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Spatial and temporal variation of macro-, meso- and microplastic abundance on a remote coral island of the Maldives, Indian Ocean

Hannes K. Imhof [1], Robert Sigl [1], Emilia Brauer, Sabine Feyl, Philipp Giesemann, Saskia Klink, Kathrin Leupolz, Martin G.J. Löder, Lena A. Löschel, Jan Missun, Sarah Muszynski, Anja F.R.M. Ramsperger, Isabella Schrank, Susan Speck, Sebastian Steibl, Benjamin Trotter, Isabel Winter, Christian Laforsch *

Department of Animal Ecology I and BayCEER, University of Bayreuth, Universitätsstr. 30, 95447 Bayreuth, Germany

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ABSTRACT

Plastic debris is ubiquitous in the marine environment and the world's shores represent a major sink. However, knowledge about plastic abundance in remote areas is scarce. Therefore, plastic abundance was investigated on a small island of the Maldives. Plastic debris (>1 mm) was sampled once in natural long-term accumulation zones at the north shore and at the high tide drift line of the south shore on seven consecutive days to quantify daily plastic accumulation. Reliable identification of plastic debris was ensured by FTIR spectroscopy. Despite the remoteness of the island a considerable amount of plastic debris was present. At both sites a high variability in plastic abundance on a spatial and temporal scale was observed, which may be best explained by environmental factors. In addition, our results show that snapshot sampling may deliver biased results and indicate that future monitoring programs should consider spatial and temporal variation of plastic deposition.

1. Introduction

Plastic can be used for countless applications; it is durable, lightweight and has low production costs. These properties favor plastic as an everyday mass product, which can be seen in the exponential increase in its production and use since the 1950s (PlasticsEurope, 2015). There are a multitude of pathways by which plastic intentionally or unintentionally enters the environment (Bergmann et al., 2015; GESAMP, 2015). Once introduced into the environment, plastic debris probably persists for decades due to its chemical properties (Barnes et al., 2009; Corcoran et al., 2009). The majority of plastic items in the environment are present as 'microplastic', either as fragments of larger plastic litter, or 'microplastic by design' like microbeads or pre-production pellets (Van Cauwenberghe et al., 2015).

Once introduced, plastic litter finally accumulates in the surface water of the world's oceans (van Sebille et al., 2015; Cózar et al., 2014) and disperses throughout the oceans due to its durability, longevity and the capacity for long-distance transport (Eriksen et al., 2014; Ebbesmeyer and Ingraham, 1994). Many particles end up being washed ashore (Van Cauwenberghe et al., 2015), hence beaches are considered to be a major sink for plastic debris (GESAMP, 2015). Microplastic particles can contribute up to 27,606 items/m^2 or 3.3% of the sediment by weight on heavily polluted beaches (Lee et al., 2013; Carson et al., 2011).

The occurrence of plastic debris in the marine environment could elicit severe impacts on organisms of different trophic levels, when microplastic particles are ingested. In addition to direct mechanical effects, (e.g. gut impaction or food depletion, Wright et al., 2013), a variety of indirect effects may arise. For example, harmful substances from microplastic particles may leach into the digestive tract reducing survival, feeding, immunity or antioxidant capacity (Browne et al., 2013). Likewise, environmental contaminants that adsorb to the surface of the particles may elicit adverse effects (Rochman, 2015; Bakir et al., 2012). However, a critical evaluation of the current literature by Koelmans et al. (2016) reveals a limited importance of leaching chemicals. Additionally, microplastic particles may act as a vector of potentially harmful microorganisms and alien species (Kirstein et al., 2016; Zettler et al., 2013).

Although, plastic contamination of shorelines has been recorded in large areas all over the globe, knowledge about the amount of plastic debris in areas remote to human civilization is scarce (Bergmann et al., 2015; GESAMP, 2015; van Sebille et al., 2015). Furthermore, the understanding and interpretation of spatial and temporal patterns of local and global scale is hampered by several reasons which were outlined by extensive reviews of Browne et al. (2015), Van Cauwenberghe et al. (2015), Löder and Gerdts (2015) and Hidalgo-Ruz et al. (2012): Firstly, existing studies

* Corresponding author.
E-mail address: christian.laforsch@uni-bayreuth.de (C. Laforsch).
[1] Shared first authorship.

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exhibit a low comparability due to variation in the sampling design (a.o.: sampling only the drift line, the upper or lower beach, the entire beach, beach surface or deep sediment samples, accumulation zones or random sites, number of samples per area or time). Secondly, the results of most studies are only a snapshot in time and the natural variation of plastic abundance on a spatial and temporal scale is largely influenced by local characteristics that are often unknown or ignored. Thirdly, many studies only rely on the visual identification of plastic debris, which might be possible for larger fragments, but this method is not reliable for particles of the microplastic size.

To address these issues, the aim of the present study was to quantify the contamination of the shoreline of a remote and small coral island with macroplastic (>25 mm), mesoplastic (5–25 mm) and large microplastic particles (1–5 mm) in a spatial and temporal context. The island is located in the central Indian Ocean, a region where plastic pollution has been investigated scarcely on the water surface (van Sebille et al., 2015; Eriksen et al., 2014) and in beach sediments (Browne et al., 2015; Barnes, 2004). Due to the remoteness of the island and because of being almost unpopulated, we expected to find very low amounts of plastic debris, as plastic abundance is usually correlated with population density, urbanization and beach use (e.g. Browne et al., 2015). We quantified (I) the 'long-term accumulation' of plastic debris in natural aggregation zones of organic material and marine debris on the north shore and (II) the daily abundance of plastic debris deposited in the drift line after high tide on seven consecutive days on the south shore. For a reliable identification, all potential plastic particles were analyzed using attenuated total reflection (ATR) FTIR spectroscopy.

2. Materials and methods

2.1. Sampling location

The sampling was performed on Vavvaru Island (5°25′05″ N, 73°21′16″ E), Lhaviyani Atoll, Republic of Maldives, a scarcely inhabited island only used for research and environmental education with strongly limited on-island waste disposal. The island only houses a marine station, which provides laboratories and logistics for scientists and educational groups. Vavvaru is located in the south-west of the Lhaviyani atoll with its western side oriented to the open sea (Fig. 1). It has a circumference of about 1200 m and an area of ~31,000 m^2. The longest distance from north to south is ~270 m and ~450 m from east to west. The south of the island is dominated by a wide lagoon (facing from south to southeast) and the transition from land to sea is level with a long sandy beach (Fig. 1). Thus, plastic debris may be gently washed ashore but can also be washed away again. Therefore, a constant import and export is assumed. In contrast, the rest of the shoreline (spreading from west to northeast, besides a small east-facing part of the coast; Fig. 1) is steeper with a short intertidal zone and a wide reef flat facing the open sea. This part is dominated by underbrush on sand barriers. Due to the terrain profile, large areas of the northern part of the island, including the underbrush, are completely flooded during high tide. The water gathers in hollows and organic material and marine debris is trapped in accumulation zones behind the natural sand barrier and the underbrush (Fig. S1).

Two experiments were conducted taking into account the differing morphology of the island.

(I) We quantified the long-term accumulation of plastic debris gathered in natural accumulation zones behind the steep coastline. Six sites

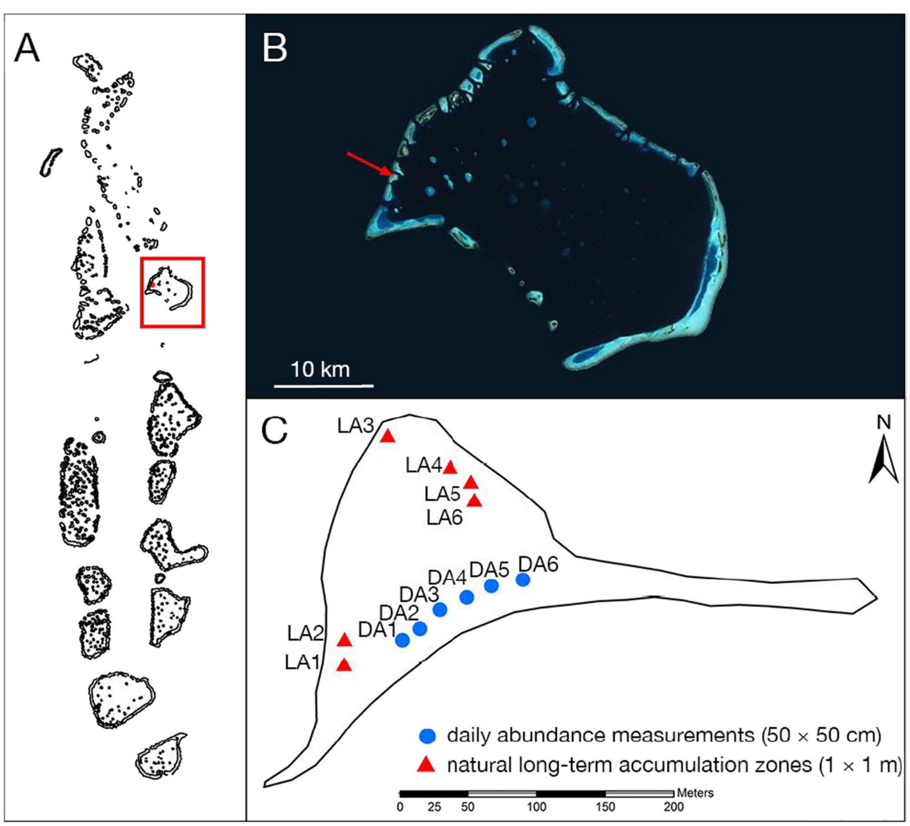

Fig. 1. Map of Vavvaru and location of sampling sites. (A) Republic of Maldives with red box outlining the Lhaviyani atoll. (B) Satellite image of the Lhayiyani atoll. The red arrow marks Vavvaru. (C) Perimeter of Vavvaru during the sampling period in 2015. The blue dots mark the sampling sites for the daily abundance of intertidal plastic debris on the south-facing shore of Vavvaru (DA1–DA6) and the red triangles mark the sampled natural long-term accumulation zones of organic material and marine debris (LA1–LA6). (A) and (B) from ESRI DigitalGlobe, GeoEye and NOAA. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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