Marine Pollution Bulletin xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Baseline

# A baseline assessment of beach debris and tar contamination in Bonaire, Southeastern Caribbean

Adolphe O. Debrot [a,*], Jimmy van Rijn [b], Patrick S. Bron [b], Ramon de León [c]

[a] Institute for Marine Research and Ecosystem Studies, Wageningen UR, P.O. Box 57,1780AB Den Helder, The Netherlands
[b] Hogeschool Van Hall-Larenstein, Coastal Zone Management, P.O. Box 1528, 8901 BV Leeuwarden, The Netherlands
[c] Stinapa Bonaire, Barcadera z/n, P.O. Box 368, Bonaire, Dutch Caribbean, The Netherlands

ARTICLE INFO

*Keywords:*
Tropical
Caribbean
Marine
Beach
Debris
Pollution

ABSTRACT

Data on beach debris and tar contamination is provided for 21 natural beach sites in Bonaire, Southeastern Caribbean. Transects amounting to a combined length of 991 m were sampled March–May 2011 and a total of 8960 debris items were collected. Highest debris and tar contamination were found on the beaches of the windward east-coast of the island where geometric mean debris concentrations (± approx. 70% confidence limits) were 115 ± 58 items $m^{-1}$ and 3408 ± 1704 g $m^{-1}$ of beach front. These levels are high compared to data collected almost 20 years earlier on the nearby island of Curaçao. Tar contamination levels averaged 223 g $m^{-1}$ on windward beaches. Contamination levels for leeward west-coast beaches were generally two orders of magnitude less than windward beaches.

## 1. Introduction

Marine debris and tar contamination affect ecosystems and the provision of ecosystem services in various ways, among which deleterious effects on wildlife and habitat quality, economy and aesthetics and even human health and safety (UNEP, 2006). Marine debris (litter) is a particularly wide-spread problem and is considered to be one of the most serious threats to sustainable use of the marine and coastal resources of the Caribbean (UNEP, 2006). Nevertheless, studies on beach debris, and general environmental pollution levels in the Caribbean remain sparse, which makes it difficult to provide conclusive arguments for policy and management action. A review by Ivar do Sul and Costa (2007) specifically emphasises the continuing paucity of recent studies on the debris problem for the Caribbean and the need for new data.

In this study we document beach debris and tar contamination at 21 natural beaches distributed around the island of Bonaire (Fig. 1). The first and only study on this topic for Bonaire dates from the mid-1980s and concerns a study of beach tar at four beach sites (Newton, 1987). To facilitate comparison to results obtained almost 20 years earlier on the nearby island of Curaçao, we closely followed the methods by Debrot et al. (1995, 1999). The data collected in this study provides base-line information on anthropogenic contaminants on the beaches of Bonaire which can be used to help direct both local and regional litter management efforts. Beach site selection followed the IOC manual for petroleum pollution monitoring (UNESCO, 1984; Ribic et al., 1992). Due to the predominant wind, wave and current direction, the beaches on the east side of the island are high-energy beaches (sites 12–21) while the beaches along the west side of the island (sites 1–11) are relatively sheltered. The beaches of the northern half of Bonaire further are basically small pocket beaches, ranging in width from just a few to more than 100 m, while the beaches of southern Bonaire are much longer and not forming distinct pocket beaches.

Sampling was conducted in the central part of each pocket beach in northern Bonaire and on an arbitrarily predetermined sampling point on the long stretches of beach in southern Bonaire. For the grossly contaminated windward sites, transect widths for debris collection was 5 m, whereas for the much less contaminated leeward beaches transect widths varied between 10 m (in the case of the pocket beach of Playa Benge) to 100 m or more in southern Bonaire to increase the debris sample size for comparison. Transect widths for tar collection were principally 2-m on windward beaches, and 5 m on leeward beaches. However, transect widths were extended in the case of extremely low soiling. Consequently, this approach maximized the chance of detecting tar on any given beach.

Sampling on all beaches was limited to the zone stretching from the low tide mark to the point where permanent beach vegetation first appeared (e.g. Santos et al., 2009). The upper few centimetres of the transects were raked and all debris and tar balls and oil found within the transect with a maximum diameter of 5 cm or greater was removed, identified, measured, cleaned where necessary and weighed. Data by Debrot et al. (1999) had indicated that

---

* Corresponding author. Tel.: +31 (0) 317 487 395.
*E-mail addresses:* dolfi.debrot@wur.nl (A.O. Debrot), jimmy.vanrijn@wur.nl (J. van Rijn), patrick.bron@wur.nl (P.S. Bron), marinepark@stinapa.org (R. de León).

0025-326X/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.marpolbul.2013.01.027

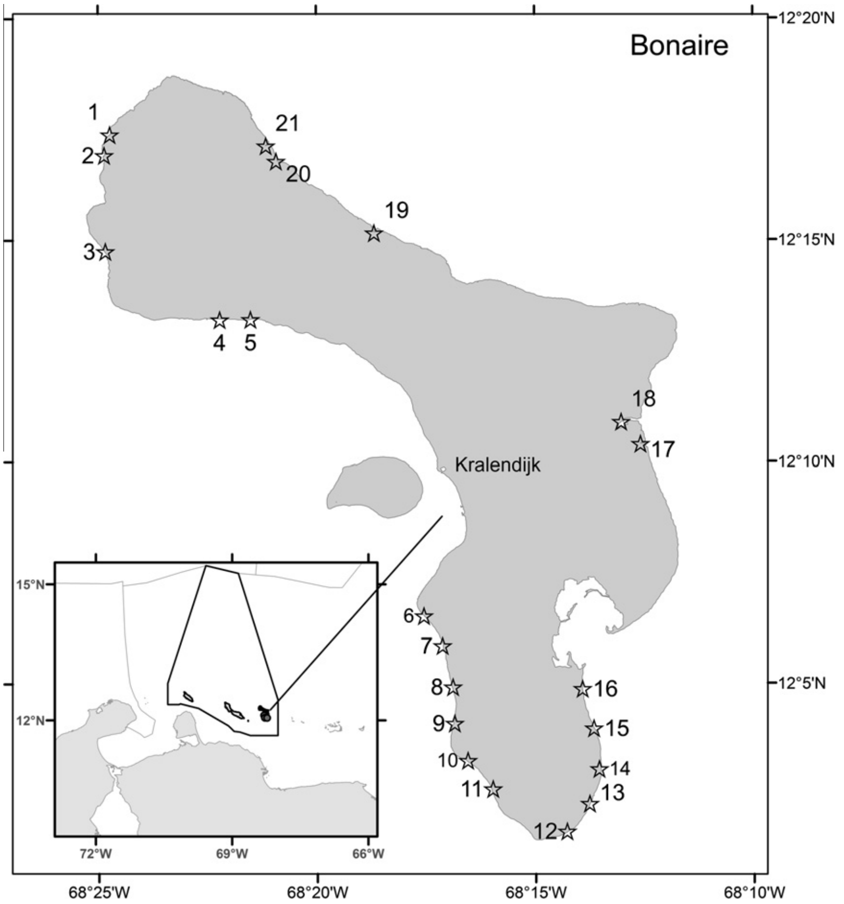

**Fig. 1.** Map of Bonaire showing the location of the 21 beach sites selected for debris and tar contamination assessment.

collection of fragments smaller than 5 cm by hand picking was incomplete. Plastic bottle caps (2 cm diameter) were an exception and were efficiently sampled at such small sizes and therefore were included in this analysis.

Whereas lighter items were taken back to the lab for more accurate weighing pooled by category of material, heavy items, such as boards and beams were weighed in the field to the nearest kg. Materials were identified as either plastic, wood, glass, polystyrene foam (styrofoam), metal, cloth, paper, rubber or masonry. Debris items were also identified according to use.

Debris concentrations were expressed as numbers and weights of items $m^{-1}$ of beach front and tar only as weight $m^{-1}$ of beach front. As beach debris concentrations are typically highly variable and appear to be generally log-normally distributed (e.g., Butler et al., 1998), the geometric mean is a statistically more robust measure of central tendency than the arithmetic mean. Therefore, we expressed debris densities in terms of geometric means with approximate 70% confidence limits based on the log-normal distribution. Statistical comparison of debris concentrations between coastal categories was done using the distribution-free Mann-Whitney U-test. The differences in relative frequency of debris type, and size were tested for by Chi-square Goodness-of-Fit tests. For comparison of size-distributions between coasts, comparison was only considered if the number of objects of a particular material collected exceeded 30 items. All statistical tests were conducted using IBM SPSS vers. 19.

On windward beaches, a total of 7988 items were collected for a combined weight of 246.3 kg from a total of 46 m of beach front. Contamination levels on windward beach sites ranged from an average of 9–1640 items $m^{-1}$ of beach front (Table 1), for a geometric mean of 115 ± 59 items $m^{-1}$. In terms of debris weight, corresponding contamination levels ranged from 545 to 35,306 g $m^{-1}$ (Table 2), for a geometric mean value of 3408 ± 1704 g $m^{-1}$. The leeward beaches had much lower levels of debris contamination. In this, the leeward beaches of the extreme northern and southern promontories of the island, directly under the windward coast of the island, were an exception. However, as these were atypical leeward beaches, they were not included in our study. On leeward beaches, a total of 972 items were collected for a combined weight of 43.1 kg from a total of 945 m of beach front. Debris densities on leeward beach sites ranged from 0.1 to 5 items $m^{-1}$ and from 5 to 716 g $m^{-1}$ of beach front. Corresponding geometric mean levels were 1 ± 0.4 items $m^{-1}$ and 38 ± 19 g $m^{-1}$. The differences in debris contamination between windward and leeward beaches were statistically significant in terms of both numbers and weight ($p = 0.000$). Tar was only encountered on two of the eleven leeward beaches studied for an average of 4 g $m^{-1}$. On the windward coast, tar was collected at 5 of the 10 beach sites (range: 7.5–1424 g $m^{-1}$) for an average of 223 g $m^{-1}$ across all 10 sites.

Plastics were numerically the most important material component of the collected debris and represented 72% of all items collected. The next principal components were respectively, styrofoam (16%) and wood (7%) (Table 1). The numerical differences in material distribution by coast differed significantly (Pearson Chi-square = 61.3, df = 5, $p = 0.000$). While plastics followed by styrofoam fragments were thus numerically dominant on both beach categories, their contribution to the total weight of debris differed significantly (Table 2). On windward beaches, the weight

Please cite this article in press as: Debrot, A.O., et al. A baseline assessment of beach debris and tar contamination in Bonaire, Southeastern Caribbean. Mar. Pollut. Bull. (2013), http://dx.doi.org/10.1016/j.marpolbul.2013.01.027

**Table 1**
Abundance of debris in terms of number of items collected from the twenty-one Bonaire beach sites studied.

| Site no./ sector | Site name | Beach width (m) | Beach length (m) | Plastic | Wood | Glass | Polystyrene foam | Metal | Cloth | Paper | Rubber | Masonry | | Total no. ($m^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Leeward* | | | | | | | | | | | | | | |
| 1 | Playa Benge | 10 | 16.5 | 21 | 6 | 1 | 4 | 1 | – | – | 1 | – | | 3.4 |
| 2 | Playa Funchi | 50 | 9.0 | 33 | 16 | – | 19 | 1 | – | – | 3 | 4 | | 1.5 |
| 3 | Playa Frans | 100 | 20.0 | 65 | 4 | 1 | 28 | 4 | – | – | 5 | 1 | | 1.1 |
| 4 | | 100 | 10.5 | 144 | 8 | 1 | 13 | – | 1 | 3 | 4 | – | | 1.7 |
| 5 | | 100 | 11.0 | 154 | 21 | 2 | 12 | 1 | – | – | 8 | – | | 2.0 |
| 6 | | 100 | 22.5 | 60 | 6 | 1 | 55 | – | 1 | – | 9 | – | | 1.3 |
| 7 | | 100 | 18.5 | 3 | 2 | – | 1 | – | 2 | 2 | – | – | | 0.1 |
| 8 | | 100 | 24.5 | 35 | 3 | 5 | 9 | 4 | 2 | – | 8 | 1 | | 0.7 |
| 9 | | 170 | 18.0 | 21 | 2 | – | 3 | 6 | 1 | – | – | 2 | | 0.2 |
| 10 | | 100 | 17.0 | 47 | 2 | 2 | 6 | 2 | – | – | 4 | – | | 0.6 |
| 11 | | 15 | 12.0 | 63 | 5 | 2 | 3 | – | – | – | 2 | – | | 5.0 |
| | | Total (%) | | 66.5 | 7.7 | 1.5 | 15.7 | 2.0 | 0.7 | 0.5 | 4.5 | 0.8 | Avg. | 1.4 |
| *Windward* | | | | | | | | | | | | | | |
| 12 | | 5 | 19.5 | 389 | 65 | 8 | 34 | 7 | – | – | 22 | – | | 105.0 |
| 13 | | 5 | 26.0 | 127 | 39 | 1 | 6 | 13 | – | – | 15 | – | | 40.2 |
| 14 | | 5 | 31.0 | 27 | 3 | 4 | 3 | 1 | – | – | 2 | 7 | | 9.4 |
| 15 | | 5 | 21.0 | 278 | 7 | 8 | 12 | – | 1 | – | 2 | – | | 61.6 |
| 16 | | 5 | 19.0 | 101 | 6 | – | 2 | – | – | – | 1 | – | | 22.0 |
| 17 | Boka Washikemba | 1 | 65.0 | 1190 | 141 | 18 | 239 | 5 | – | – | 47 | – | | 1640.0 |
| 18 | Lagoen | 5 | 11.5 | 1372 | 98 | 10 | 186 | 6 | – | – | 35 | – | | 341.4 |
| 19 | Boka Onima | 5 | 28.0 | 577 | 74 | 1 | 279 | 12 | 3 | – | 26 | – | | 194.4 |
| 20 | Playa Chikitu | 5 | 25.0 | 195 | 13 | 1 | 86 | 1 | – | – | 14 | – | | 62.0 |
| 21 | Boka Chikitu | 5 | 53.5 | 1606 | 70 | 3 | 394 | 5 | – | – | 90 | – | | 433.6 |
| | | Total (%) | | 73.4 | 6.5 | 0.7 | 15.5 | 0.6 | 0.1 | 0.0 | 3.2 | 0.1 | Avg. | 291.0 |

**Table 2**
Abundance of man-made debris and tar in terms of weight (g) collected from the twenty-one Bonaire beach sites studied.

| Sector/site no. | Site name | Beach width (m) | Plastic | Wood | Glass | Polystyrene foam | Metal | Cloth | Paper | Rubber | Masonry | Total debris ($g\,m^{-1}$) | Tar ($g\,m^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Leeward* | | | | | | | | | | | | | |
| 1 | Playa Benge | 10 | 701 | 5959 | 190 | 70 | 49 | – | – | 193 | – | 716 | – |
| 2 | Playa Funchi | 50 | 416 | 4125 | 10 | 78 | 12 | – | – | 390 | 318 | 107 | – |
| 3 | Playa Frans | 100 | 554 | 249 | 47 | 21 | 101 | – | – | 166 | 87 | 12 | 41.9 |
| 4 | | 100 | 1745 | 3731 | 189 | 99 | – | 65 | 127 | 57 | – | 60 | – |
| 5 | | 100 | 2992 | 9789 | 200 | 15 | 19 | – | – | 2850 | – | 159 | – |
| 6 | | 100 | 530 | 482 | 122 | 45 | – | 13 | – | 573 | – | 18 | – |
| 7 | | 100 | 84 | 1800 | – | 6 | – | 39 | 66 | – | – | 20 | – |
| 8 | | 100 | 313 | 811 | 249 | 8 | 405 | 25 | – | 235 | 71 | 21 | – |
| 9 | | 170 | 119 | 42 | 110 | 4 | 393 | 36 | – | – | 91 | 5 | – |
| 10 | | 100 | 411 | 24 | 92 | 5 | 167 | – | – | 155 | – | 9 | – |
| 11 | | 15 | 581 | 490 | 206 | 14 | – | – | – | 57 | – | 90 | 0.5 |
| | | Total (%) | 19.0 | 61.8 | 3.2 | 0.8 | 2.6 | 0.4 | 0.4 | 10.5 | 1.3 | 111 | 3.9 |
| *Windward* | | | | | | | | | | | | | |
| 12 | | 5 | 10,052 | 5997 | 1966 | 170 | 110 | – | – | 1278 | – | 3915 | – |
| 13 | | 5 | 4799 | 7321 | 135 | 46 | 213 | – | – | 836 | – | 2670 | – |
| 14 | | 5 | 568 | 130 | 225 | 8 | 23 | – | – | 156 | 1899 | 602 | – |
| 15 | | 5 | 5075 | 836 | 303 | 122 | – | 305 | – | 240 | – | 1376 | – |
| 16 | | 5 | 1900 | 787 | – | 31 | – | – | – | 6 | – | 545 | 1424 |
| 17 | Boka Washikemba | 1 | 11,548 | 18,891 | 1239 | 740 | 88 | – | – | 2800 | – | 35,306 | 714.5 |
| 18 | Lagoen | 5 | 17,301 | 37,188 | 1352 | 545 | 345 | – | – | 2380 | – | 11,822 | – |
| 19 | Boka Onima | 5 | 72,73 | 12,046 | 210 | 498 | 44[*] | 84 | – | 3272 | – | 4685 | 7.5 |
| 20 | Playa Chikitu | 5 | 4239 | 1758 | 137 | 290 | 105 | – | – | 1068 | – | 1519 | 77 |
| 21 | Boka Chikitu | 5 | 42,688 | 22,944 | 446 | 2726 | 229 | – | – | 6326 | – | 15,072 | 11 |
| | | Total (%) | 42.8 | 43.8 | 2.4 | 2.1 | 0.4 | 0.2 | 0.0 | 7.5 | 0.8 | 7751 | 223.4 |

[*] A car wreck of 300+ kg originating from land was excluded as an outlier.

contribution of plastics (43%) was equal to that of wood (44%), whereas on leeward beaches, plastics (19%) were exceeded markedly in terms of weight by wood (62%) (Table 2).

Fig. 2 shows the relative size-distributions for the different material types collected, excluding those represented by less than 30 items per coastal category. The overall mean item weight of

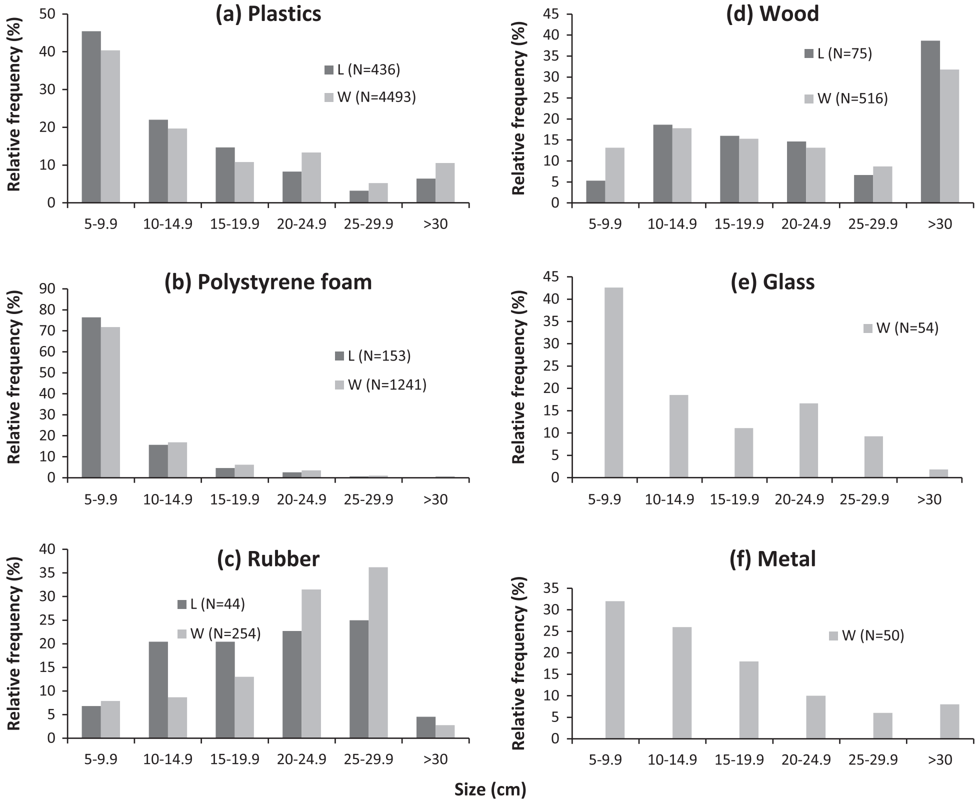

**Fig. 2.** Relative size-frequency distributions (%) of items of (a) plastic, (b) polystyrene foam, (c) rubber, (d) wood, (e) glass and (f) metal collected on leeward (L) and windward (W) beach sites. Sample sizes for glass and metal on leeward beaches were less than 30 items and the data were not plotted.

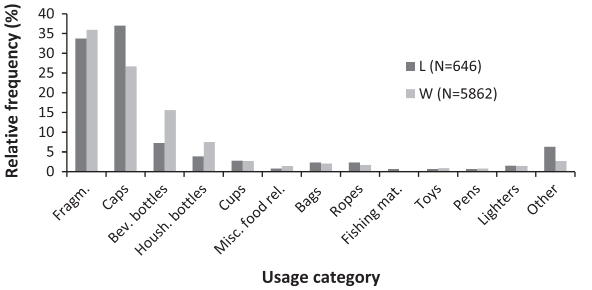

**Fig. 3.** Relative size-frequency distributions (%) of plastic items according to usage category for leeward (L) and windward (W) beach sites.

objects collected from the leeward beaches was somewhat higher (44 g) than from windward beaches (31 g) but the differences in material size-frequency distribution between windward and leeward beaches were small. Only plastics showed a significant difference in size structure between windward and leeward coasts (Pearson Chi-square = 37.8, df = 5, $p = 0.000$) and test results for wood, styrofoam and rubber were not significant. Fig. 3 provides an overview of the different categories of plastic items collected. The differences between coastal categories in debris usage-type were statistically significant (Pearson Chi-square = 75.2, df = 8, $p = 0.000$). The most pertinent contrasts were (a) the higher preponderance of (small) plastic beverage bottle caps on leeward beaches and (b) the higher preponderance of plastic beverage and (large) household bottles on windward sites. While on wind-exposed windward beaches, light plastic bottles are blown up onto beaches, on leeward beaches where the wind direction is off-shore, plastic bottles will more often roll into the water and be carried away under conditions where bottle caps stay behind.

The debris contamination levels found for Bonaire in this study (115 ± 58 items $\mathrm{m}^{-1}$) were on the high side compared to those found in nearby Curaçao (60 ± 62 items $\mathrm{m}^{-1}$) almost 20 years ago and the numerical contribution of plastic is also higher by about 10% (Debrot et al., 1999). These findings of high debris concentrations on exposed beaches in Bonaire correspond to the world-wide growth of the marine debris problem in recent decades (UNEP, 2006). However, notwithstanding increased general and scientific awareness of the severity of the problem in recent years, there have been very few recent studies and no measurable progress in addressing this issue in the Southeastern Caribbean, where beach debris densities appear acutely high. For comparison, beach debris densities in a recent surveys of 79 beach transects on a 150 km section of undeveloped tropical beaches in north–east Brazil, averaged only 9.4 items $\mathrm{m}^{-1}$ of beachfront (Santos et al., 2009).

Municipal dumping of domestic waste into the sea in Bonaire, at the west-coast dumpsite at Wecua, had already stopped by the mid-1970s, when the current landfill was opened. Illegal dumping and littering on Bonaire is very limited compared to many other Caribbean islands, including Curaçao, and most beach debris drifts in from elsewhere. Therefore, the problem of beach debris should ideally be addressed at a joint regional level. To this end UNEP's Caribbean Environmental Programme (CEP/UNEP) has developed a regional marine litter action plan (UNEP, 2008).

As for beach tar contamination levels, based on 12 collection sessions between 1980 and 1985, Newton (1987) documented average tar contamination levels for four transects on three windward beaches of Bonaire at between 56 and 278 g $\mathrm{m}^{-1}$ (avg: 121 g $\mathrm{m}^{-1}$). Newton found tar at all collections (12 collecting sessions between 1980 and 1985 × 4 transects = 48 collections) on in his windward transects but none at his three leeward coast beach transects. Debrot et al. (1995) previously documented an average tar concentration of 1019 g $\mathrm{m}^{-1}$ of tar for 10 windward

Please cite this article in press as: Debrot, A.O., et al. A baseline assessment of beach debris and tar contamination in Bonaire, Southeastern Caribbean. Mar. Pollut. Bull. (2013), http://dx.doi.org/10.1016/j.marpolbul.2013.01.027

beach transects in Curaçao. In that study, also only one out of the nine transects was tar-free. In contrast, in this study the average tar density on Bonaire windward beach sites was 223 g m$^{-1}$ and 5 of the 10 transects were tar-free, notwithstanding a (non-random) sampling approach aimed towards ensuring that if tar was present on the beach, it would not be missed because of effects of transect placement and width. Hence, at present the level of tar contamination for Bonaire appears to be in the same range or possibly less than it used to be in the early 1980s. It certainly appears to be less than it was in the early 1990s for Curaçao. Bonaire has less oil industry and oil-related traffic than Curaçao, and also appears to be less affected by oil contamination than Curaçao. There, heavy soiling by tar was found to have long-term negative consequences for shore mollusc populations in terms of both density and diversity (Nagelkerken and Debrot, 1995).

## Acknowledgments

Principal funding was provided by the Ministry of Economic Affairs, Agriculture and Innovation (EL&I) under Project number 4308701003 as part of the Wageningen University BO research program (BO-11-011.05-007, A. Debrot, principal investigator). IMARES provided supplemental funding through student internship grants to J. van Rijn. The authors further thank Frank van Slobbe, Dr. R. Peachey and Elze Dijkman for their critical assistance, and an anonymous reviewer for giving constructive critiques of earlier versions of this manuscript.

## References

Butler, J.N., Wells, P.G., Johnson, S., Manock, J.J., 1998. Beach tar on Bermuda: recent observations and implications for global monitoring. Marine Pollution Bulletin 36, 458–463.

Debrot, A.O., Bradshaw, J.E., Tiel, A.B., 1995. Tar contamination on beaches in Curaçao. Marine Pollution Bulletin 30, 689–693.

Debrot, A.O., Tiel, A.B., Bradshaw, J.E., 1999. A study of beach debris contamination in Curaçao, Netherlands Antilles. Marine Pollution Bulletin 38, 795–801.

Ivar do Sul, J.A., Costa, M.F., 2007. Marine debris review for Latin America and the wider Caribbean region: from the 1970s until now, and where do we go from here? Marine Pollution Bulletin 54, 1087–1104.

Nagelkerken, I., Debrot, A.O., 1995. Mollusc communities of tropical rubble shores of Curaçao: long-term (7+ years) impacts of oil pollution. Marine Pollution Bulletin 30, 592–598.

Newton, E., 1987. Tar on beaches, Bonaire, Netherlands Antilles. Caribbean Journal of Science 23, 139–143.

Ribic, C.A., Dixon, T.R., Vining, I., 1992. Marine Debris survey manual. NOAA Techn. Rpt. NMFS 108. US Department of Commerce.

Santos, I.R., Friedrich, A.C., Ivar do Sul, J.A., 2009. Marine debris contamination along undeveloped tropical beaches form northeast Brazil. Environmental Monitoring and Assessment 148, 455–462.

UNEP (United Nations Environment Programme), 2006. Marine litter in the wider Caribbean. pp. 18. <http://www.cep.unep.org/operational-components/amep/marine-litter.pdf>.

UNEP (United Nations Environment Programme), 2008. Marine litter in the wider Caribbean: a regional overview and action plan. Car. Envir. Progr./CRCU. Kingston, Jamaica. pp. 81.

UNESCO, 1984. Intergovernmental oceanic commission manuals and guides No. 13. Manual for monitoring oil and dissolved/dispersed petroleum hydrocarbons in marine waters and on beaches. UNESCO, Paris.

Please cite this article in press as: Debrot, A.O., et al. A baseline assessment of beach debris and tar contamination in Bonaire, Southeastern Caribbean. Mar. Pollut. Bull. (2013), http://dx.doi.org/10.1016/j.marpolbul.2013.01.027