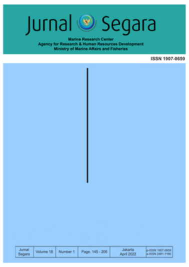

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SEAGRASS CONNECTIVITY BASED ON OCEANOGRAPHIC CONDITION IN THE MARINE PROTECTED AREA OF BIAWAK ISLANDS, INDRAMAYU

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ABSTRACT

Seagrasses are an essential component of the coastal environment with provide many ecosystem services beneficial to humans. Understanding the pattern of dispersal of segrasses is important for conservation management. The aimed of this research was to analyze the seed dispersal of the seagrass *Enhalus acoroides* in the Marine Protected Area of Biawak Islands, Indramayu, based on hydrodynamic modelling. Oceanographic data were downloaded from several open acces website and location of seagrasses based one insitu observation. Then, oceanographic parameters and seed traits were used to develop the particle trajectory model. Our analysis showed that the seafloor's depth around the islands varied, ranging from 8 m to 48 m. The seed dispersal was strongly influenced by alternating tidal currents (reversing current). The particle trajectory showed that most of the seeds would be transported outward away from each source in the islands, and they settled in deeper areas further from the coast of the islands. This result indicates that the seagrass population in Biawak Islands might depend predominantly on vegetative recruitment, which is slow. This may be related to the low seagrass canopy cover in Biawak Islands.

Keywords: Seagrass seeds, bathymetry, tides, atoll, Java seas.

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INTRODUCTION

Seagrass beds are one of the ecosystems that have an essential role in the vastness of the oceans worldwide (Nagelkerken *et al*., 2000). Seagrasses are marine flowering plants (*Angiospermae*) that live in shallow waters where sunlight still penetrates (Rahman *et al*., 2016). The seagrass *Enhalus acoroides* is a common seagrass species found in Indonesia. The characteristic of this spesies is reproduce in vegetative and generative ways (Irawan & Matuankotta, 2015). The period of flowering and fruiting of seagrass varies depends on the spesies and location. Based on the previous research, the flowering phase of *Enhalus acoroides* occurs during the lowest tide phase during the day (Waycott *et al*., 2004). In the process to settle in suitable locations, *Enhalus acoroides* seeds will float on the sea surface for 14 hours until the seed coat rots or breaks (Lacap *et al*., 2002).

Seagrass has many functions in the ecosystem such as its sediment can be a habitat for various biota, as ocean currents and wave breaker, to trap sediments, circulating nutrients, and carbon absorbtion (Tasabaramo *et al*., 2015). Despite the fact that it plays a vital role in coastal areas, the seagrass ecosystem has suffered enormous damage from natural force and dominantly by the human activities (Tangke, 2010). In the era of climate change and marine pollution, It is need long time for seagrass to grow (Fonseca *et al*., 1987) .

Seagrass cover percentage in Indonesia is around 41.79% (Hernawan *et al*., 2017). Based on the previous research, it is found that since 1980, seagrass meadows in the world decreased significantly, and reaching 58% in 2008 (Dennison, 2009). In the end, this degradation can disrupt ecosystems sustainable in coastal areas and coastal areas become less protected (Guannel *et al*., 2016). Tangke (2010) stated that the three ecosystems are associated with coastal areas and make coastal areas fertile and productive.

One of the Marine Protected Areas (MPA) is Biawak Island located in Java Seas and administrated by West Java Province. Previous research has stated that seagrass cover in these islands has a low category of 5-10% with the types of seagrass found are *Enhalus acoroides* and *Halophila sp* (Purba *et al*., 2018; Purba & Harahap, 2013). Previous research (Fitriadi *et al*., 2017; Salsabilla *et al*., 2020) have discussed the movement of coral reef planula and mangrove propagule in the MPA of Biawak Islands, however, there is still no modeling study for seagrass to completed the research of ecosystems connectivity.

This research focuses on analyzing the particle trajectory of the seagrass seed *Enhalus acoroides* in the MPA of Biawak Islands, Indramayu. As this MPA located in Java Seas, there are many stress that disturb especially by human activities (Abimanyu *et al*., 2021; Purba *et al*., 2020). Furthermore, with the connectivity in the three islands, it will arranged in the marine conservation area of Biawak Islands, Indramayu. Finally, the result of this research can be as foundation to manage the restoration and reconstruct marine zone in the three islands.

METHODOLOGY

Geographic Characteristics

MPA of Biawak Islands is located at coordinates 5°56'002" South and 108°22'50" East with 120 ha total area. Biawak island located 40 km from Indramayu District in the northern part of Tirtamaya Indramayu Beach. Biawak Islands surrounded by three islands, including Candikian, Gosong, and Biawak Islands (Purba *et al*., 2022). The main island and also the biggest island is Biawak Island located in the southern side (Figure 1).

There were nine seagrass spots in this area and mostly located in Biawak island. This is also become a Starting Point (SP) for simulation. The spots of seagrasses already define from previous in-situ sampling (Purba & Harahap, 2013). In general, the characteristics of the waters on the Marine Protected Area of the Biawak Islands represent the Java Seas. The waters surrounding the Marine Protected Area (MPA) of Biawak Islands is influenced by monsoons and tides (Purba *et al*., 2017). The ocean currents velocity on Biawak Islands ranges from 0.17 to 0.32 m/s. The sea depth is relatively shallow compare to other seas with around from 5 - 60 meters. Furthermore, the depth of the Java Sea has an average of 40 meters (Purba *et al*., 2018). Monsoon patterns occurred twice a year with wind comes from Australia in June, July, and August and other months (December, January, and February) come from Asia.

Data and Method

The data were obtained from several sites that provided open data acces. First, Tidal and Wind were using same resolution 0.125° x 0.125° monthly from Global Tide Model Toolbox and European Centre for Medium-Range Weather Forecasts (ECMWF: http://apps.ecmwf.int/datasets/) respectively. Second, For bathymetry, the data provided from General Bathymetric Chart of the Oceans (GEBCO: http://www.gebco.net/data_and_products/) using 0.04° x 0.04° resolution.

In the next step, tidal, wind and bathymetry data are used to create a hydrodynamic model in a designated area. The particle trajectory model was made after the hydrodynamic model gave trusted result. Using data on the weight of seagrass seeds

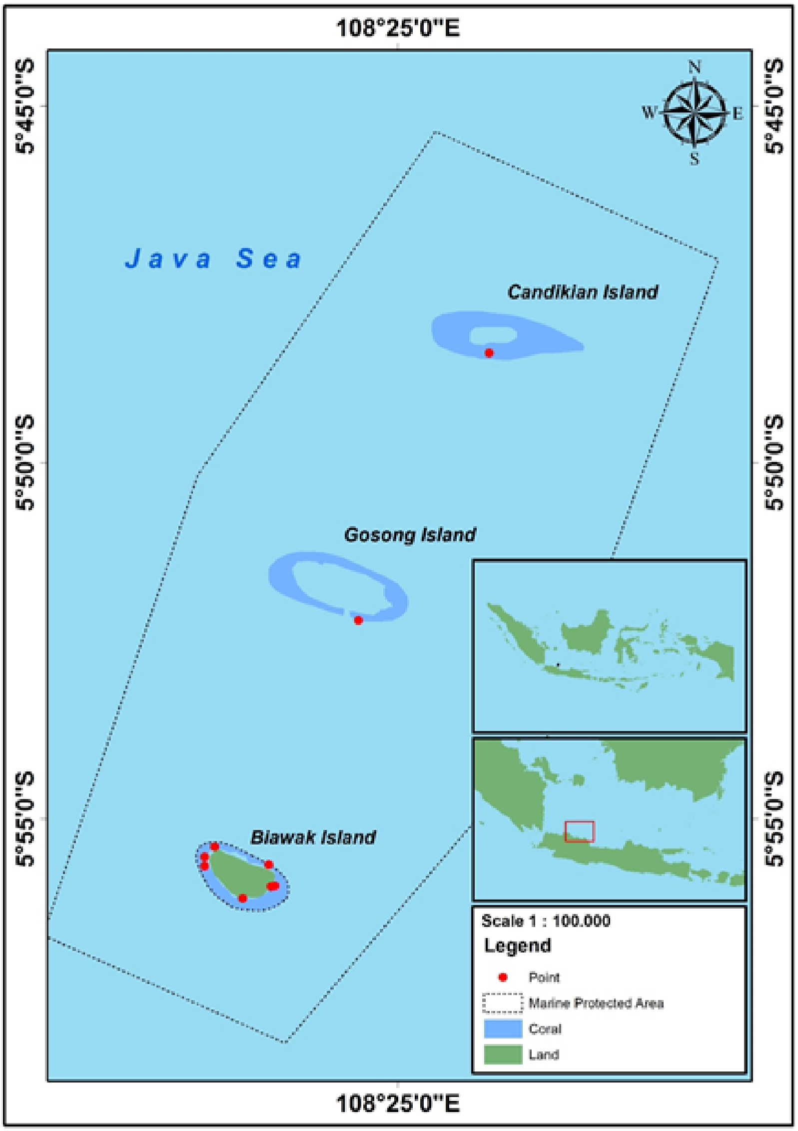

Figure 1. Geographic Location of Marine Protected Area Biawak Islands, Indramayu, West Java. The red dot represent the seagrass spots.

(249 mg) (Lacap *et al*., 2002), the model will produce the movement of the *Enhalus acoroides* seagrass seeds. The model of seagrass movement was run for seven days because it assumed that *Enhalus acoroides* seagrass seeds floated in the waters for seven days. The running model was carried out during four monsoon cycles in Indonesia, namely the West Monsoon (Dec, Jan, Feb) , Transition 1 Monsoon (Mar, Apr, May), East Monsoon (Jun, Jul, Aug), and Transition 2 monsoons (Sep, Oct, Nov).

Model Validation

Model validation is done to measure the level of accuracy in a model. Parameters that need to be validated include wind, shoreline and tides. Coastline data was obtained from google earth. Wind data obtained from the ECMWF website has a relatively significant accuracy, especially in the tropics, so there is no need for model validation (Haiden *et al*., 2016). Validation of the model on the tides using the Root Mean Squared Error (RMSE), a mathematical formula used in evaluating a linear regression model to measure a model's accuracy level. The formula for determining model validation on tides can be seen below:

$$\text{RMSE} = \frac{1}{N}\ (Total\ of\ data\ \left|\frac{y_i - \hat{y}_i}{tidal\ difference}\right|)$$

where,
N : Number of data
yi : Data model 1
y î : Data model 2

RESULTS AND DISCUSSION

Oceanographic Conditions on Biawak Islands

The bathymetry of the Biawak, Candikian and Gosong islands has a depth of 8 - 48 m. These waters are one of the shallow waters in the Indonesian Seas. The waters in KKP (Kawasan Konservasi Perairan) Kepulauan Biawak have currents that are influenced by the monsoon cycle. In the West Monsoon, the highest tide reaches 0.35 m and the lowest reaches 0.27 m below sea level. In Transitional Monsoon 1, the highest tide reaches 0.30 m, and the lowest tide reaches 0.29 m below sea level. In the East Monsoon, the highest tide reaches 0.32 m and the lowest reaches 0.27 m below sea level. In Transitional Monsoon 2, the highest tide reaches 0.28 m, and the lowest tide reaches 0.29 m below sea level. This type of tidal water is Mixed and predominantly diurnal. The tidal type in Indramayu waters has a mixed type, which tends to be a single day (Budi & Ultimate, 2017)

The wind in the study area has a maximum speed during the West and East Monsoon cycles, namely 10 m/s and 7.6 m/s. Two monsoon cycles have the highest speed in one year, namely in the West and East Monsoons (Sakti, 2004). The average wind speed in Transition 1 and Transition 2 monsoons are 3.29 m/s and 3.52 m/s. During the West Monsoon, the wind tends to blow from the West.While in the East Monsoon, the wind tends to blow from the East.

Hydrodynamic Model and Particle Trajectory Model

The model validated using the tidal data model that has been processed with a value of Chezy Number (CN).CN 30 was selected with the error 14.15%, slightly smaller than other two CN (32 and 34) 14.18% and 14.22% respectively. The level of accuracy in this model is 85.85%.

Particle trajectory model simulations have been carried out on four monsoon cycles: the West, Transition 1, East and Transition 2 monsoons. In each trajectory simulation result, the seagrass seed particles of *Enhalus acoroides* have the same tendency of movement patterns, namely rotating circularly on each island where the sources are located (Figure 2).

The pattern of alternating tidal currents or what is commonly called reversing current is the cause. This is similar to the previous research (Handyman *et al*., 2019; Salsabilla *et al*., 2020) that the current movement pattern in the waters of the KKPKI Biawak Islands tends to go back and forth. In other research (Nurulita *et al*., 2018) mentioned that the tidal current pattern in the waters of the Biawak Islands has a reversing current pattern. The ocean currents movement pattern occurs because the current does not tend to be affected by seasonal winds but tends to be affected by tidal conditions in these waters. Distribution of seagrass seeds *Enhalus acoroides* is strongly influenced by ocean currents. Seeds will be carried away by currents and grow in a suitable environment (Hidayatullah *et al*., 2018).

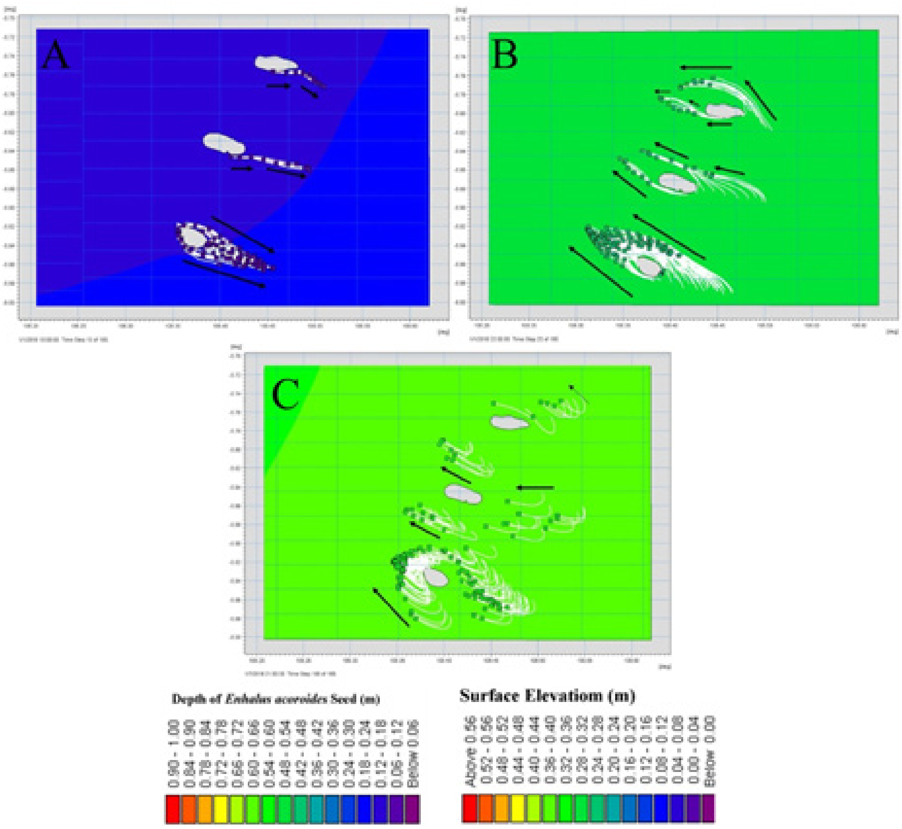

Figure 2. Particle trajectory model in the West Monsoon by Day. Note: A = Day 1, B: Day 3, C: Day 7.

Visualization A in Figure 2 is the initial condition in the 10th timestep of *Enhalus acoroides* seagrass seeds on each island moving away from their respective sources to the island's East. The movement of seagrass seeds *Enhalus acoroides* is classified into 2, namely abiotic and biotic. Abiotic is done by wind, and biotic is done by animals (Orth, 2006). In this study, the movement of *Enhalus acoroides* seagrass seeds was only assumed to be moved by abiotic factors.

In visualization B, on the 22nd timestep, the seagrass seeds on Candikian Island move in 2 directions: the North and south of the island. *Enhalus acoroides* seagrass seed particles move to the West. The same thing happened on Gosong Island. The particles moved in two different directions, namely in the North and South parts moving towards the West. This is because, in the West Monsoon, the wind tends to blow from the West.

In the final condition of visualization C, the West Monsoon particle trajectory model is assumed that the particles stop moving and start looking for a place to grow (Figure 2). Biawak Island's Particles dominate in the East, North and West parts of the island. No particles on Biawak Island that settle or are in the coastal area of Biawak Island. On Gosong Island, the dominant particles are far to the island's East, North, and South. There are no particles that settle on the coast of Gosong Island. While on Candikian Island, the dominant particles are in the northern part of the island, there are no visible particles that settle on the coastal area of Candikian Island.

Visualization A in Figure 3 is a visualization of the Transitional Monsoon 1 on the 10th timestep on March 1, 2018, at 10.00 WIB. On Candikian Island, the particles move towards the East of the island and then towards the southeast, while on Pulau Gosong, the particles move towards the southeast. On Biawak Island, the particles move towards the southeast away from the island, from each sources.

Visualization B is the 22nd timestep, on March 1, 2018, at 22.00 WIB. On Candikian Island, the particles move in 2 directions, namely toward the north and south of the island, which then go to the West of the island. In contrast, on Gosong Island, the particles move past the southern part of the island. The particles move towards the northwest, away from Gosong Island. On Biawak Island, in every sources the particle moves in the opposite direction from the previous timestep to the northwest of the island.

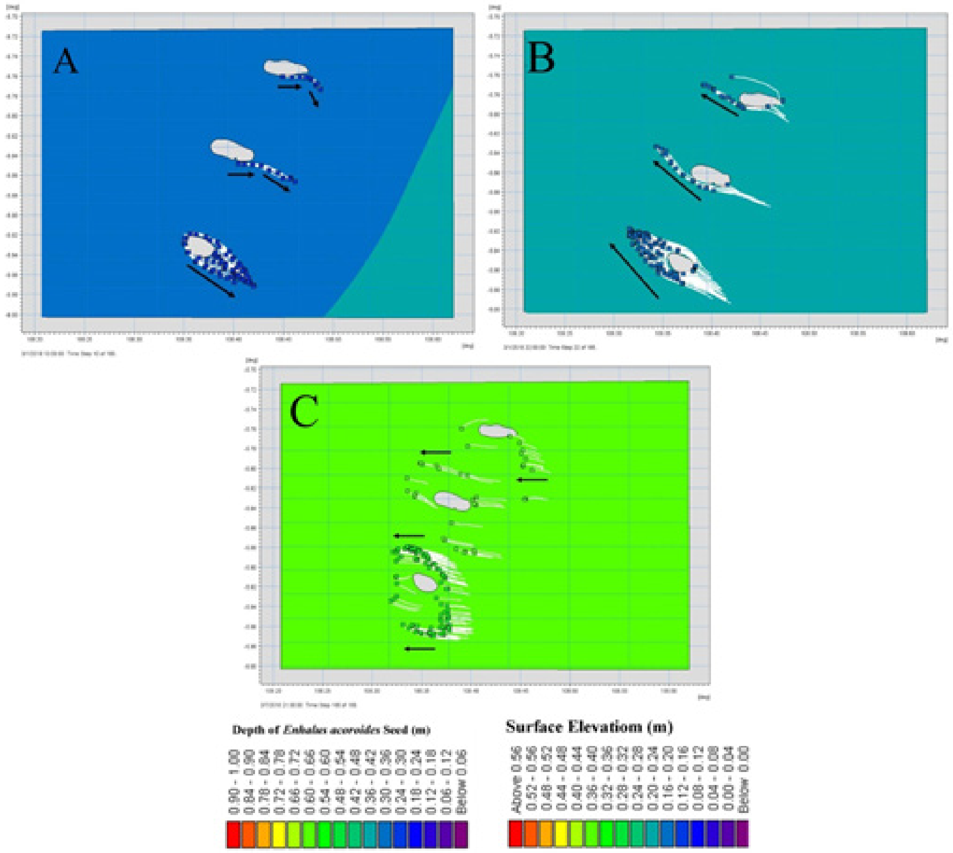

Figure 3. Particle Trajectory Model in Transitional Monsoon by day 1. Note: A = Day 1, B: Day 3, C: Day 7 ay 7.

Visualization C of the Muson Transition, one particle trajectory model, is assumed to be the final state of the particle. On Biawak Island, the particles are around the island, but it can be seen that there are no particles deposited on the island coast (Figure 3). Particles on Gosong Island dominate in the southern part of the island near Biawak Island. There are no particles that settle on the coast of Gosong Island. Meanwhile, the movement of particles on Candikian Island is in the southeastern part of the island. The movement of particles in the south of the island moves closer to Gosong Island.

The movement of *Enhalus acoroides* seagrass movement seeds at the 10th timestep on June 1, 2018, at 10.00 WIB. It can be seen on Candikian Island that the origin of seagrass seeds in the southern part of the island moves straight to the West of Candikian Island. In contrast, on Gosong Island, seagrass seeds in the south part of the island also move straight to the island's West. On Biawak Island, seagrass seeds from 7 sources located around Biawak Island move northwestward away from the island.

Visualization B is a visualization on the 22nd timestep on June 1, 2018, at 22.00 WIB. On Candikian Island, the particles move back to the island's East through the southern part of Candikian Island. The particle movement spreads away from Candikian Island. On Pulau Gosong, the particles move back eastward past the Southern part of the island. On Biawak Islands, at each source, the particles move around back to the southeastern part of the island

The East Monsoon particle trajectory model in visualization C is assumed to be the final state of the particle (Figure 4). On Biawak Island, the dominant particles are in the southern part, away from the island, and there are no particles that settle on the island's coast. Particle conditions on Gosong Island are in the South and West of the island. In the western part of the island, the particles are away from the island. Particles in the southern part of the island are close to Biawak Island. The particles on Candikian Island are in the Northeast and East of Gosong Island.

In visualization A, figure 5 shows particles' movement at the 10th timestep on October 1, 201,8 at 10.00 WIB. On Candikian Island, the particles located in the southern part of the island are the initial conditions for the particles to move eastward, combing the island's coast and then slowly descending towards the island's southeast. Meanwhile, on Gosong Island, the particles in the southern part of the island begin to move towards

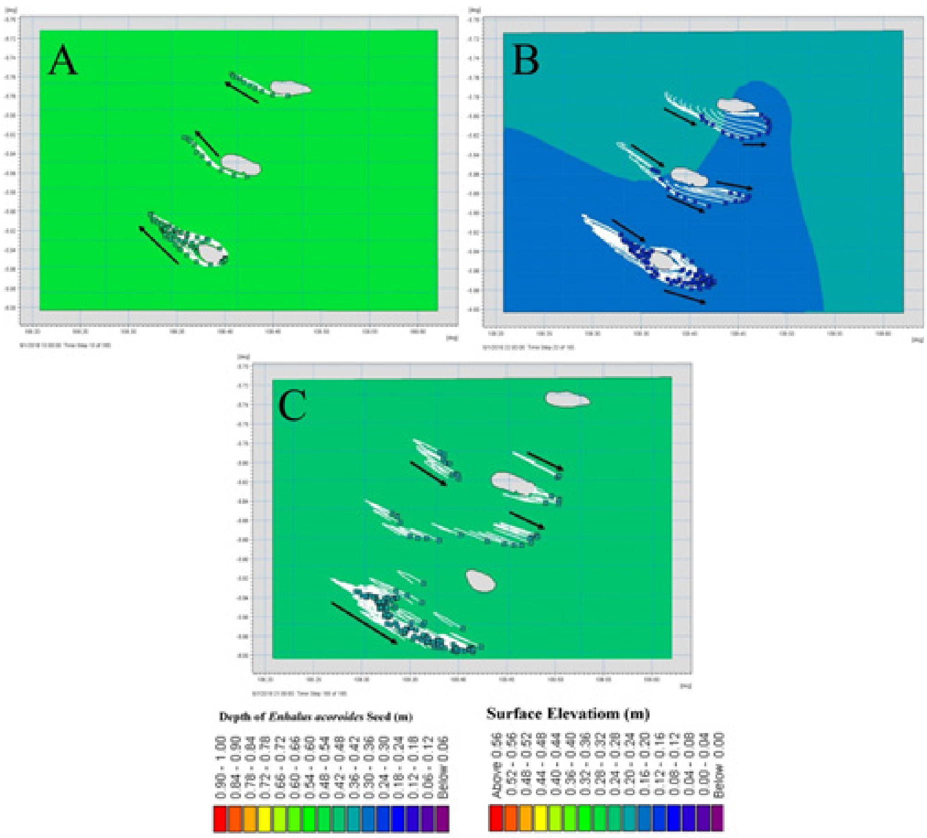

Figure 4. Particle Trajectory Model in the East Monsoon. Note: A = Day 1 of the trajectory particle modelling, B: Day 3 of the trajectory particle modelling, C: Day 7 of the particle trajectory particle modelling.

the East. Then it down towards the island's southeast, away from the island. On Biawak Island, particles in 7 sources move simultaneously towards the island's southeast away from the sources, the starting point for moving particles.

Visualization B is the movement of particles at the 22nd timestep on October 2, 2018, at 22.00 WIB. Particles on Candikian Island move in both directions, namely in the northern and southern parts of the island. In the north part of the island, the particles move northwestward away from the island. While in the south part of the island, the particles move westward along the island's coast. On Pulau Gosong, the particles move to the north. In the island's north, the particles move back through the north and move towards the West. Particles on Biawak Island, located in the eastern part of the island, move around in the opposite direction, namely towards the island's West through the northern region.

In the transitional Monsoon particle trajectory model, two visualization C is assumed to be the final state of the particle (Figure 5). The final condition of the particles on Biawak Island is dominant in the southern part of the island. On Gosong Island, the particles are in the southeastern part of Gosong Island, approaching Biawak Island. On Candikian Island, the particles are in the northeast, East and Southeast of the island. The distance of the particle trajectory seagrass seeds *Enhalus acoroides* from Starting Point (SP) to End Point (EP) provided on table below (Table 1).

As seen from the bathymetry in the areas of Biawak Islands and seen from the dominant position of particles in the model, the particles are in a slightly deep water column, ranging from 25 to 45 m in depth. This depth makes the seagrass type *Enhalus acoroides* have a tiny chance of survival. Seagrass *Enhalus acoroides* is often found and abundant in shallow waters to a depth of 4 meters (Rahman *et al.*, 2016). This can be one of the reinforcing factors for research that has been carried out (Purba & Harahap, 2013) which states that the coverage in the Biawak Islands KKPKI area is low, around 5-10%. The overall sketch of the movement of the particles can be seen in the image below.

In addition to these two factors, the movement of seagrass seeds *Enhalus acoroide* can still be influenced by biotic factors, namely animals (Orth, 2006). The influence of water quality and the resistance

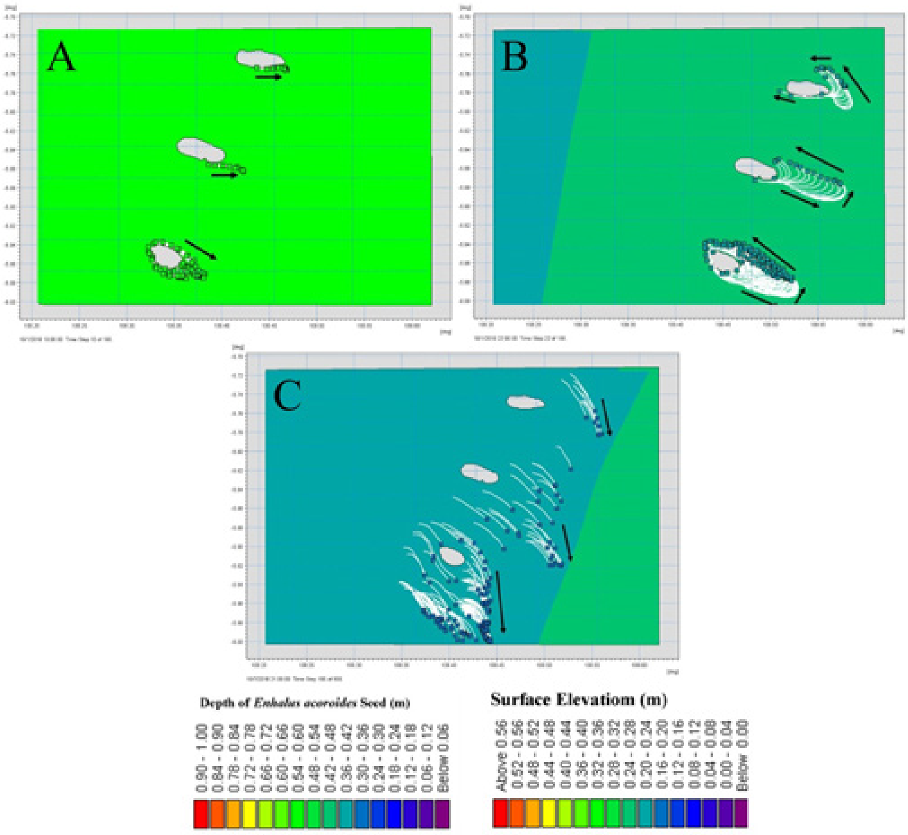

Figure 5. Particle Trajectory Model at Transitional Monsoon 2. Note: A = Day 1 of the trajectory particle modelling, B: Day 3 of the trajectory particle modelling, C: Day 7 of the particle trajectory particle modelling

Table 1. Distance of the Particle Trajectory of Seagrass Seeds Enhalus acoroides from the starting points

Source	Coordinate		Distance (km)			
	Longitude	Latitude	West Monsoon	East Monsoon	Transitional Monsoon 1	Transtitional Monsoon 2
1	108.40743	-5.571608	96.29	87.88	61.85	70.04
2	108.4385	-5.809678	99.32	79.76	63.30	83.44
3	108.37931	-5.938633	103.87	85.78	61.28	66.41
4	108.39004	-5.936343	104.63	87.94	57.83	65.76
5	108.39122	-5.935034	104.18	89.63	57.93	65.44
6	108.3869	-5.925938	87.51	85.08	59.80	66.57
7	108.36922	-5.928836	108.32	84.52	56.73	67.77
8	108.36889	-5.924657	101.98	85.12	55.83	68.64
9	108.3732	-5.921783	97.36	84.90	61.57	65.93

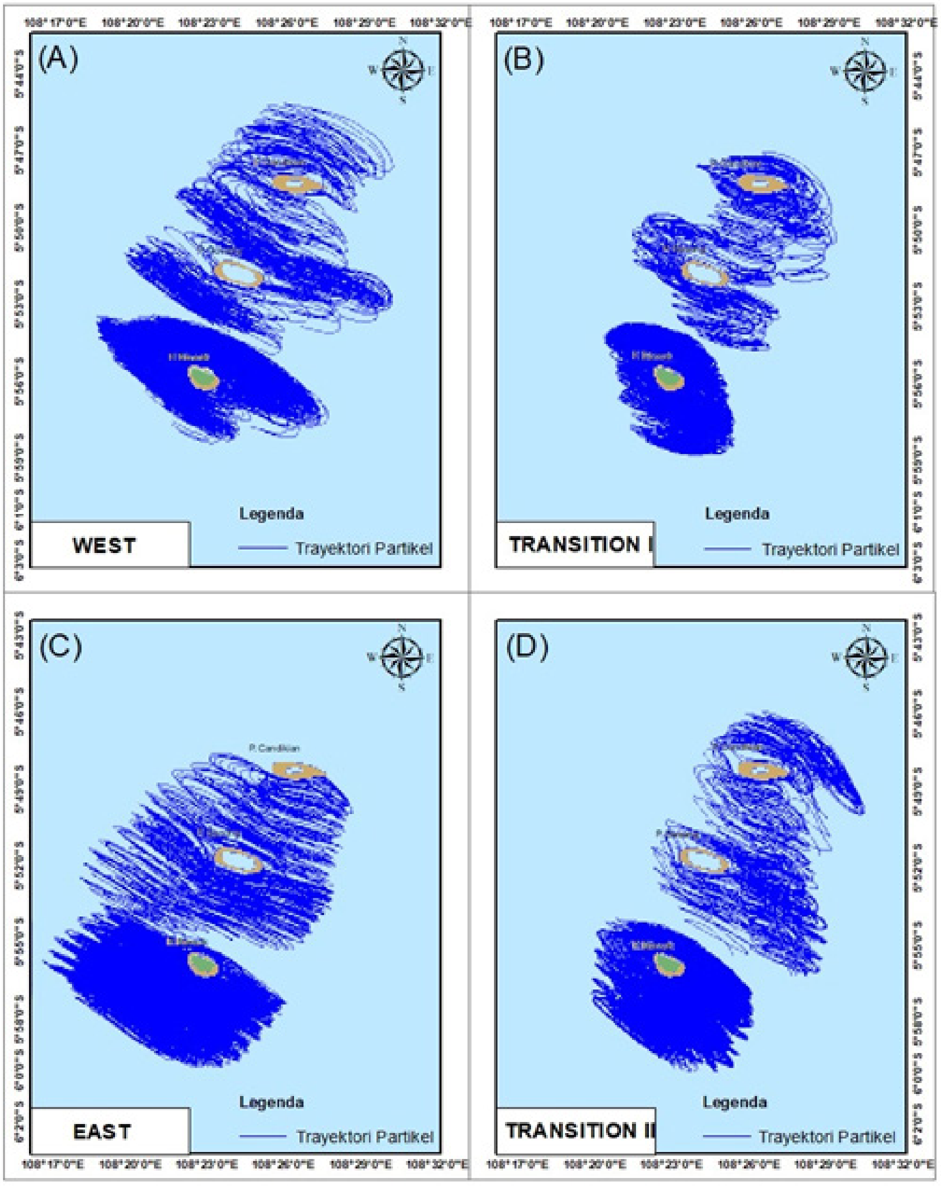

Figure 6. A sketch of the trajectory particle of *Enhalus acoroides* seagrass seeds from its starting points near the island. Note A: West Monsoon, B: Transition 1 Monsoon, C: East Monsoon, D: Trasition 2 Monsoon.

of seagrass seeds when floating is another factor in the movement of seagrass seeds. The increase in mass in the actual condition of the particles is also a factor in the movement of *Enhalus acoroides* seagrass seeds. Seagrass *Enhalus acoroides* can reproduce generatively by producing seeds and vegetatively using rhizomes (Listiawati *et al*., 2018). Seagrasses are generally dioecious where male and female flowers are separated. Pollination of seagrasses is carried out in three forms, namely pollination in the water (hydrophilous pollination), pollination on the water surface (ephyhydrophilous pollination), and pollination in the air (subaerial pollination) (Sari & Lubis, 2017).

CONCLUSION

The movement of the seagrass seed particles of *Enhalus acoroides* in each monsoon cycle has a movement pattern that tends to be similar because it is influenced by the alternating tidal currents in the KKPKI area. Particles move and stop at various depths, namely at a depth of 25 m - 45 m. The particle trajectory model of *Enhalus acoroides* seagrass seeds in each monsoon shows that most of the particles move outward from each source on each island and do not settle on the island's coast.

ACKOWLEDGEMENTS

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