ANALYSIS OF PARABOLIC EQUATION (RAMGEO) PROPAGATION MODEL IN NORTH NATUNA SEA

Agustinus[1*], Henry Munandar Manik[2], Nawanto Budi Sukoco[3], Eka Yudha Muharrom[4], Taufiq Supriyanto[5]

[1]S2 Oceanography Program, Naval Technology College (STTAL), North Jakarta, Indonesia

[2]Department of Marine Science and Technology, Faculty of Fisheries and Marine Science, Bogor Agricultural University (IPB), West Java, Indonesia

[3-4]Naval Hydro-Oceanography Center (PUSHIDROSAL), North Jakarta, Indonesia

[5]Doctoral Student, Indonesia Defense University (UNHAN RI), Jakarta Centre, Indonesia

E-mail: 1) agushanan2011.at@gmail.com, 2) henrymanik@apps.ipb.ac.id, 3) nawantobudi@yahoo.com, 4) YoEdha_EK@yahoo.com, 5) topiksupri@gmail.com

Abstract

The waters of the North Natuna Sea are one of Indonesia's conflict-prone maritime areas, frequently traversed by foreign vessels due to its direct border with several neighboring countries, necessitating effective maritime security assurance. To ensure this security, meticulous sea control and surveillance, particularly through the utilization of monitoring tools such as SONAR to detect foreign objects traversing or entering the North Natuna Sea waters, are required. This research aims to analyze the characteristics of underwater acoustic wave propagation patterns, particularly in the formation of silent areas or Shadow Zones, using the Parabolic Equation method (RAMGeo). Parabolic Equation propagation model (RAMGeo) simulations are conducted utilizing the AcTUP v2.2L Toolbox. Temperature and salinity data against depth obtained from Marine Copernicus for one year are utilized in this study, spanning from January 1, 2023, to December 31, 2023, encompassing both the west and east monsoon seasons. Sound propagation velocity calculations are based on the empirical Medwin equation, with a focus on a source depth of 10 meters at frequencies of 100 and 1,000 Hz in the North Natuna Sea. Simulation results indicate that both the west and east monsoon seasons exhibit similar and dense underwater acoustic wave propagation patterns. At a frequency of 100 Hz, the Transmission Loss ranges between 30 to 60 dB, with Shadow Zone areas extending from 0 - 500 meters and from 500 - 1,500 meters. Meanwhile, at a frequency of 1,000 Hz, the Transmission Loss ranges between 30 to 70 dB, with almost no Shadow Zone area present.

Keywords: *North Natuna Sea Waters, SONAR, Parabolic Equation Propagation Model (RAMGeo), Transmission Loss*

1. INTRODUCTION

The North Natuna Sea is a region with tremendous potential located in Southeast Asia. It holds abundant natural resources and minerals beneficial for the surrounding countries (Novianto et al., 2020). Additionally, the North Natuna Sea plays a vital role in trade distribution routes and international shipping (Adikara et al., 2021), making it vulnerable to maritime security threats.

The climate of the North Natuna Sea is influenced by the Australian-Asian Monsoon (Ilahude, 1997) or monsoon winds. These monsoon winds are categorized into the West Monsoon and East Monsoon. The West Monsoon blows from December to February, while the East Monsoon blows from June to August (Fadika et al, 2014;

Hidayat et al, 2015). The peak of the West and East Monsoons occurs in January and July, respectively (Sudarto, 2011; Triadmodjo, 1999).

The presence of the West and East Monsoons undoubtedly affects the characteristics of water masses in the North Natuna Sea, especially its temperature and salinity, which are crucial data for underwater acoustic technology like SONAR. SONAR can be used to track submarines and foreign underwater acoustic equipment infiltrating Indonesian territorial waters through the North Natuna Sea. Submarine infiltrations and foreign underwater acoustic equipment often exploit areas of silent propagation of underwater acoustic waves known as Shadow Zones (Agustinus et al, 2016). These zones are where the temperature and salinity of seawater bend incoming sound waves, allowing submarines and foreign underwater acoustic equipment to evade detection by enemy SONAR. One way to anticipate this is through simulation of underwater acoustic wave propagation patterns.

Simulation of underwater acoustic wave propagation patterns can show the shape of the propagating waves at a location so that it can be known what water conditions and phenomena occur in these waters (Lalita et al, 2024). Simulation of underwater acoustic wave propagation patterns is an efficient way to parametrically investigate and hypothesise sonar performance under various environmental conditions (Etter, 2003). Environmental conditions include information on the speed of sound and the density corresponding to its depth.

Underwater acoustic wave propagation is the process of transmitting acoustic signals through a water medium. The ocean, along with its materials and boundaries, forms a complex medium for the propagation of underwater acoustic waves. The physical features of the ocean, such as its surface and seabed, influence the propagation of acoustic energy underwater. This is because the ocean's surface and seabed can reflect, scatter, and absorb energy from the acoustic signals passing through them, ultimately resulting in transmission loss and the formation of Shadow Zones. According to OS Suharyo (2018), transmission loss above 90 dB or 40% of the source level (SL) is designated as a shadow zone.

One method of underwater acoustic wave propagation is the Parabolic Equation Method (RAMGeo). The Parabolic Equation Method (RAMGeo) is one of the methods for underwater acoustic wave propagation that utilizes the split-step Padé algorithm (RAM) to achieve high efficiency and the ability to model underwater acoustic wave propagation at large horizontal angles (Collins, 1993).

There is a compromise between angle range and calculation speed set by the number of terms described by the user for the Padé approximation - the more terms, the wider the angle, but the longer the execution time. RAM implementation is also included in AcTUP (Duncan & Maggi, 2006), which includes RAMGeo for fluid seabeds and RAMSGeo for elastic seabeds.

This research is a preliminary study to analyze underwater acoustic wave propagation using the Parabolic Equation Method (RAMGeo), focusing on Transmission Loss and Shadow Zone areas in the North Natuna Sea at a source depth of 10 meters with frequencies of 100 Hz and 1000 Hz during the West and East Monsoons. This analysis is based on temperature and salinity data from Marine Copernicus for one year, with depths reaching up to 541 meters.

2. RESEARCH METHODS

2.1. Research Location and Time

The research approach used is quantitative, the type of research used is modelling and computational research using matlab software. This research only simulates acoustic wave propagation in the surface layer area and is based on secondary data from Marine Copernicus through the website https://data.marine.copernicus.eu/, which includes oceanographic data such as temperature and salinity for one year starting from 1 January 2023, until 31 December 2023, covering the west season and east season. The research location will be focused on the North Natuna Sea (Figure 1).

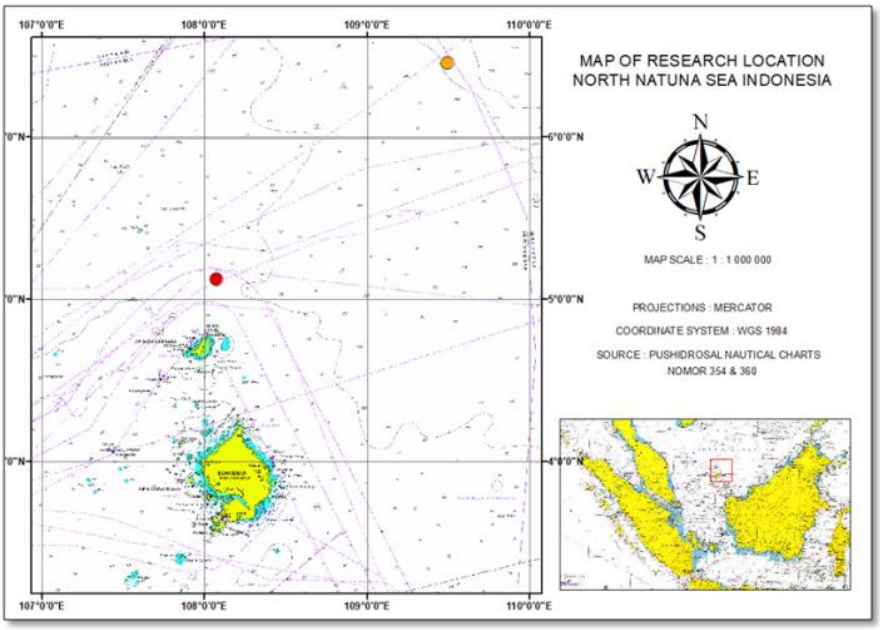

Figure 1. Map of the research location

2.2. Tools and Materials

The tool used in this research is a laptop with the data used including secondary data including temperature and salinity data. Data requirements for the Parabolic Equation (RAMGeo) method are as follows: acoustic properties (depth, sound velocity and density), Code-Independent Propagation Parameters (frequency, source depth and minimum and maximum distance) and Code-Dependent Propagation Parameters (depth resolution number of terms in pade expansion, reference phase velocity). The software used for this research are: Arcmap 10.8, Matlab R2016a toolbox AcTUP (Acoustic Toolbox User-Interface and Post- Processor), Microsoft Office 2010.

2.3. Research Procedure

Temperature and salinity data were used to obtain sound velocity profile (SVP) values using Medwin's empirical equation (Medwin, H, 1975), where the empirical medwin equation has the smallest error value with direct observation sound velocity data at the surrounding karimata strait location (Aulia Yoga Maharddika, 2013). According to Urick (1983), the empirical equation for sound velocity profile is divided into three parts, one of which is Medwin's empirical equation, $c = 1449.2 + 4.6 \times T$ - 5.5

× 10-2T 2 + 2.9 × 10-4T 3 + (1.34 - 10-2T) × (S - 35) + 1.6 × 10-2z, with the following restrictions:

$0 \leq T \leq 35°C$ (in Celsius)
$0 \leq S \leq 45‰$
$0 \leq z \leq 1000$ metres

From the sound velocity data used to obtain underwater acoustic wave propagation patterns with the Parabolic Equation (RAMGeo) method. This propagation pattern uses MATLAB toolbox Actup v.2.2L. To run the MATLAB toolbox Actup v.2.2L simulation toolbox, first done by creating an environment followed by entering values in the code dependent and code independent sections. When all the data has been entered, the pattern simulation is performed by running the run propagation function. The underwater acoustic wave propagation pattern will determine the Transmission Loss value and Shadow Zone area in the North Natuna Sea location, as illustrated in the research flow chart (Figure 2).

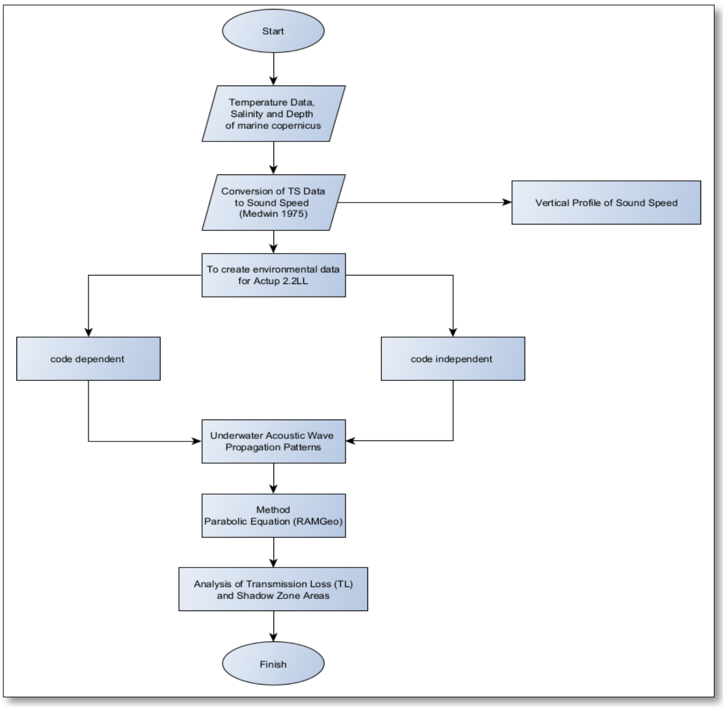

Figure 2. Research Flowchart

2.4. Data Analysis

Data analysis of Temperature, Salinity and Sound Velocity was conducted using Ocean Data View (ODV) software (R Schlitzer, 2022) and Ms Excel. The data were displayed in underwater acoustic wave propagation patterns with the Parabolic Equation (RAMGeo) method in the North Natuna Sea at depths reaching 541 metres in the west season and east season using MATLAB toolbox Actup v.2.2L.

3. RESULTS AND DISCUSSION

In the simulations conducted at the Research Station with a depth of 541 metres, frequency limits in the range of 100 Hz to 1000 Hz were chosen to understand the differences in acoustic wave propagation patterns. Lower frequencies have larger wavelengths and can penetrate deeper depths, while higher frequencies have shorter wavelengths and can experience faster reflection or diffraction by underwater obstructions. This is because attenuation in water increases with frequency. High-frequency sound waves experience greater absorption and scattering, resulting in higher transmission losses in shallow water (Lalita et al, 2024).

Using a transducer depth of 10 metres, simulations were conducted for the west and east seasons. Seasonal differences cause differences in salinity and water temperature values. Salinity and temperature along with depth affect the speed of sound (Winanta et al, 2015) that propagates in a body of water (Supiyati and S. Romauli, 2016) which in this case is also called underwater acoustic wave speed. Underwater acoustic wave speeds in the west and east seasons are influenced by factors such as wind direction, water temperature and local geographical characteristics. Therefore, considering both seasons provides a more thorough understanding of the dynamics of the underwater acoustic environment at the site.

Simulation results obtained from the Parabolic Equation Method (RAMGeo) provide an in-depth visualisation of how sound waves propagate beneath the water surface at different frequencies and changing seasonal conditions. This data can be used for a variety of applications, including underwater navigation, underwater object detection, and understanding marine ecology. The images generated from these simulations, Figures 3, 4, 5 and 6, provide visual information showing the differences in acoustic wave propagation patterns between the two frequencies and seasons.

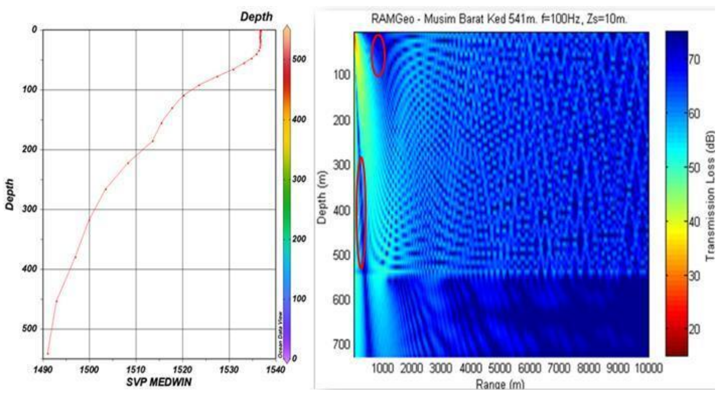

Figure 3. Underwater Acoustic Wave Propagation Pattern at 100 Hz frequency during the west monsoon season

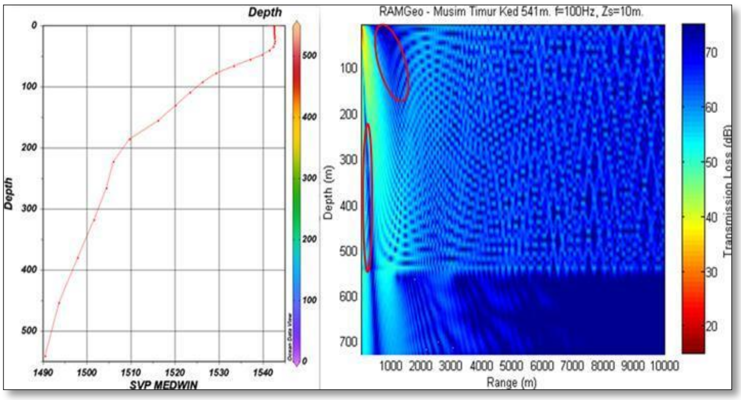

Figure 4. Underwater Acoustic Wave Propagation Pattern at 100 Hz frequency during the east monsoon season

Figure 3 and Figure 4 are the results of Matlab Actup 2.2vL simulations in the form of Underwater Acoustic Wave Propagation Pattern of Parabolic Equation Method (RAMGeo) with a frequency of 100 Hz in the deep waters of the North Natuna Sea in the west and east seasons. The results obtained are similar between the west and east seasons, the value of transmission energy loss (Transmission Loss) increases with increasing distance and depth. In underwater acoustic wave propagation, the value of transmission energy loss is quite large reaching 70 dB and above. At a distance of 0 - 1,000 metres the Transmission Loss value is quite small around 30 - 50 dB at a depth of 0 - 541 metres and a distance of 1,000 - 10,000 metres the Transmission Loss value increases to around 50 - 75 dB at a depth of 0 - 541 metres, underwater acoustic wave propagation begins to weaken, this can be seen from the Transmission Loss value which is getting closer to 70 - 80 dB. Shadow Zone areas (red circles) are formed between underwater acoustic wave propagation, including at a distance of 0 - 1,000 metres at a depth of 0 - 100 metres and a distance of 0 - 500 metres at a depth of 300 - 541 metres.

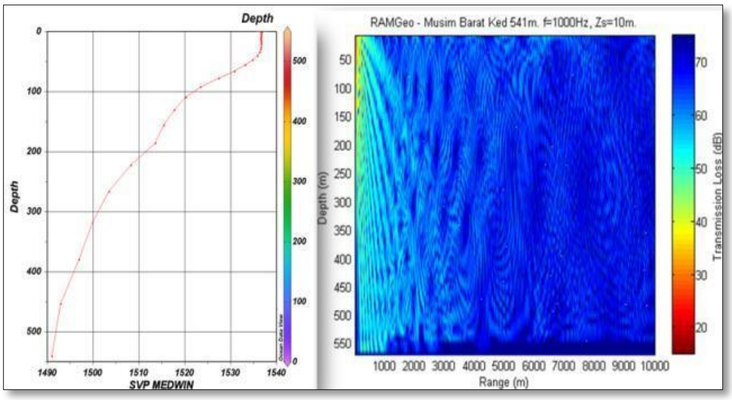

Figure 5. Underwater Acoustic Wave Propagation Pattern at 1.000 Hz frequency during the west monsoon season

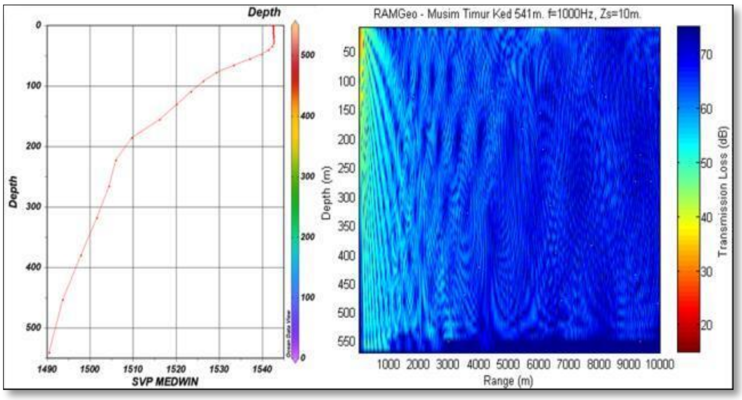

Figure 6. Underwater Acoustic Wave Propagation Pattern at 1.000 Hz frequency during the east monsoon season

In Figure 5 and Figure 6 are the results of Matlab Actup 2.2vL simulations in the form of Underwater Acoustic Wave Propagation Patterns Parabolic Equation Method (RAMGeo) with a frequency of 1000 Hz in the deep waters of the North Natuna Sea in the west and east seasons. The results obtained are almost the same between the west and east seasons, the value of transmission energy losses (Transmission Loss) is quite large reaching 70 dB and above. At a distance of 0 - 3,000 metres the Transmission Loss value is quite small ranging from 30 - 50 dB at a depth of 0 - 541 metres and a distance of 3,000 - 10,000 metres the Transmission Loss value increases ranging from 50 - 75 dB at a depth of 0 - 541 metres, underwater acoustic wave propagation begins to weaken, this can be seen from the Transmission Loss value which is getting closer to 70 - 80 dB. The Shadow Zone area in this simulation is almost no maximum distance specified which is as far as 10,000 metres or 6.2 miles from the acoustic source, this is because the acoustic wave energy propagates evenly throughout the propagation area.

The simulation results of underwater acoustic wave propagation patterns using the Parabolic Equation method (RAMGeo) at a depth of 541 metres in Figures 3, 4, 5 and 6 show that there are differences in transmission losses at frequency. Frequency is one of the factors that cause the accumulation of attenuation when acoustic waves propagate (Irwan and Syam, 2013). At frequencies of 100 Hz and 1000 Hz the value of transmission energy loss (Transmission Loss) increases with distance and depth. The underwater acoustic wave propagation pattern in this method is very tight and long, with the propagation distance reaching about 10 km or 6.2 miles from the acoustic source. In underwater acoustic wave propagation, the value of transmission energy losses is quite large, reaching 70 dB and above. According to OS Suharyo (2018) transmission energy loss (Transmission Loss) above 90 dB or 40% of the Source Level (SL) is designated as a silent area (Shadow zone) and from the results of Wu's research (2022) also shows that the silent area (Shadow zone) with a transmission energy loss value (Transmission Loss) above 80 dB.

At a frequency of 100 Hz with a distance of 0 - 1,000 metres the Transmission Loss value is quite small around 30 - 50 dB at a depth of 0 - 541 metres and a distance of 1,000 - 10,000 metres the Transmission Loss value increases around 50 - 75 dB at a depth of 0 - 541 metres while at a frequency of 1000 Hz the transmission energy loss value is quite large reaching 70 dB and above. At a distance of 0 - 3,000 metres the Transmission Loss value is quite small around 30 - 55 dB at a depth of 0 - 541 metres and a distance of 3,000 - 10,000 metres the Transmission Loss value increases around 50 - 75 dB at a depth of 0 - 541 metres, underwater acoustic wave propagation begins to weaken, this can be seen from the Transmission Loss value which is getting closer to 70 - 80 dB and increases with depth (Pravitasari D, 2010).

For the Shadow Zone area (red circle) at a frequency of 100 Hz is formed between the underwater acoustic wave propagation, including at a distance of 0 - 1,000 metres at a depth of 0 - 100 metres and a distance of 0 - 500 metres at a depth of 300 - 541 metres while at a frequency of 1000 Hz the Shadow Zone area is almost non-existent because the acoustic wave energy that propagates evenly fills the entire propagation area to a maximum distance of 10,000 metres or 6.2 miles from the acoustic source.

4. CONCLUSION

Simulation results of underwater acoustic wave propagation patterns using the Parabolic Equation method (RAMGeo) at a depth of 541 metres show that the propagation patterns between the west and east seasons are similar, but there are differences in relative frequency changes. At a frequency of 100 Hz, Transmission Loss ranges from 30 to 50 dB at a distance of 0-1,000 metres and increases to 50 to 75 dB at a distance of 1,000-10,000 metres. At 1000 Hz, the transmission loss ranges from 30 to 55 dB at a distance of 0-3,000 metres and increases to 50 to 75 dB at a distance of 3,000-10,000 metres. This indicates a weakening of acoustic wave propagation with Transmission Loss values approaching 70 to 80 dB at a maximum distance of 10,000 metres. Shadow Zones are formed slightly at a frequency of 100 Hz, while at a frequency of 1000 Hz, energy propagation is more evenly distributed and Shadow Zones are almost not formed.

REFERENCES

Adikara, A. P. B., Zuhdi, M. L., & Purwanto, W. H. (2021). Analysis of intelligence mobilization methods in the implementation of the deradicalization program by BNPT. Sociology: Journal of Social Sciences, 18(1), 61-71.

Agustinus, W.S. Pranowo, H.M. Manik, A. Rahmatullah, T. Aji. (2023). Relationship between water mass characteristics to sound velocity profiler (SVP) from South China Sea and Indonesian Throughflow Currents in Sulawesi Sea.. Depik Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan, 12(3): 346-353.

Agustinus. (2016). Study on Water Mass Characteristics to Determine the Shadow Zone in the Makassar Strait. J. Chart Datum, 2(2) : 69-78.

Badihi, F. A. (2021). Description of Sound Speed and Movement of Acoustic Waves in the Makassar Strait. 1–45.

Collins, M. D. (1993). A split-step Pade solution for the parabolic equation method, J. Acoust. Soc. Am., 93, 1936-1942.

Defrianto., & Pratama, N. (2019). Determination of the shadow zone area in the ocean computationally by simulating the propagation of acoustic rays. Proceedings of SNFUR-4, 1(1), 1-5.

Duncan, A. J., & Maggi, A. L. (2006). A consistent, user friendly interface for running a variety of underwater acoustic propagation codes. *Proceedings of ACOUSTICS 2006*, (20-22), 471-477.

Etter P.C. (2003). Underwater Acoustic Modelling and Simulation. London. CRC Press.

Fadika, U., Rifai, A., & Rochaddi, B. (2014). The direction and speed of seasonal winds and their relationship with the distribution of sea surface temperature in the south of Pangandaran, West Java. Journal of Oceanography, 3(3), 429-437. Retrieved from https://ejournal3.undip.ac.id/index.php/joce/article/view/5881.

Harianto, P. A., W, T. E., & Yumm, R. H. (2020). The influence of environmental conditions on the ability of kri sonar to detect underwater contact. Journal of Marine: Indonesian Journal of Marine Science and Technology, 13(1), 1–10. https://doi.org/10.21107/jk.v13i1.5845

Hidayat, R., Subardjo, P., Ismanto, A., Department,), Marine, I., & Fisheries, F. (2015). Sea surface temperature variability on the north coast of Semarang using Fashionable Aqua satellite imagery. Journal of Oceanography, 4(1), 166–170. http://ejournal-s1.undip.ac.id/index.php/jose

Hutabarat, S., & Evans, S. M. (1985). Introduction to oceanography. *Universitas Indonesia. Jakarta*.

Ilahude, A. G. (1997). Distribution of temperature, salinity, sigma-T and nutrients in the waters of the South China Sea. In:Suyarso (ed.). Oceanographic atlas of the South China Sea. Center for Oceanology Research and Development, LIPI Jakarta. pp.: 25-34.

Irwan, Y., & Syam, I. I. (2013). Pengujian Transmission Loss pada Papan Serat Sabut Kelapa dan Aluminium Hollow Bar dengan Matriks Gypsum. *Rekayasa dan Aplikasi Teknik Mesin di Industri Teknik, ITENAS, Bandung*.

Jensen, F.B., W.A. Kuperman, M. B. Porter, H. Schmidt. (1994). Computational Ocean Acoustics. AIP Press. New York.

Lalita, R. K., Manik, H. M., & Brojonegoro, I. S. (2024). Underwater Acoustic Propagation using Monterey-Miami Parabolic Equation in Shallow Water Kayeli Bay Buru Distric. Journal of Applied Geospatial Information, 7(2), 1086–1091. https://doi.org/10.30871/jagi.v7i2.2802.

Mahardhika, A. Y., & Brodjonegoro, I. S. (2013). Modeling the mapping of the location of the shadow zone with. International Conference for Environmental Research and Technology, 1–18.

Medwin, H. (1975). Speed of sound in water: a simple equation forrealistic parameter. Journal of the Acoustical Society of America 58: 1318-19.

Novianto, R. D., Firmansyah, D. A., & Pratama, N. A. (2020). Dispute Resolution in the North Natuna Sea. 3. 3, 69-78.

Pravitasari, D. D. (2010). Analysis of the Kraken Propagation Model on Underwater Acoustic Signal Transmission. Thesis. Sepuluh Nopember Institute of Technology. Surabaya.

Romauli, S. and N. (2016). Sound Propagation in Water in Bengkulu Sea Waters Using the ODE (Ordinary Differential Equation) Model. SYMMETRY, Indonesian Journal of Physical Sciences, 2, 63–67.

Schlitzer, R., Schlitzer, Reiner. (2022). Ocean Data View. Software.

Sudarto. (2011). Utilization and Development of Wind Energy for Salt Production Process in Eastern Indonesia. Triton Journal, 7(2), 61–70.

Suharyo, O. S., Adrianto, D., & Hidayah, Z. (2018). Pengaruh Pergerakan Massa Air Dan Distribusi Parameter Temperatur, Salinitas Dan Kecepatan Suara Pada Komunikasi Kapal Selam. *Jurnal Kelautan: Indonesian Journal of Marine Science and Technology*, *11*(2), 104-112.

Supiyati, S Romauli N. (2016). Sound propagation in water in the waters of the Bengkulu Sea uses the ODE (Ordinary Differential Equation) model. SYMMETRY, Indonesian Journal of Physical Sciences. 2(2): 63-67.

Wijaya, T. H. (2010). Analysis of Bellhop Propagation Model on Underwater Acoustic Signal Transmission. Thesis. Sepuluh Nopember Institute of Technology. Surabaya.

Triatmodjo, B. (1999). Teknik Pantai. Yogyakarta: Beta Offset Publisher.

Urick, R.J. (1983). Principles of Underwater Sound. 3rd edition. New York: Peninsula Publishing.

Winanta, J., Kuswardani, A. R. T. D., Setiadi, H., & Riyadi, N. (2015). Thermoclin Layer Study to Determine Sound Wave Propagation Patterns. Journal of Chart Datum, 1(2), 143–150. https://doi.org/10.37875/chartdatum.v1i2.112.

Wu, S., Li, Z., Qin, J., Wang, M., & Li, W. (2022). The Effects of Sound Speed Profile to the Convergence Zone in Deep Water. Journal of Marine Science and Engineering, 10(3). https://doi.org/10.3390/jmse10030424

Copyrights