The trajectory of marine debris from Cirebon City Estuary, West Java, Indonesia

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Abstract. Marine debris is a global issue due to its negative impact on the marine environment, marine biota, and human health. The current study aimed to predict the spreading of marine debris in the surface water to analyze the stranded area in the coast of Cirebon. The research area was located in the four estuaries. The method used combines portable artificial debris tracking with GPS, visual naked eye observation and a trajectory model. The simulation used the General NOAA Operational Modeling Environment (GNOME) suite, a set of modeling software tools for predicting the fate and transport of pollutants. The simulation was based on different types of waste at high and low tides. The results showed that waste movement is mainly affected by wind, ocean currents and tidal patterns. The direction of waste in each season follows the seasonal pattern. Marine debris pollution occurred during the South East Monsoon period in several areas, including Gunung Jati, Bondet and Klayan. The pollution also occurred during the North West Monsoon.
Key Words: GNOME, marine pollution, marine debris, modeling, ocean currents.

Introduction. Recently, marine debris (MD) has become a global challenge. Debris, specifically plastic contamination, is dangerous due to its impact on the marine environment (Chenillat et al 2021). Based on previous research, it has been found that MD pollutes several parts of the world ocean, such as the Pacific Ocean, Atlantic Ocean, and Indian Ocean (Eriksen et al 2014). Furthermore, MD is found around the coastline, surface water, and seabed, with an accumulated amount of 75% in those areas, with the potential to increase (Browne et al 2011). Furthermore, ocean currents are the main factor that causes cross-border contamination problems between countries (Purba et al 2021). Previous research has stated that Indonesia is one of the largest polluters (Lebreton et al 2017), with a generated MD volume of around 0.48-1.29 MMT year^{-1} (Jambeck et al 2015). The problem of MD in Indonesia is unavoidable due to the behavior of people who have the habit of disposing of the massive amount of waste, particularly single-use waste, on the river (Kusumawati & Setyowati 2020). MD pollution in Indonesia mostly comes from human activities on lands near the riverbanks (Lestari & Trihadiningrum 2019).

One of the cities with waste pollution diffusing from the estuary to the sea is Cirebon City, which has four large estuaries with heavy levels of contamination, including marine debris. This area is one of the polluted cities due to uncontrolled waste management, especially terrestrial pollution (Sudirman & Husrin 2014). MD has already impacted the fishing industry, as fishing boats are hampered by the garbage in the fishing nets, affecting fishers' activities (Hermawan et al 2017). Another risk is that caught fishery products are polluted by micro-sized marine debris in certain capture fishery areas (Lusher et al 2017).

One of the recent modelling software used to predict material spreading is the General NOAA Operational Modeling Environment, GNOME (Purba et al 2021a). Previous research mentioned that NOAA's GNOME software could predict pollution that occurs in the sea, with particle motion as an assumption of contamination diffusion models (Zelenke et al 2012). The modeling of marine debris in Indonesia using NOAA's GNOME has been carried out in Indonesian waters with different results, according to the scenario carried out in the modeling (Purba et al 2020).

The current research focused on predicting the movement of marine debris trajectories in the city of Cirebon from four estuaries to the sea waters of the city of Cirebon and its surroundings. There is a windage class scenario, which refers to the actual pollution condition by classifying the pollution weight assumptions generated in the running models.

Material and Method

Description of the study sites. The research was carried out in the waters of Cirebon City (Figure 1). Observations were made near Cirebon waters, precisely in the river mouth, where the source's presence indicated marine debris pollution (Putra & Husrin 2017). The research area is spread over four major river estuaries, including Kesenden Estuary, Sukalila Estuary, Kesunean Estuary, and Kalijaga Estuary.

Figure 1. Geographic location which has four estuaries that flow to the Java Sea. All rivers surrounded by settlements and local industries.

The Tangkil Estuary, Kesunean Estuary and the Kalijaga Estuary have a length of 51,850 m, and the Sukalila estuary has a 20,400 m length (RPIJM 2016). The condition of the Java Sea waters is strongly influenced by the tidal system, which is influenced by the monsoon (Putra et al 2020). This is based on the existence of a tidal system in Indonesia that influences wave propagation from surrounding seas including the Pacific Ocean, Indian Ocean, and South China Sea (Wei et al 2016). The tide characteristics around the Java Sea is a mixed type which occurring twice daily by experiencing two cycles of high tide and low tide conditions (Mustaid & Tetsuo 2013). Furthermore, monsoon winds influence the characteristics of ocean currents in the Java Sea area in each season, as shown by previous research that states that the Java Sea waters depend on the monsoon system (Budi & Pamungkas 2017).

Data analysis. In situ sampling was carried out in September 2021 by observing the movement of waste to be able to find out the direction of the movement of garbage originating from the contamination of four river estuaries in the site area towards the sea.

Then, by tracking each movement of each type of waste within 15 minutes at four experimental points around the river estuary in high and low tidal conditions. The GNOME model approach is carried out on seasonal timescales in Cirebon waters, in different seasons: the west monsoon (December, January, and February) and the east monsoon (June, July and August). Three windage class data (1-2, 2-3 and 3-4%). This is a scenario in waste pollution that occurs in the area were identified by previous studies to determine differences in the movement of marine debris, based on scenarios (Purba et al 2020). The model used secondary data and a map that includes bathymetry and boundary conditions, ocean currents, winds, and tides. The data used have certain specifications in obtaining the results of the model in the study (Table 1).

Table 1

Source and resolution of the dataset

No	Tools	Data	Resolution	
			Spatial	*Temporal*
1	Ocean currents	https://ncss.hycom.org/ NetcdfSubsetService at HYCOM.org	0.083^o	3 hours
2	Wind	http://coastwatch.pfeg.noaa.gov/erddap/Tidal	0.5^o	3 hours
3	Tides	http://tides.big.go.id/	-	30 days
4	Model	GNOME	50 m	30 days
5	Basemap data	https://gnome.orr.noaa.gov/goods	-	-

The simulation modeling of marine debris movement using NOAA's GNOME software. The software uses a Lagrangian dispersion model. The data model has three scenarios (based on windage classes) which make the windage stress to the surface as contamination in the research area. The simulated weight of waste released is around one kg originating from four estuaries in Cirebon City.

Results

The trajectory of marine debris. The results of the simulation are as follows (Figure 2): in January and February, marine debris particles tend to follow the direction of currents and winds originating from the west, so in scenarios 1-3, it can be seen that garbage accumulates around the coast of the Cirebon Regency. The model in March has differences in each scenario. In scenario 1, the waste tends to float around the Java Sea. The experiment considers waste contamination of 1 kg per scenario. In contrast to scenario 1, in scenarios 2 and 3, the waste particles tend to exceed the base map threshold and move towards the Northwest. During the April-August period, garbage particles tend to move around the mouth of the river estuary due to the direction of currents and winds blowing from the Northeast and East, so that the coastal area to the mouth of the coastal estuary of Cirebon City experiences garbage contamination. From September to December, the movement of MD particles changes towards the Cirebon Coastal area, the border of West Java and Central Java. It is assumed that MD particles tend to move to the Brebes City Coastal area.

Wind characteristics. Overall, wind conditions in the waters of Cirebon City have different characteristics in each month as the monsoons influence it (Figure 3); therefore, the direction of the wind movement changes in 2-3 months which follow monsoon situations. the pattern of the wind direction during the transition season, in January-March 2020, indicates a movement from the West-Northwest direction. In April and May, the wind tends to blow from various directions and dominantly from the North, East and Southeast. In contrast to transitional season 1 in June, July, and August, the wind blows from the East and Southeast. The wind direction in the period September-November experienced a change. In September, the winds come from the southeast. In October and November, it comes from various directions, and in December, it comes again from the west. The wind speed in the Cirebon City Waters ranges from 1.3 to 3 m s^{-1}. The peak is in the range of 1.3–2.7 m s^{-1}, changing direction every 2-3 months.

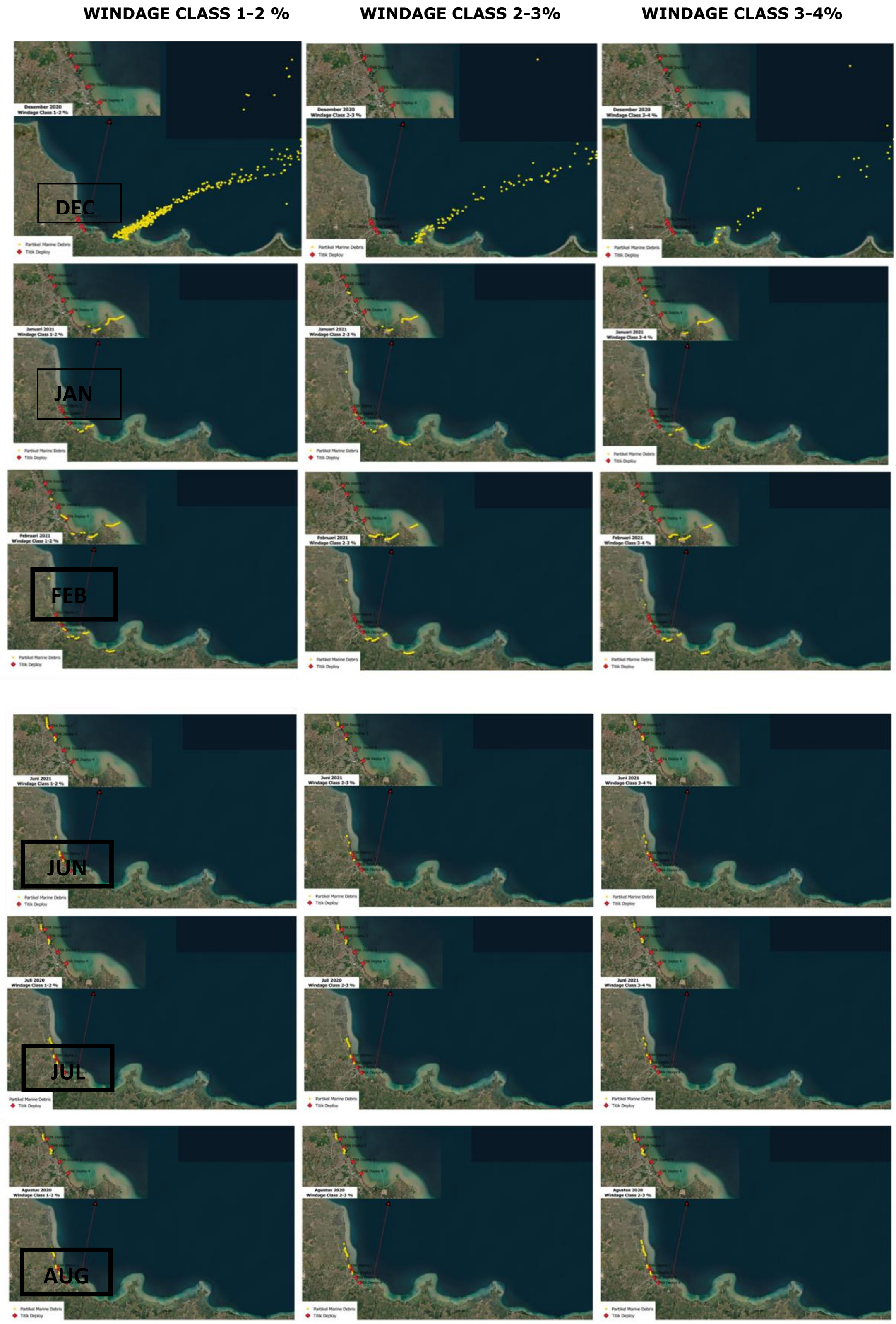

Figure 2. Marine debris trajectory during NWM and SEM.

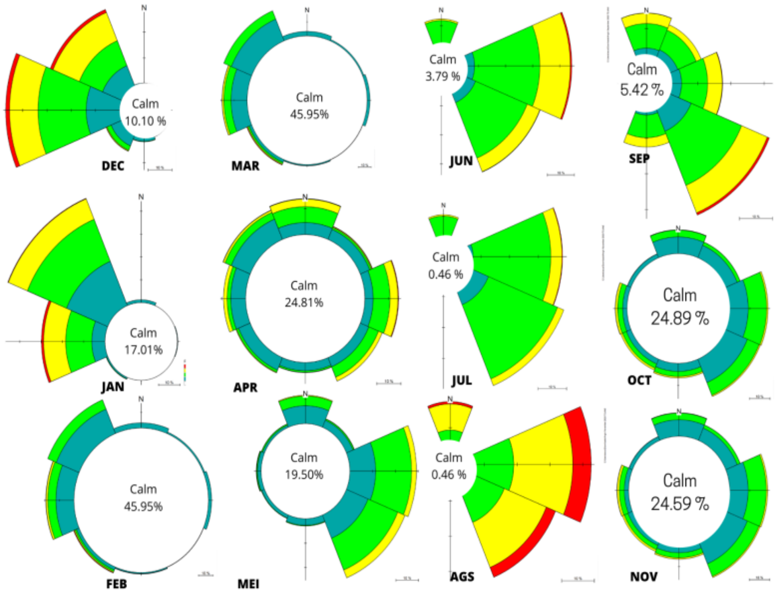

Figure 3. The wind rose plot diagram of the tidal.

Characteristics and waste movement model. Based on the results of tidal data (Figure 4), Cirebon City waters have a different mean sea level each month, with a value range of 0.68–0.94 and mixed tidal types leading to semidiurnal cycles (two high tide periods and two low tide periods). The highest high tide is 1.4 m, and the minimum low tide is 0.4 m. This affects the direction of movement of marine debris (Sá et al 2016) more obviously. The waste is stranded around the coast and is carried away by tidal factors (Van Sebille et al 2020).

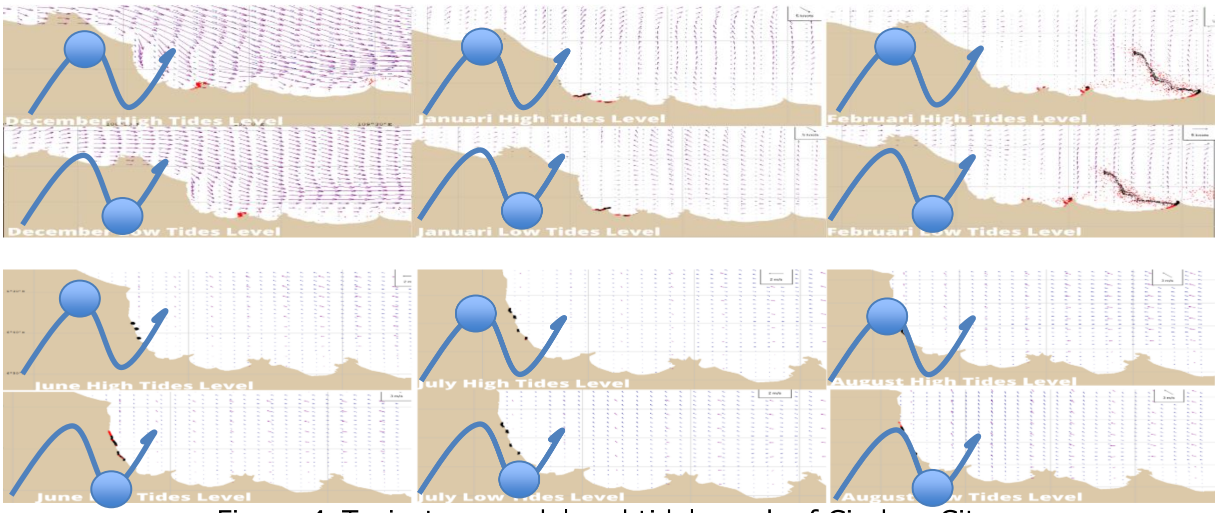

Figure 4. Trajectory model and tidal graph of Cirebon City.

Based on the results of data processing, the flow of currents in the waters of Cirebon City in the West Monsoon has a pattern of movement from West to East, with an average speed of 0.20–0.53 m s^{-1}, dominantly towards the Northeastern direction of Java, reaching a speed of 0.50-0.53 m s^{-1} in the coastal area of Cirebon City, The ocean currents velocity in open seas is in the range of 0.20–0.26 m s^{-1}, with the movement of currents tending to be faster in the Coastal area (Figure 5). In the East Monsoon, the average current speed ranges from 0.30 to 0.42 m s^{-1}, with the direction of the current vector being different from the previous monsoon, which has a movement from East to West. The Cirebon Coastal Area tends to have a current speed range of 0.25–0.33 m s^{-1}, being directed towards the coast, while in open waters, precisely in the Java Sea area, the current speed tends to reach 0.38–0.42 m s^{-1}, in the Cirebon City waters' area.

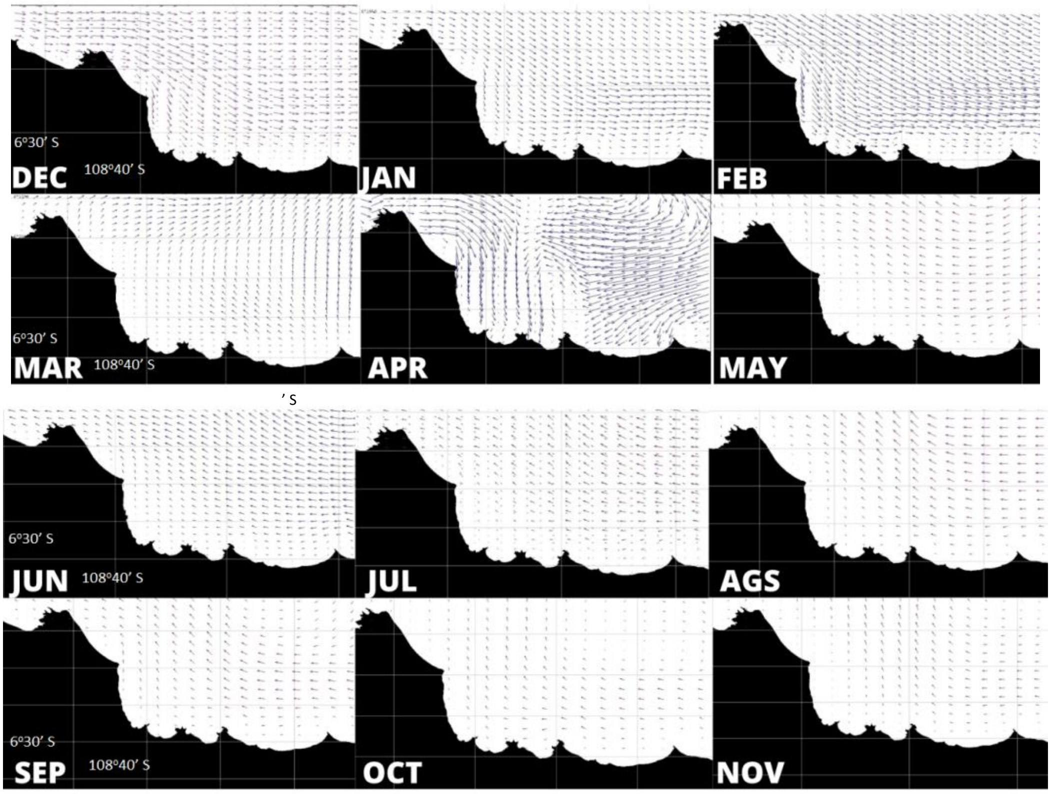

Figure 5. Ocean current patterns during SEM and NWM.

Discussion. MD in the surface water is influenced by the movement of ocean currents and winds. Therefore, this research used hydro oceanographic data (Table 1). The main factors that affect particle motion are caused by the ocean currents and winds, which determine in large proportions the waste particle spreading, as reflected by the GNOME modeling (Balogun et al 2021). The results of the research also show that the pollution occurs in several points and one of the natural impacts is that the contamination affects the concentration level of the chlorophyll concentration. This has an impact on the fishing ground area (Figure 6). The pollution comes from four estuaries, and the hydro oceanography factor affects the transfer of contamination at several points in Cirebon City.

In each condition, the movement of marine debris is greatly influenced by several factors, such as the hydro oceanographic factors that affect its direction and displacement (Purba et al 2021b). This occurs in the both seasons, where the oceanographic characteristics of each season are different due to change in wind directions (Mahagnyana et al 2017). Another factor that affects the movement of marine debris is the difference between the scenarios carried out by the model being run. From simulation in December scenario (1-2%), the movement of marine debris tends to locate more on the sea surface, while in the windage (of 2-3 or 3-4%), it tends to be in the coastal area of Cirebon City. This scenario is carried out to detect the direction of movement of marine debris, with variations due to the influence of the weight of the contaminant particles and of the hydro oceanographic conditions are different (Jasmin et al 2019).

One of the challenges in Cirebon waters is fishing activities. Fishery areas in the waters of Cirebon City are included in the Potential Fishing Zone (ZPPI 712) (Arief 2012). The Cirebon City waters area has fish resources consisting of several species, namely Black Pomfret, Tongkol, Mackerel and Snapper (Anas et al 2017). The potential fishing areas of several of these species are located on the border of West Java and Central Java Sea waters, precisely in the vicinity of Cirebon City and Tegal Regency (Arief 2012).

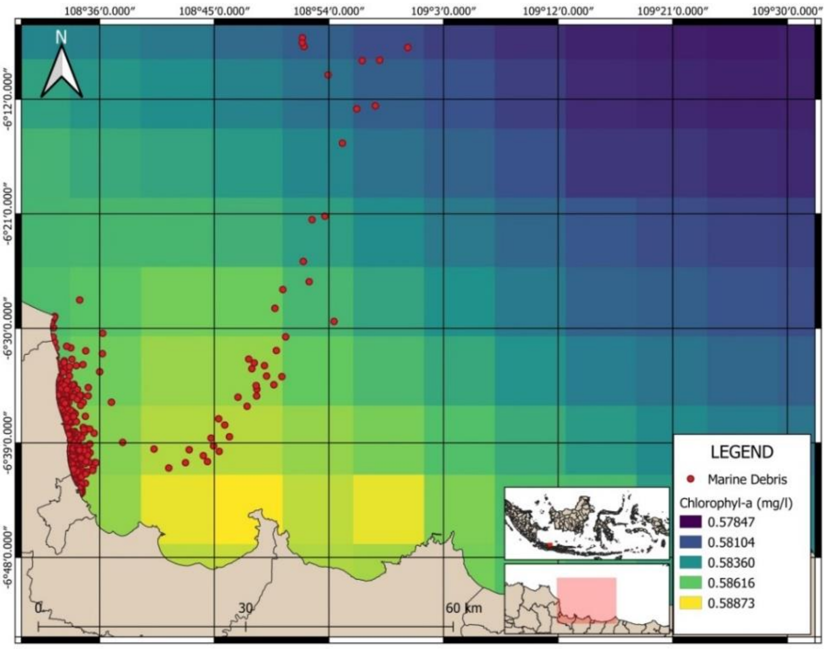

Figure 6. The distribution of chlorophyll concentration and of marine debris that pollutes the fishing ground in January.

The potential for MD pollution from the estuary of Cirebon City, correlated with the prediction of the MD contamination distribution model, indicates a peak of pollution during the west monsoon from a distance up to 70 KM. This harms fisheries biodiversity, in particular, due to the microscopic size of MD particles included in the micro debris class (Derraik 2002).

Conclusions. This research succeeded in making a model of the movement of marine debris with several scenarios to predict the direction of garbage in Cirebon waters. Some of these MDs move around the coastal areas of Cirebon City, with different patterns in the east monsoon and the west monsoon. Another factor that affects the movement of marine debris, considered by the three scenarios of the model, is the waste weight, based on the observation that weight can influence the direction of marine debris movement. MD originating from 4 estuaries in Cirebon City has the potential to contaminate the WPP RI 712 Fisheries Management Area of the Republic of Indonesia, located in the Cirebon City-Tegal Regency area, with a peak of pollution in January.

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Conflict of interest. The authors declare no conflict of interest.

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