Beach orientation and exposure accumulate types of marine debris on the coast of Dullah Island, kei archipelago, Indonesia

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Abstract Marine debris has become the world’s attention from various aspects. The survey was conducted in April and May 2019, at 6 coastal locations on Dullah Island which have a coastline of 74,796 km. The purpose of this survey is to find out how beach orientation and beach exposure affect the type of marine debris that accumulates on the beach on the coast of Dullah Island. The survey results show that statistically, there is a very significant and positive correlation between island orientation and beach exposure with total accumulation of marine debris, but negatively and insignificantly correlated with accumulation of plastic debris, i.e; the greater the beach exposure will accumulate total debris the sea but conversely the greater beach exposure causes light plastic debris to be swept from the beach by waves and tides. Of the average total marine debris, 46% consists of plastic items while the most plastic clusters that accumulate on the beach are ”common items” (53%).

1. Introduction

The accumulation of litter at sea and along coastlines worldwide and the many open questions concerning the amount, distribution and fate of marine litter and potential implications for marine wildlife and humans have raised public awareness, stimulated scientific research and initiated political action to tackle this environmental problem [30]. Many studies have shown that it consists primarily of plastics with a continuously increasing global annual production of 299 million [16]. It has been estimated that 10% of all plastic debris ends up in the oceans [28], and [2] suggested that the 1982 figure of 8 million litter items entering the oceans every day probably needs to be multiplied several fold. [10] estimate a minimum of 5.25 trillion plastic particles weighing 268,940 ton x Preface afloat in the sea. The increasing use of single-use products, uncontrolled disposal of litter along with poor waste management and recycling practices is the main reason for the accumulation of litter in the sea. Increasing quantities of litter are lost from municipal waste streams and enter the oceans [3].

There is a well-established consensus about marine debris being an increasing environmental issue [15]; [4]. Marine debris, also often termed marine or beach litter, may include any item showing on beaches or at sea (including the open oceans and coastal regions), mainly due to human activities [32]; [4]. Marine debris may also affect the structure and composition of the bentos communities developing on soft and hard substrata [22]. The environmental areas that are most affected by marine debris include the open oceans and coastal regions [7]; [8]. Sand beaches represent very valuable
ecosystems used for outdoor recreation worldwide, among other human activities [1]; [6]. Not surprisingly, the majority of the studies of marine debris was conducted on beaches [13]; [33]. Beach surveys are a widely used method for measuring potentially harmful marine and land derived debris accumulating in a specific area at a given time [32]; [27]; [24]. However, the accumulation of debris on beaches are affected by natural processes such as erosion, local tides and winds and by anthropogenic factors like littering behavior [20], [21]. Hence, it is expected that marine debris deposited on the beach may vary spatially and temporally [17]; [9]; [26]; [5]. Furthermore, the amount of marine debris is considered to be inversely related to its geographical distance to a population center and directly to the number of users [12]; [11]; [14]. Other factors affecting the types and amounts of marine debris include topography, environmental variables (e.g. currents and storms) and extent of beach user [27], among others. Still, a number of methods are employed to assess marine debris, turning the comparison of works difficult [31]; [29]. The accumulation of types of marine debris on the beach on Dullah Island is a function of the direction of the wind and the orientation of the beach, while the source of the marine debris comes from coastal residents who dispose of waste directly on the beach, also from inter-island transportation facilities (ferries) and fishing vessels fish, as well as from seaweed farming activities using rope and plastic bottles. This survey is intended to find out how the influence of beach and wind orientation on the accumulation of marine debris on the beach.

2. Material and Method

2.1. Study area

Dullah Island is an island in the Kei Islands, Indonesia. The kei archipelago consists of 132 small islands located between the deep Banda sea and the shallow Arafura Sea[18]. Dullah Island itself is located between the large Kei Island in the east and Nuhuroa Island in the west. The average distance between the big kei island and Dullah island is 20.9 km and is separated by the Nerong Strait and the average distance of Dullah Island and Nuhuroa Island is 475 meters, separated by the Rosenberg Strait. The length of the Dullah Island coastline is 74.8 km and the intertidal zone substrate consists of gravel, sand and mud. The island is surrounded by coral reefs. Marine debris survey was conducted at four open beach locations and two bay beach locations in April and May 2019. Two open beach locations on the East coast of Dullah Island namely Ohoitahit Beach at coordinates 5° 36’ 1 "S; 132° 48’ 8" E, and Vatran Beach at coordinates 5° 37 ’ 5 "S; 132° 48’ 4" E. Tamedan beach location is at coordinates 5°31 ’ 34 "S; 132°47’34" E, and Hangirit beach location is at coordinates 5°32 ’7 "S; 132°46’57 "E. Location at Difur bay at coordinates 5°32’39" S; 132°47’57 "E, and location of Luv bay beach at coordinates 5°39’6” S; 132°47’50 "E. Both the bays are relatively unaffected by the wind and waves (Figure 1).
2.2 Determination of wind and beach exposure

The daily wind direction and velocity from April to May 2019 (until the time of collection of marine debris) was obtained from the Windy application, and the Meteorology and Geophysics Agency Station, Tual, Kei Islands, which are 5 km to 12 km from the survey site. The size of the fetch is measured from an unobstructed distance in the direction of the wind to the coast of the survey location on the Landsat satellite imagery. A Relative Exposure Index (REI) is used as an indicator of possible forcing of debris accumulation, it provides a useful summary of the wind [23]. Using a modified method of [25], an REI is used to calculate 2 locations on the east coast and 2 locations on the west coast according to the direction and speed of the wind and fetch which is converted to speed (kmh-1) by formula,

$$\text{REI} = \sum_{i=1}^{36} \left( \frac{V_i P_i F_i}{100} \right)$$

Where, $V_i$ is the mean daily wind speed (kmh-1) for wind directions; $P_i$ is the percent frequency from which the wind blew and; $F_i$ is the fetch distance (km).

The intertidal zone topography at each survey location was measured using the water passing method, calculated from the highest tide boundary to the lowest tide based on the average maximum tidal width in the kei islands, which is 2.66 meter [19].

2.3 Sampling of marine debris

Sampling of marine debris using 4 transects measuring 25 square meters placed randomly at each survey location. Collection of marine debris items follows Protocol [23], which is collected debris classified as macro debris (≥5 mm). The measurement limits start from 1 meter behind the highest tidal line, sometimes even to the tree area behind the coastline. Debris collected is only on the surface, without digging up the rubbish below the surface of the soil, except if there is a piece of garbage that protrudes from the surface of the soil that can be taken. The time of collection of marine debris is carried out at low tide based on the Global Tide Application which has been adapted to some field measurement data using a tide pole. Marine debris after collection is then sorted according to plastic debris and non-plastic debris groups, for the plastic group, it is grouped into 5 categories including common items, plastic remnants and plastic containers, fishing litter, plastic consumer, plastic foam (polystyrene).

Associations between total marine debris and plastic debris at each location were statistically analyzed using Pearson correlation bivariate analysis at an accuracy level of 0.01. Likewise, an analysis of the association between the Relative Exposure Index (REI) values in the four exposed locations (Ohoitahite, Vatran, Tamedan and Hangirit) on the total number of marine debris and plastic debris using bivariate Pearson correlation analysis with a level of accuracy 0.01.

3. Result and Discussion

3.1 Beach orientation, and wind

Beach orientation and wind direction determine the level of beach exposure to wind and waves, which control the accumulation of marine debris on the beach. Ohoitahit Beach is oriented to 120°SE, and Vatran Beach is oriented towards 99°E, and therefore, in April (transition period) and May 2019 where Southeasterly winds start blowing, Ohoitahit and Vatran Beaches are exposed to winds and waves from 110° to 130°, with frequency the wind blows 7 times (22.58%) with a speed of 2.5 to 3.7 knots. Tamedan Beach is oriented to 330° NW and Hangirit Beach is oriented to 300°W, exposed to winds from 230° to 290° in April with a speed of 0.6 to 4.2 knots with a frequency of 3 gusts. Luv Bay is a bay with a mouth width of 600 meters, oriented at 210°SW, wide mouth at Difur bay at 752 meters, oriented at 30°NE, so the beaches at the bay are relatively unexposed to wind and waves in April and May 2019.
3.2. Accumulation of marine debris
A total of 13969 items of total marine debris were collected at 6 coastal locations on the island of Dullah. The average amount of marine debris at a coastal location on the East coast is 4 times more than the average number of marine debris on the west coast and 28 times more than the bay beaches (Figure 2).

![Figure 2. The average number of marine debris and plastic debris in 25 m², collected at 6 beach locations on Dullah Island in May, 2019](image)

Of the total marine debris collected, 46% consisted of plastic items, dominated by common items (53%), plastic remnants (19%) and plastic containers (18%), while the smallest group was fishing litters (5%), plastic foam (4%) and plastic consumer (1%).

![Figure 3. Percentage of the total group of plastic debris at the survey site](image)
Analysis of the association between the average amount of marine debris and the average number of plastic debris at each Dullah Island beach location shows the Pearson correlation ($r = 0.4$) at an accuracy level of 0.01. That is, an increase in the total amount of marine debris is not significantly correlated with an increase in plastic debris.

### 3.3. Effect of Beach exposure on the accumulation of marine debris

The analysis shows that the average REI on the Ohoitahit coast is 6.7 and the REI on the Vatran beach is 6.95 in April and May 2019. REI on the Tamedan 1.7 and Hangirit 2.0 beaches, only in April 2019 (Figure 4).

![Figure 4. Direction of wind and beach exposure at 4 survey locations](image)

The correlation between REI and total accumulation of marine debris in four coastal locations exposed to wind and waves in April and May 2019 showed a very significant correlation ($r = 0.992$), but the plastic debris was negatively correlated ($r = -0.049$). In conditions of stronger beach exposure, lightweight plastic debris will be swept away with low tide to another place.

### 4. Conclusions and recommendation

#### 4.1. Conclusion

Beach orientation and beach exposure determine the amount of accumulation of types of marine debris on the beach. The accumulation of total marine debris on the beach does not correlate with plastic debris. The higher the beach exposure, the more total sea debris carried to the beach and settles, but lightweight plastic debris is swept away from the beach due to reflection and refraction of waves and receding movements. The accumulated plastic debris 53% are common items, the rest consists of plastic remnants, plastic containers, fishing litters, plastic foam, and plastic consumers.

#### 4.2. Recommendation

We recommend that waste management on the beach needs to consider beach orientation, beach exposure and type of the marine debris.

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References

[1] Araújo, M C B., da Costa, M F., 2007. Visual diagnosis of solid waste contamination of a tourist beach: Pernambuco, Brazil. Waste Manag. 27, 833–889. http://dx.doi.org/10.1016/j.wasman.2006.04.018.

[2] Barnes, D K A. (2005). Remote Islands reveal rapid rise of Southern Hemisphere, sea debris. The Scientific World Journal, 5, 915–921.

[3] Barnes, D K A, Galgani F, Thompson R. C, & Barlaz M (2009). Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B, 364, 1985–1998.

[4] Bergmann M., M. Klages and L. Gutow., 2015. Marine Anthropogenic Litter. AWI, Germany

[5] Browne, M.A., Chapman, M.G., Thompson, R.C., Amaral Zettler, L.A., Jambeck, J., Mallos, N.J., 2015. Spatial and temporal patterns of stranded intertidal marine debris: is there a picture of global change? Environ. Sci. Technol. 49, 7082–7094. http://dx.doi.org/10.1021/acs.est.5b03806.

[6] Cervantes O, Espejel I, 2008. Design of an integrated evaluation index for recreational beaches. Ocean Coast. Manag. 51, 410–419. http://dx.doi.org/10.1016/j.ocecoaman. 2008.01.007.

[7] Corcoran P L, Biesinger M C & Grifi M. (2009). Plastics and beaches: A degrading relationship. Marine Pollution Bulletin, 58(1), 80–84.

[8] Cózar A, Echevarría F, González-Gordillo J. I, Irigoien X, Úbeda B, Hernández-León S, et al. (2014). Plastic debris in the open ocean. Proceedings of the National Academy of Sciences of the United States of America, 111(28), 10239–10244

[9] Edyvane K.S, Dalgetty A, Hone PW, Higham J S, Wace N M, 2004. Long-term marine litter monitoring in the remote Great Australian Bight, South Australia. Mar. Pollut. Bull. 48, 1060–1075.

[10] Eriksen M, Lebreton L C M, Carson H. S, Thiel M, Moore C. J, Borerro J. C, et al. (2014). Plastic pollution in the world’s oceans: More than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. xiv Preface

[11] Frosten, A, Cullen M. 1997. Marine debris on northern New South Wales beaches (Australia): sources and the role of beach usage. Mar. Pollut. Bull. 34, 348–352.

[12] Gabrielides GP, Golik A, Loizides L, Marino MG, Bingel F, Torregrossa MV. 1991. Man-made garbage pollution on the Mediterranean coastline. Mar. Pollut. Bull. 23, 437–441.

[13] Law, KL., 2011. Understanding sources, sinks, and transport of marine debris. Eos 92, 235.

[14] Leite AS, Santos LL, Costa Y, Hatje V. 2014. Influence of proximity to an urban center in the pattern of contamination by marine debris. Mar. Pollut. Bull. 81, 242–247.

[15] Macfadyen G, Huntington T. & Cappell R. (2009). Abandoned, lost or otherwise discarded fishing gear. UNEP Regional Seas Reports and Studies No. 185; FAO Fisheries And Aquaculture Technical Paper No. 523. UNEP/FAO, Rome. pp. 88.

[16] Plastics Europe. (2015). Plastics—the Facts 2014/2015. http://www.plasticsandeurope.fr/Document/plastics—the-facts2013.aspx?Pag DOCUMENTn& FolID=2, http://issuu.com/plasticsandeeuropeebook/docs/final_plastics_the_facts_2014_19122

[17] Rees G, Pond K. 1995. Marine litter monitoring programmes – a review of methods with special reference to national surveys. Mar. Pollut. Bull. 30, 103–108.

[18] Renjaan EA. 2003. The role of hydrodynamic regimes and water properties on transports, retentions, and settlements of mollusk larvae at a lagoon and its adjacent open shore in kai islands, Indonesia. Dissertation zur Erlangung des Doktorgrades der Mathematisch-Naturwissenschaftlichen Fakultät der Christian-Albrechts-Universität zu Kiel

[19] Renjaan EA, Makailipessy MM. 2017. Impact of tidal phenomenon “Met Ef” on the exploitation of benthos at inshore shoals in Kei Islands, Indonesia. IOP Conference Series: Earth and Environmental Science, Volume 89, conference 1

[20] Ribic CA, Sheavly, S B, Rugg DJ, Erdmann ES, 2010. Trends and drivers of marine debris on the Atlantic coast of the United States 1997–2007. Mar. Pollut. Bull. 60, 1231–1242.
[21] Ribic CA, Sheavly S B, Rugg D J, Erdmann ES, 2012. *Trends in marine debris along the U.S. Pacific Coast and Hawaii*’*T 1998–2007*. Mar. Pollut. Bull. 64, 994–1004.

[22] Richards Z T & Beger M. (2011). *A quantification of the standing stock of macro-debris in majuro lagoon and its effect on hard coral communities*. Marine Pollution Bulletin, 62, 1693–1701.

[23] Rodil IF, Lstra M. 2004. *Environmental Factors affecting benthic macrofauna along a gradient of intermediate sandy beaches in northern Spain*. Estuar. Coast. Shelf Sci. 61: 37-44.

[24] Rosevelt C, Los, Huertos M, Garza M, Nevins HM. 2013. *Marine debris in central California: Quantifying type and abundance of beach litter in Monterey Bay, CA*. Mar. Pollut. Bull. 71, 299–306.

[25] Shafer DJ, Streever WJ 2000 *A comparison of 28 natural and dredged material saltmarshes in Texas with an emphasis on geomorphological variables*. Wetlands Ecol. Manage. 8:353-366.

[26] Smith SDA & Markic A (2013) *Estimates of Marine Debris Accumulation on Beaches Are Strongly Affected by the Temporal Scale of Sampling*. PLoS ONE 8(12): e83694. https://doi.org/10.1371/journal.pone.0083694

[27] Storrier KL, McGlashan, DJ Bonellie S,Velander K 2007 *Beach litter deposition at a selection of beaches in the Firth of Forth, Scotland*. J. Coast. Res. 23, 813–822.

[28] Thompson R C (2006) *Plastic debris in the marine environment: Consequences and solutions*. In J. C. Krause, H. Nordheim, & S. Bräger (Eds.), Marine nature conservation in Europe (pp. 107–115). Stralsund, Germany: Bundesamt für Naturschutz.

[29] Tudor DT, Williams AT, Randerson P, Ergin A, Earll R E 2002 *The use of multivariate statistical techniques to establish beach debris pollution sources*. J. Coast. Res. 36, 716–725.

[30] UNEP (2014) *UNEP year book: Emerging issues in our global environment. Chapter 8: Plastic debris in the ocean*. United Nations Environment Programme, Nairobi, Kenya. pp. 49–53.

[31] Velander K, Mocogni M 1999 *Beach litter sampling strategies: is there a best method?*. Mar. Pollut. Bull. 12:1134–1140.

[32] Walker TR, Grant J, Archambault MC 2006 *Accumulation of marine debris on an intertidal beach in an urban park (Halifax Harbour, Nova Scotia)*. Water Qual. Res. J. Can. 41, 256–262.

[33] Williams AT, Pond K, Ergin A, Cullis, MJ 2013 *The hazards of beach litter*. In: Finkl, C.W. (33Ed.), Coastal Hazards, first ed. Springer Science+Business Media, Dordrecht, pp. 753–780.