Vulnerability of Java Sea marine protected areas affected by marine debris

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Abstract. Marine Protected Areas (MPA) is an area that potentially poses stress from outside such as human activities and ocean pollution. One of the global issues that threat ecosystems include MPA is ocean debris. The aim of this paper is to assess vulnerability of MPA based on the trajectory of debris affected by oceanographic condition. Three MPAs were chosen in the Java Sea region including: Seribu Islands National Parks, Biawak Island Conservation Area, and Karimunjawa Islands National Parks. The data provided by The Hybrid Coordinate Ocean Model surface current and Global Forecast System surface wind were used to determine the trajectory of the debris. We simulate the ocean condition in two monsoons. The results showed that debris floating around the MPAs have a potential of reaching beaches inside the MPAs and have different patterns between the monsoon. Furthermore, in Seribu Islands and Karimunjawa Islands which are designated as National Parks, the debris managed to land in the most crucial zones, Core Zone and Buffer Zone. Modelling of marine debris, such as the one used in this study can be used to inform authorities regarding the landing points of floating debris to create better management decisions in battling global marine debris issues.

1. Introduction
Marine debris is a global issue and Indonesia has committed to reduce plastic debris up to 70% in 2025 [1]. Having a low density makes plastic float on the sea surface and can be transported over long distances by winds and currents [2,3]. Marine debris abundance in Indonesia comes from two main sources, via ocean currents that linked the Pacific to the Indian Ocean and rivers [4]. Plastic is also one type of marine debris that is significantly growing, forming between 60% to 80% of global marine debris [5]. Around 5 to 13 million metric tons of plastic waste enter the ocean constantly every year, making up 80% of total marine debris [6,7]. Furthermore, other studies have also shown that anthropogenic marine debris gets washed to the shore and coastal areas [6,8].

The efforts to manage marine conservation areas worldwide is depending on the regulations and support from stakeholders. One of the efforts to manage the conservation of each maritime region around the world is to establish Marine Protected Areas (MPA). Based on the book Division for
Sustainable Development Department of Economic and Social Affairs United Nations (2017) with goal number 14 on SDGs on conservation and sustainable use of marine, oceanic, and maritime resources for sustainable development, at least 10% of the coastal and marine areas are marine protected area-based management. The number and spatial extent of marine protected areas are increasing globally in the effort to preserve 10% of the coast and marine environment in 2020 [9,10]. According to statistical data from the Protected Planet website (https://www.protectedplanet.net) Indonesia has an area of 181.849 km² as marine protected area from 5.947.954 km² of total sea area or 3.06% of total sea area coverage. In total, there are 108 Marine Protected Areas (MPAs) in Indonesia [11]. Java island also has several MPA, which is Karimunjawa Marine National Park, Seribu Islands Marine National Park, and district-based MPA Biawak Island. The information regarding these areas can be accessed from http://kkji.kp3k.kkp.go.id/index.php/en/marine-protected-area-data. In general, those three MPAs are affected by monsoon [12]. It is known that in the areas mentioned, the same circulation is also found in the reversing pattern [13]. Tidal current circulation, especially in the Java Sea can be marked by observing at the flow. It changes alternately to the opposite direction (reversing current) with an average current speed of 0.04 – 0.32 m/s. [14,15].

Various research of macro debris in Indonesia states that macro debris is scattered on the surface and the water column of the sea, the mangrove ecosystem [16], and the seabed [4]. These floating particles accumulate toxic pollutants on their surface during their long-residence time in polluted seawater and can therefore represent a concentrated source of environmental pollution, or serve as a vector for toxic pollutants that accumulate in the food webs (bio-accumulation of contaminants) [17]. Trajectory modeling will help find out which marine debris is originating and help policymakers make the right decision [18]. Numerical modeling is one of the main tools that can be used to gain knowledge about the distribution of marine debris [19,20]. Simulation of marine debris can also be used to predict their existence in the ocean environment [21]. Marine debris modeling has been used to predict the movement of marine debris in the ocean and also to track the possible origins of marine debris [22–24]. Ocean circulation and global atmospheric data can be essential in marine debris numerical modeling as the basis of the main driving force of the marine debris model. Besides, when coupled with other ecological and geographical information, this global circulation model can be used to determine marine debris risks and hotspots [25,26]. This paper presents results regarding the vulnerability of MPAs in Java Sea to marine debris in different seasons based on GNOME (General NOAA Modeling Environment) simulation. Our objectives were: (1) to examine the trajectory of marine debris particles in the MPAs of Java Sea, (2) assess the potential hotspots of marine debris in the MPAs of Java Sea. It is crucial to detect which area of the MPA affected the most by the debris movement.

2. Materials and methods
2.1. Study sites
The study areas for this study are the three MPAs in the Java Sea, Seribu Islands Marine National Park (107.489 Ha), Biawak Island Conservation Area (720 Ha), and Karimunjawa Marine National Park (110.117 Ha) [13] (Figure 1). Starting points of marine debris models are scattered around the MPA border. It can be assumed that there is a possibility of debris coming from various directions. These three areas have different characteristics, where some part of Seribu Islands and Karimunjawa Marine National Park are used for residents and tourists, while Biawak Island is a population-free conservation area.
The Java Sea is a shallow water area influenced by oceanic and atmospheric phenomena [14,16]. The reversing monsoonal winds blow from the Australian region (southeast) from June to August (JJA) and from the Asian region (northwest) from December to February (DJF). The Java Sea is also affected by water masses transported by the Indonesian Throughflow and water mass transported from the South China Sea [12]. One study regarding the transport of coral larvae showed a trajectory of west – east movement [13].

2.2. Materials and data

GNOME Software is an integrated and modular software that is designed for the rapid modeling of pollutant trajectories in the ocean [27]. GNOME generates a hindcast series of possible debris locations according to the specified time [28]. The simulated particles were given a randomly distributed windage value of 0-2% [23]. In order to run a particle model, GNOME requires several data inputs, including GNOME-specific map format, ocean current, wind, and windage (Table 1). The map used in this study was obtained from GNOME Online Oceanographic Data Server (GOODS, https://gnome.orr.noaa.gov/goods). For ocean currents and wind data, we utilized the HYCOM ocean current and Global Forecast System (GFS) 10-meter wind (Table 1). The version of GNOME used in this study was version 13.1.11. To verify the movers’ data used in this study (HYCOM and GFS), wind speed data from BMKG (Meteorological, Climatological, and Geophysical Agency of Indonesia) were used as a comparison.

Two examples of surface circulation are currents originating from the global drifter (http://www.aoml.noaa.gov/phod/dac/dacdata.html) [29] and satellite-derived current data known as OSCAR (Ocean Surface Current Analyses – Real time; http://www.oscar.noaa.gov/index.html) [30]. Another common global circulation model used in marine debris coupling models is HYCOM (Hybrid Co-ordinate Model). HYCOM combines features of layer-, level-, and sigma-coordinate models. The basic theory of using the coordinates is explained [29,31]. In its use for tracking debris particle in the ocean, ocean circulation data can be used as an input for PTM (Particle Tracking Module) in various software (Table 2).
Table 1. Dataset for model simulation

| No | Parameters | Source | Spatial resolution | Temporal resolution |
|----|------------|--------|-------------------|-------------------|
| 1  | Current    | HYCOM  | 1/12 degree       | 3 hours           |
| 2  | Wind       | GFS    | 1/4 degree        | 3 hours           |
| 3  | Coastline  | GOODS  | -                 | -                |
| 4  | MPA Area   | protectedplanet.net | - | - |

Table 2. Statistics for wind and current dataset

| Wind (m/s) | Currents (m/s) |
|------------|----------------|
| NW Monsoon | SE Monsoon     |
| Min        | 0.009          | 0.006          |
| Max        | 13.8           | 14.6           |
| Average    | 3.81           | 4.78           |
| St. dev.   | 2.41           | 2.55           |
| Field Average | 2.21       | 3.44           |

2.3. Modelling scenario

The debris trajectory model in this study was conducted in two periods, in December to represent conditions in the Northwest Monsoon (NWM), and in June to represent conditions in the Southeast Monsoon (SEM). The starting points for the modelled debris located around the MPA polygon. The model duration was seven days and with a computational time step of 5 minutes. Starting point of debris released around the MPA polygon, during two seasons NWM and SEM, with randomly distributed 0 - 2% windage representing plastic and other low windage debris (bottle caps, Styrofoam, etc.) [23]. We also have in-situ measurement in Biawak island that includes marine debris type and locations in order to verify the model. The analysis separated into two monsoons which are JJA as Southeast Monsoon, and DJF as Southeast Monsoon.

3. Results and discussion

3.1. Physical parameters

Results of wind data and currents data visualization shown in the form of direction and velocity of the two quantities. In the Southwest Monsoon of December, January, and February, Biawak Island has a dominant current velocity of 0.1 to 0.4 m/s followed by currents that moves from the southeast with a dominant velocity of 0.2 to 0.4 m/s and a slight current from the northeast that moves 0.1 to 0.2 m/s with a wind that moves dominantly from the west and northwest with variations in velocity from the lowest of 2 m/s and the highest is above 8 m/s (Figure 2). Also, there is a movement of wind from the north and southwest with a speed of 2 m/s to 4 m/s. These results also similar with [12,32] and concluded that monsoonal situation dominantly affected Java Seas.
Also, in Karimun Jawa Island, the water currents move dominantly from the east with a velocity of 0.1 to 0.5 m/s followed by the wind that flows from the northwest with a speed that starts from 2 m/s to the highest above 8 m/s. Besides, the wind from the southwest with a speed of 2 to 8 m/s. However, in the same period of time there is a slight distinction in Seribu Islands, where currents spread towards several directions. The dominant ones coming from the southwest with a velocity of 0.1 to 0.4 m/s and several other directions coming from the southwest and south with a velocity of 0.1 to 0.2 m/s and also from the east and west with a velocity of 0.1 to 0.4 m/s dominant from the east, while the wind data recorded is dominant from the northwest with a velocity of 2 m/s to the maximum of 8 m/s. Biawak Island is located on the Java Sea, whereas this water is passed by monsoon winds, so the movement of the current is heavily influenced by monsoon winds. The west monsoon influences the DJF current that flows dominantly from the west to the east, and the east monsoon influences the JJA current that flows dominantly from the southeast to the northwest [12,33].

In the Seribu Islands on DJF season, the currents moved from the northeast towards the southwest, opposite to the direction in which the dominant winds came from northwest. This anomaly is due to its geographical location adjacent to Sunda, where the average monthly current flow in Sunda Strait always flows from the Java Sea to the Indian Ocean. This condition is estimated to occur because the Java Sea is dominated by the Monsoon [33,34], which during the East Monsoon, the water mass is flowing from the Flores Sea to the Java Sea, resulting in a buildup of water mass in the northern waters of West Java. A portion of the water mass will seep out through the Sunda Strait. So, the flow of current throughout the year from the Java Sea to the Indian Ocean is due to differences in sea level between the Java Sea and the Indian Ocean [35], so the influence of water mass from the Java Sea is more dominant than the Indian Ocean [36]. During the JJA months, the currents flow from the east to the west due to the east monsoon winds that influence the currents condition in Seribu Islands on east monsoon, and it is known that during the east monsoon, the ITF’s transport rate is at its highest.

3.2. Marine debris trajectory

Figure 3 shows the result of waste abundance in each location. The modeling result in image (a) in TNKS area shows that there are marine debris both in the core zone and in the jungle zone. In JJA season, one core zone out of three core zone is free from incoming marine debris, whereas on JJA season all of the core zone is found based on the modeling result.

Area in Biawak Island and the result of the marine debris model also found marine debris abundance in Biawak Island. Karimun Jawa has the least marine debris abundance compared to the other two locations due to geographical influence of the island. As for TNKS, more debris spots are found during NWM compared to SEM. This occurred due to the input and the circulation of water that comes from the west and southwest which is the Java Island. In the core zone, more debris spots are also found during NWM. The most common marine debris in Kepulauan Seribu (Thousand
Islands) National Park is Polyethylene bags [37]. The abundance comes from land-based debris through rivers, estuaries, trade activities on the coast and the sea, and deliberate disposal of debris into the sea [16,37].

Figure 3. Abundance of Marine Debris in the three MPAs, a. TNKS, b. Biawak Island, c. Karimun Jawa Island
The interesting thing in these waters is the discovery of marine debris during SEM on the Candikian Atoll (topmost island), which has never been studied. In the Biawak islands area, marine debris spots are found the most during NWM. This is in accordance with research from [14], which also found marine debris in Biawak Island. The dots on the model is also in accordance to what was found on [4], especially in Biawak Island. The distribution of marine debris in Biawak Island in coastal areas mostly consists of foams, ropes, bottles, and bottle caps. The majority of debris found in the mangrove area consists of ropes. It is either transported by the ocean currents or trapped in the mangrove roots [4]. This indicates that the mangrove roots influence the level of trapped debris [16].

A study from [38] regarding the measurement of microplastic density in the Karimun Jawa National Park has shown numerous types of microplastic were found consisting of fiber, fragment, films, and foam. Most of the planktons are microscopic. Thus, microplastics with the size <5 mm [39] may be mistakenly eaten as plankton (food) by fishes or larger planktons. Coastal dynamics and circulation of currents in the middle of the sea are often linked to be the cause of a high abundance of microplastic.

From the three MPAs studied, it can be known that Seribu Islands is the most affected. It extends from north to south, in which the islands are functioned to trap debris. This indicate the need for regular monitoring to detect debris spots on each island. The assumption used in placing the starting point in all directions is one of the challenges going forward. In addition to being an active sailing area, the Java sea area is also an area where many rivers end.

4. Conclusion
Although protected from destructive human activities, MPAs are not necessarily protected from Marine Debris. This is because MPAs accept other external factors that affect marine debris movement, such as the parameters we examined, namely oceanographic factors such as currents parameter, wind parameter, coastline parameter, and MPA polygon parameter itself. Furthermore, debris trajectory in Java Seas is related to the ocean currents system and monsoonal winds, which is the section of the mapping of movement patterns of marine debris. Based on the model, the three MPAs in the Java Sea, namely Seribu Islands Marine National Park, Karimun Jawa Marine National Park, and Biawak Island Marine Conservation Area have a potential of debris accumulation. Indeed, the most crucial zones in National Parks, Core Zone, and Buffer Zone also showed a vulnerability to debris accumulation. This model simplifies to investigate the distribution and movement patterns of marine debris in the marine protected area in the sea of Java to find out the appropriate method for handling marine debris in the study area.

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