STUDY ON DOPPLER EFFECT BASED ON FREQUENCY AND VELOCITY OF SOUND SOURCE IN THE WATERS

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ABSTRACT

The Doppler effect is an important factor in studying marine resources using hydroacoustic technology. Several factors that influence the Doppler effect in waters are the frequency and velocity of the sound source. This research aimed to study the characteristics of sound received based on the frequency and velocity of the sound source as a representation of the Doppler effect. The research was designed using 5 lines as a variation in frequency (1000 and 5000 Hz) and velocity of sound source. The result showed that the Doppler effect was determined by changes in frequency, but was not significantly measured by changes in sound intensity. The frequency of the sound was increased as the frequency of the sound source increased. The receiver frequency also be higher if the angle between the receiver and the sound source was smaller or if the sound source was further away from the receiver.

Keywords: *Doppler Effect; Frequency; Sound Speed*

INTRODUCTION

The enormous potential of marine resources in Indonesia requires adequate exploration technology to be optimized. Hydroacoustic technology has an important role in exploring the existence of underwater objects (Setiyatmoko, 2020). Target detection using this method is carried out by sound waves and their propagation in the water medium using acoustic instruments. Several types of acoustic applications in the marine field are mapping sea depth (bathymetry), studying marine ecosystems, describing bottom water substrates, estimating fish density and biomass, and detecting sound pollution (Anderson, 2007). Hydroacoustic utilizes transducer equipment that can convert electrical energy into mechanical energy and vice versa, so that it can emit and receive sound reflections (Urick, 1996).

The application of acoustic technology as an underwater communication medium has high complexity both in terms of sound transmission and signal processing. There are several factors that influence this condition, including absorption, attenuation, delay spread, multipath, noise, and Doppler shift (Fedosov et al., 2017). In both active and passive acoustic systems, the phenomena that occur with sound when it is propagated are very important to be study so that this method can be applied in marine resource exploration. One example of its application is the detection and observation of fish resources by utilizing the Doppler effect (MacLennan and Simmonds, 2005). Several instruments have optimized the symptoms of the Doppler effect, and one of them is the ADCP (Acoustic Doppler Current Profiler). ADCP applies the Doppler effect by transmitting sound at a fixed frequency and analyzing echoes from sound generating sources in waters (Gordon, 2011).

The Doppler effect is the impact of changes in the frequency of acoustic waves emitted by the source and detected by the receiver due to the movement of either the transmitter, receiver or both (Razi et al., 1995). In underwater acoustic technology, the Doppler effect can disrupt underwater communications. The occurrence of frequency changes in underwater communication channels is one of the impacts of the Doppler effect which causes communication systems to become difficult (Lee-Leon et al., 2019). This condition is greatly influenced by the relative speed between the sound source and the receiver. As the sound source approaches the receiver, the intensity will increase but the frequency will remain constant. Conversely, when the sound source moves away, the intensity and frequency will change because there is a delay in sound transmission from the source to the receiver (Serway and Jewett, 2008).

The very important influence of the Doppler effect on hydroacoustic applications has not been followed by many studies regarding this theme. Changes in intensity and frequency based on the distance between the sound source and receiver due to the Doppler effect are important in studying underwater acoustics, so this phenomenon is the focus of this research.

METHODS

The research using the field observation method to study the changes in intensity and frequency based on the distance between the sound source and the receiver was conducted in July 2022. This research was carried out by simulating ships movement on different trajectories in the waters of Ketapang Beach, Pemalang Regency. The hydrophone as a sound recorder at the receiving position was placed at 109°33'05.6" E and 6°49'13,7" S (Figure 1).

Omnidirectional hydrophone (Sea Phone SQ26-08; sensitivity -194 dB re 1 V.µPa-1, 20 Hz to 45 kHz flat response, and 25 dB gain) was deployed at a depth of 1.5 meters below the water surface and connected to a sound recorder. Sound sources with various frequencies were transmitted using underwater speakers that were installed on the ship at a depth of 1.5 meters. The ship (equipped with GPS) was operated to transverse 5 (five) lines which designed to vary the distance between the sound source and the receiver (Figure 1). The transmitted sound frequencies were 1 and 5 kHz with the sound source moving according to the trajectory. The sound was received by the receiver at a fixed position and stored in *.WAV format. The ship's movements were recorded using an HD CCTV camera (1080 MP) which was synchronized with the time on the GPS and hydrophone (Figure 2).

The intensity and frequency of sound at the receiver were determined using envelope and power spectral density (PSD) analysis. Sounds S(t) were recorded in volts and then converted to pressure, P(t) in µPa based on the time-domain (t). This was conducted using the following equation $P(t) = S(t) \times 10^{\frac{-G}{20}} \times D \times 10^{\frac{-SH}{20}}$, and *RL* (*t*) in dB re 1 µPa $= 20\log P(t)$, where *G* (dB) is the recorder gain (here *G* = 25 dB), *D* is a constant for the dynamic response of the recorder (1.4 V for this model) and *SH* is the sensitivity of the hydrophone (Amron et al., 2022). The recorded data was filtered using a high pass filter and noise reduction. In addition, the pattern of changes in intensity based on time recording for each vessel was analyzed from the power spectra density (PSD).

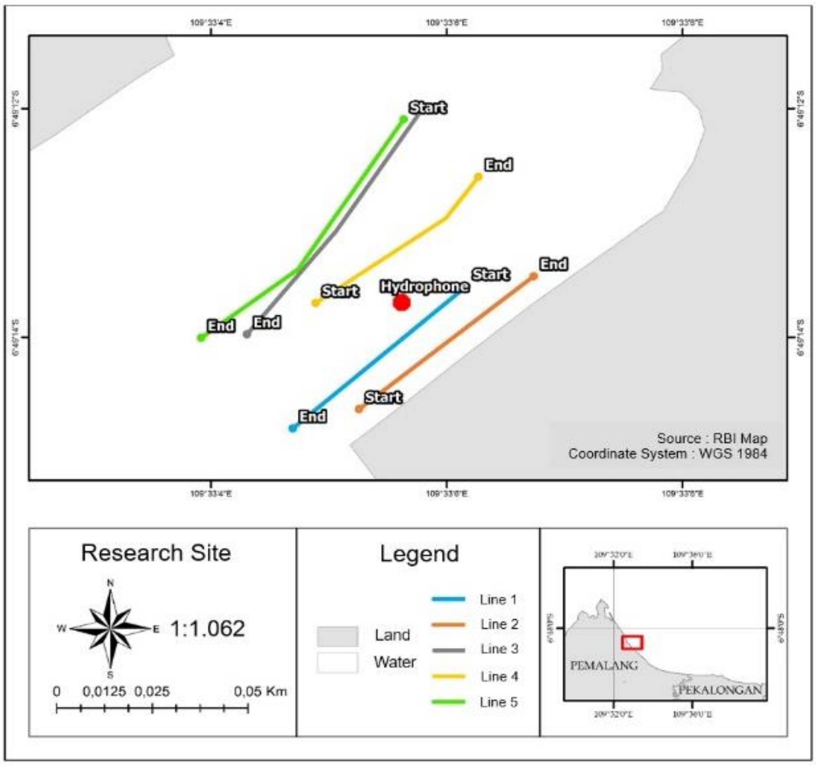

Figure 1. Research Site (The color of line represents the difference in frequency and velocity of the sound source)

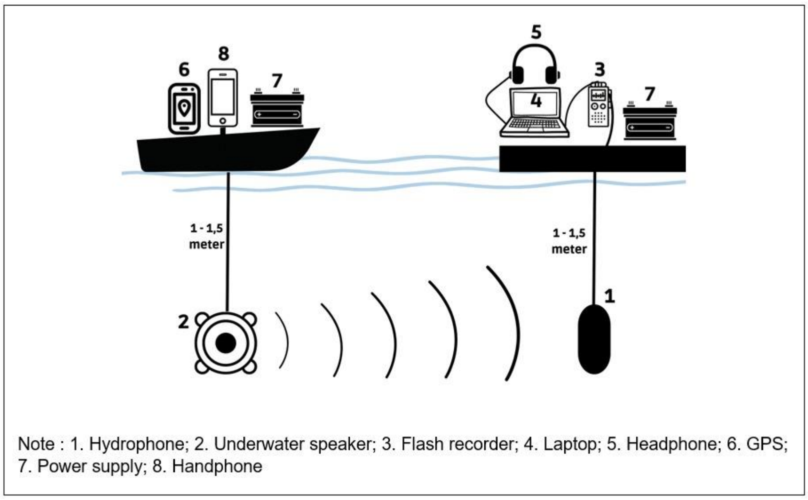

Figure 2. Research Layout (Numerical notation represents the position of the instrument)

In this study, the receiver position was stationary, and the source was moving along a trajectory line with an invariant angle relative to the *x* axis. This line made the variable angles with the source and receiver. The source moves along an angle to the *x* axis, the frequency received by the receiver (f_r) in Hz was calculated using the following formula $f_r = \frac{c}{c - V_s \cos(\propto)} \times f_s$, where $v_s = \frac{\Delta_d}{\Delta_t}$ is sound speed (m.s-$_1$), f_s is sound frequency of source (Hz), Δd dan Δt are the changes in distance (m) and time (s) (Ahmad et al., 2018). The pattern of changes in intensity and frequency based on the distance for each source frequency were analyzed by simple linear regression.

RESULTS AND DISCUSSION

Characteristics of the sound received based on the frequency and velocity of the sound source

The sound intensity received by the receiver was seen different in both quantity and pattern of change based on the distance as a representation of the travel time of the source movement for each line (Figure 3). In general, the sound intensity received from a source changed over time as a representation of distance (Figure 3 right). The sound intensity increases as the sound source approaches the receiver and then decreases thereafter. This pattern was closely related to the distance between the sound source and the receiver. If the distance to the sound source was closer, the intensity will also be higher, and vice versa. Even though they have the same pattern, differences in intensity at source level (SL) and path distance to the receiver position caused differences in sound pressure level (SPL) and its changes. The speed of movement of the sound source also influenced the pattern of decreasing sound intensity received, where relatively rapid changes in sound intensity occur when the movement of the sound source is faster.

The intensity of the sound received decreases due to changes in propagation distance (Halliday et al., 2017; McKenna et al., 2012). The decrease in intensity for each frequency is the amount of transmission loss (TL) which is greatly influenced by the absorption coefficient and beam spreading (Amron, et al, 2021). This parameter is closely related to the frequency of sound sources and aquatic media (such as temperature, salinity and depth) (Krishnaswamy and Manvi, 2015). A high frequency will have a high impact on changes because the absorption coefficient also increases. Meanwhile, another factor that influences TL is beam spreading, where the sound source propagates omni-directionally (Etter, 2018).

In contrast to the sound intensity, the received frequency increased when the sound source moves closer to the receiver. This was illustrated by the changes in the receive frequency based on the travel time from the sound source as a representation of the distance between sound source and receiver (Figure 3 left). Differences in frequency and velocity of the sound source greatly influenced the receive frequency and its changes. The source frequency in lines 1, 3 and 5 of 1 kHz caused the received frequency to also approach the source frequency with a linear change in relative distance (Figures 3A, 3C and 3E). The received frequency seen significantly different on lines 2 and 4 because the source frequency was 5 kHz (Figures 3B and 3D). Even though the frequencies received were different, there were similarities in the decreasing pattern based on the distance. Therefore, variations in source frequency influence differences in receiver frequency and change patterns. The frequency increases due to changes in the position of the sound source when moving (Fillinger et al., 2011; Sutin et al., 2010), because of the Doppler effect (Ahmad et al., 2018; Amron et al, 2021).

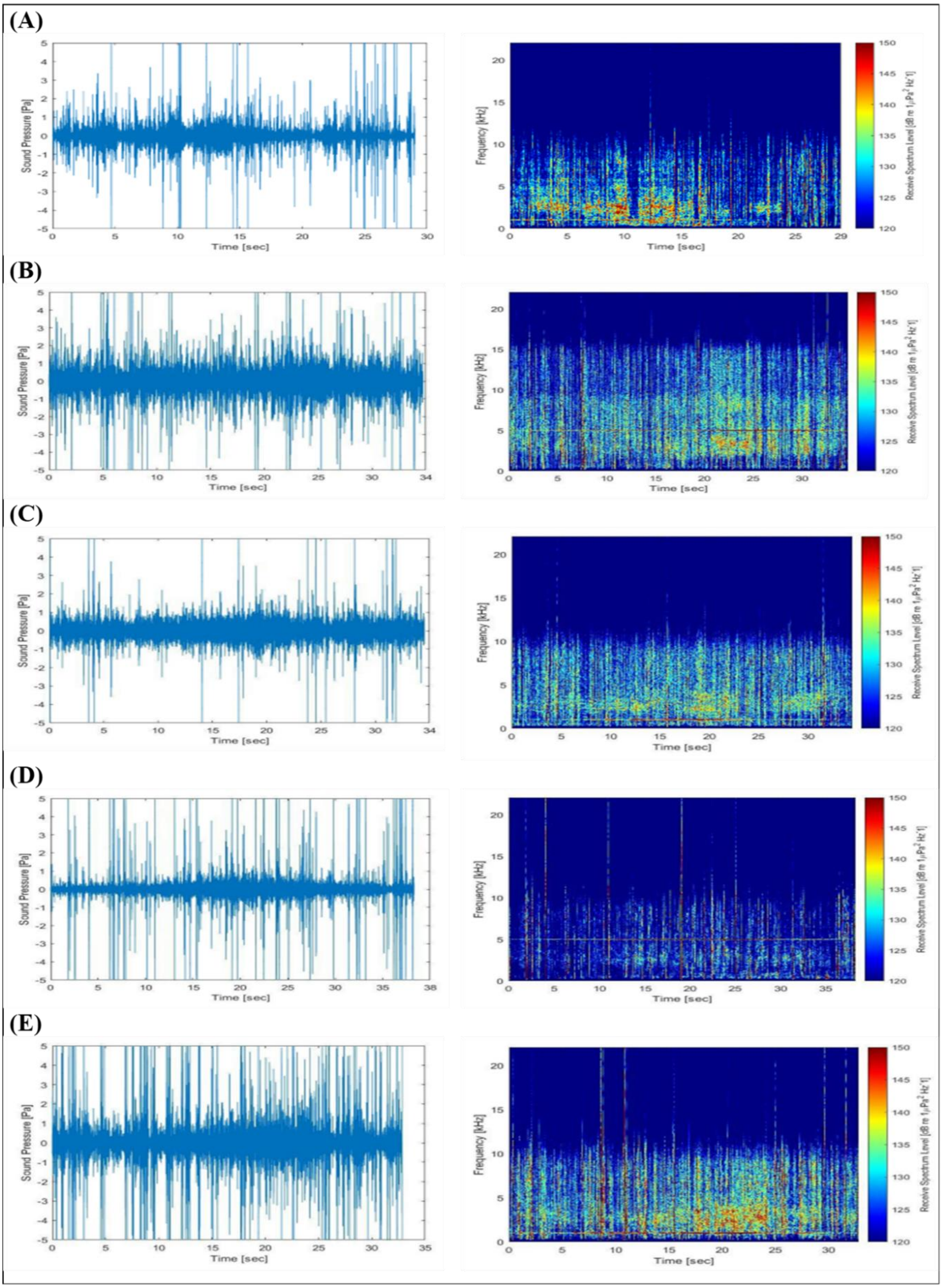

Figure 3. Characteristics of Sound Received. (A - E) represents the intensity (left) and frequency (right) of each line (1 – 5)

The changes in intensity and frequency as a representation of the doppler effect

The changes in the intensity and frequency of sound received because of the movement of the sound source were indicators for studying the Doppler effect in waters. The received sound intensity and its trend (time and distance domain) varied based on the frequency and speed of the sound source (Figure 4). Figure 4A shown that different source frequencies for each track apparently had an impact on the sound pressure level (SPL) and its decline pattern. A higher sound source frequency caused the received sound intensity to be lower and the pattern of decline was relatively faster based on increasing the distance. The magnitude of the SPL was not only influenced by the frequency of the source, because the intensity of the sound source and distance were more dominant in influencing this phenomenon.

Meanwhile, the changes in sound intensity trends were very clearly seen as an impact of the sound source movement (Figure 4B). The higher the velocity of sound source movement, the greater the decrease in sound intensity. On line 1, a higher sound source speed caused a faster decrease in sound intensity. The opposite happened on line 5, the relatively slow speed of the sound source resulted in a slow decrease in sound intensity as well. This fact indicated that the Doppler effect as an impact of the sound source movement cannot be represented by the changes in the intensity of the sound received. Or in other terms, the Doppler effect did not affect the sound intensity at the receiving point and its change pattern.

The changes in sound intensity which were a function of changes in distance due to speed, frequency, and intensity of the sound source can be explained from changes in transmission loss because of these parameters. The higher the sound intensity, the closer the sound source was to the receiver (MacLean et al, 2020). This condition also applied in shallow water, the closer the distance as a representation of recording time with a constant speed of the sound source, the higher the recorded sound intensity (Kozaczka et al. (2010).

Figure 5 shown the variations in the sound frequency received and its changes based on the frequency and speed of the sound source movement. The frequency of the sound received cannot be separated based on the frequency of the sound source (Figure 5A). The higher the frequency of the sound source, the higher the sound spectrum received, and vice versa. The changes in increasing the sound frequency of the receiver were also clearly described due to increasing the frequency of the sound source. The higher the frequency of the sound source, the faster the frequency changes.

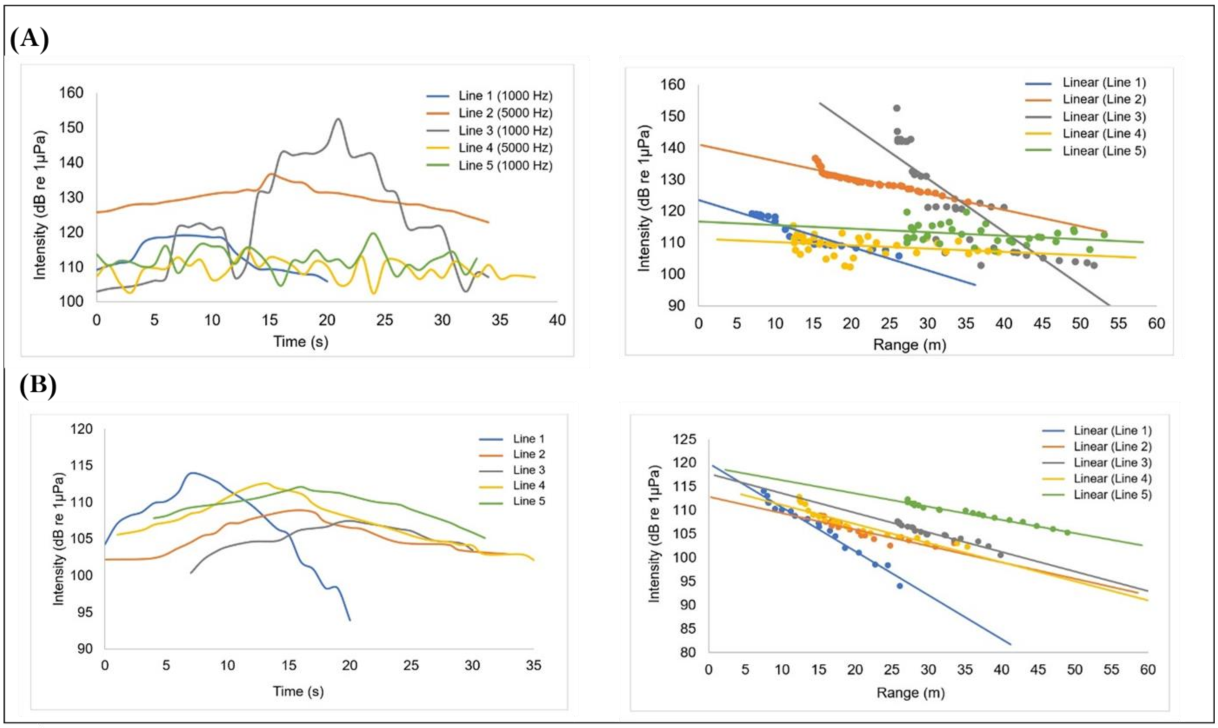

Figure 4. Intensity of Sound received. (A) and (B) represents the pattern of intensity received is based on changes in frequency and velocity of the sound source.

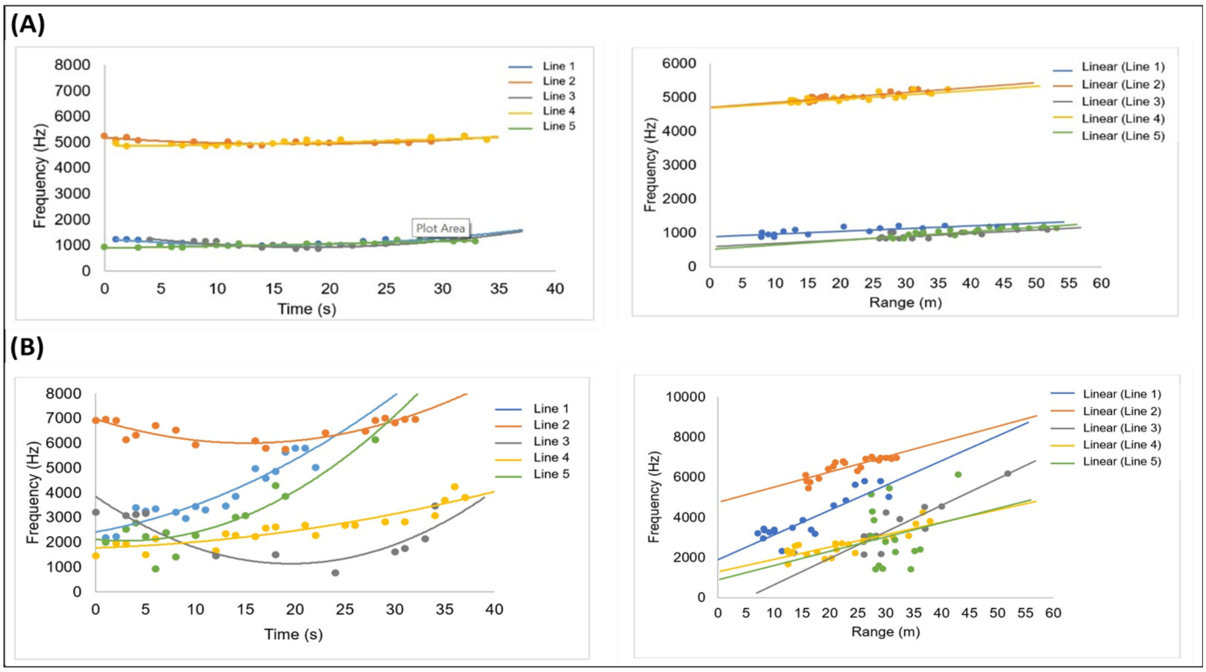

Figure 5. Frequency of Sound Received. (A) and (B) represents the pattern of frequency received is based on changes in frequency and velocity of the sound source.

In addition to the frequency of the sound source, the velocity of sound source movement also significantly influenced the changes in the sound frequency received based on the distance for all lines (Figure 5B). The faster movement speed of the sound source as a representation of relative distance influenced an increase the changes in receiver frequency which was also higher. This pattern in frequency was due to the influenced of the Doppler effect which was a function of the source frequency and the speed the sound source movement. It indicated that the Doppler effect can be represented by the changes in the frequency of sound received.

The Doppler effect causes an increase in the frequency of sound received due to an increase the distance between the source and receiver (Amron et al, 2021). This is related to changes in angle (α), where the formation of the angle results from changes in the sound source movement. Inversely proportional to the intensity pattern where the further away from the source, the intensity will decrease (Sutin et al., 2010; Fillinger et al., 2011), the frequency increases due to the changes position of the sound source as a consequence of the Doppler effect (Ahmad et al., 2018). The Doppler effect will occur if the wave source and receiver move relative to each other, the received frequency is not similar to the source frequency (Tipler and Mosca, 2008). This phenomenon is a change or shift in frequency that is observed when the source or receiver moves relative to the transmission medium (Walker et al. (2014).

CONCLUSION

Study on the Doppler effect in the waters can be carried out by investigating the changes in sound characteristics based on the frequency and movement of the sound source. Although the Doppler effect phenomenon significantly influenced the sound frequency received, it was different for the intensity of the sound received. Limitations in the number of simulated movements of both sound sources and receivers in this study mean that the quantity of the Doppler effect cannot be clearly described. However, it has become the basic study for further research regarding the Doppler effect in the waters.

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