the measurement process.

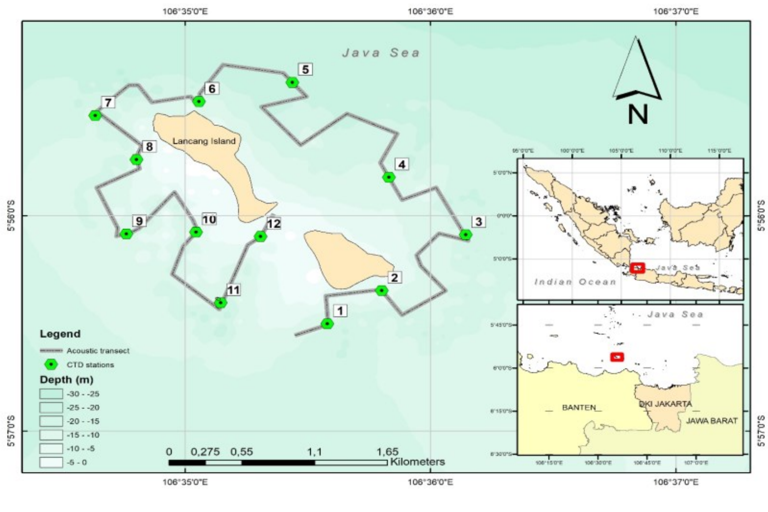


Figure 1. The data acquisition sites were located in Lancang waters. The acoustic survey track is delineated with gray lines while the 12 CTD sites are indicated with green dots.

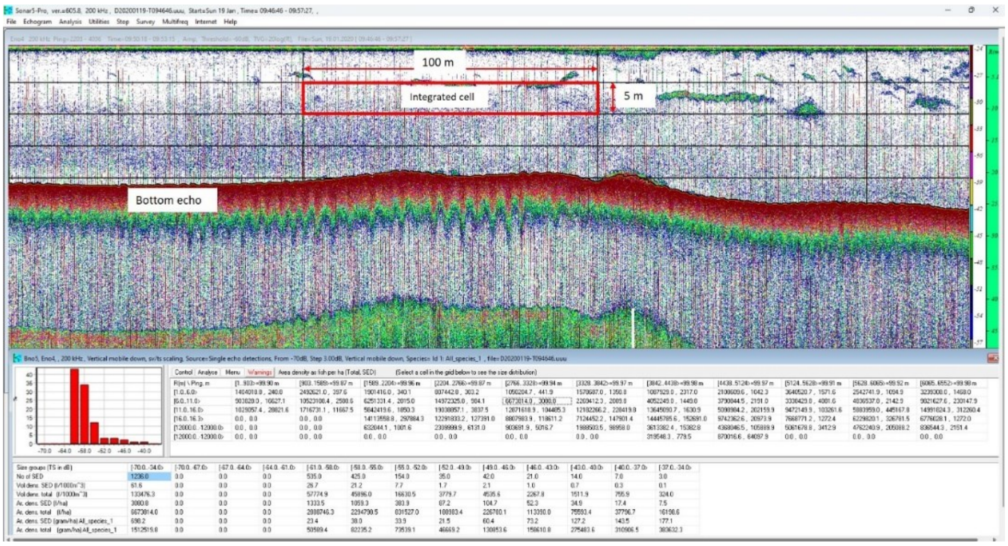


Figure 2. Sonar5-Pro post-processing software interface. The integrated cell is divided by sub-segments within 100m horizontally and layer widths within 5m.

Oceanographic parameters

Alongside acoustic data acquisition, oceanographic parameters such as temperature and salinity were also collected using a CTD type AML Minos-x. Temperature and salinity data profiles were conducted by lowering the CTD from the water surface with a depth interval of 0.1 m to depths near the seabed. These measurements were taken at a total of 12 stations, located between acoustic data collection transects around Lancang waters. The processing of vertical profiles of temperature (in degrees Celsius) and salinity (in parts per thousand - ppt) that have been obtained involved plotting the data on X-Y diagrams. Additionally, to derive a representative value for the acoustic value integration column, the temperature and salinity parameter values were averaged per 5-meter depth vertically at each of the 12 data collection transects.

Data analysis

The default data format outputted by the Simrad EK-15 is a *.raw file. The data processing was done in this study using the post-processing software Sonar5-Pro (Balk and Lindem 2014), which required a dongle to convert the *.raw extension to *.uuu, and then displayed it as an echogram (Figure 2.). Echograms itself is a graphic visualization of amplitude values that represent sound waves (echo) reflected by objects below the surface of the transducer.

The data integration process was done with caution and consideration of the potential noise generated in the area around the transducer surface. For this reason, the water column selection process was conducted from a depth of 1 m below the transducer surface to eliminate near-field factors and surface noise. The integration layer was created based on an elementary sampling distance unit (ESDU) of 100 m horizontally with an integration width of 5 m vertically.

Target identification was performed using the Target Strength (TS) parameter generated by sound reflections generated from underwater objects. TS is an acoustic parameter that measured the echo strength (dB) from targets such as fish when they are located in the beam area of the transducer. These measurements are inherently biased if the fish are not separated enough to be observed as a single target, requiring analysis software that includes algorithms to filter out single echoes.

For this reason, this research applied the Single Echo Detector (SED) available in the software. SED is a technique to recognize a single echo produced by a single target detected in the echosounder beam. It also separates the target echo from any overlapping noise, therefore ensuring a good signal-to-noise ratio (Manik and Nurkomala, 2016). Data filtering was also performed by applying a threshold over the processed data to eliminate unwanted object reflections. The threshold value was set at -70 to -35 decibels, with intervals of 5 dB.

The maximum reflection of a fish target is produced when the target is located on the axis of the acoustic beam (Traynor, 1990). A basic calculation of TS target reflection (dB) can be determined based on the value of the received signal returned to a transducer (signal excess, SE), following the simple equation below:

$$SE = SL + TS + G_R + G_{TVG} + 2B(\theta, \varphi) - TL \quad (1)$$

where SE = signal excess; SL = source level (dB); TS = Target Strength (dB); Gr = receiving gain (dB); G_{TVG} = time-varied-gain; B(θ,φ) = beam-pattern factor; and TL = Transmission loss (dB). Transmission Loss calculates the amount of sound energy loss when propagated in the water column, consisting of absorption by the water column and spreading loss, calculated following (eq. 2):

$$TL = 40\log(R) + 2\alpha Ra \quad (2)$$

Where 40 log(R) is spreading loss (dB); 2αR is absorption loss (dB); R is range (m)

The strength of the returning echo is determined by fish characteristics such as length-weight, where the coefficient value used follows (Herzig and Kubecka, 2001). The general relationship between TS value and fish length is explained by the eq. 3:

$$TS = A\log(L) + B. \quad (3)$$

For biomass analysis, the Sv/TS Scaling technique was also applied. Fish density value (fish/m3) can be obtained by using eq. 4:

$$\rho = \frac{N}{V} \quad (4)$$

where ρ is Fish density (fish/m3); N is the number of good samples; V is the beam volume sum.

Result and Discussion

Hydro-oceanographic parameters

Data extraction of oceanographic parameters showed changes in temperature and salinity as a function of water depth. The highest recorded water temperature was 30.4 ºC and the lowest was 28.6 ºC, resulting in an average of 29.15±0.46 ºC. Water temperature tends to be warmer at the surface and becomes lower at higher depths. On the other hand, the salinity profile showed higher values as the depth increased. Salinity in Lancang waters was recorded between 29.3 ppt to 32.4 ppt with an average of 31.71±0.65 ppt. The temperature and salinity profiles obtained from a total of 12 stations on Lancang Island are presented in Figure 3.

Water temperature and salinity are two oceanographic parameters that have a significant influence on the availability of fish in a particular water area (Lehodey *et al*., 2006). As a tropical region, sunlight conditions that shine throughout the year make this area has high productivity. Consequently, the temperature of the waters is found to be warm at the surface and cooler in the deeper water column due to the conduction factor which is not ideal for transferring heat. Salinity values exceeding 30 ppt in this area are very typical for marine waters. This could be a consequence of the lack of nearby freshwater discharge since the Seribu Islands consist of a cluster of small coral islands devoid of river flow. Low salinity values found at the surface could result from precipitation events that lower salinity in the surface area, while high salinity extends to deeper layers.

Additional results obtained on the condition of the Lancang waters include the depth of the seabed measured from the acoustic data acquisition. The depth of the seabed measured by the acoustic instrument was 29.6 m at the deepest and 17.7 m for the average obtained. These results indicate that the waters of Lancang Island are likely to be shallow, as it is partly a coral area.

Target distribution

Along the track, we found a total of 1,166,361 #SED, where the maximum #SED was found at a depth range of 11-16 m with 454,766 of SED. The average SED information resulted from dividing the total #SED value by the number of integration cells in each depth range (SED/cell). The SED/cell value at the surface was found to be 134.2 and increased in the next layer until the maximum number was found in the third layer, 11-16 m depth, with 3419.3 (Table 1.). It is evident that the upper layer near the surface contains the highest number of integrated cells. The number of integration cells of the water column gradually decreases in deeper layers, this reduction in integration cells is mainly due to the limited water depth, especially in certain areas where the bottom is relatively shallow.

Additionally, the area density values based on sub-layers exhibit a pattern consistent with the distribution of #SED. The middle layers, in particular, demonstrate higher area density values compared to both the surface and deeper layers. Specifically, the highest density is observed in the 16-21 m sub-layer with a value of 64,838.4, which is comparable to the density of the sub-layer above it, valued at 63,940.9. However, there is a significant difference with the surface sub-layer, which is valued at only 1712.3. This observation indicates a tendency for numerous objects to aggregate at intermediate depths, highlighting the noticeable density of these layers.

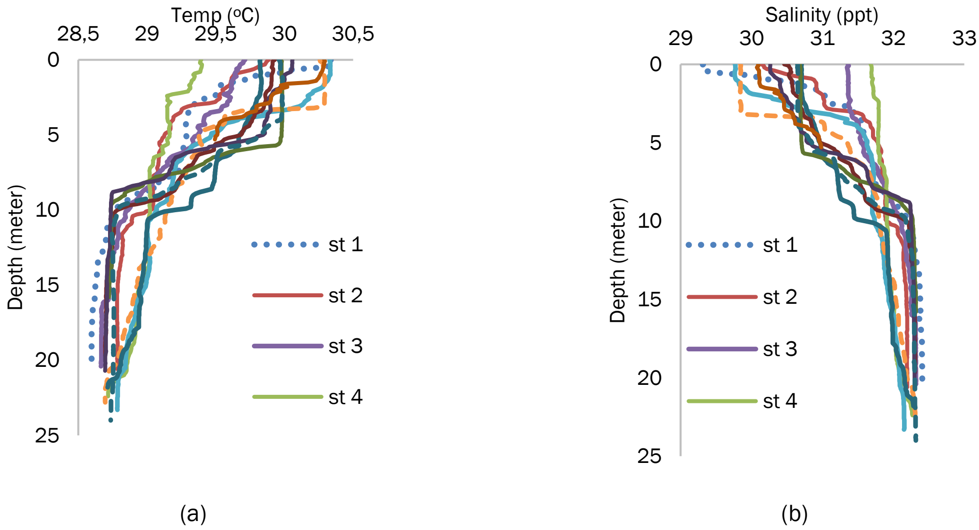


Figure 3. Vertical profiles of: (a) temperature; and (b) salinity, versus water depth at 12 stations.

Table 1. Number of SEDs and cells per depth layer

no	Layer (m)	# SED	#cell	SED/cell	Area Density (#/ha)
1	1-6	18514	138	134.2	1712.3
2	6-11	222684	135	1649.5	14330.2
3	11-16	454766	133	3419.3	63940.9
4	16-21	399190	124	3219.3	64838.4
5	21-26	69877	65	1075.0	27894.1
6	26-31	1330	2	665.0	32438.7

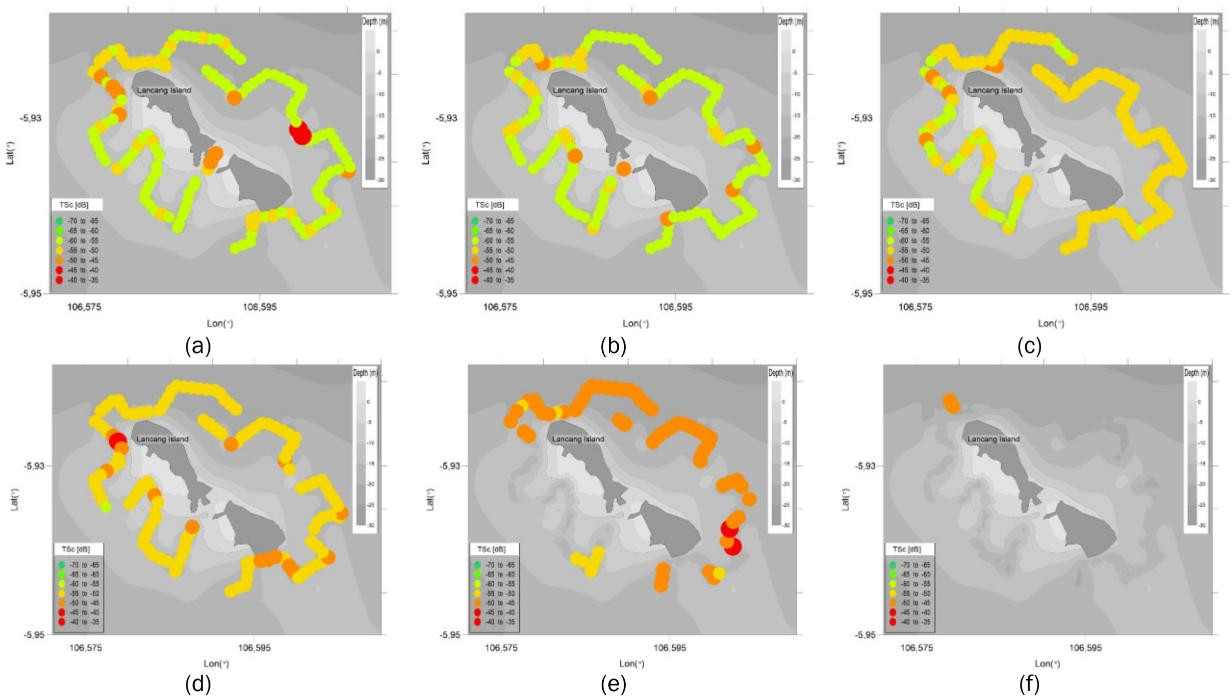


Figure 4. Spatial distribution of the TSc on every depth layer: (a) 1-6 m; (b) 6-11 m; (c) 11-16 m; (d) 16-21 m; (e) 21-26 m; (f) 26-31 m. The color scale of the TSc displayed has the same range on every depth layer.

Target strength

The distribution of TSc values per depth layer, as depicted in Figure 4, offers valuable insights into the spatial distribution of TSc across the Lancang Island waters. These values, categorized at 5 dB intervals from -70 dB to -35 dB, represent the acoustic reflection intensity generated by each target in a cell, calculated as the average Target Strength value per cell. Specifically, the distribution of fish in the water column adheres to certain criteria, with the surface layer predominantly characterized by low TSc values, followed by deeper layers exhibiting higher TSc values. However, noteworthy exceptions exist, particularly in the eastern and northern regions, where some spots in the surface layer display relatively high TSc values. This indicates distinct variations in TSc values between the surface and deeper layers, suggesting a clear stratification of acoustic reflection intensity. In the depth range of 21 to 26 m (Figure 4e.), higher TSc values are found mainly in the eastern and northern parts, whereas the western side has shallower waters. Notably, in the depth range of 26 to 31 m (Figure 4f), only two integrated cells with TSc values are depicted, situated in the northern part of the survey area.

Figure 5a illustrates the results of the calculation conducted to obtain the average TSc value at each depth. These values were derived by initially calculating TS in its linear form. This result validates the previous statement indicating an increasing trend in TSc values with increasing water depth. Target Strength (TS) is pivotal in determining fish size distribution within the water column. Smaller fish generally exhibit lower TS values, whereas larger fish tend to have higher TS values (Manik, 2009). Figure 5b, derived from equation (3), illustrates that larger fish predominantly inhabit deeper water columns. Nonetheless, it's noteworthy that the standard deviation was notably higher in the surface layer compared to deeper water layers.

Based on the data presented, it can be inferred that while there is a notable standard deviation at the surface for both fish TSc values and fish size (as depicted in Figures 5a and 5b), fish in the surface layer generally exhibit smaller sizes but with a relatively wide range. In contrast, as depth increases, fish tend to be larger and exhibit less diversity. The prevalence of smaller fish near the surface may be attributed to their feeding habits, as they typically feed on plankton or other small organisms present in surface waters. Conversely, larger fish are more likely to inhabit deeper layers, where they have the ability to tolerate conditions in the deeper water column.

SV and biomass

Volume Backscattering Strength (SV) is a critical parameter in acoustics, indicating the intensity of scattering in the water column originating from various objects (Czudaj *et al*., 2021). Especially in fisheries, the observed scattering can be attributed to backscatter from various fish species. Figure 6 illustrates the average SV value associated with sub-layer depths in the waters surrounding Lancang Island, showing lower average SV values near the surface and an increasing trend with greater depth. Notably, the 5th layer (21-26 m) exhibits a significant average SV value, although with a substantial standard deviation, indicating a diverse range of SV values at this depth.

The estimation of fish biomass using acoustic methods is also highly dependent on the value of SV. This is because biomass estimation relies on SV and TS scaling techniques, which enable the derivation of fish biomass distribution throughout the water column. Figure 7 illustrates the distribution of biomass across each sub-layer, indicating higher biomass values in the deeper layers of the water column. This trend is supported by data revealing that intermediate depths have the highest target densities, further reinforced by evidence showing larger fish predominantly inhabiting these deeper regions, as indicated by higher TSc values. While the average biomass value in deeper waters increased, there was also an increase in variability. This contrasts with the biomass value near the surface, which is lower and more uniform. Although the highest average biomass was found at depths of 26-31 m, it is derived from only two cells in that sub-layer. The 21-26 m sub-layer specifically exhibits noteworthy biomass potential, with an average biomass value of 14,219.8 $g.ha^{-1}$. It's also important to admit the standard deviation accompanying this average (Figure 8), highlighting the considerable variability in biomass values within this depth range. Certain areas display high biomass values, while others demonstrate lower values. Upon closer examination of spatial distribution patterns, it becomes evident that the waters around Lancang Island, particularly its northern part, are more likely to host significant fish populations. This highlights the potential influence of geographic location on fish distribution and abundance within the study area.

Correlation analysis

The distribution pattern of fish in the water column can be analyzed by correlating it with environmental parameters in the waters of Lancang Island by extracting salinity and temperature data. In order to examine this relationship, particular emphasis was placed on the correlation between TSc and the temperature and salinity variables. Each of these parameters had a $P<0.05$, as temperature produced an R-square of 0.1027 and salinity of 0.0852. In this regard, simple linear regression analysis demonstrated that both temperature and salinity significantly influenced the distribution of TS values in Lancang waters. Figure 9 illustrates a tendency for TSc values to decrease with increasing temperature, while the opposite trend was observed with higher salinities. Based on a simple linear regression function, it is argued that temperature influenced the distribution of TSc in Lancang waters more than salinity.

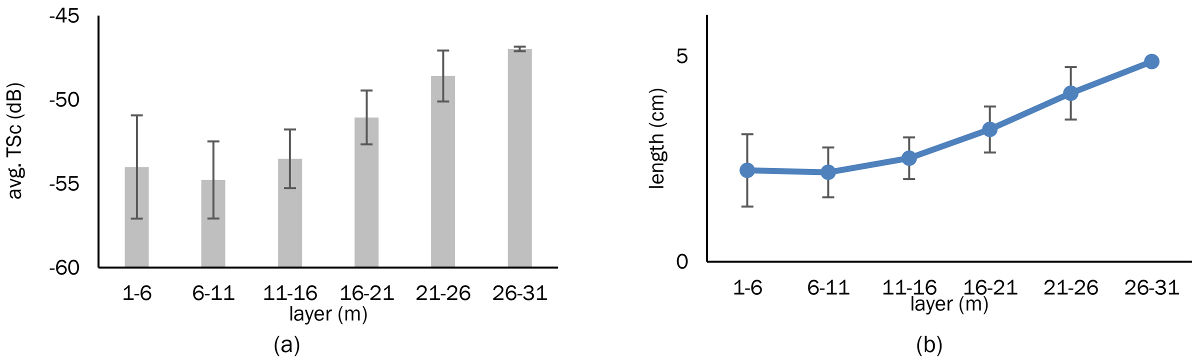


Figure 5. (a) The average value of TSc in each layer with 5-meter intervals along with the standard deviation value. (b) Fish length value obtained from fish TS-L relationship.

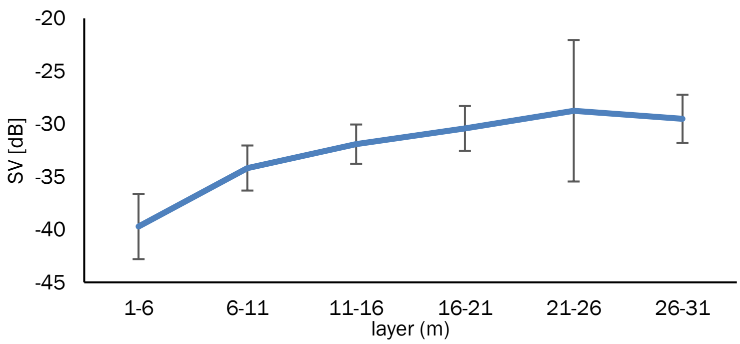


Figure 6. SV value by depth layer

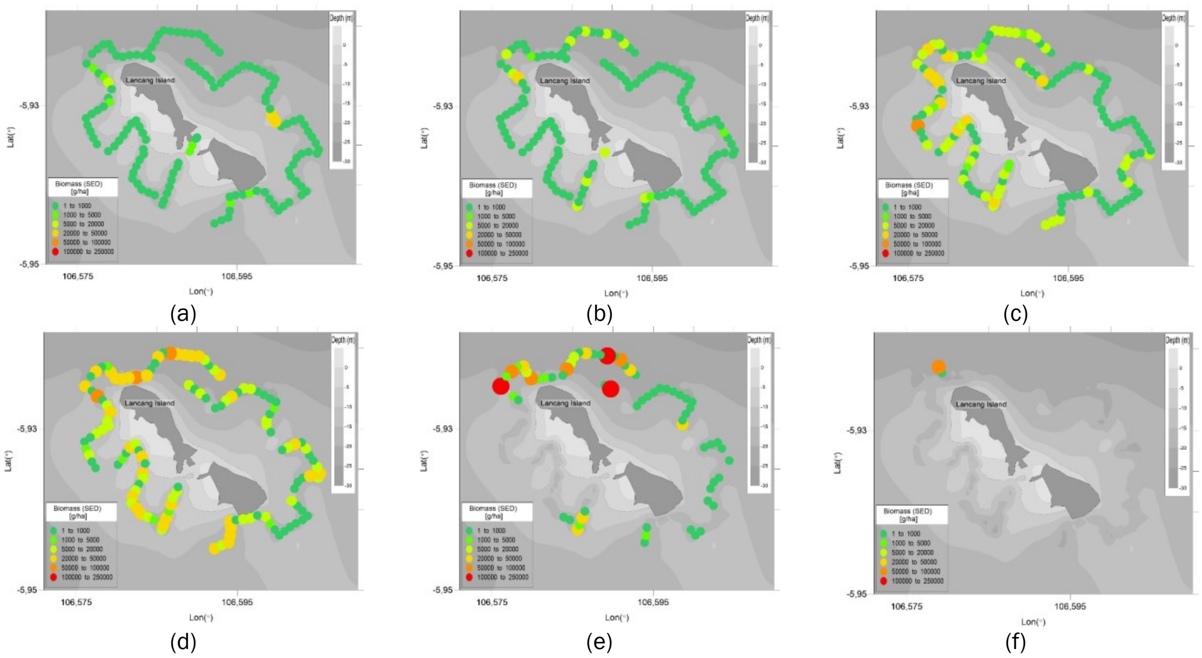


Figure 7. Spatial distribution of the biomass on every depth layer: (a) 1-6 m; (b) 6-11 m; (c) 11-16 m; (d) 16-21 m; (e) 21-26 m; (f) 26-31 m. The color scale for displaying biomass remains consistent across all depth layers.

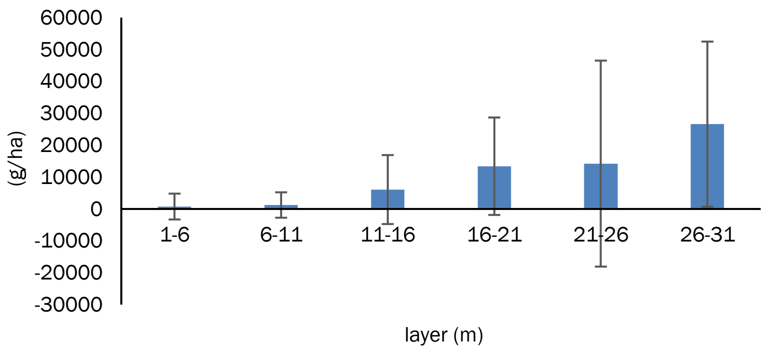
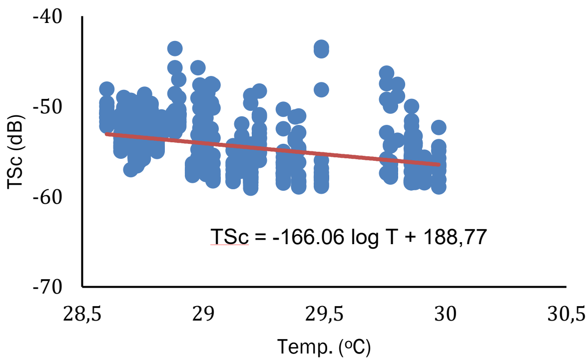
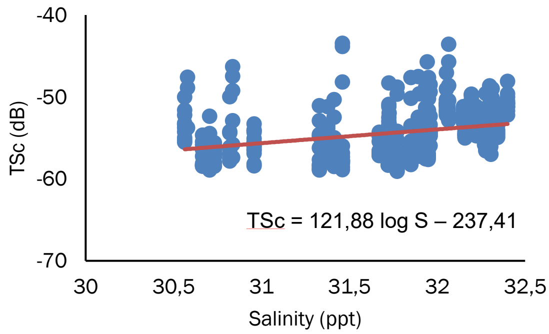


Figure 8. Average biomass (g.ha^{-1}) divided by #cells based on depth layer.



(a)



(b)

Figure 9. Oceanographic parameter relationships versus TSc values. Oceanographic parameters such as: (a) temperature, and (b) salinity, are expressed in logarithmic.

Notably, a multiple linear regression equation was employed when both parameters were included in the correlation analysis with TSc values. The resulting equation was TSc= 1582.1 - 684.2 log T - 422.6 log S, where T represents temperature and S represents salinity. Moreover, the analysis yielded a statistically significant R-square of 0.1276 with a $P<0.05$. When the two parameters were tested together, an improved R-square value of 0.1216 was obtained, surpassing the individual measurements. This indicates that the assessment of fish distribution in Lancang waters is more effectively achieved by considering both oceanographic parameters, temperature, and salinity, which jointly influence fish distribution through TSc values, rather than analyzing them separately.

The modest R-square value suggested that additional parameters were likely to have a greater influence on the distribution of fish in Lancang waters. This would certainly be quite complex and requires further analysis by considering habitat factors, for example, the condition of coral reefs in these waters or the types of seabed substrates. Considering that this area is partly composed of coral reef ecosystems, it can be speculated that some of the fish that live in this area are reef fish associated with coral reef habitats (Alvarez-Filip *et al*., 2011).

Conclusion

This study revealed distinct variations in TSc values across different depths of the water column, suggesting a clear stratification of acoustic reflection intensity. This trend aligns with biomass distribution patterns, with lower values observed at the surface and higher values in deeper layers, particularly concentrated in the northern region of Lancang Waters. Furthermore, regression analysis focusing on temperature and salinity highlights their significant influence on TSc values, emphasizing the role of environmental factors in influencing fish distribution. However, while these factors explain a portion of the variance in TSc values (as indicated by the R-square value of 0.1276), it is evident that additional unexplored factors, potentially including habitat and substrate type, may contribute to observed distribution patterns.

Acknowledgement

This research was funded by the Deputy for Strengthening Research and Development of the Ministry of Research and Technology-Agency for Research and Innovation in accordance with the 2021 Assignment Agreement for the research subject Development of Biomass Active Sonar Transducer Intelligence Algorithm for Exploration and Utilization of Maritime Resources to Principal Investigator Prof. Henry M Manik, PhD. We would like to acknowledge Sri Ratih Deswati and Muhammad Hasbi Sidqi their assistance during field data acquisition in Lancang Waters.

References

Achmadi, A., Hestirianoto, T. & Manik, H. 2014. Deteksi Schooling Ikan Pelagis Dengan Metode Hidroakustik Di Perairan Teluk Palu, Sulawesi Tengah. *J. Teknol. Perikan. Kelaut.,* 5(2): 129–137. https://doi.org/10.24319/jtpk.5.129-137

Alvarez-Filip, L., Gill, J.A. & Dulvy, N.K. 2011. Complex reef architecture supports more small-bodied fishes and longer food chains on Caribbean reefs. *Ecosphere* 2(10): 1-17. https://doi.org /10.1890/ES11-00185.1

Balk, H. and Lindem, T. 2014. *Sonar4 and Sonar5-Pro Post processing systems Operator manual version 6.0.3*. Oslo, Norway: Lindem Data Acquisition.

Czudaj, S., Koppelmann, R., Möllmann, C., Schaber, M. & Fock, H.O. 2021. Community structure of mesopelagic fishes constituting sound scattering layers in the eastern tropical North Atlantic. *J. Mar. Syst.,* 224: p.103635. https://doi.org/10.1016/j.jmarsys.2021.103635

Dwinovantyo, A., Manik, H.M., Prartono, T. & Susilohadi, S. 2017. Quantification and Analysis of Suspended Sediments Concentration Using Mobile and Static Acoustic Doppler Current Profiler Instruments. *Adv. Acoust. Vib.,* 2017(1): p.4890421 https://doi.org/10.1155/2017/4890421

Elson, L., Manik, H.M., Hestirianoto, T. & Pujiyati, S. 2022. Kuantifikasi Hambur Balik Akustik Dasar Laut Menggunakan Scientific Single Beam Echosounder. *J. IlmuTeknol. Kelaut. Tropis,* 14(1): 15–29. https://doi.org/10.29244/jitkt.v14i1.37184

Hersey, J.B. 1969. Engineering Applications of Underwater Acoustics in the Ocean. *J. Pet. Technol.*, 21(10): 1277–1284. https://doi.org/10.2118/2317-PA

Herzig, A. & Kubecka, J. 2001. Fish biomass distribution in Neusiedler See (Austria): a hydroacoustic assessment of fish stock. *Verh. Int. Ver. Theor. Angew. Limnol.,* 27(6): 3660–3665. https://doi.org/10.1080/03680770.1998.11902511

Hilborn, R., Amoroso, R.O., Anderson, C.M., Baum, J.K., Branch, T.A., Costello, C., De Moor, C.L., Faraj, A., Hively, D., Jensen, O.P. & Kurota, H. 2020. Effective fisheries management instrumental in improving fish stock status. *Proc. Natl. Acad. Sci.,* 117(4): p.201909726. https://doi.org/10.1073/pnas.1909726116

Laouar, H. & Djemali, I. 2018. Seasonal inter-calibration between acoustic and multi-mesh gillnets sampling for fish biomass assessment in reservoirs. *J. Appl. Ichthyol.,* 34(4): 850–860. https://doi.org/10.1111/jai.13696

Lee, Y.H., Kim, J.H., Lee, S. & Kim, S.B. 2021. Underwater Excavation Records Using Underwater Acoustic Survey: A Case Study in South Korea. *Appl. Sci.,* 11(19): p.4252. https://doi.org/10.3390/app11094252.

Lehodey, P., Alheit, J., Barange, M., Baumgartner, T., Beaugrand, G., Drinkwater, K., Fromentin, J.M., Hare, S.R., Ottersen, G., Perry, R.I. & Roy, C.V.D.L. 2006. Climate Variability, Fish, and Fisheries. *J. Clim.,* 19(20): 5009–5030. https://doi.org/10.1175/JCLI3898.1.

Mackenzie, K.V. 1981. Nine-term equation for sound speed in the oceans. *J. Acoust. Soc. Am.,* 70(3): 807–812. https://doi.org/10.1121/1.386920

Manik, H.M. 2009. Quantification of tuna fish target strength using quantitative echo sounder. *J. Ilmu Teknol. Kelaut. Trop.,* 1(1): 33-38. https://doi.org/10.28930/jitkt.v1i1.7936

Manik, H.M. 2012. Seabed identification and characterization using sonar. *Adv. Acoust. Vib.,* 2012(4): 1–5. https://doi.org/10.1155 /2012/532458

Manik, H.M. 2014. Teknologi Akustik Bawah Air: Solusi Data Perikanan Laut Indonesia. Risalah Kebijakan Pertanian Dan Lingkungan Rumusan Kajian Strategis Bidang Pertanian dan Lingkungan, 1(3): 181-186. https://doi.org/10.20957/jkebijakan.v1i3.10295

Manik, H.M., Furusawa, M. & Amakasu, K. 2006a. Measurement of sea bottom surface backscattering strength by quantitative echo sounder. *Fish. Sci*., 72: 503–512. https://doi.org/10.1111/j.1444-2906.2006.01178.x

Manik, H.M., Furusawa, M. & Amakasu, K. 2006b. Quantifying Sea Bottom Surface Backscattering Strength and Identifying Bottom Fish Habitat by Quantitative Echo Sounder. *Jpn. J. Appl. Phys*., 45(5S): p.4865. https://doi.org/10.1143/JJAP.45.4865

Manik, H.M. & Nurkomala, I. 2016. Measurement of Target Strength and Fish Stock in Pari Islands Seawaters Using Single Echo Detector Method. *J. Mar. Fish. Technol. Manage*., 7(1): 69-81. https://doi.org/10.29244/jmf.7.1.69-81

Manik, H.M., Syakti, A.D., Jaya, J.V., Apdillah, D., Solikin, S., Dwinovantyo, A., Fajaryanti, R., Siahaan, B.O. and Sanubari, M. 2017. Autonomous Underwater Vehicle untuk Survei dan Pemantauan Laut. *J. Rekayasa Elektrika,* 13(1): 27-34. https://doi.org/10.17529/jre.v13i1.5964

Manik, H., Sujatmiko, T.N., Ma'mun, A. & Priatna, A. 2018. Penerapan Teknologi Hidroakustik untuk Pengukuran Sebaran Spasial dan Temporal Ikan Pelagis Kecil di Laut Banda. *J. Mar. Fish. Technol. Manage.,* 9(1): 41-53. https://doi.org/10.29244/jmf.9.1.39-52

Orduna, C., Encina, L., Rodríguez-Ruiz, A. & Rodríguez-Sánchez, V. 2021. Hydroacoustics for density and biomass estimations in aquaculture ponds. *Aquaculture,* 545: p.737240. https://doi.org/10.1016/j.aquaculture.2021.737240

Peck, M., Tapilatu, R.F., Kurniati, E. & Rosado, C. 2021. Rapid coral reef assessment using 3D modelling and acoustics: Acoustic indices correlate to fish abundance, diversity and environmental indicators in West Papua, Indonesia. *PeerJ,* 9: p.10761. https://doi.org/10.7717/peerj.10761

Purnawan, S., Karina, S., Kang, M. & Manik, H. 2023. Fish Stock Status Assessment in Alue Naga Waters Using A 200 Khz Single Beam Echosounder. *Ilmu Kelautan: Indonesian J.ournal of Mar.ne Science.* 28(1): 57–68. https://doi.org/10.14710/ik.ijms.28.1.57-68

Purnomo, P.W. & Ruswahyuni, R. 2009. Kondisi Terumbu Karang Di Kepulauan Seribu Dalam Kaitan Dengan Gradasi Kualitas Perairan. *J. Imiah Perikanan Kelaut.*, 1(1): 93–102. https://doi.org/10.20473/jipk.v1i1.11704

Rivai, A.A., Siregar, V.P., Agus, S.B. & Yasuma, H. 2017. Potential Fishing Ground Mapping Based on Gis Hotspot Model and Time Series Analysis: A Case Study on Lift Net Fisheries in Seribu Island. *J. Ilmu Teknol. Kelaut. Trop.,* 9(1): 337–356. https://doi.org/10.29244/jitkt.v9i1.179 48

Sachoemar, S.I. 2008. Evaluasi Kondisi Lingkungan Perairan Kepulauan Seribu. *J. Rekayasa Lingkungan,* 4(1): 19–26. https://doi.org/10.29122/jrl.v4i1.1839

Simmonds, J. & Maclennan, D.N. 2005. Fisheries acoustics: Theory and practice. John Wiley & Sons.

Thomas, G.L. & Kirsch, J. 2000. Nekton and plankton acoustics: an overview. *Fish. Res.,* 47(2-3): 107–113. https://doi.org/10.1016/S0165-7836(00)00162-4.

Traynor, J.J. 1990. Fish and standard sphere target-strength measurements obtained with a dual-beam and split-beam echo-sounding system. *Rapp. P.-v. Réun. Cons. int. Explor. Mer.,* 189: 325–335.