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Baseline

Daily apportionment of stranded plastic debris in the Bintan Coastal area, Indonesia

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ABSTRACT

This study aims to provide a baseline report of the apportionment of stranded plastic debris (macro) in Bintan Island beaches. Their quantity and composition were assessed during a 45-day survey demonstrating the occurrence of the 3378 plastic fragments, which were, in decreasing order, constituted by LDPE (22.9%), PS (19.5%), PP (16.6%), PET (10.4%), HDPE (9.2%), PVC (7.2%), PU (4.9%), polyester (4.7%), polyamide (4.3%), and styrene/butadiene (0.3%). The abundance ranged from 1.2 to 4.7 items/m^2. Additional apportionment ranged from 0.03 to 0.15 items/m^2 per day with an arithmetic mean of 0.09 ± 0.05 items/m^2 per day, mainly related to domestic waste influenced by hydrodynamic action such as longshore current and wind dynamics. Furthermore, we suggested mitigation measures focused on local action to address the plastic debris problem in Bintan beaches, which are typical of the coasts of small islands in Indonesia.

Since 2015, plastic pollution has attracted public attention in Indonesia. After being declared as the second largest plastic contributor to the marine environment (Jambeck et al., 2015), through public information dissemination acts, i.e., conferences, seminars, and community action, all related stakeholders (academia, business sector, community, government, and media) enforced their roles to solve the claimed problem. However, the Indonesian Government has stipulated recent regulations through Presidential Decree No. 83 concerning waste handling in the sea, which constituted the national action plan to reducing 70% of marine plastic in the marine environment by the year 2025 (Perpres 83/2018). Nevertheless, the real data to contradict Jambeck's model are still lacking in Indonesia. Limited studies have been conducted by Indonesian scientists. Marine contamination with plastic debris has been reported in the Indonesian area by several authors. For instance, Syakti et al. (2017, 2018) reported the occurrence of macroplastics and floating microplastics in the southern part of Java in the adjacent Indian Ocean and the Bintan area. Cordova et al. (2018) reported the presence of microplastics in coral reef sediment in Lombok and in the deep sea of the southwestern Sumatra coast (Cordoba and Wahyudi, 2016). Recent studies were also conducted on the occurrence of microplastics in biota (Rochman et al. 2015; Lubis et al., 2019) and the absorbed co-pollutants, i.e., PAHs and PCBs (Bouhroum et al. 2019), as well as the impact of microplastics (Syakti et al. 2019). The present study investigated the apportionment of stranded plastic debris (macro) on Bintan Island (Fig. 1), an area in Indonesia that is close to the Malacca and Singapore Straits, which is recognized as the most crowded sea-lane and a maritime traffic zone and could potentially experience a sea-based leakage of plastic from ship lines.

Seven sites with different orientations and nearby activity were studied around Bintan and were classified as touristic (S1–S4), industrial (S5), and domestic (S6) harbors and/or as for industrial activities. For each station, a 180 m^2 permanent quadrat (6 × 30 m) was designed in the intertidal zone, and the plastic items were then enumerated. The polymers were also identified directly on site using a Mobil-IR Portable FTIR Spectrometer (Bruker Optik GmbH, Germany) with Bruker OPUS software. Each site was visited at least three times

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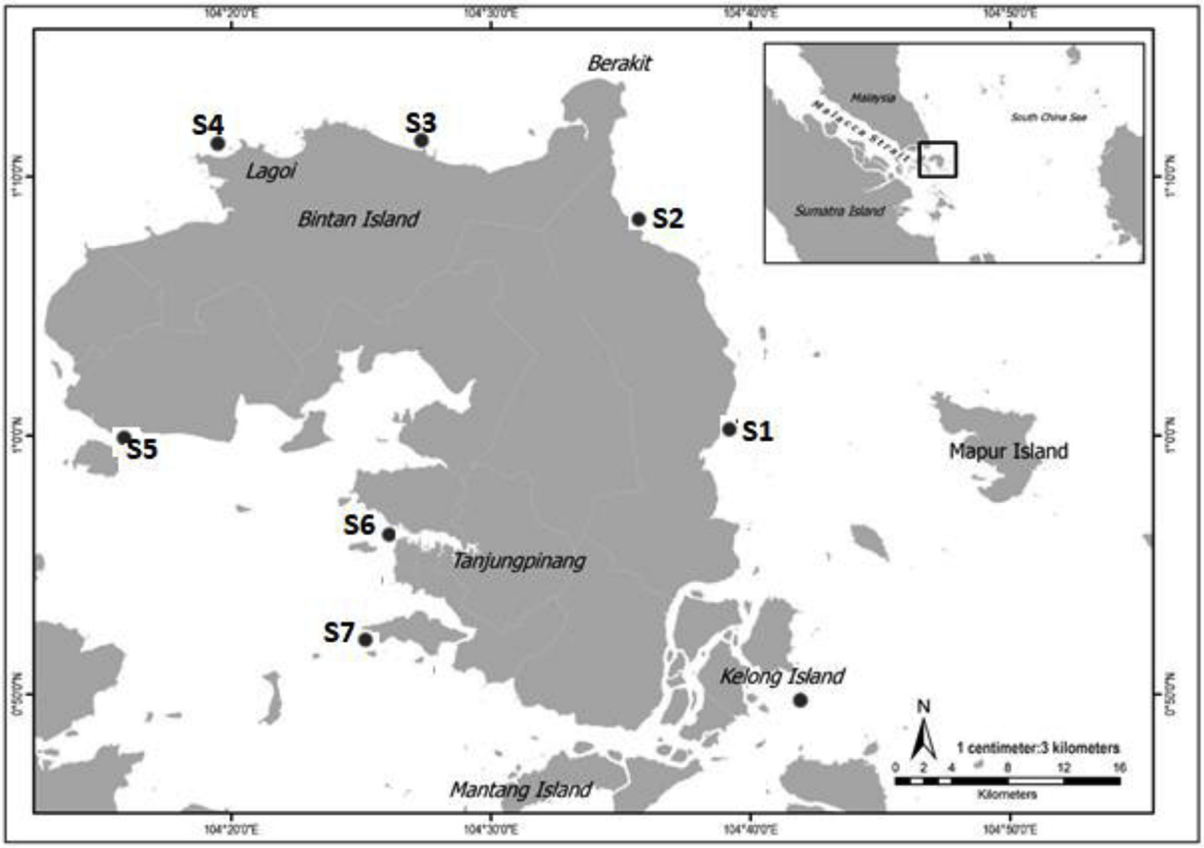

Fig. 1. Sampling sites in the coast of Bintan, Indonesia.

during a period of 45 days, with a minimum waiting time of 7 days between each visit. The stranded plastics occurring from several products such as fishing nets, ropes, bottles, plastic cups, plastic bags, straws, rubber items, sandals, and lighters were analyzed using the Mobil-IR Portable FTIR system. We conducted 10–15 analyses for each of the found products, and the remaining products with the same/similar visual perception could be directly counted as the same specific polymer. We completed at least 250–300 analyses with the FTIR system. Next, to assess the impact of weathering on plastic, a seabed inspection for sunken debris was performed to compare the different aging conditions of the sunken PET as a polymer model. PET was chosen because of its easy identification through visual inspection before confirmation by FTIR and its stability under outdoor light (Summers and Rabinovitch, 1999). PET samples were visually analyzed, and some samples were removed for further FTIR analysis. Two-dimensional hydrodynamic models were conducted using MIKE 21 software with the *mesh generator* module to estimate the boundary conditions limiting the open and enclosed areas of the model (Salim et al., 2016). Wind data were obtained from the European Centre for Medium Range Weather Forecast (ECMWF), which was subsequently extracted using Ocean Data View software to obtain zonal and meridional wind components. Data were then converted to obtain the direction and wind speed values simulating the current hydrodynamic model for August 1, 2018.

To assess the baseline level, from the 180 m^2 area at each permanent sampling point, we found that the plastic debris number ranged from 214 to 842 items (1.2 items/m^2–4.7 items/m^2). The highest number was at station S6 (842 items), followed by stations S4 (533 items) and S7 (511 items) (Table 1). Three other stations that shared the same large magnitude were S1 (457 items), S5 (411 items), and S3 (398 items). The cleanest station was S2 (214 items).

As shown in Table 2, the amount of stranded plastic found on Bintan

Table 1
Baseline of plastic debris level and polymer identification in Bintan beaches.

Debris polymers	Sites						
	S1	S2	S3	S4	S5	S6	S7
LDPE	101	5	20	22	71	361	193
PP	45	39	55	97	49	197	80
Polyester	17	31	11	27	25	41	8
Polyamide	12	30	10	27	24	35	8
PET	52	37	116	87	40	7	11
HDPE	39	14	52	109	38	21	38
PS	144	21	59	62	132	85	157
PVC	28	30	47	98	16	15	11
PU	16	5	17	27	16	77	6
Styrene/Butadiene	4	1	2	0	0	4	0
Total	457	214	389	533	411	842	511

Table 2
Comparison of the abundance of stranded plastics relative to that in other coastal areas worldwide.

Region	[items/m^2]	Reference
Bintan coast (Indonesia)	1.2–4.7	This study
Mediterranean (Western)	0.2–6.9	Asensio-Montesinos et al. (2019)
Cape Town, South Africa	0.2–24.5	Chitaka and von Blottnitz (2019)
Northwestern Mediterranean	92–4653	Constant et al. (2019)
Sri Lanka beaches	4.1–158	Jang et al. (2018)
Luzon beach, Philippines	0.7	Paler et al. (2019)
Guandong coast, China	3–347	Fok et al. (2017)
Korea beaches	0–44	Lee et al. (2017)
Cilacap coast, Indonesia	16.8–41.6	Syakti et al. (2017)
South China Sea	3–347	Zhao et al. (2015)
Hawaiian Archipelago	4-17,645	McDermid and McMullen (2004)
Portugal coast	29–393	Martin and Sobral (2011)

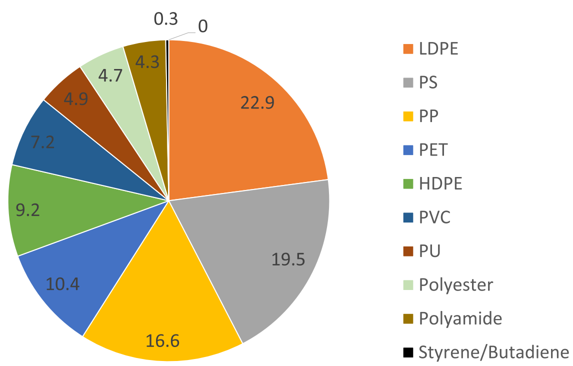

Fig. 2. Plastic polymers found in Bintan beaches. *the black part represents styrene/butadiene, representing 0.3%.

Table 3
Dominant plastics stranded on the Bintan coast.

Site location	Baseline (items/m²)	Additional plastic debris (30–48 days)			Dominant plastic type
		(items/m²)	(items/day)	(items/m²/day)	
S1	2.5	4.2	25.3	0.14	PS, LDPE, PET
S2	1.2	1.3	5.3	0.03	PP, PET, Polyester
S3	2.2	2.7	9.3	0.05	PET, PS, PP
S4	3	4.0	22.0	0.12	HDPE, PVC, PP
S5	2.3	3.4	12.6	0.07	PS, LDPE, PP
S6	4.7	6.4	27.6	0.15	LDPE, PP, PS
S7	2.8	4.4	15.6	0.09	LDPE, PS, PP

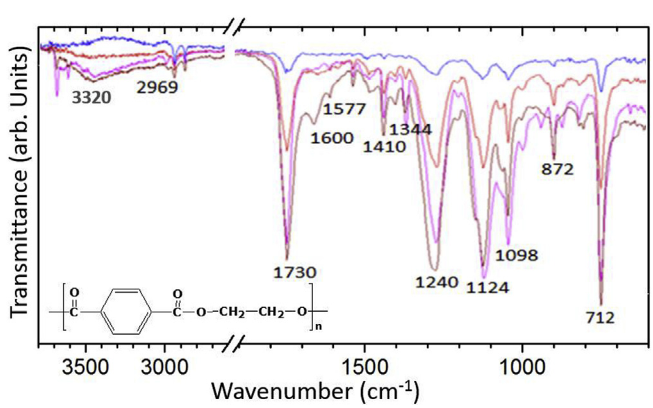

Fig. 3. Observable PET characterization. The colors represent different ages. Brown = recent release, violet = low aging, Blue = somewhat degraded, Red = degraded. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

beaches was the same as that of the macroplastics found in the western part of Mediterranean, i.e., the amount of stranded plastic found on Bintan beaches. An amount of 0.2–6.9 items per m^2 (Asensio-Montesinos et al., 2019) can be classified as extremely dirty according to Alkalay et al. (2017) and Paler et al. (2019), but in terms of accumulation, it was less polluted than the plastic debris in Cape Town (Chitaka and von Blottnitz, 2019) and the Northwestern Mediterranean (Constant et al., 2019). Table 2 shows the results of stranded plastics from different studies for clear comparison with our study results.

Using the portable FTIR, we directly analyzed plastics from 3378 plastic fragments among the stranded litter on the Bintan coast. We observed that low-density polyethylene (LDPE), polystyrene (PS), polypropylene (PP), polyethylene terephthalate (PET), and high-density polyethylene (HDPE) were indeed in the top 5 (Fig. 2), comprising 22.9%, 19.5%, 16.6%, 10.4%, and 9.2% of the total stranded plastics, respectively. This result was comparable with the quantities of world's plastic demand by type in 2015, i.e., PP, LDPE, HDPE, polyvinyl chlorid (PVC), and polyurethane, respectively (PlasticEurope, 2017).

For instance, the quantity of PS in Bintan was much higher than its production percentage worldwide, which might reflect its common usage. The amount of PS may be due to fishing activities on nearby coasts and from the wide consumption of single-use cutlery and packaging for takeaway food. The PET stranded on Bintan was even more visible, but the explanation was simple: as plastic bottles travel longer distances in the ocean, an isolated island such as Bintan is likely to receive more.

The average percentage of plastic items found is shown in Table 2, where S6 was still the most contaminated station by approximately 4.7 items/m^2, while the cleanest station S2 had 1.2 item/m^2.

1. Additional apportionment

We calculated the arithmetic mean of the number of items/m^2 during the 45 days of observation (Table 3). The additional apportionment was 1.3–6.4 items/m^2, and during the observation for 30–48 days, we estimated that the apportionment rates ranged from 0.03 to 0.15 items/m^2 per day, with an arithmetic mean of 0.09 ± 0.05 items/m^2 per day, depending on the studied sites. The largest amount of newly stranded plastic was found in S6, showing an average of 6.4 items/m^2 and 27.6 items per day with an apportionment rate of 0.15 items/m^2 per day. We suggest that this result can be related directly to the large population living close to the Tanjung Pinang City, which is the capital of the Riau Islands. Another meaningful contamination of plastics on the Bintan coast was found in S1 (4.2 items/m^2 and 25.3 items/day) and S4 (4.0 items/m^2 and 22.0 items/day), which are tourist sites with many pleasant activities. Both have a similar daily apportionment that reaches 0.14 items/m^2 per day (S1) and 0.12 items/m^2 per day (S4). S7 and S5 shared the same large magnitude, with 15.6 and 12.6 items/m^2 and 4.4 and 3.4 additional items/day, respectively. Their rates were 0.07 items/m^2 per day (S5) and 0.09 items/m^2 per day (S7), respectively. Two other sites (S2 and S3) had a lower number of additional items per m^2, ranging from 1.3 to 2.7 and 5.3 to 9.9 plastic items per day, respectively. Their daily apportionment rates were 0.03 items/m^2 per day (S2) and 0.05 items/m^2 per day (S3). Such conditions can be attributed to a variety of factors including currents and semi-diurnal tidal patterns on the Bintan coast (Suhana et al., 2018). Previous studies have investigated the influence of wind, waves, tides, seasonal patterns, and upwelling on the spatial distribution of floating plastic debris (Browne, 2010; Pereiro et al., 2019).

Most of the plastic debris encountered was predominantly from domestic use. As the site is surrounded by coastal houses and markets, most plastic comes from the nearby lands rather than from the sea. One of the supporting hypotheses to confirm this argument was the predominance of LDPE found in this study, which is primarily recognized through visual inspection as a domestic use product.

There was a slight difference for the S4 and S1 sites, which are private resort areas that, regardless of their orientation, are less prone to plastic pollution. This finding may be due to beach clean-ups on the nearby beaches, which halt debris from blowing into our site. Interestingly, with regard to S2 and S3, most plastics probably come from the sea because human activity in this area is less frequent. We noted in this site that PET was the most abundant, followed by PP, PS, and polyester. Therefore, we can assume that bottles made of PET arrived through sea-based circulation from longer distances in the sea. In addition, the bulk of PS can be attributed to the food industry because it is associated with household packaging.

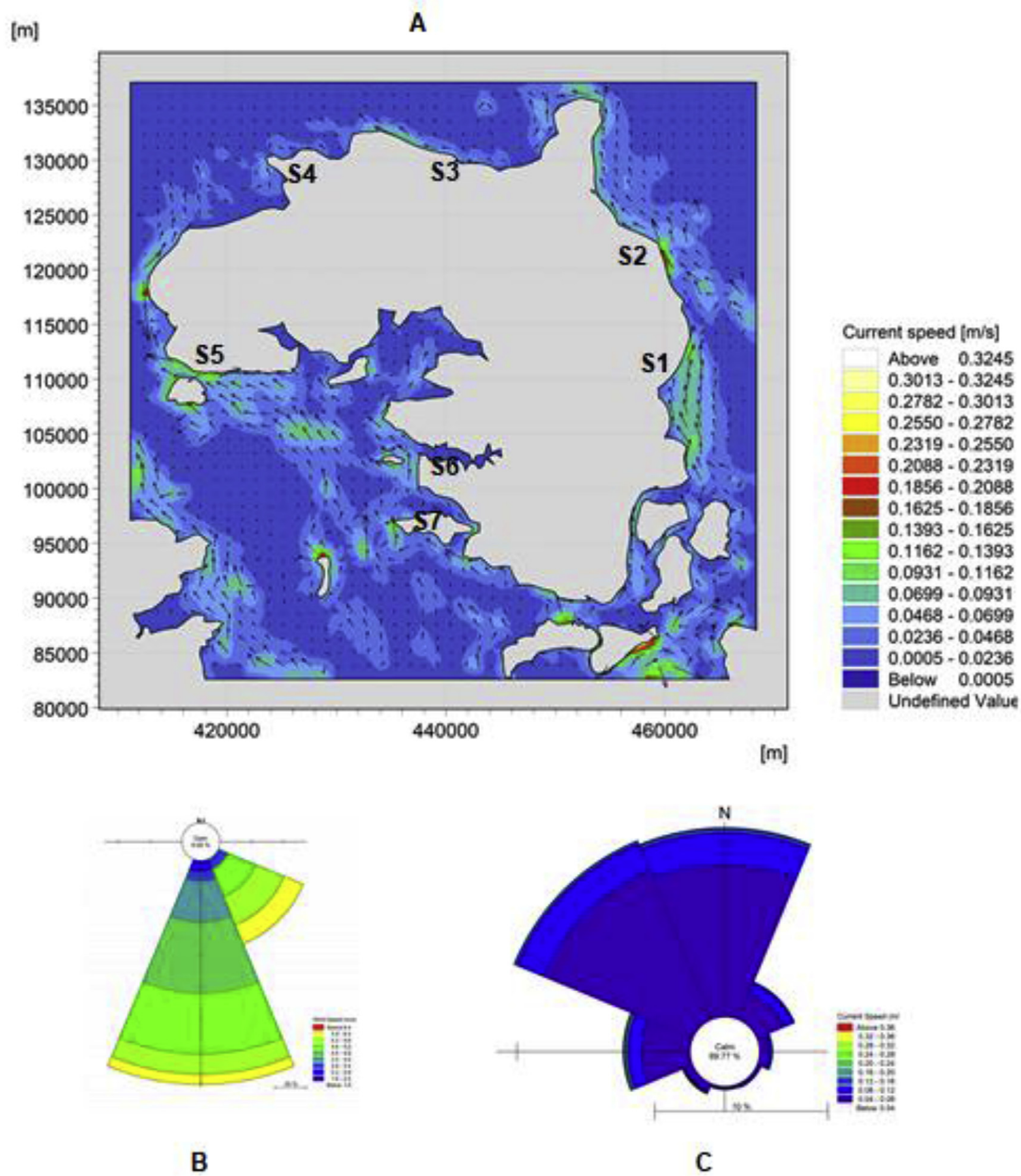

Fig. 4. Current direction (A), wind speed and direction (B), and current speed (C) in the area surrounding Bintan Island on one sampling day (August 1st, 2018).

2. PET bottles found in the ecovillage remote beach

In the EV, which is the most remote beach and is far from rural areas, we would expect the stranded plastic to be apportioned from the sea. At this station, PET was the most important; therefore, in this baseline, we focused our particular interest on PET apportionment and aging levels. We analyzed the different spectra from PET bottles with varying exposure times on the beach. The bottles were chosen by their appearance.

All collected data correspond to a PET spectrum. PET is recognized by the presence of a carbonyl group in conjugation with an aromatic ring at 1730 cm^{-1}. Two strong peaks at 1240 cm^{-1} and 1124 cm^{-1} were attributed to the terephthalate group ($OOCC_6H_4$-OOC) in the polymer. They are usually assigned to the C(=O)–O and C–O stretching vibrations of the ester function. The presence of the characteristic bands at 1344 cm^{-1} corresponded to the wagging mode of ethylene units (Duchesne et al., 2002). Other bands reported in this study were the peaks at 2969 and 2909 cm^{-1} (CH_2 stretching), 1577 cm^{-1} (aromatic C–C stretching), and 1410 cm^{-1} (C–H bending from the ethylene group). Finally, aromatic C–H wagging also appeared at 872 cm^{-1} and 712 cm^{-1} and was assigned to CH out-of-plane bending.

Aging degradation is not apparent owing to infrared absorption. Fig. 3 shows the presence of a large band at approximately 3320 cm^{-1}. This band is probably due to the contamination of the plastics by organic contaminants or live species. We can also assume that the presence of this band is the signature of the beginning of PET hydrolysis after an extended time in the sea and under natural UV light. We should stress the presence of 2 unusual thin bands at approximately 3432 cm^{-1}. The presence of these bands is unclear and most likely deserves more attention in future studies. There were no other visible changes in the four different PET spectra. Unsurprisingly, this finding is probably due to the very high stability of PET with time in the natural environment.

Fig. 4 shows that the current patterns in the coastal Bintan waters were predominantly moving north and northeast (Fig. 4A). The current pattern of motion was estimated following the shape of the island, with an overall current speed ranging between 0.05 and 0.32 m/s (Fig. 4C). Additionally, the wind speed ranged predominantly from 5.5 to 5.8 m/s in the southern part (Fig. 4B). This phenomenon supports our finding that S4, S5, S6, and S7 were the worst beaches in terms of litter content and abundance due to land-based input and concomitant apportionment from the sea, partially from the west-southwest part of island through the current and through the wind from the south. In general, Bintan beaches are largely affected by the plastic debris issued by human activities related to coastal use and hydrodynamic action, such as the longshore current and the wind speed and direction.

Because the government of the province of the Riau Islands relies on tourism and fisheries as the leading sector to increase the regional domestic product, a very good quality and healthy marine environment, free from plastic waste, should be maintained in Bintan, Riau Islands. Thus, environmental authorities should focus more attention on strengthening the institutional arrangement among penta-helix stakeholders, i.e., academia, the business sector, the government, and the community including NGOs and the media, to prevent beach pollution and to promote high-quality tourism at the national and regional levels through integrated approaches to plastic waste management. For instance, as suggested by several authors (Zielinski et al., 2019), a beach management strategy should be based on both land-based and sea-based leakage reduction. To recall the political commitment, we proposed several recommendations as follows: (i) increase public awareness through media information, such as local television, newspapers, and social media including websites; (ii) enforce paid plastic usage; (iii) reduce the use of single-use plastics in formal government activities; (iv) speed up efforts to clean the beach of existing plastic waste with a focus on plastic waste hotspots (e.g., stations S6 and S7); (v) improve our understanding of the plastic waste problems by financing research; and (vi) encourage and facilitate the regional mechanism (ASEAN countries) for marine debris surveillance at the ASEAN level, including tracking, monitoring, reporting, and law enforcement mechanisms.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2019.110609.

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