Asian Journal of Fisheries and Aquatic Research

8(4): 1-9, 2020; Article no.AJFAR.59348
ISSN: 2582-3760

Mangrove Ecosystem Connectivity Based on Oceanographic System in Biawak Island, West Java, Indonesia

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AVS and NPP designed the study, performed the analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MLS and IF managed the analyses oft the study. Author CAF managed the figure. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJFAR/2020/v8i430143
Editor(s):
(1) Dr. Ahmed Karmaoui, Southern Center for Culture and Sciences, Morocco.
Reviewers:
(1) T. Kongeswaran, Alagappa University, India.
(2) Sourav Das, Jadavpur University, Kolkata, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/59348

Original Research Article

Received 19 May 2020
Accepted 24 July 2020
Published 20 August 2020

ABSTRACT

This research aims to determine the ecosystems connectivity by observing the distribution of inter-island mangrove propagules in the territorial waters of Biawak Island. The data used are wind, tidal, and bathymetry of 2018. They are modeled according to the propagules' weight and the particle trajectory module. The results showed that the entire propagules (*Rhizopora sp, Sonneratia sp,* and *Brugueira sp*) dominantly moved to the west and southeast. They are carried by the currents that are influenced by the west and east monsoon. The propagules of *Rhizopora sp* moves from east to southeast, *Sonneratia sp* moves from east to south, and propagules *Brugueira sp* moves from west to north. In addition to oceanographic factors, other parameters that can influence the pattern of propagules movement is the propagule's mass; the lighter it is, the easier it is to be carried away.

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Keywords: Bonpies; ocean currents; ecosystem connectivity; Rhizophora sp; Sonneratia sp; Bruguera sp; monsoon; Java sea.

1. INTRODUCTION

One of the unique ecosystems in the coastal seas is mangrove. As an ecosystem, with coral reef and seagrass, it used to protect coastal areas from the tsunami, waves, and coastal erosion. Mangroves are one of the typical tropical vegetation that can be found in the banks of rivers, estuaries, and coastal areas that are mainly affected by tides [1] and high salinity condition (halophytic vegetation) [2]. In its habitat, mangroves are mostly viviparous with seeds germinate before falling into the seas [3]. Furthermore, after floating in the surface water, propagules are carried by wind or ocean currents to shallow waters. The propagules will grow in the new area if it is fit for its condition [4].

The mangrove ecosystem is the leading chain that acts as a producer in the food web of a coastal ecosystem [5]. It is one of the main components that must be present in the MPA (Marine Protected Area) [6]. At present, mangroves cover only 2% of the earth's landmass and Indonesia has the largest mangrove forest in Southeast Asia with around 23% which equals to 7.2 ha [7].

Ecosystem connectivity is one of the central main in MPA. It brings new knowledge about spreading of larvae and others seed between the ecosystem. This research studied about mangrove ecosystem connectivity in Biawak island. These islands are one of the areas that have been designated as MPA since 2006. The MPA consists of two small islands (Biawak island and Gosong island) and one atoll (Candikia) which characterized by the shallow water ecosystems [8,9]. The types of mangroves that grow in Biawak Island include *Sonneratia sp, Avicennia sp, Bruguiera sp, Rhizophora sp, Ceriops sp., Lummitterae, Xylocarpus, Aigicera, Nipa sp,* and *Heriera sp*. In the Gosong island and Candikia, there is *Rhizophora sp and also become the dominant species in the entire area*.

The study of ecosystem connectivity in Biawak Island has been carried out by several previous researchers [10,11]. Ecological spatial connectivity is an essential process in the ecology and evolution of marine species, which is useful for the effective use and management of MPA [12,13]. Several studies have been modelled larvae distribution in the Java Sea [10,11]. At present, the establishment of MPAs in Indonesia has not included ecosystem connectivity as a parameter. It found that larvae of coral reef flow with the ocean dynamics. Ocean currents, wind pattern, tides are the main force to spread particle include larvae and propagules. Hence, comprehensive regional and network design is needed to represent all aspects of biodiversity, including population, species, and biogenic aspects [14].

Therefore, this study aims to determine the path and distribution of mangrove propagules using particle trajectories module. The basis of this research was the oceanographic condition. Finally, the analysis focused on identifying the location of mangroves brood and their connectivity between islands. In addition, this study also described oceanographic factors that influence the movement of mangrove propagules in the waters of the Indramayu Biawak Island. This research expected to be one of the basic research for MPA management. The efforts to manage marine conservation areas worldwide are depending on the regulations and management system. Recently, MPA is an area that potentially poses stress from outside, such as human activities and ocean pollution.

2. MATERIALS AND METHODS

2.1 Geographic Location

Biawak Island, as a conservation area, has 720 Ha and consists of two islands (Biawak, Gosong) and one atoll (Candikia). It is located about 19.2 nm from Indramayu, West Java Province (Fig. 1). The distance between the islands is around 3.51 nm. Biawak Island is the largest island with the ecosystem in coastal dominantly by mangrove and coral reef. Gosong island and Candikia are dominantly coral reefs. Java Sea (JS) is one of the seas with unique characteristic with especially in biodiversity and oceanographic condition (SImanjorang et al., 2018). These islands are one of 4 remote islands in the Java Sea, which have been intensively observed by Marine Science Department of Universitas Padjadjaran in the last six years by several research and projects.

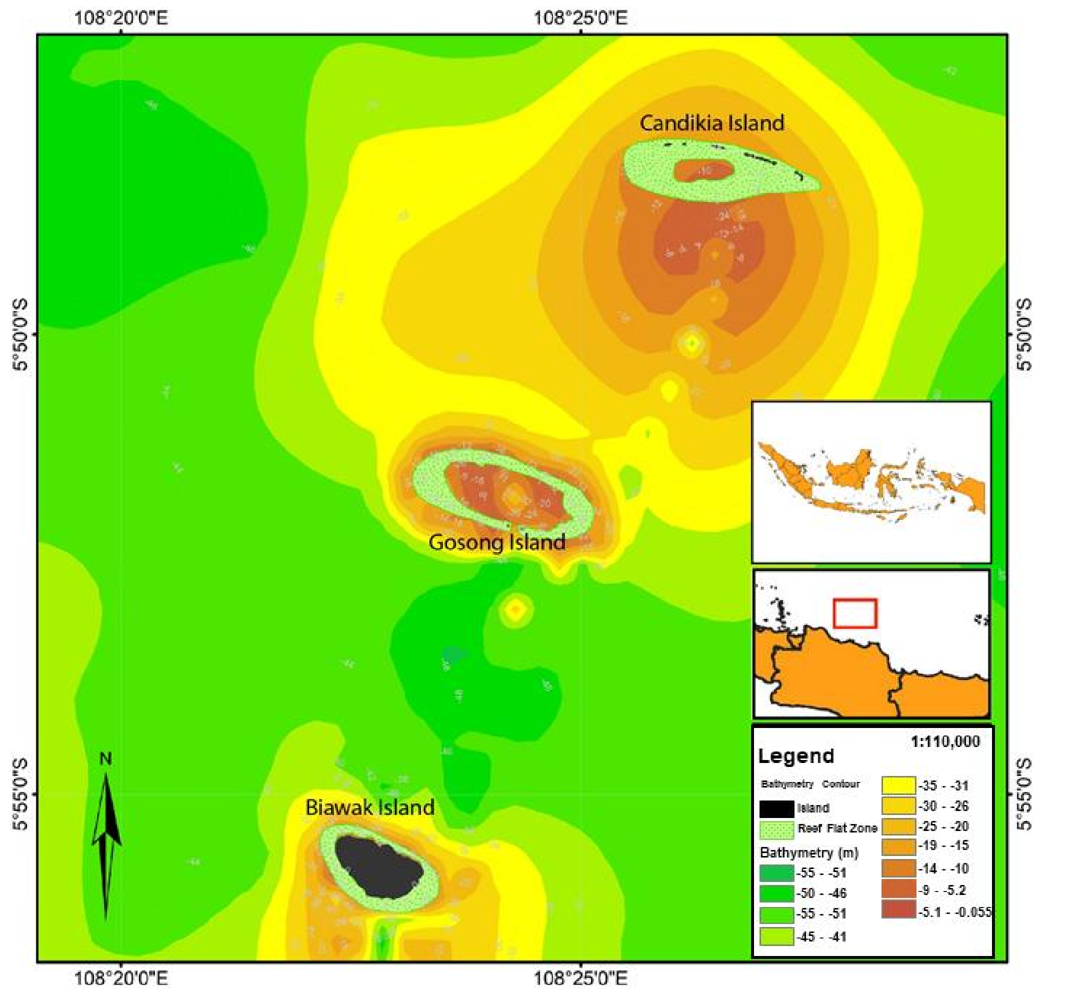

Fig. 1. The geographical location of the MPA in Biawak islands overlaid with bathymetry

In general, it is located in the Java Sea which is shallow water with depths ranging from 5 – 60 m [10], and ocean currents ranging from 0.17 - 0.32 m/s [15] and affected by monsoon situation. Alternating currents with a speed of 0.15 - 1 m / s are typically affected by tides [16] and monsoons [17]. Due to its location in the centre of Java Sea (JS), variations of the oceanographic condition at Biawak Island is supposed to be a similarity with JS characteristics. The monsoon mostly influences seasonal changes in this shallow-flat topography of JS due to the sea level difference between the Pacific and the Indian Ocean. Water masses from the South China Sea (SCS) flow to enter JS at two distinct monsoon seasons.

To simulate the propagule spreading, there were four stations in Biawak Island, one station in the Gosong Island, and one station in the Candikia. In the coastal area of Biawak Island, there are various mangrove species such as *Sonneratia, Bruguera*, and *Rhizophora apiculata*. Rhizophora species can be found throughout the south and east of coastal area. In contrast, Sonneratia and Brugueira can be found mostly in the western and northern parts of Biawak Island. In Gosong Island and Candikia, mostly covered by Rhizophora [16]. The selection of sampling point locations in the area is based on the site of the type of growing species and based on the results ecosystem connectivity study conducted by [10,11].

2.2 Data Collection

This study used data from several sources. For mangrove propagule, data were collected from field sampling in 2019 and from secondary data

[18]. The data consist of propagules weight and life cycle of mangrove (Table 1). Propagule sampling in 2019 was done by using GPS to find the propagule in coastal area.

Mangroves in Thailand started to seed in the rainy season [19]. Then, Rhizopora takes 60 - 61 weeks to become a ripe fruit while Sonneratia requires 15 weeks, and Brugueira needs 9 months to be a mature fruit [20,21]. For this purpose, we also assumed that November is the beginning of the mating season, and the process of Rhizophora to grow until the fruit is ripe is in July of the following year. For the Sonneratia species, it was assumed that the fruit ripens in March of the next year, and Burgueira in August of the following year.

Furthermore, physical parameters are collected from several portal data. The data downloaded and analyzed in 2018. data were simulated by global tide model and the type of tides in Biawak Island can be determined by calculating the Formzahl numbers, with the obtained Formzhal value of 1.03 fulfilling the requirements of 0.25 <F <1.50 [8]. To validated the data, field measurement done by TRAX and Marine Science Department were used.

In addition to oceanographic parameters, particle data is required propagule data. Particle data needed is mass, length, and average mass of propagules, assuming there is no increase in the propagule's weight as long as it floats to find a substrate to grow. The data visualized by GIS (Geographic Information System) Software and simulate with modelling software. The analysis focus on propagule trajectories and oceanographic system.

2.3 Validation

Model validation is done by comparing the tidal model data with primary data using the formula:

$Error$ = 1N [Σ|$X\hat{i}-XiTP$|Ni=1] × 100%.

Information:

- $X\check{i}$: Modeling results
- *Xi*: Field data
- *TP*: Mount Tide, a large range of observations is the difference between the largest and smallest values
- N: Number of data

From this formula, the error value obtained from the model is 0.03959131%. This means, the data model used is feasible to use and is approaching the real situation. The propagule trajectory simulation uses the particle trajectory module by combining the results of the hydrodynamic model with the propagule's mass [10]. Rhizophora mangrove samples are assumed to start

Table 1. Propagule sample mass data

No	Type	Mass (gram)	Source
1	*Rhizophora sp*	17.09	Field sampling (09/22/2019)
2	*Rhizophora sp*	9.39	Field sampling (09/22/2019)
3	*Rhizophora sp*	22.77	Field sampling (09/22/2019)
4	*Sonneratia sp*	48.06	[18]
5	Bruguera sp	8.25	[18]

Table 2. Oceanographic data

No.	Data	Resolution		Source	Remarks
		Temporal	Spatial		
1.	Tide	Monthly	0,125° x 0,125°	GTM	*Global Tide Model*
2.	Wind	Monthly	0,125° x 0,125°	ECMWF	*European Centre for Medium-Range Weather Forecasts* (http://apps.ecmwf.int/datasets/)
3.	Bathymetry	-	-	GEBCO	*General Bathymetric Chart of the Ocean* (http://www.gebco.net/data_and_products/)
4.	Mangrove Propagule Sample	2019	-	Insitu sampling	Calculated weight & length of mangrove propagules.

reproducing in November 2016, and November 2017 for Sonneratia and Burgueira samples. Each mangrove sample is made Three Months post-visualization of the ripe fruit, assuming that after the ripe month, not all fruits will fall at the same time. Therefore three visualizations are made three months after the fruit is ripe. The Rhizophora visualization of post-ripe fruit was formed in February, March, and April 2018, Sonneratia in March, April May 2018, and Burgueira in August, September and October 2018.

3. RESULTS AND DISCUSSION

3.1 Oceanographic Condition

Based on GEBCO model data and primary data fromT-RAX KOMITMEN survey from 2012-2016, the bathymetry of Biawak Island ranges from 4-50 m [8]. The tides in Biawak island during the transition season I (March up to May) with the highest tides up to 0.35 meter and the lowest tides was around 0.34 meter. The averages tidal range in this season was around 0.6 meters. In the Southeeast monsoon (SEM) which normally occurred from June to August, the highest tide reaches 0.4 meters, and the lowest tide was around 0.36 meter. The average tidal range in this season was 0.72 meters. In the transition season II (September to November) the highest tides reached 0.38 meters and the lowest was 0.35 meters. The average tidal range for this season was 0.64 meters, indicating that the Biawak Island's tide consists of a mixed tide prevailing semidiurnal. It means that in one day, there were two tides and two ebbs, but the height and period between those two tides are different.

Based on the model data, the ocean currents in the Northwest Monsoon (NWM) was 10,079 m/s, with minimum velocity was 0.054 m/s. In the SEM the ocean currents velocity was 10,079 m/s with minimum value was 0.509 m/s. Furthermore, the average wind speed in the NMW was 3.99 m/s, while in the SEM, the average speed was around 4.262 m/s, similar to [8,22]. Furthermore, there are two periods have high wind speeds, and mainly in the SEM and NWM. This is in accordance with the research [23], where the highest wind speed occurs during the East and West monsoon

3.2 Trajectory Patterns

Based on the simulation results, the propagules from each starting points move towards the open sea by following the direction of ocean current movement. The motion direction of the currents in Biawak Island is influenced by the direction of NWM and SEM patterns. Based on the result, the ocean currents flow in the SEM was faster than in the NWM. Then, each type of propagule has a different mass, and the distance and time for each kind of propagule also different. Variation in the propagules' weights also affected the velocity. Bruguera propagules faster compare to other propagules due to its mass.

Propagules of Rhizopora, on February it moved from every start point to the west, on March it moved from starting point moved to East, and on April it moved from starting point to East. The movement of Rhizopora's propagules causes by the NWM. Propagules of Sonneratia, on March it moved from every start point to the northeast, on Apr it moved from starting point moved to southeast, and on May it moved from starting point to South. The movement of Sonneratia's propagules causes by the transition season from NWM to SEM. Propagules of Brugueira, on August it moved from every start point to the South - Southwest, on September it moved from starting point moved to West, and on October it moved from starting point to West - South. The movement of Brugueira's propagules causes by the transition season from SEM.

The results of this modelling only show the trajectory pattern of the propagules using hydrodynamics to predict the direction of propagule propagation. The assumption is that the propagules have excellent resistance under extreme conditions. Propagules in each sample type show dynamic movements following the direction and speed of the current. The influence of the west monsoon and the east monsoon is dominant on the direction and speed of the current, which led all the propagules to be dragged along by the ocean currents, and not a single propagule is carried to one of the islands. This is following the research conducted by [10,16,17,24] which states that the west and east monsoons strongly influence the waters of Biawak Island. During the west monsoon, the propagule will be carried by the current to the east, and vice versa when the east monsoon occurs the propagule will be carried towards the west. Besides that, the lightness of the propagules' mass makes it easy for them to be carried by the current.

3.3 Discussion

All propagules are carried by the current; some to the south and some to the west. This occurred due to the east monsoon in August to October, where the wind blows from east to west. Therefore the propagules movement pattern tends to go back and forth. Wind drive will affect the surface elevation of the waters. When the wind blows from east to west, surface elevation in the eastern waters will be lower than the western side because the water column on the surface will be partially carried to the west, and vice versa.

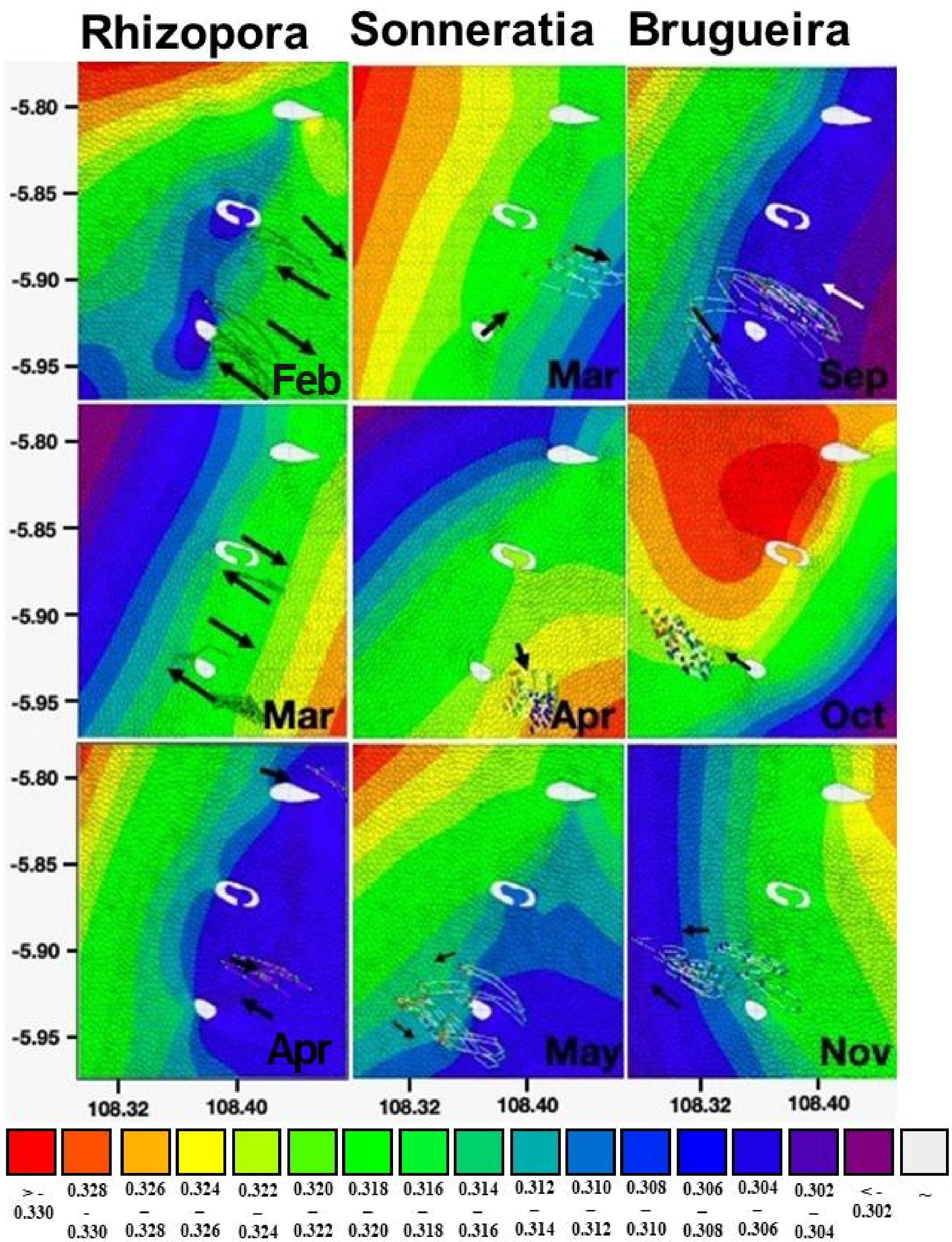

Fig. 2. Rhizophora, sonneratia and bruguiera propagul pattern trajectory with background ocean currents velocity (vector) and sea level (coloured)

Arrow represents the direction of motion of the propagule trajectory

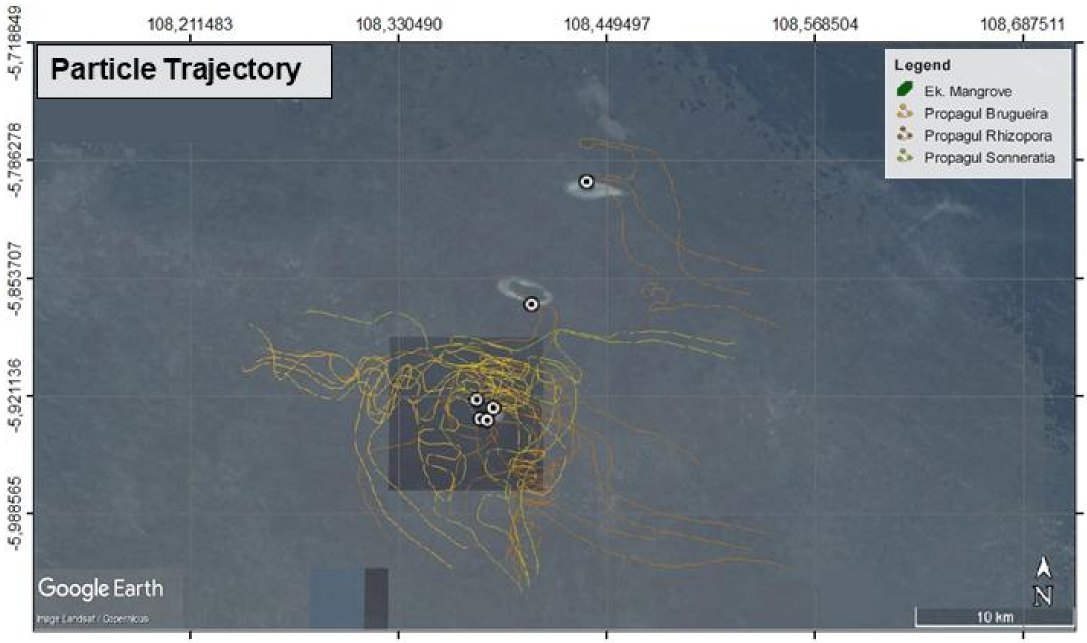

Fig. 3. Sketch pattern of mangrove propagule trajectory overall
The yellow colour is the Brugueira pathway. The green colour is the Sonneratia pathway, and the Brown colour is the Rhizophora pathway type

In the results of the study [10], planula originating from the western part of Biawak Island moved to Biawak Island, and some moved north towards Gosong and Candikia island. From the modelling results, it is predicted that the source of coral reef broodstock originates from the western part of Biawak Island, and it is also predicted that the coral reefs that are in charred and Candikia also come from the Western part of Biawak Island.

In the propagule modelling results, it is not known where the source of broodstock is from the mangroves, because none of the propagules is seen stuck on the coast of the three islands. In addition, the factor that can influence the propagules movement pattern is the period of the propagule itself. The lighter it is, the easier for it to be carried along with the flow, and vice versa. The propagules' resistance when it falls from its parent is an important factor [18]. If a mature propagule has resistance to extreme conditions that are not the same as the environment close to its broodstock, the propagule can survive in water columns until it can finally be plugged into the right substrate [25].

The particle trajectory model analysis shows that of the three mangroves (Rhizophora, Sonneratia, and Bruguera), none are stranded on any of the coasts of the three islands. The ocean currents carry all propagules. This is due to the east monsoon in June - October, where the wind blows from east to west, and in November - May there is west monsoon, where the wind blows from west to east, causing propagule movement pattern to go back and forth [10,24] due to the strong wind. Wind drive will affect surface elevation. When the wind blows from east to west, surface elevation in the eastern waters is lower than the ones in the west because the water column on the surface will be partially carried to the west, and vice versa. Propagule's mass will affect its buoyancy and movement [25]. The lighter it is, the easier for it to be carried along with the flow, and vice versa. The propagules' resistance when it falls from its parent is an important factor.

4. CONCLUSION

Analysis of the particle trajectory model shows that of the three mangroves (Rhizophora, Sonneratia, and Bruguera), none were stranded on any of the coasts of the three islands. The movement of mangrove propagules in Biawak Island is affected by two things: oceanographic conditions and propagules mass. The monsoon wind will change the direction of motion and the movement speed of the propagule. The weight of each propagule will influence its buoyancy and movement. The lighter it is, the easier the propagules are carried by the flow, and vice versa. The propagule's resistance when it has fallen from its parent is also an important factor.

The limitation of this research are we did not calculate the average number of mangrove propagules per year goes from one island to the next because we just focused on the trajectory of propagules. In the future, this research can be developed by widening boundary of research location, so we can find where the source of brood-stock is from the mangroves.

ACKNOWLEDGEMENT

I would like to express my gratitude to MEAL staff (Universitas Padjadjaran) for their logistical support and facilities for data processing, OSEANIK colleagues and KOMITMEN who helped collect data during the study, and D'ASarajevos colleagues who aided in data processing and discussions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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