Characteristics of Sea Waves Condition at The Northern and Eastern of Bintan Island within Period of 2015-2019

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Abstract. The objective of this research was to collect the comprehensive information about the characteristics of sea waves in the northern and eastern of Bintan Island Sea based on differentiation in oceanographic conditions between the north and east coast of Bintan Island. The north coast of Bintan Island faces the open seas directly with a potential high wave and cause several characters of coastal damage, including coastal abrasion. The characteristics of sea waves are obtained by forecasting, namely converting wind speed values using the SPM (Shore Protection Manual) method. The results of this study collected comprehensive information of sea waves on the north coast during the 2015-2019 period showed a dominant pattern with the direction of sea wave propagation from north and south, while for the eastern region the wave propagation trends prevailing from north and southeast. The maximum sea wave height in the northern of Bintan Island Sea reaches 3.32 m with a period of 8.70 s while in the eastern of Bintan Island Sea the maximum of wave height condition reaches 2.90 m with a period of 8.32 s. The maximum sea wave conditions on the north and east coasts of Bintan Island occur during the north wind season (December-February) and is directly proportional to the requirements of higher wind speeds. The minimum sea wave conditions occur during the east monsoon (March-May) where during that period the wind speeds that blow are very low condition. The results of this study indicate that wind speeds in northern Bintan Island are related to wave conditions. Our research proves that higher wind speeds form higher wave conditions.

1. Introduction

Sea waves are a phenomenon of rising and falling sea levels that move perpendicularly to form a sinusoidal curve [1]. Sea waves in the oceans can be triggered by several factors, including wind force, the gravitational force between the earth-moon-sun (tidal waves), and the earth's plate [2, 6]. However, in general, waves generated by wind, especially during strong winds, are more dominant than other factors [7, 9]. The energy that is converted from the wind into wave energy propagates and interacts with ocean waves in other areas [10, 11]. Several theories that the uncertainty of wind blow turbulence cause fluctuations in the sea surface, which results in small waves or ripples with several centimeters of a wavelength [12]. Sea waves are a variable that significantly affects various dynamics and activities that occur at sea, including some activities, such as sea transportation, are highly dependent on weather conditions that are influenced by wind and waves [13]. Sea waves also determine the industry's layout,
port terminals, shipping lanes, and coastal structure planning [14]. Sea waves will also affect tourism activities and conditions in coastal areas.

The dynamics of sea waves are formed from wind pressure provides different energy between each atmosphere layer [15]. The energy transferred depends on the wind speed, time blowing duration, and the distance travelled [16,17]. The direction, speed, and length of the area where the wind blows (fetch) is the most determining factor for wave height and period. The direction of the waves automatically follows the direction of the wind unless a refraction or diffraction phenomenon appears, causing the wave direction to change [18,19]. When the sea level is affected by wind pressure, the wave height will be formed. The significance of sea wave height variation is influenced by the wind gust factor, where the wind with high speed can produce high sea waves [20]. Several studies stated that the longer the wind blows, the stronger the wind speed [21, 23].

Furthermore, the greater the distance travelled, the greater the wave energy produced [24, 26]. If the wave height is much higher, the current velocity will be higher and form a strong longshore current and causing the coast to undergo a gradual abrasion process [27]. The coastal area is always changing because it interacts directly with the land, oceans, and the atmosphere. Changes in the configuration and direction of propagating waves radiating from the open sea towards the coast are generally called wave deformations. Several forms of wave deformation processes include refraction, reflection, diffraction, shoaling, and breaking waves [28, 29] and moving towards the coast will cause friction between the seabed waves causing the waves to break and potentially give a significant impact to erode and changing coastline [30, 32]. Therefore, the coastal area is very vulnerable to all physical processes [33].

The Strong wave energy has an impact on the potential for damage and has an impact on the sustainability of the utilization activities area in the northern and eastern coast Bintan Island location. This will affect the regional foreign exchange generated from certain tourism activities. Therefore, it is necessary to comprehensively investigate sea waves' characteristics at the northern and eastern coast of Bintan Island to collect information on the sea wave components in the five-year analysis period. The information regarding sea waves' characteristics becomes a recommendation authorization for development planning in coastal areas, especially in Bintan Island.

2. Materials and Methods

2.1. Research Location

The research was conducted in March-May 2020 on the north and east coast of Bintan Island, Riau Archipelago Province (Figure 1). The geographic location of northern and eastern Bintan Island is between the South China Sea, the Malacca Strait, and the Karimata Strait, and has great potential in the marine and fisheries sector, including marine fisheries, seaweed, coral reefs, mangrove forests, seagrass ecosystems and tourism [14]. The high potential marine resource proffers the northern and eastern regions of Bintan Island as one of the centers of economic growth, especially for the community living in the area. Geographically, the Bintan Island region is also used as a channel for national and international sea traffic due to directly opposite the South China Sea.

The various riches originating from the ocean lie along the northern and eastern of Bintan Island. The coastal community depends on these natural resources, including the fisheries cultivation sector, which depends on the wind season conditions in these locations. The north monsoon in the northern and eastern regions of Bintan Island had a high wave condition, and these monsoons become one of the obstacles for the coastal community who depend on the sea, mostly fishermen. Therefore, this study's results are expected to be an essential authorization of information for the surrounding community to obtain an overview of the seawater's condition in the north and east of Bintan Island to determine essential decisions long-term sustainable economic progress for the coastal community.
2.2. Tools and Materials

The materials (data) used is the wind component data $U$ and $V$ obtained from Copernicus website https://cds.climate.copernicus.eu/cdsapp#!/home while the research equipment in the form of data analysis software is presented in Table 1.

| No. | Software Analysis  | Function                                      |
|-----|--------------------|-----------------------------------------------|
| 1   | Ocean Data View    | Extraction wind speed and direction data      |
| 2   | WRPlot View        | Displays wind rose plots for wind speed and direction |
| 3   | ArcGIS             | Mapping                                       |

2.3. Wind Speed and Direction Data Analysis

The research method used is the hindcasting method (forecasting/predicting), referring to [34] used wind speed data to predict sea waves characteristics. This research using daily wind speed and direction data with a spatial grid of $0.125^\circ \times 0.125^\circ$ with data recording intervals every 1 (one) hour during 2015-2019.

Wind data collected from Copernicus was not in the form of direction and speed data. The data is in the form of wind components $U$ and $V$, which only have magnitude values with negative and positive values. Therefore, several comprehensive stages of analysis are necessary, including conversion of $U$ and $V$ components, height correction, correction duration, stability correction and wind stress factor conversion. After the conversion of the wind component has been completed, the final stage of the analysis of wind direction and speed data is to determine the value of the wind stress factor ($U_A$) using the following equation refers to [35]:

$$U_A = 0.71 U_W^{1.23}$$
Where $U_A$ is wind stress factor and $U_W$ is location effect due to surface roughness with analysis the ratio between wind speed over water and wind speed over land.

### 2.4. Prediction of Sea Wave Characteristics

Forecasting or predicting sea waves using the SPM method (Shore Protection Manual) refers to [34]. The ocean wave forecasting stage consists of filtering wind data, determining the effective fetch length, calculating the height, period, and ocean wave growth duration. Ocean wave forecasting analysis begins by examining to compare the conditions for ocean wave formation through the following equation:

$$\frac{t_d}{U_A} = 68.8 \left( \frac{gF_{eff}}{U_A^2} \right)^{\frac{2}{3}} \leq 7.15 \times 10^4$$

Where $g$ is the gravity acceleration (ms$^{-1}$); $t_d$ is the duration of the wind gust; $U_A$ is adjusted wind speed (m/s); $F_{eff}$ is the effective fetch (m). If it does not fulfill the above equation, the sea waves that are formed are the result of the formation of fully developed sea, and the calculation of the wave height and period was using the following equation:

$$H_{m0} = \frac{0.2433U_A^2}{g}$$

$$T_p = \frac{8.314U_A}{g}$$

Where $H_{m0}$ is the wave height (m); $T_p$ is the wave period; $U_A$ is wind speed (m/s). If the equation fulfills the initial equation, the sea waves formed are not fully developed sea, and it is necessary to determine in advance the type of waveform that has a duration limited or fetch limited. The determination of this difference is obtained by calculating the critical duration ($t_c$) using the following equation:

$$t_c = \frac{68.8U_A}{g} \left( \frac{gF_{eff}}{U_A^2} \right)^{\frac{2}{3}}$$

Following, verify the specified duration ($t_d$) and compare it to the critical period ($t_c$). If $t_d > t_c$, the wave form is fetch limited and for calculating wave height and wave period using the following equation:

$$H_{m0} = 0.0016 \frac{U_A^2}{g} \left( \frac{gF_{eff}}{U_A^2} \right)^{\frac{1}{2}}$$

$$T_p = 0.2857 \frac{U_A}{g} \left( \frac{gF_{eff}}{U_A^2} \right)^{\frac{1}{3}}$$

### 3. Results

#### 3.1. Wind Characteristics at the Northern and Eastern of Bintan Island

The percentage of wind occurrences shows quite varied results each year. There are differences in wind patterns in the two regions. At the northern region has the same wind occurrence frequency, particularly 19.38 % which dominantly blows from the north and south. Meanwhile, at the eastern region has an appearance frequency of 18.61 %, which dominantly blows from the north and 21.29 % from the southeast. The comparison of the percentage of wind occurrences in each region are presented in Figure 2.

During 2015-2019, the wind speed ranges from 3.60-5.70 m/s is very dominant. The proportion of wind events ranged from 3.60-5.70 m/s for the northern and eastern regions of Bintan Island with the proportion of frequency of incidents of 32.95 % for the northern region and 34.70 % for the eastern
region of Bintan Island. The percentage of light winds in the range of 2.10-3.60 m/s is dominant occurs in Bintan Island northern region with a frequency of incident at 24.96 %. Apart from the northern region, the appearance of light wind speed also occurred in the eastern region of Bintan Island with the range wind speed of 0.50-2.10 m/s in the eastern region has a wind occurrence frequency proportion of 20.80 %, and in the range, 2.10-3.60 m/s the frequency of wind occurrence is 26.49 % (Figure 3).

Figure 2. The wind rose diagram in the north (left) and east (right) of Bintan Island in 2015-2019

Figure 3. Comparison percentage occurrence of wind in the northern and eastern Bintan Island 2015-2019

3.2. Sea Waves Characteristics at the Northern and Eastern of Bintan Island

Based on the wind gusts direction, in the northern region, the waves come from the north with a percentage of 18.45 % and from the south with a percentage of 19.27 %. In comparison, the wave conditions in the eastern region of Bintan Island originated from the north with 18.51 % and 20.20 % from the southeast (Table 2 and Table 3). The minimum significant wave height generally dominates the northern and eastern regions of Bintan Island. The range of minimum wave heights was 0.10 -0.50 m, with the percentage of wave height occurrence for each area of 60.10 % for the northern region and 61.36 % for the eastern region Bintan Island. This is comparable to the low wind speed conditions that dominated from 2015-2019. The comparative pattern of wave height and wind speed is shown in Figure 4. In comparison, the highest wave peak occurred in 2016, where the wave height reached 3.32 m and a wave period of 8.70 s in the northern region of Bintan Island. In comparison, in the eastern region, the maximum wave height reaches 2.90 m with a wave period of 8.32 s. The range of minimum elevations in 2015-2019 in northern and eastern Bintan Island was only 0.01 m (Figure 5).
### Table 2. Percentage of wave height in the northern region of Bintan Island in 2015-2019

| Direction | 0.10 - 0.50 | 0.50 - 1.00 | 1.00 - 2.00 | 2.00 - 2.50 | >= 2.50 | Total (%) |
|-----------|-------------|-------------|-------------|-------------|---------|-----------|
| N         | 6.62        | 0.05        | 9.91        | 1.70        | 0.16    | 18.45     |
| NE        | 6.90        | 0.00        | 8.16        | 0.88        | 0.16    | 16.09     |
| E         | 2.24        | 0.00        | 0.05        | 0.00        | 0.00    | 2.30      |
| SE        | 10.13       | 0.00        | 6.40        | 0.00        | 0.00    | 16.53     |
| S         | 19.16       | 0.11        | 0.00        | 0.00        | 0.00    | 19.27     |
| SW        | 8.05        | 0.55        | 0.00        | 0.00        | 0.00    | 8.59      |
| W         | 4.98        | 0.22        | 0.05        | 0.00        | 0.00    | 5.25      |
| NW        | 2.03        | 2.46        | 1.53        | 0.00        | 0.00    | 6.02      |
| **Total (%)** | **60.10**   | **3.39**    | **26.11**   | **2.57**    | **0.33**| **-**     |

N: North; NE: Northeast; E: East; SE: Southeast; S: South; SW: Southwest; W: West; NW: Northwest

### Figure 4. Comparison of sea waves height and wind speed on northern (top) and eastern (bottom) region of Bintan Island in 2015-2019
Table 3. Percentage of wave height in the eastern region of Bintan Island in 2015-2019

| Direction | 0.10 - 0.50 | 0.50 - 1.00 | 1.00 - 2.00 | 2.00 - 2.50 | >= 2.50 | Total (%) |
|-----------|-------------|-------------|-------------|-------------|---------|-----------|
| N         | 6.84        | 1.00        | 9.74        | 0.93        | 0.00    | 18.51     |
| NE        | 8.10        | 0.00        | 5.97        | 0.22        | 0.05    | 14.34     |
| E         | 2.24        | 0.00        | 0.00        | 0.00        | 0.00    | 2.24      |
| SE        | 12.32       | 0.00        | 7.88        | 0.00        | 0.00    | 20.20     |
| S         | 17.73       | 0.05        | 0.00        | 0.00        | 0.00    | 17.79     |
| SW        | 6.51        | 0.11        | 0.00        | 0.00        | 0.00    | 6.62      |
| W         | 5.80        | 0.33        | 0.05        | 0.00        | 0.00    | 6.19      |
| NW        | 1.81        | 2.68        | 1.70        | 0.00        | 0.00    | 6.19      |

Total (%) 61.36 4.12 25.34 1.15 0.05 -

N: North; NE: Northeast; E: East; SE: Southeast; S: South; SW: Southwest; W: West; NW: Northwest

Figure 5. Comparison of sea waves height and sea waves period on northern (top) and eastern (bottom) region of Bintan Island in 2015-2019

4. Discussion

Wind speed data can predict the height and period of ocean waves [8,35–37]. Ocean waves generated by wind are the most dominant waves occurring in marine meteorological information. This is based on the general conditions that occur in the oceans, where most of the ocean waves are formed by energy produced by wind [2,15]. Previous studies by [35] stated that wind energy operating at sea level would experience a sheltering effect due to wind friction against the sea surface resulting in variations in the size of random waves in the sea. Referring to the Beaufort Scale, there are five types of wind classifications, particularly light wind ranging from 0-21 knots or the equivalent of 0.00-10.70 m/s, high wind ranging from 22-33 knots (10.80 -17.10 m/s), gale force ranges from 34 -47 knots (17.20-24.40 m/s), storm force range from 48-63 knots (24.5-32.6 m/s) and hurricane force more than 63 knots (>32.6 m/s) [38,39]. The percentage of light wind occurrences in northern and eastern regions of Bintan Island is generally quite dominant, particularly in the range of 3.60-5.70 m/s.
The pattern of wind direction and speed in the northern and eastern seawaters of Bintan Island is strongly influenced by the monsoon wind system, which is very dominant in Southeast Asian seawaters, this is because the northern and eastern seawaters of Bintan Island are in the northern hemisphere [35,40,41]. The western season (northern season in Bintan Island waters) takes place during October-April and the peak occurs in December-January, while the eastern season (southern season in Bintan Island waters) lasts for April-October and the peak occurs in June-August [35]. The results of forecasting sea waves generated by wind in the northern and eastern regions of Bintan Island in 2015-2019 show that the direction of these waves arrival is the same as the direction of the wind gusts. According to [35], the wind direction affects the formed ocean wave pattern.

The wave height graph shows that the high waves generally occur during the northern monsoon (west monsoon) period. According to [35], the maximum wave heights in the northern and eastern Bintan Island regions generally reach 2.67 m. The high wave condition will seriously endanger the safety of shipping and fishing activities by fishers. Although the percentage of high wave events is not significantly dominant, the high waves that occur along the north and east coast of Bintan Island need to be considered. Entered west monsoon the wave high nearly reaches 1.50-2.00 m that engulfed most of the coastal area and resulting in disturb of fishing activities and give abrasion along the coast of Bintan Island as stated by form of ocean wave patterns. The appearance of high waves during the northern monsoon in the northern and eastern regions of Bintan Island is caused by the wind speed that blows relatively high.

Meanwhile, the appearance of a weak wind is quite dominant, indicated by the high percentage of incidents in Bintan Island's northern and eastern regions. In general, the minimum wave height occurs in the eastern monsoon (transition I). The minimum wave height in the eastern monsoon is also reinforced by the results of research conducted by [35]. During that season, the wave height in the eastern waters of Bintan Island was only 0.43 m. In the transitional monsoon I and II, the height pattern that is formed tends to be lower. The condition due to during the transition monsoon, the sun's position is in the equatorial area so that the temperature on the continents of Asia and Australia is relatively low. The low-temperature conditions make the wind speed blowing over Indonesia also relatively low [2].

The ratio between wave height and wind speed has a different perpendicular pattern. Based on these results concluded that the wind speed determines the height of the waves on the water surface and in line with [16] research, the longer the wind blows, the higher the waves are formed. Wind speed frequency is essential, considering the direction and wind speed that occurs varies from time to time [42]. Generally, the pattern of wave height and wind speed did not significantly differ, but in 2016 in the northern monsoon, the wave height and wind speed were low. This is due to anomalies influenced by the El Nino and La Nina phenomena during 2015 and 2016.

El Nino is a process of increasing sea surface temperature on the west coast of Peru and Ecuador and resulted in global climate disruption. Meanwhile, La Nina is a weather condition that returns to normal after El Nino (opposite of El Nino) [43]. According to [44], El Nino and La Nina events do not affect the resultant wind direction, but from observations when La Nina occurs, there is a low-pressure center in northeast Indonesia. When El Nino occurs, zonal winds are dominant with a negative value from the equator to southern Indonesia in August-November 2015 and begin to change (positive value) in December 2015. This shows that the wind zone is dominated by east winds, which contain little water vapor. Meanwhile, at La Nina, the positive dominant zone wind (west wind) is more dominant than the north with more water vapor. Even in December 2016, this phenomenon was more apparent.

The maximum wave forecasting results will be used in the design of coastal structures, both for determining waves with a return period and in designing the dimensions of the coastal protection structure to be planned. This is intended so that the planned coastal protection structure remains safe when big waves arrive. However, waves with maximum height do not occur all the time and cannot be considered a representative pattern of coastal waves. During March-May, the first transitional season (eastern season in the Bintan Island region) after the Asian monsoon, is characterized by weak wind speeds and irregular direction. This condition causes the wave height in the transitional season to also weaken where the South China Sea has a wave height of only 0.50-1.00 m, while in the western Pacific Ocean, it has a wave height of 0.50-2.00 m, which previously could reach a height of up to 3.00 m.
5. Conclusion
The wave pattern formed with the highest range in the northern and eastern waters of Bintan Island from 2015-2019 occurred in the northern monsoon period (December-January). Meanwhile, the dominant minimum wave height occurs in the eastern monsoon (March-May). The research shows that sea waves characteristic conditions show that the wave pattern formed is directly proportional to each season's wind speed. It can be concluded that the sea waves forecasting method using wind direction and speed data is one of the appropriate methods and the results obtained are entirely accurate.

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