TYPE AND QUANTITY OF MARINE DEBRIS AT SELECTED PUBLIC BEACHES IN SABAH (TG. ARU & KOSUHOI) DURING DIFFERENT MONSOON SEASONS

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ABSTRACT. *Marine debris is widely distributed at the coastal area of the global oceans, but their specific sources, quantities and distribution remains inconclusive. Although the threat from marine debris pollution has beginning to be recognized in Malaysia, comprehensive studies are still lacking to document the pollution. This study has adopted a standard method of beach marine debris survey to assess the type, amount and sources of debris on a one kilometer section in Tg. Aru and Kosuhoi beaches, Sabah, during surveys in December 2012 (northeast monsoon, NEM), May 2013 (intermediate monsoon, IM) and July 2013 (southwest monsoon, SWM). The mean total debris items was 1,220±532 items/km and weighing at 52.8±17.2 kg/km, where, Kosuhoi beach (1,241 items/km or 57 kg/km) received substantially greater quantities of debris compared to Tg. Aru beach (1,199 item/km or 48 kg/km). Total debris items were more abundant during SWM (1,789 items/km) compared to NEM (1,139 items/km) and IM (733 items/km) seasons. Plastic category objects were the most numerous amounting to 1,057 item/km (86.64%) in total debris items. Clear plastic bottles, food wrappers, plastic fragments, colored plastic bottles and cups were the most abundant objects collected which they contributed 606 items/km (49.69%) from the total debris item collected. The main source of debris objects abundance was from common source which contributed 52% from the total debris objects, whereas, those from terrestrial and marine sources contributed 32% and 16% respectively. The high percentage of terrestrial and common sources debris require marine environment stakeholders to diversify their approach and priority in mitigating this alarming result especially during SWM period. Awareness program was an effective preventive measure that should be continued and intensified. However, the program should focus on target group to ensure the awareness effectiveness to reduce if not totally eliminate the debris in the marine environment.*

KEYWORDS. Beach pollution, plastic, monsoon seasons, marine debris source, Sabah

INTRODUCTION

Marine debris can be found on coastal areas or surfaces of the ocean as a result of improper handling of rubbish that may derived from land, blown by winds, intentionally dumped from shore and from ocean-based activities (Somerville *et al.*, 2003; Horsman, 1982). Marine source debris is light weighted and can travel long distance which may result in ingestion and entanglement to marine wildlife (Derraik, 2002; Ryan & Moloney, 1993) beside threaten global biodiversity through colonization of alien marine organism (Barnes, 2002).

Marine debris can be found in Malaysian beaches, however, less attention is given as compared to water quality and toxicology pollution (Ngah *et al.*, 2012; Abdullah *et al.*, 2011; Law & Hii, 2006). The local government is the responsible body in managing solid waste found on beaches and enforcing Uniform (Anti-Littering) by-Laws 2010. This regulation may impose a compound of not more than RM 500 to littering offenders in public areas. However, only beaches in the urban areas are maintained by local authorities or appointed contractors. Furthermore, the presence of marine debris is not regulated and law enforcement in beaches is difficult (Agamuthu *et al.*, 2012).

Previous marine debris study in Malaysia had applied various survey methods only during northeast monsoon (NEM) season. Those studies found plastic materials as the most abundant type of marine debris found in Port Dickson (Khairunnisa *et al.*, 2012), Sarawak (Hassan & Mobilik, 2012) and Terengganu (Chan *et al.*, 1996) beaches. Among the identified debris, 65% were from land-based debris, include; food wrappers, plastic shopping bags, cardboard cartons, aluminum cans, cloths, clear and colored plastic bottles. Although, these studies gave an overview debris pollution level in Malaysia beaches, however, were insufficient to generalize the contamination level and effects of marine debris on Malaysian beaches.

This paper presented the data collected for surveys at Kushoi and Tanjung Aru beaches conducted on December 2012(NEM), May 2013(IM) and July 2013(SWM). This study assessed debris abundance during different monsoon seasons, categorized them by type of materials, and determined possible sources/origin. In addition, wind exposure of the beach was explored to determine marine debris abundance under different monsoon wind conditions.

MATERIALS & METHODS

Study Area

Two beaches had been selected for this study namely Tg. Aru and Kosuhoi beaches situated in the west coast of Sabah (Figure 1). These beaches were chosen due to factors that may contribute to garbage accumulation, including adjacent to residential areas, major shipping routes, popular among beach visitors and meteorological influence (Khairunnisa *et al.*, 2012; Garcon *et al.*, 2010; Walker *et al.*, 2006). Tg. Aru beach is popular among visitors located 7.4 km from Kota Kinabalu City. Whereas, Kosuhoi beach adjacent to village land, resort and privately owned land with one public entrance to the beach, located at the tip of Borneo Island, 28.3 km from Kudat town. Due to the location of Tg. Aru beach is within the urban area, regular schedule of rubbish collection of at least twice a week are maintained by the local authority appointed contractor. Unlike Kosuhoi beach, beach clean-up were organized and initiated regularly by villages, hotel and resort operators since there was no schedules of rubbish collection. Facing South China Sea, these beaches were exposed to swells and wind waves between 1.0-2.0 m during the NEM, 1.0-1.5 m during IM and 1.0-1.5 m during SWM seasons from the South China Sea (Chiang *et al.*, 2003). The directions of wave in Malaysia are influenced by the monsoon winds.

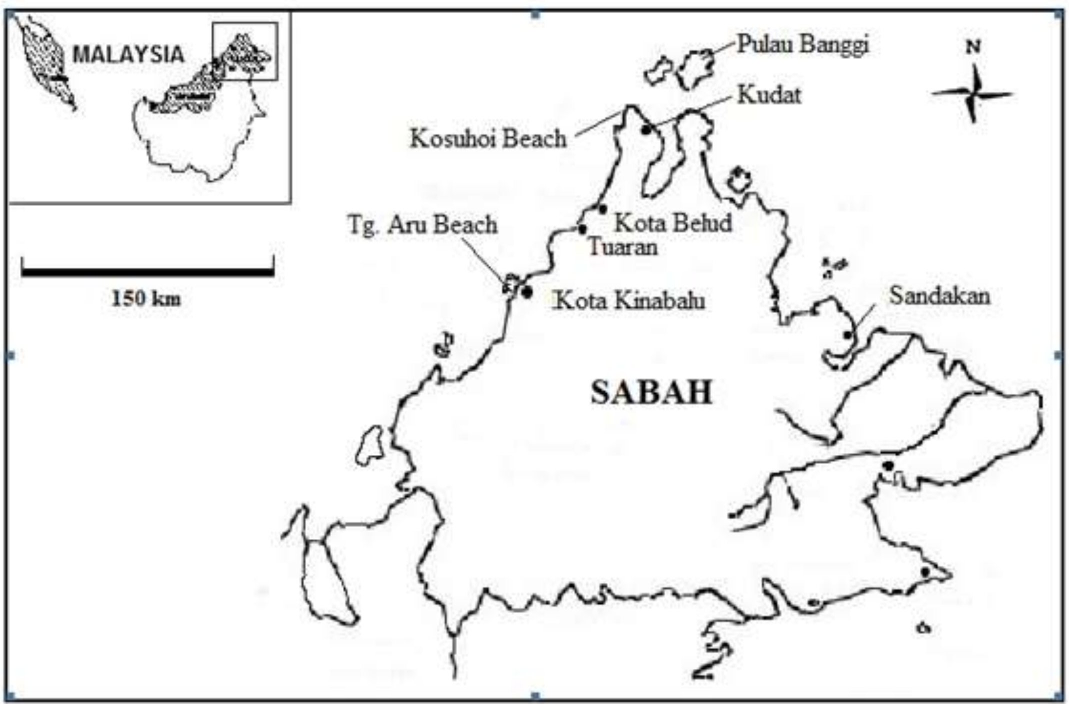

Figure 1: Map showing sampling sites involved in this study

Survey Methods

Beach surveys were conducted at the study sites during the NEM, IM and SWM seasons (Table 1) according to standing crop method (Cheshire *et al.*, 2009). Identification of the starting and ending points of one km along the beaches were measured and recorded. During low tide, samples other than fragments smaller than 0.25 cm^2 covering from the high tide mark to the low tide mark at each study sites were collected and sorted into six categories; plastic, rubber, metal, glass, wood and cloth (Ribic *et al.*, 1992), then each category was further sorted into objects. Each sample collected was then identified according to potential source of origin according to list of items proposed by Ribic (1998) and were categorized as: marine, terrestrial and common sources. Common source refers to objects that could be originated from either terrestrial or marine sources. Results were presented in two different units; number of items (items/km) and weight (kg/km).

Table 1: Study sites with their respective GPS coordinates correspond to start and end points.

Study Site	Start Point	End Point	Sampling date	Beach Characteristic
Tg. Aru	05^o 56' 4.1" N 116^o 2' 48.6" E	05^o 56' 29.3" N 116^o 2' 47.5" E	NEM-6.12.12 IM-6.5.13 SWM-19.7.13	-7.4 km from Kota Kinabalu city -Public beach with one entry - Length 2.2 km - Width 30 m
Kosuhoi	07^o 1' 24.3" N 116^o 44' 39.1" E	07^o 1' 53.4" N 116^o 44' 47.4" E	NEM-21.12.12 IM-8.5.13 SWM-21.7.13	-28.3 km from Kudat town -163.4 km from Kota Kinabalu city -Public beach with one entry - Length 2.4 km - Width 30 m

Beach Exposure

The wind and wave condition may determine the direction of floating debris that was present on the beach (Garcon *et al.*, 2010; Keddy, 1984). Using a method adopted from Keddy (1984), wind exposure was calculated for Tg. Aru and Kosuhoi beaches using Equation (1);

$$REI = \sum_{i=1}^{16} (V_i P_i F_i) \qquad (1)$$

where REI is Relative Exposure Index, i is the cardinal wind direction 0º to 360º for every 22.5º interval; V_i is the average wind speed (km/h); F_i is the fetch distance (km); and P_i is the percent frequency from which the wind blew within each wind directions.

The REI is then normalized by dividing the site REI value with the average of total REI values. The calculated REI value was then rank following and adopted the proposed method by Guannel *et al.*, (2011) and Gornitz *et al.*, (1994)), from very low exposure (rank=1) to very high exposure (rank=5). The statistical software package R openair (Carslaw & Ropkins, 2014) was used to develop wind rose diagram using data collected by the Malaysian Metrology Department at Kota Kinabalu and Kudat weather observation stations.

For statistical analysis, relationship between total debris items (items/km), number of ships call to the port, rainfall, wind exposure (REI) and the total debris weight (kg/km) were analyzed using Pearson's correlation. If this test indicated significant difference, a linear regression model was used to identify the variable contributed to the total debris items abundance. Paired *t*-test was used to compare total debris items between debris categories and debris sources according to the study sites and monsoon seasons. All the data analyses were conducted using SPSS version 22.

RESULTS & DISCUSSION

Debris Abundance

A total of 7,320 items weighing at 316.3 kg were collected and sorted over the study period. This represented a mean total debris item accumulated of 1,220±532 items/km and weight of 52.8±17.2 kg/km respectively. The means which the total debris item accumulated during SWM season (1,789±640 items/km) was higher when compared to NEM and IM at 1,139±853 items/km and 733±122 items/km respectively. Tg. Aru beach accumulated the highest total debris during IM and SWM at 819 items/km and 2,241 item/km respectively. Whereas, Kosuhoi beach had the highest amount of debris during NEM season (1,742 items/km). In terms of weight, the mean total debris weight was higher during SWM (63.8±24.0 kg/km) season as compared to NEM (61.6±40.7 kg/km) and IM (32.9±1.2 kg/km) seasons. Kosuhoi beach had the heaviest debris accumulated during NEM and IM seasons at 90.3 kg/km and 33.7 kg/km respectively. While, Tg. Aru beach had the highest total debris weight during SWM at 80.4 kg/km. This indicated the increasing number of marine debris items stranded on beaches was a growing problem, which was related to solid waste pollution, depleting beaches aesthetical value, loss of economic revenue and possible invasion of alien organisms (Browne *et al.*, 2011; Barnes *et al.*, 2009; Barnes, 2002; Derraik, 2002). When compared monsoon seasons with higher total debris items accumulation were not significantly correlated with numbers of ship (r=0.26) visiting to ports nearest to the study sites at Kota Kinabalu and Sandakan ports during the same month, with more debris items actually collected during SWM at Tg. Aru beach during low numbers of ship calls (Figure 2). The irregular distribution of rainfall (r=-0.36), showed no significant correlation with total debris items abundance. However, total debris items (items/km) were significantly correlated ($p<0.05$, n=6) with total debris weight (r=0.91). Linear regression result (R^2=0.96, $p<0.05$) showed total debris item increased by 23 items/km for every one kg/km (β=0.98, t=11.63, p=0.00).

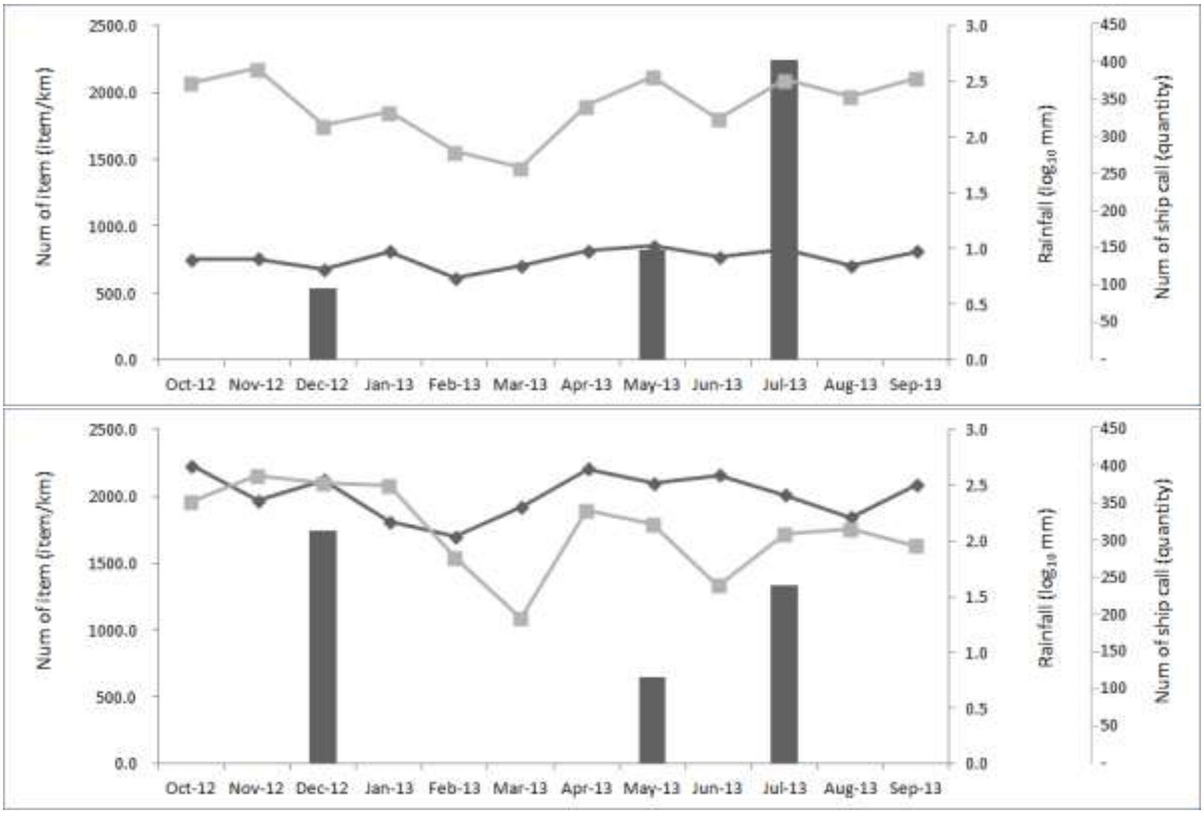

Figure 2. Comparison numbers of ships call (—), rainfall (—) and total number of items ( ) accumulating on (A) Tg. Aru and (B) Kosuhoi beaches.

Debris Category

The total debris items according to category (Table 2) showed plastic category contributed 1,057 item/km (86.64%) ranging from clear plastic bottles, plastic fragments, cups, packaging, food wrappers, plastic bottle caps, colored plastic bottles to plastic shopping bags. Similar studies (Rosevelt *et al.*, 2013; Barnes *et al.*, 2009; Walker *et al.*, 2006) also recorded that plastic-based objects were dominant. When compared these study site plastic category abundance to other studies in the region (Table 3), Tg. Aru accumulated the highest for plastic category. Relatively big size plastic-based materials would transform into plastic fragments through degradation process (O'Brine & Thompson, 2010) and remain contaminating the beach environment (Khairunnisa *et al.*, 2012; Barnes *et al.*, 2009) if effort to eliminate the source is neglected. Other categories contributed 13.36% to the overall composition. In term of weight, plastic category represents 58.65% of the total debris weight. Objects contributed 22.29% of the total debris weight in rubber and glass categories includes; glass bottle from kitchen household (*e.g.* ketchup), alcohol bottle and footwear. Clear plastic bottles, food wrappers, plastic fragments, colored plastic bottles and cups were the most abundant objects collected which they contributed 606 items/km (49.69%) from the total item collected (Table 4). However, in terms of weight they only contribute 14.8 kg/km

(28.14%). A paired samples *t*-test result shows that total debris item in plastic category was significantly difference ($p=0.006$, $n=6$) between rubber (1,021±553 items/km), metal (1,013±528 items/km), glass (1,056±569 item/km), wood (1,055±569 items/km) and cloth (1,048±564 items/km) categories.

Table 2: Total number of items (item/km) and weight (kg/km) according to debris categories.

No.	Category	No. of item	% of total	Weight	% of total
1	Plastic	1,057	86.64	30.9	58.65
2	Wood	51	4.21	2.0	3.86
3	Metal	43	3.54	4.8	9.11
4	Rubber	35	2.90	6.1	11.60
5	Glass	25	2.01	5.6	10.69
6	Cloth/Fabric	9	0.71	3.2	6.10

Table 3: Comparisons of the percentage debris items represented by plastics on beaches in the present study with literature values.

No.	Study Site	Percentage of debris items represented by plastics	Reference
1	Japan	92.2	Kusui & Noda, 2003
2	Tg. Aru	90.0	Present study
3	Sarawak	87.8	Mobilik *et al.*, 2014
4	Taiwan	85.5	Kuo & Huang, 2014
5	Kosuhoi	83.4	Present study
6	Mengabang Telipot, Terengganu	67.0	Chan *et al.*, 1996
7	Port Dickson	55.7	Khairunnisa *et al.*, 2012
8	Indonesia (23 Islands)	50.3	Willoughby *et al.*, 1997
9	Northern South China Sea	42.0	Zhou *et al.*, 2011

Table 4: Ten most numerous objects found at the survey site.

No.	Objects	Tg. Aru		Kosuhoi		Total	
		item/km	kg/km	item/km	kg/km	item/km	kg/km
1	Clear plastic bottles	118	4.2	284	6.9	201	5.6
2	Food wrappers	170	2.4	61	2.5	116	2.5
3	Plastic fragments	199	2.9	12	1.1	105	2.0
4	Coloured plastic bottles	65	2.3	122	4.6	94	3.5
5	Cups	108	1.5	74	1.2	91	1.4
6	Bottle caps	86	0.5	83	1.4	84	1.0
7	Plastic food wrapper	122	1.5	37	0.5	79	1.0
8	Others (Plastic)	57	1.7	98	1.4	78	1.6
9	Packaging	41	0.6	90	1.6	66	1.1
10	Cardboard cartons	37	2.0	65	2.1	51	2.0

Debris Source

The proportion of debris sources reflected the abundance of debris items in Kosuhoi beach was seasonal (Figure 3). Overall, common source represented the majority of items collected (52%), followed by terrestrial (32%) and marine (16%) sources. The highest debris items found in this study was associated with household trash such as detergent plastic bottles, cooking oil plastic bottles, food wrappers, plastic shopping bags, plastic drinks straws, cosmetic plastic bottles, aluminum beverages cans, broken plastic toys and ketchup glass bottles. A study by Jayasiri *et al.,* (2013) and Walker *et al.,* (2006) also concluded land-based debris source was the highest debris items found on the beaches. Similar results obtained during this study were possibly due to the close proximity of coastal villages and inhabited islands with study sites since municipal dids not provide waste disposal service to the islands and villagers (Daily Express Newspaper online, 2014).

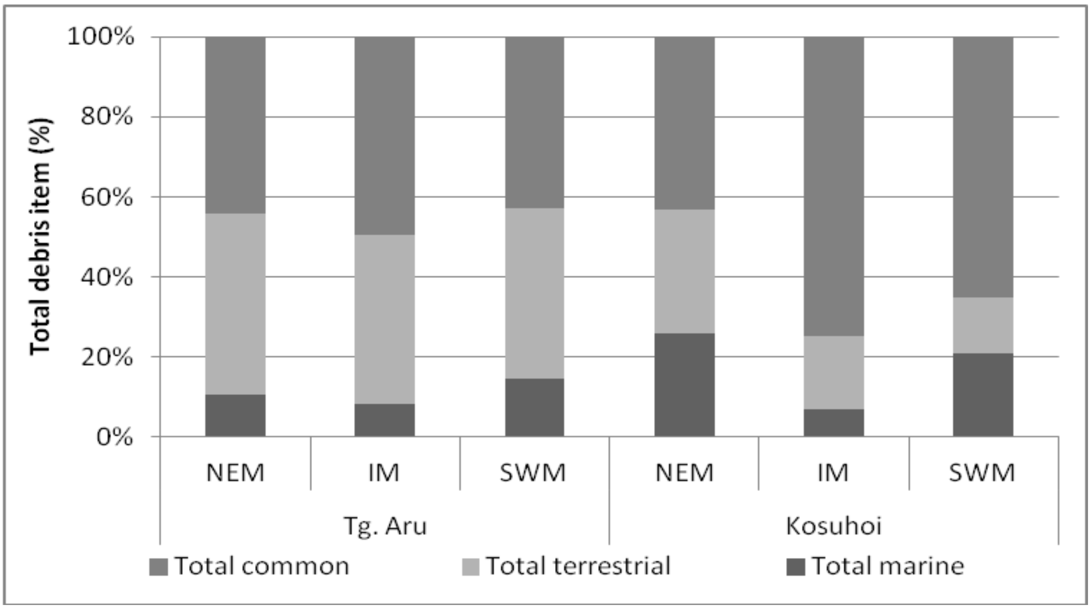

Figure 3: Percentage of debris by sources according to monsoon seasons at the study sites.

A paired samples *t*-test result showed that there was a significant difference (-363±153 items/km; p<0.01, n=6) of total debris items between marine (174±142 items/km) and common (537±236 items/km) sources. This provided indication that the amount of debris and pollutant increased after rain events as a result of runoff flows along the ground in the urban area, rubbish eventually entered into river and the ocean (Gasim *et al.*, 2013; Waters *et al.*, 2011; Silva-Cavalcanti *et al.*, 2009; Golik & Gertner, 1992). The other possibility was the effect of longshore drift (Taffs & Cullen, 2005; Sonu *et al.*, 1966), since the coastal villages along Putatan river located within 2 km from Tg. Aru beach. For the villagers, throwing garbage into the water was an easy alternative method for rubbish disposal. Relatively high amount of plastics had been recorded, possibly because plastic were cheaply available.

Despite high volume of vessel traffic within Sabah coastal state water, the amount of debris items from marine source were less abundant, which included; clear and colored plastic bottles from other country, used navigational light bulbs and plastic lubricating oil bottles. Similar studies (Barnes *et al.*, 2009; Walker *et al.*, 2006; Otley & Ingham, 2003) also observed an inverse relationship between number of vessel and debris items accumulation. Although, these results suggested that illegal discharge occured infrequently, however, the presence of debris items associated with shipping activities indicated that not all vessels complied to the new revised Annex V of the MARPOL 73/74 (International Maritime Organization, 2012) which prohibited discharge of all types of plastics material and required a port to provide facilities to receive shipborne garbage from any vessel that required garbage disposal service.

Analyzing debris objects origin, only 20% were still affix with labels indicating country of origin. Malaysia (82%) was the major sources, followed by Indonesia (7%), Singapore (2%), Thailand (2%), China (1%), Australia (1%) and Vietnam (1%). The highest objects affix label indicating the country origin were clear plastic bottles (45%), food wrappers (24%) and colored plastic bottles (17%). Kosuhoi beach accumulated the most objects for clear plastic bottles (68%) and colored plastic bottles (63%), while, Tg. Aru beach accumulated for food wrappers (56%) object. These objects were the highest during SWM seasons. The result showed that the 94% of the clear plastic bottles originated from Malaysia. Although domestic regulations and conventions might be in place for the prohibition of ocean dumping of waste materials, the temptation to ignore the regulation was obvious, particularly when enforcement was relaxed. Thus, monitoring national regulation compliance and efficient enforcement measures were necessary.

Relative Exposure Index

Although the study sites faced west, the prevailing winds at Tg. Aru beach were from the southeast during the monsoon seasons, whereas, Kosuhoi beach corresponded with the monsoon seasons prevailing winds (Figure 4). The frequency of southwest wind during SWM season in Kosuhoi beach was 48% at maximum wind speed of 8.75 m/s, while, the frequency of northeast wind was 38% with maximum wind speed of 6.69 m/s during NEM season. From wind exposure analysis, the REI rank value during the monsoon seasons was higher at Kosuhoi beach compared to Tg. Aru beach (Figure 5). This result corresponded with the total debris items accumulated at 1,241±554 items/km (57.0±29.6 kg/km) and 1,199±914 items/km (48.4±27.7 kg/km) at Kosuhoi and Tg. Aru beaches respectively. Although, Kosuhoi beach showed a positive relationship between REI value and total debris items during IM and SWM seasons (Figure 5), statistical analysis showed no significant correlation ($p>0.05$, $r=0.06$, $n=6$). This analysis explained, a higher total debris items accumulated during NEM compared to SWM season when REI value ranked lower at Kosuhoi beach. In contrast, Tg. Aru beach received substantially higher total debris items when the REI value ranked very low wind exposure during the monsoon season.

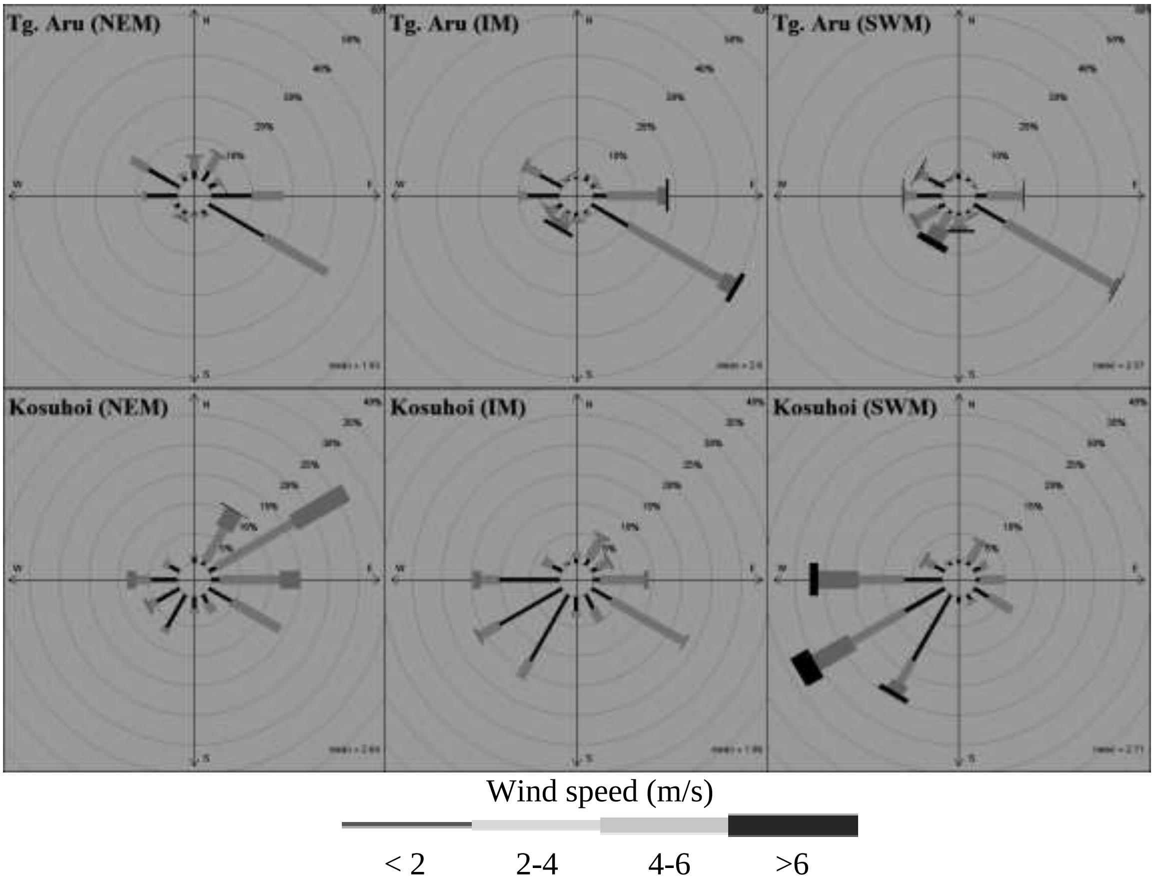

Figure 4: Distribution of wind speed and direction according to study sites and monsoon seasons sampling. Concentric circles represent percent frequency of occurrence during monsoon season.

Previous studies suggested that REI was a possible indicator to determine marine debris accumulation, besides providing a summary of the wind exposure on the beach (Garcon *et al.*, 2010; Walker *et al.*, 2006; Rodil & Lastra, 2004; Keddy, 1984). Although, wind exposure might have influenced the abundance of debris items in Kosuhoi beach, the REI analysis in this study was statistically inconclusive. Therefore, comprehensive and long-term monitoring along the coastline of Sabah should be carried out to identify relationship between debris item abundance and wind exposure.

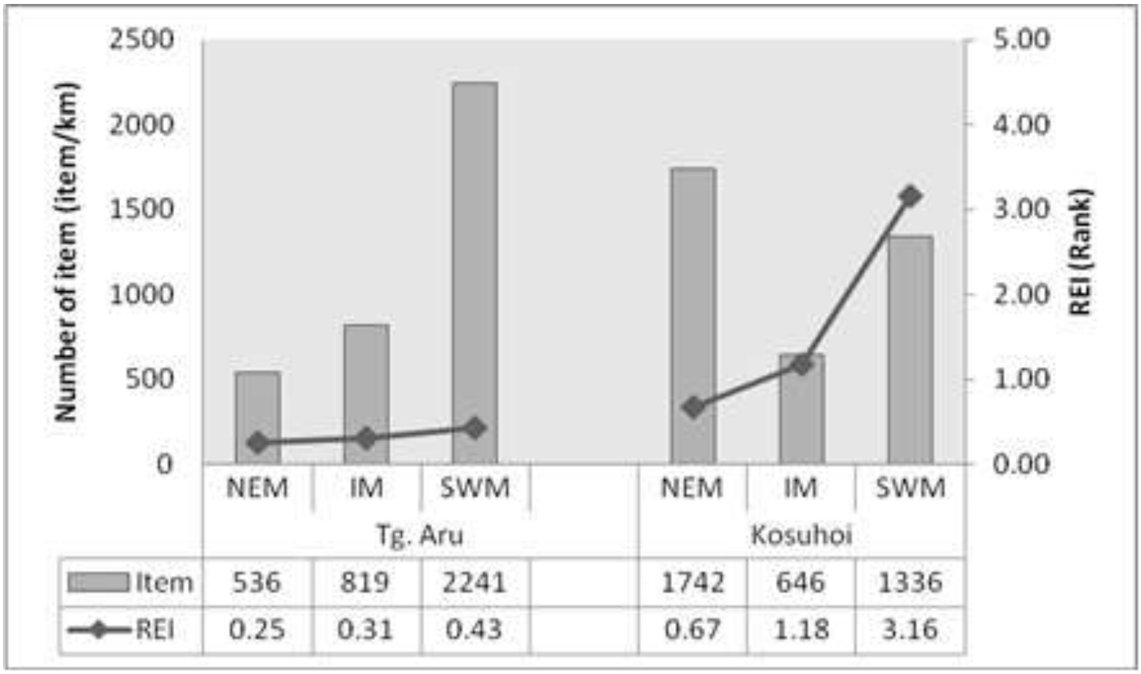

Figure 5: Relationship between relative exposure index (REI) and number of debris items at the study sites according to monsoon seasons.

CONCLUSION

The abundance of marine debris was determined in this study. Debris accumulation was higher during SWM seasons (1,789±640 items/km). Plastic category (1,057±569 items/km) was the most abundant item which may derived from land-based sources. The general public, villagers, beach visitors, vessel crews, garbage collection contractors, local government authorities and other stakeholders had the ability to reduce marine debris problem, by improving waste reduction, practicing effective waste management and introducing recycling initiatives. At local authority level, municipalities we required to provide waste disposal services to the coastal community to reduce or eliminate garbage disposal into the rivers or the sea. Although, marine environmental education can play an important role in mitigating ocean dumping, this process may take time for successful results. However, instilling the love of marine environment and awareness on the younger generation could mould them into responsible adults. For that reason, it was important to target the appropriate groups such as coastal villagers and vessels crews to initiate mitigation program. Nevertheless, identifying the root cause and introducing solutions to mitigate each garbage categories and sources were essential to ensure total eradication of illegal discharge at sea.

ACKNOWLEDGEMENTS

This project was funded by UNIMAS Dana Principal Investigator 01 (DPI22)959/20I3 (05). The assistance of Mariana Norman, Marian Madonna, Jerome Marcus and Jason Mark, during the beach surveys were greatly appreciated.

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