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HYDRO-OCEANOGRAPHIC CHARACTERISTICS IN KARIMUNJAWA COASTAL WATERS DURING THE 1ST TRANSITIONAL SEASON

Yulius[1)], Joko Prihantono[1)], Dino G. Pryambodo[1)], Muhammad Ramdhan[1)], August Daulat[1)], & Nur Kholik Kurniana Putra[2)]

[1)]Marine Research Center, Marine and Fisheries Research and Human Resources Agency, MMFA
[2)]Diponegoro University

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ABSTRACT

This study aims to determine oceanographic characteristics such as tides, waves, and currents in Karimunjawa Coastal Waters during the 1st transitional season and to update the oceanographic database for spatial management evaluation in the region. The tidal characteristics were obtained from the least square method analysis using World Tide software based on Matlab programming language, while wave and current characteristics obtained from 2-dimensional numerical modeling using Mike 21 software on the flow model and spectral wave module. The primary data used were the significant wave height (Hs), wave peak period (Tp), and ocean current components (u and v velocity) on 13-26 May 2016 using the Sontex Argonaut XR type Acoustic Doppler Current Profiler (ADCP) equipment. Tide data were predicted for the Kemujan Islands station from 1-31 March 2020. Secondary data for additional numerical model input were obtained from ERA5-reanalysis in the form of Hs, Tp, u, and v wind velocity data for May 2020 with a temporal resolution of 20 minutes, while bathymetry data derived from GEBCO Satellite Derivated Bathymetry (SDB) data. The tide analysis results showed that Karimunjawa waters are a single daily mixed tidal type. The wave characteristic moves from east to west with high waves reached 0.9 meters and a peak period of 7 seconds. The eastern side of Karimunjawa Island, Kemujan Island, and the western area have a calmer wave. The current characteristic moves northeastward with a speed of 5-28 cm/s, which concludes that in several locations, such as the Menjangan Besar-Menjangan Kecil strait, the currents depend on the tidal conditions.

Keywords: Tidal, wave, current, karimunjawa.

Corresponding author:
Jl. Pasir Putih I Ancol Timur, Jakarta Utara 14430. Email: yulius.lpsdkp@gmail.com

INTRODUCTION

Karimunjawa waters are a semi-enclosed sea type, where the interaction between Karimunjawa Island and its surrounding islands has an impact in terms of economic activities such as cultivation, transportation, and tourism. Cultivation activities in the community are seaweed and sea cucumber, which often attract local and foreign tourists. The existence of a seaport on Kemujan Island as a link between Karimunjawa Island and Java Island indicates the active and mobile community, and transportation activities, in addition to tourism activities which are dominated by beach tourism, snorkeling, and diving, as well as shark breeding attractions, and other recreational tours visited by tourists (Muh Yusuf, 2013). Given the importance of the above activities as a driving force for the community's economy, it is necessary to have information on the physical condition of waters as the primary data for sustainable water management (Kusumah & Widjarnako, 2007).

The physical conditions and characteristics of the waters, including currents, waves, and tides, are dynamic, needed for the maintenance, operation, planning, and development of aquaculture, tourism, and transportation activities. This hydrodynamic condition is a component in the waters that influence coastal and marine areas (Dijkstra, 2008). Flow is defined as water masses' movement from one place to another (Trujillo & Thurman, 2006). Current can be generated by wind or a density gradient, and waves can also generate it under certain conditions. Waves are the up and down seawater movement perpendicularly, which forms a sinusoidal chart (Holthuijsen, 2010). In their propagation, waves carry energy that can cause sediment flow and transport both perpendicular and along the coastline (Nair *et al.*, 2015). Meanwhile, tides are the periodic and harmonic movements of rising and falling water due to the attractive forces between the earth and celestial bodies, especially the moon and the sun (Boon, 2013).

The ocean currents in Karimunjawa waters generally shows the dominance of the current direction from east to west with a maximum speed at the surface reaching 0.31 m/s and a minimum of 0.06 m/s, and an average speed of 0.16 m/s (Yusuf *et al*., 2012). In this study, information on ocean currents was obtained using numerical models for surface currents and verification of field data using drifter, which had low accuracy. While the wave conditions show that the wave height is in the range 0.01 m - 0.38 m with Hs 0.13 m, and the period is in the range 0.1 s - 2.9 s with Ts 1.578 s. (Hidayat *et al*., 2013). This information was obtained through numerical modeling on Parang Island, which is not far from the study site, which validated by field verification using the scaled board visual method. Tides causing tidal currents flow eastward during high-tide and westward at low tide (Yusuf, 2013). Due to the lack of hydrodynamic information available, a more in-depth review of the Karimunjawa waters, including Kemujan, Menjangan Besar, Menjangan Kecil, and Cemara Besar, using ADCP (Acoustic Doppler Current Profiler) needed for more accurate and precise results. It is hoped that this research will help all stakeholders to make policies for maintenance, operations, planning, and development for economic activities in the region.

METHODOLOGY

Coastal current and wave measurement

The water flow data were collected using the eulerian method, while the wave data were obtained using the pressure gauge method. Measurements conducted using the ADCP Argonaut Sontek XR with a sensor wavelength of 0.75 mhz beam and an autonomous multi-cell system. ADCP Argonaut Sontek XR is installed at the location of Karimunjawa waters close to Menjangan Island with coordinates S05.88305° E110.42980°. The ADCP installation is located at a depth of ± 12 meters with the sensor forming an angle to the vertical axis of 20° and above and forming a Cartesian coordinate system (ENU) for the current component in the E (west-east /u), N (north-south /v), and U (vertical water column /z).

Current and wave data in the study site were obtained from recording on 13-28 May 2016. The recording interval for the current measurement was 1200 seconds with a total recording time of 15 x 24 hours. The Euler method in ADCP measure currents with the concept of following the motion of water particles by firing a single beam at each sensor in a certain way and dividing the layers that have been set.

This tool uses acoustic waves that are emitted through a transducer along the water column, where the current velocity is measured based on the waves reflected towards the transducer by sediment and plankton particles moving at the same speed as the speed of water, the frequency change that occurs is proportional to the velocity between the measuring instruments. and the current layer being measured.

Tidal Least Square Analysis

The tidal calculation method carried out using the Least Square method. This method was developed by Boon & Kiley (1978). The calculations were carried out with the World Tide programming developed by Boon (2013). A program equipped with a Graphical User Interface (GUI) can calculate tidal harmonic components from tidal data and make predictions based on these harmonic components. The data used are BIG tidal data for the Kemujan Island station, Karimunjawa, on 1-31 March 2020 with a temporal

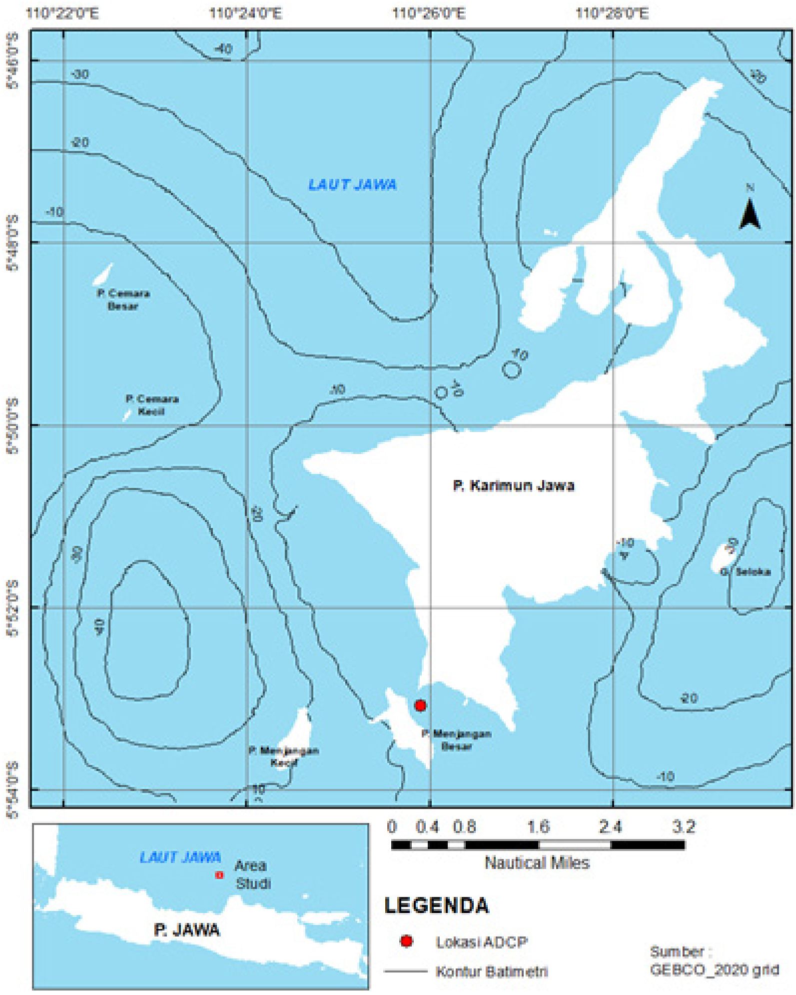

Figure 1. Study site, Karimunjawa archipelago.

resolution of 1 minute.

The calculated harmonic component is used to calculate the formzahl (F) value, which obtained based on (Wytki in Pariwono, 1989) using the following equation 1.

$$F = \frac{K_1 + O_1}{M_2 + S_2} \qquad \text{.1)}$$

Where F is the formzhal value, K1 is the harmonic constant, which is influenced by the sun's declination and the moon. O1 is the harmonic constant that is influenced by the moon's declination, M2 is the harmonic constant that is influenced by the moon's position, and S2 is the harmonic constant that is influenced by the position of the sun. Based on the value of F, the type of tide can be determined with the following ranges:

$F \leq 0.25$: Semidiurnal tides
$0.25 < F \leq 1.5$: Mixed mainly semidiurnal tides
$1.5 < F \leq 3.0$: Mixed mainly diurnal tides
$F > 3.0$: Diurnal tides

Wave Model

The wave conditions of Karimunjawa waters are obtained from wave modeling using the spectral waves module model software Mike 21, which known as the latest generation of wave models in the unstructured mesh. This model simulates the occurrence and transformation of wind-generated waves in offshore and coastal areas. Spectral waves consider several physical phenomena, including the generation of waves by wind, non-linear wave interactions, dissipation, refraction and breaking of waves, wind-wave interactions, and the effects of changes in water surface depth (DHI, 2006).

This study uses several model attributes and variable input, where the summary of the model settings is shown on Table 1. The mesh is the basis for modeling using bathymetric data obtained from GEBCO. Wind and current variable inputs are obtained from different ERA-5 reanalysis data for each side of

Table 1. Model attributes and input variables in spectral wave mode

Model Attributes		Variable Input	Value
Batrimetry data	Gebco	Grid resolution	0.020 x 0.010
Spectral formulation	Fully spectral formulation	Spectral resolution	25 intervals from 0.055 to 1.1 Hz
Time Formulation	Instationary formulation	Time interval	30 min
Directional discretization	360°	Number of directions	16
Tidal forcing	Varying in time	Tidal elevation	Data from BIG Kemujan station
Current input	Varying in time	Current velocity	Data from ERA-5 reanalysis and in situ data
Wind forcing	Varying in time	Wind data	Data from ERA-5 reanalysis
Energy transfer	Included	Transfer cofficient	0.25
Wave breaking	Statistical (Battjes & Janssen, 1978)	Gamma parameter (γ)	Function from (Ruessink *et al*. 2003). alpha coefficient: 1
Bottom friction	Sand grand size, d50	Friction factor	0
Initial Condition	Spectra from empirical form. SPM 1973	• Sigma a • Sigma b • Peakness	• 0.07 • 0.09 • 3.3
Boundary condition	Wave parameter. Jonswap (Hasselmann *et al*., 1973) in situ data	• Wave parameter (Hs, Tp, direction) • Index spreading	• Data from ERA-5 reanalysis & • 5

the boundary. The flow data from field observations are added to the current input in one of the boundaries. Field flow data were obtained using the Sontex Argonaut Acoustic Doppler Current Profiler (ADCP) XR type recording on 13-28 May 2016. The boundary conditions using input data Hs, Tp, and the direction of wave propagation originate from ERA5-reanalysis and ADCP recording on the same one. This input is used as a spectral wave analysis from each side of the boundary to the research area.

Current Model

Current conditions are obtained from modeling ocean currents using FM software Mike 21 flow model. The modules used are hydrodynamic modules based on numerical calculations of shallow water two-dimensional equations, Navier Stokes equations, and incompressible equations integration. There are input options for continuity, momentum, temperature, salinity, and density variables in this module. Spatial descriptions were obtained using the cell-centered finite volume method. This module is suitable for modeling water flow in marine and coastal areas (DHI, 2007).

Ocean current modeling is carried out with several model attributes and variable input, as shown in Table 2. The bathymetry data used are obtained from GEBCO data. The input variables consist of wind data, density, bed resistance, eddy viscosity, and Coriolis force, while wind data were obtained from ERA5-reanalysis for 1-hour daily wind data. This model's boundary conditions are water level elevation based on the tidal data for Kemujan Station from BIG.

RESULTS AND DISCUSSION

Tidal Characteristic

The results of the analysis of the tidal harmonic components in Karimunjawa waters are shown in Table 3. The constant harmonic components influenced by the sun's declination and the moon K1 have the highest amplitude compared to other components. Of course, this is influenced by the coordinates of the Karimun Jawa waters around the equator. M2 harmonic components. S2 and N2 have adjacent phases, meaning that these components reinforce each other so that water levels appear with an extensive range between high tide and low tide. The three components superposition / mutually eliminate the K1 and O1 components. Thus, the difference in phases of several harmonic components causes a difference in the number of tides and ebbs each day with a much different elevation.

By calculating the formzahl value (equation 2), the formzahl value is 2.19. These values indicate that the tidal in the study site is a (mixed mainly diurnal tides) as shown in Figure 2 appears that the ebb in the transitional seasons 1 in one day occurred one high tide and one low tide, with some time show twice high tide and two low tides.

The research area is an archipelagic coastal waters area. Thus, tides become a significant factor in ocean currents' characteristics apart from the influence of wind friction (Boon, 2013). The tidal conditions with the mixed type tilted single daily support aquaculture activities in several water areas. Besides, several mangrove zones on Kemujan Island grow well with a

Table 2. Model attributes and input variable in Flow Model FM

Model Attributes		Variable Input	Value
Batrimetry data	Gebco	Grid resolution	0.020 x 0.010
Space discritization	Higher order	CFL number	0.8
Time integration	Higer order	CFL number	0.8
Flood and dry	Included	• Drying depth • Flooding depth • Wetting depth	• 0.001 m • 0.002 m •0.003 m
Directional discretization	360°	Number of directions	16
Density	Barotropic	-	-
Eddy Viscosity	(Smagorinsky, 1963)	Cs	0.28
Bed Resistance	Manning number	M	32 $m^{(1/3)}$/s
Coriolis forcing	Included	-	-
Wind forcing	Varying in time	Wind data	Data from ERA-5 reanalysis
Precipitation	Not included	-	-
Evaporation	Not included	-	-
Wave radiation	Not included	-	-
Initial Condition	contant	Surface evelation	0 m
Boundary condition	Specified level	Water level	Data from BIG Kemujan station
Decoupling	Not included	-	-

Table 3. Tidal characteristic components of Karimunjawa waters

Tide Component	M2	S2	K1	O1	N2
Amplitude	0.064	0.071	0.188	0.107	0.041
Phase	346.85	318.48	233.93	84.94	318.48

strong influence on these tides (Sulisyati *et al.*,2019).

Wave Model Results

The wave simulation results in Figure 3 illustrate the wave's propagation with the characteristic wave height and peak period in May. In the model, during May, wave appears to be moving from the east with a wave height of 0.9 - 1 m and a peak period of 6.5-7 s. The waves hit the east side of Kemujan Island, and then they reacted on the north and south sides of the island. The west side of Kemujan Island has the characteristics of a smaller wave height of about 0.1-0.3 meters.

The wave in area A see Figure 3 has a wave height ranging from 0.9-1 meter before hitting the scorch. Then it gradually decreases due to the refraction of the burnt. The waves on the inside of the burnt are calmer than on the outside. The peak period of waves ranging from 6.5 - 7 s was able to hit the eastern side of Kemujan

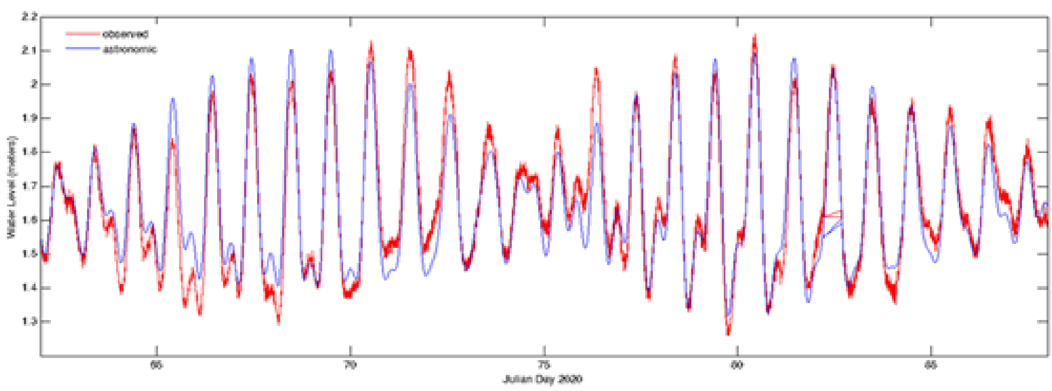

Figure 2. Tide elevation in March 2020.

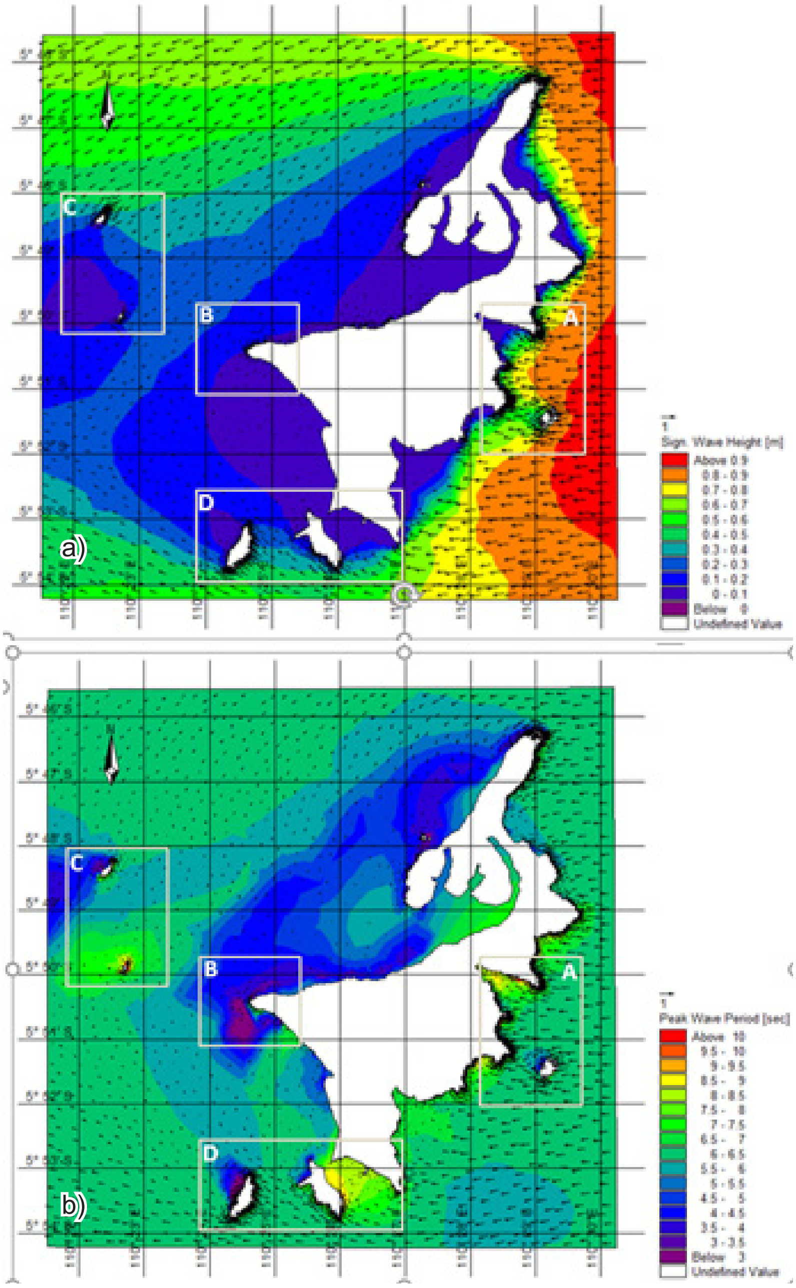

Figure 3. a) Significant wave height model (Hs) and; b) Peak wave period model (Tp) during the 1st transitional season.

Island. This characteristic that tends to be high is influenced by the non-sloping bathymetry conditions and direct wave propagation from the east side. Thus, in May, the transition season of 1 wave on the east side of Kemujan Island has higher characteristics than other areas.

Area B is on the west side of Karimunjawa Island, precisely at Ujung Gelam Beach, which has the characteristics of calm waves. Wave height ranges from 0.1-0.3 meters with a peak period of 3-4 seconds. Thus, Ujung Gelam Beach in transition season 1 occurs with calm waves for a short period. This wave condition results from wave refraction from the east side of Kemujan Island, plus Ujung Gelam Beach is right behind area A.

Area C includes the waters around Cemara Besar and Cemara Kecil Islands. Wave characteristics in this area ranged from 0.1-0.5 meters with a peak period of 3-10 seconds. The bathymetry between Cemara Besar and Cemara Kecil Island is classified as shallow. So that the area is classified as calm waters with wave heights below 0.2 meters. Meanwhile, the west side of Cemara Besar Island has a wave height of about 0.5-0.7 meters but with a short period due to the long-wave generation fetch from the northeast. The calm waves around Cemara Besar Island are due to the fringing reef that surrounds the island. The coral reef acts as a breakwater so that the waves hitting the island have a low height. Meanwhile, around Cemara Kecil Island, the water conditions are calmer with low waves for an extended period. The direction of propagation of the waves in this area comes from the northeast to the southwest.

Area D includes the waters around Menjangan Besar Island, Menjangan Kecil Island and the strait between Kemujan Island and Menjangan Besar Island. In this area, there are two straits, namely the strait between Kemujan Island and Menjangan Besar Island and the strait between Menjangan Besar Island and Menjangan Kecil Island. The two straits' bathymetry conditions are different, where the Kemujan and Menjangan straits are shallower than the other straits. The wave characteristics in this area move from the southeast to the northwest across the two straits. The Kemujan-Menjagan strait has a low wave height of about 0.1-0.2 meters with a peak period of up to 9 seconds. Thus, in this strait, the wave characteristics are calm for an extended period. In this strait on Kemujan Island, there are passenger and fishing ports. Meanwhile, on the east side of Menjangan Besar, there is aquaculture cultivation. The location selection for space utilization is excellent, supported by the characteristics of calm waves.

The strait between Menjangan Besar-Menjangan Kecil has wave characteristics that tend to be bigger than the last strait. In this strait, the wave height ranges from 0.1-0.6 meters with a peak of 6.5 seconds. The waves move from the southeast into the strait, which then refracts to the island's side. Based on the Karimunjawa zoning map in Sulisyati *et al*., (2019) shows that the strait between Menjangan Besar-Kecil is a tourism use zone. Meanwhile, the southern area of Menjangan Kecil Island is a marine protection zone. The characteristics of relatively calm waves in this area support tourism use activities both for beach tourism, educational tourism, and other marine tourism.

Tidal Current Characteristic

The flow pattern of transitional season 1 in Karimunjawa waters is shown in the 2-dimensional model results in Figure 4a at high tide and Figure 4b at low tide, which in general, the current moves to the northeast. In areas that are not obstructed by islands and corals, the currents are faster, reaching 28 cm/s. Whereas in the waters around the island, currents move along the island and include longshore currents that can carry sediment and move it to other locations.

In area A, the current conditions are calm with a speed of less than 8 cm/s and moving to the northeast. However, in the current along the coast area, A moves along the coast. Around the sandbar, the flowing currents are calm, ranging from 2-5 cm/s. Stronger currents located in the south of area A with speeds of up to 25 cm/s, which moves to the northeast without first passing through area A, caused by the wind blowing from the southwest and the bathymetry in area A deeper than the surroundings. The current moving to the northeast deflected to the east so that the current movement pattern is seen, as shown in Figure 4

Area B on Ujung Gelam Beach, Karimunjawa Island, has currents with speeds ranging from 10-20 cm / s. the current moves along Ujung Gelam Beach at a higher speed just at the end of the beach. In comparison, the surroundings are lower speed. In this area, space is used for tourism so that the current conditions do not have a significant effect on space utilization.

Area C has a wide range of current velocities. On the west side, Cemara Besar Island has a faster current of up to 25 cm / s. This current is an integral part of the current pattern outside area C, which reaches 28 cm / s. The direction of the current movement is towards the northeast and the current vectors moving along the coast of Pulau Cemara Besar are seen. Thus, indicated by bathymetry of the sea bad. Referring to the research (Ramdhan, Yulius, & Putra, 2020) said that the slope of the island is gentle in the majority. So that, able to deflect the tidal current flow. In connection with its space as a tourism use zone, tourism activities are often carried out on the east side of Cemara Besar Island. This current condition is closely related to the sediment transport at the tip of Cemara Besar Island. The research (Ramdhan, Yulius, & Putra, 2020) shows a dynamic change in the shoreline at the end of the island. The waters between Cemara Besar and Cemara Kecil Islands have a calm current, not more than 10 cm/s, and various directions. The bathymetry of this area is covered by fringing reefs which indicate calm ocean currents (Figure 4).

Area D has a characteristic current with a 10-12 cm / s and moves along the strait towards the south at high tide and towards the north at low tide. These conditions indicate that tidal conditions greatly influence currents in the Menjangan Besar-Menjangan Kecil strait. Simultaneously, the strait between Menjangan Besar-Karimunjawa moves to the southeast at high tide at a speed of 5-8 cm / s and northwest at a speed of 2-5 cm /s.

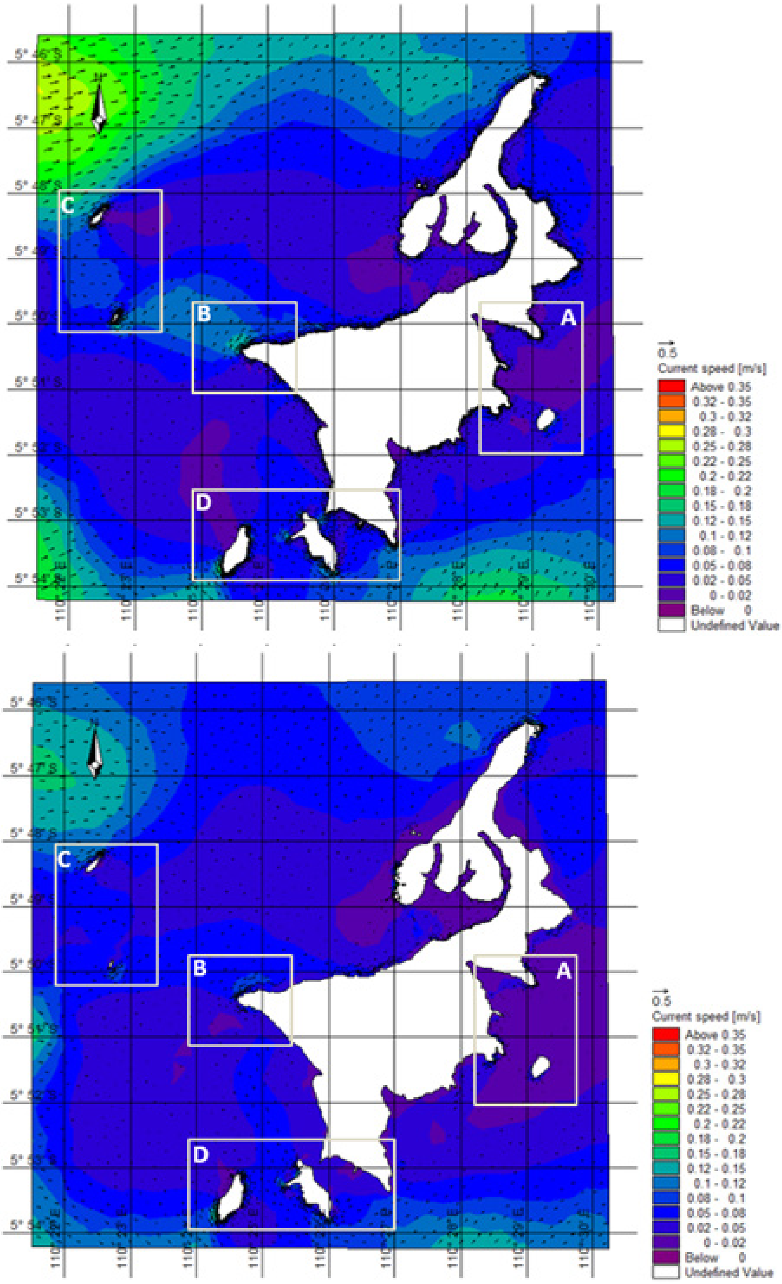

Figure 4. a) Current model during high tide; b) Model during 1st transitional season.

CONCLUSION

The mixed-type Karimunjawa tides are single daily with a formzahl value of 2.19. The tidal level occurs one tide and one ebb with two tides and two ebbs with very different elevations. During transition season, the wave conditions during transition season 1 move from the west with a height of 0.9 meters and a peak period of 7 seconds, and refraction occurs in the north of Kemujan Island and south of Karimunjawa Island. The waves on the west side of Kemujan and Karimunjawa Islands have lower wave heights than the east and long periods. Current conditions generally move towards the northeast with a speed range of 5-28 cm/s. As well as in several locations such as the Menjangan Besar-Menjangan Kecil strait, the currents depend heavily on the Tidal evelvation gradients.

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REFFERENCE

Battjes, J., & Janssen, J.P.F. (1978). Energy loss and set-up due to breaking of random waves. *Proceedings 16 International Conference in Coastal Engineering*, 569–587.

Boon, J D, & Kiley, K.P. (1978). Harmonic analysis and tidal prediction by the method of least squares. *VIMS Spec Rep Appl Mar Sci Ocean Eng, 186*, 49.

Boon, J.D. (2013). Secrets of the tide: tide and tidal current analysis and predictions, storm surges and sea level trends. Elsevier.

DHI. (2006). Mike 21 Spectral Wave. DHI Water & Environment.

DHI. (2007). MIKE 1 Flow Model FM. DHI Water & Environment.

Dijkstra, H.A. (2008). Dynamical oceanography. Springer Science & Business Media.

Hasselmann, K., Barnett, T., Bouws, E., Carlson, H., Cartwright, D., Enke, K., Ewing, J., Gienapp, H., Hasselmann, D., Kruseman, P., Meerburg, A., Muller, P., Olbers, D., Richter, K., Sell, W., & Walden, H. (1973). Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP). *Deut. Hydrography, A80(12)*, 95.

Hidayat, J.J., Yusuf, M., & Indrayanti, E. (2013, in Indonesian). Dynamics of Wave Propagation Using the CMS-Wave Model on Parang Island, Karimunjawa Archipelago. *Journal of Oceanography, 2*(3), 255–264.

Holthuijsen, L.H. (2010). Waves in oceanic and coastal waters. Cambridge university press.

Kusumah, G., & Widjarnako, E. (2007, in Indonesian). Identification of bays and headlands in Bungus Bay based on maritime toponym rules. *Jurnal Segara, 3*(2), 105-111.

Nair, L.S., Sundar, V., & Kurian, N.P. (2015). Longshore sediment transport along the coast of Kerala in southwest India. *Procedia Engineering, 116*, 40–46.

Pariwono, J.I. (1989, in Indonesian). Gaya Penggerak Pasang Surut. Ongkosongo, OSR Dan Suyarso. P3O-LIPI. Jakarta. Hal, 13–23.

Ramdhan, M., Yulius., & Putra, N.K.K. (2020). Shoreline Change Dynamics using Digital Shoreline Analysis in Cemara Besar Island. *Jurnal Segara, 16*(2), 105–114. DOI:10.15578/segara.v16i2.8360

Smagorinsky, J. (1963). General Circulation Experiments with the Primitive Equation I the Basic Experiment. *Monthly Weather Review, 91*, 99–164.

Sulisyati, R., Prihatinningsih, P., & Mulyadi, M. (2019,in Indonesian). Revision of Karimunjawa National Park Zoning as an Effort to Compromise Natural Resource Management. *Seminar Nasional Geomatika, 3*, 713. https://doi.org/10.24895/SNG.2018.3-0.1030

Trujillo, A.P., & Thurman, H.V. (2006). Essentials of oceanography. New Jersey: Pearson Prentice Hall, Pearson Education Inc.

Yusuf, M. (2013, in Indonesian). Analysis of Site Suitability for Sustainable Marine Culture at Karimunjawa National Park. *ILMU KELAUTAN: Indonesian Journal of Marine Sciences, 18(1)*, 20-29.

Yusuf, M., Handoyo, G., Muslim, M., Wulandari, S.Y., & Setiyono, H. (2012, in Indonesian). Characteristics of Flow Patterns in Relation to Water Quality Conditions and Phytoplankton Abundance in the Waters of the Karimunjawa Marine National Park Area. *Buletin Oseanografi Marina, 1*(5), 63-74.