Marine Pollution Bulletin xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Microplastic abundance, distribution and composition along a latitudinal gradient in the Atlantic Ocean

La Daana K. Kanhai [a,*], Rick Officer [a], Olga Lyashevska [a], Richard C. Thompson [b], Ian O'Connor [a]

[a] Marine and Freshwater Research Centre, Galway Mayo Institute of Technology, Dublin Road, Galway, Ireland
[b] Marine Biology and Ecology Research Centre, School of Marine Science and Engineering, Plymouth University, Drake Circus, Plymouth, Devon PL4 8AA, United Kingdom

ARTICLE INFO

Article history:
Received 13 October 2016
Received in revised form 8 December 2016
Accepted 9 December 2016
Available online xxxx

Keywords:
Microplastic
Sub-surface waters
Upwelling
Atlantic Ocean
Marine debris

ABSTRACT

Microplastics in the world's oceans are a global concern due to the potential threat they pose to marine organisms. This study investigated microplastic abundance, distribution and composition in the Atlantic Ocean on a transect from the Bay of Biscay to Cape Town, South Africa. Microplastics were sampled from sub-surface waters using the underway system of the RV *Polarstern*. Potential microplastics were isolated from samples and FT-IR spectroscopy was used to identify polymer types. Of the particles analysed, 63% were rayon and 37% were synthetic polymers. The majority of microplastics were identified as polyesters (49%) and blends of polyamide or acrylic/polyester (43%). Overall, fibres (94%) were predominant. Average microplastic abundance in the Atlantic Ocean was 1.15 ± 1.45 particles m^{-3}. Of the 76 samples, 14 were from the Benguela upwelling and there was no statistically significant difference in microplastic abundance between upwelled and non-upwelled sites.

1. Introduction

Within the past decade, microplastics in the world's oceans have emerged as an issue of global importance (UNEP, 2011). Concern regarding these particles stems from their ubiquity, persistence and the potential threat they pose to marine organisms. The gravity of the situation is compounded by the fact that even if the introduction of plastic debris to the marine environment were to be halted, microplastic abundances are projected to increase as a result of the fragmentation of plastics that are already in the world's oceans (Thompson, 2015).

Global concern about microplastics, i.e. plastic particles < 5 mm in diameter (Arthur et al., 2009), has prompted numerous investigations regarding this type of marine debris. Microplastics have been discovered in oceanic waters, deep sea sediments, sea ice and marine organisms (Lusher, 2015). Studies that investigated microplastics in surface and sub-surface waters of the world's oceans found that microplastic abundance was highest in the convergence zones of the five sub-tropical gyres which are regarded as biological deserts due to their low levels of marine biodiversity (Cozar et al., 2014; Polovina et al., 2008).

Even though information exists regarding microplastics in the world's oceans, a greater understanding of microplastic abundances in biota rich waters is particularly important due to the enhanced possibilities for interactions between microplastics and organisms (Cole et al., 2015). Areas which experience coastal upwelling sustain high primary productivity and it is this enhanced productivity which supports more complex food webs comprising biota from a range of trophic levels. Coastal upwelling in the Atlantic Ocean occurs primarily at the (i) Canary Upwelling Ecosystem (CUE) which is comprised of three zones (12–19°N, 21–26°N, 26–35°N) and, (ii) Benguela Upwelling Ecosystem (BUE) which stretches from the southern tip of Africa to approximately 15°S where it is bounded by the Angola front (Santos et al., 2012; Cropper et al., 2014).

Effectively addressing the issue of microplastics in the marine environment requires information on the abundance, distribution and composition of microplastics in the world's oceans. Information from the natural environment is particularly important as it (i) provides an indication of the extent of the problem and, (ii) informs laboratory studies by providing data on the environmentally relevant concentrations of microplastics that biota are exposed to in the natural environment. More specifically, information about microplastics at coastal upwelling sites in the Atlantic Ocean is particularly important as it could provide (i) an indication of the probability of encounter between organisms and microplastics at such sites and, (ii) insight into the potential effect of oceanographic phenomena such as upwelling on microplastics in the world's oceans. The present study investigated microplastic abundance, distribution and composition along a latitudinal gradient in the Atlantic Ocean. The specific aim was to determine whether microplastic abundance in upwelled areas were significantly different from non-upwelled areas.

* Corresponding author.
E-mail address: ladaana.kanhai@research.gmit.ie (L.D.K. Kanhai).

http://dx.doi.org/10.1016/j.marpolbul.2016.12.025
0025-326X/

2. Materials and method

2.1. Sample collection

This study was conducted onboard the RV *Polarstern* during Expedition PS95 and covered 7345 nautical miles (13,603 km) between Bremerhaven, Germany and Cape Town, South Africa. Sub-surface oceanic waters pumped onboard the vessel via the underway system were sampled for microplastics using the method described by Lusher et al. (2014). Sampling was conducted during November 2015 (1st to 28th) at vessel speeds of between 8 and 13 knots. Since each sample constituted the filtration of 2000 L of water (Lusher et al., 2014), the survey effort for this study was 152,000 L of water (76 samples).

Seawater from a continuous intake located at the keel of the ship (depth 11 m) was pumped onboard the vessel using a Klaus Union Sealex Centrifugal Pump (Bochum, Germany) at a flow rate of 25 m^3/h and transported to the laboratory via stainless steel pipes. Prior to reaching the laboratory, the seawater passed through a primary filter (pore size 2 mm) to remove large debris items. The inclusion of this primary filter was standard operating procedure onboard the vessel and thus was beyond the control of the investigator. Potential contamination of the seawater intake by waste water generated onboard did not occur since grey water from the vessel was stored onboard for subsequent treatment. In the laboratory, seawater from the vessel's underway system was allowed to flow through a covered stainless steel sieve (250 μm) by means of a connection hose fitted into a wooden sieve cover. For the duration of the sampling, the stainless steel sieve was supported in a wooden stand. For each sample, 2000 L of water was filtered. The length of time taken for the filtration of the specified volume of water was determined by calculation of the flow rate of the seawater. Once the specified volume of water was filtered, the sieve was removed and distilled water used to wash retained material from the sieve into a clean container. The collected material was then filtered under vacuum onto glass microfiber paper (GF/C); Whatman: 47 mm, pore size: 1.2 μm, using a Buchner funnel and a vacuum flask (Lusher et al., 2014). Each filter paper was then placed into a clean petri dish, covered and stored in a freezer (−20 °C) until returned to the laboratory. At the start and at the end of each sample, positioning data were collected. Data for various environmental variables were obtained from the vessel's (i) thermosalinometer-keel (water temperature, salinity, conductivity), (ii) ferrybox (chlorophyll *a* and pH), and (iii) weather station (wind speed, wind direction).

2.2. Method validation and contamination prevention

Method blanks and controls were used to determine whether there was any contamination during sample processing. Clean petri dishes and filter paper were left exposed to the air during vacuum filtration to determine if there was any airborne contamination. To determine whether there was any additional contamination during vacuum filtering, distilled water was passed through clean GF/C filter paper under vacuum. During visual identification of potential microplastics in samples, checks were also made for airborne contamination by exposing a clean petri dish and filter paper to the air. In order to prevent contamination in the laboratory, the following measures were taken (i) lab coats, cotton clothing and gloves were worn during sample processing, (ii) a wooden cover was placed over the stainless steel sieve to prevent airborne contamination, and (iii) all containers used during sample processing were covered and cleaned using distilled water before reuse (Lusher et al., 2014).

2.3. Laboratory analyses

Samples were removed from the freezer and left to dry. Individual filter papers were then visually examined under a dissecting microscope (Olympus SZX10) equipped with a polariser and camera (Q Imaging Retiga 2000R). Potential microplastics were identified based on characteristic features such as (i) colour- homogenous colour, shininess, unnatural colours, (ii) thickness-fibres homogenous in thickness and, (iii) bending-fibres demonstrated three dimensional bending. Potential microplastics from each sample were photographed and length measurements were taken prior to transferring to a clean filter paper. Filter papers with potential microplastics from each sample were stored in clean, labelled petri dishes. Potential microplastics were assigned to two broad categories (fibres, fragments) and to five length categories: 0.25–0.5 mm, 0.5–0.75 mm, 0.75–1.0 mm, 1.0–2.0 mm, 2.0–5.0 mm.

All potential microplastics as well as a subset of particles not considered to be microplastics ($n = 499$) were analysed by Fourier transform infrared (FT-IR) spectroscopy on a Bruker Vertex 70 Infrared Spectrometer coupled to a Hyperion 1000 microscope. The instrument was equipped with a potassium bromide (KBr) beamsplitter and an internal mercury cadmium telluride (MCT) detector. Microscope-transmission sampling was performed using a Specac DC-2 Diamond Compression cell. Spectra were recorded as the average of 32 scans in the spectral wave number range of 4000–600 cm^{-1} at a resolution of 4 cm^{-1} (Blackman-Harris 3-term apodisation). Bruker's Opus 7.5 spectroscopy software was used for processing and evaluating all spectra. Prior to analysing each sample, background scans were performed and sample spectra were automatically corrected. Each sample spectrum was compared with those of known standard polymers in the (i) Bruker Optics Attenuated Total Reflectance (ATR) Polymer and (ii) Synthetic Fibres ATR libraries. An initial hit quality with a score ranging between 0 and 1000 was produced for each match between sample and reference spectra, with the highest score representing the closest match. Following this preliminary matching, the top ten matches for each sample spectrum were then further evaluated using the Quick Identity Test/Euclidean Distance (ED) option. A hit quality ranging between 0 and 2 was produced for each match between the sample spectrum and the reference spectra, with the lowest number representing the closest match. Overall, matches with >70% similarity were accepted while those with 60–70% similarity were individually examined to ensure that there was clear evidence of peaks from the sample corresponding to known peaks of standard polymers. Samples which produced spectra with a match <60% were automatically rejected.

2.4. Statistical analyses

All statistical analyses were performed using R version 3.2.3 (R Core Team, 2015). Descriptive statistics, histograms and box plots were generated and tests of normality (Supplementary Table 1) were conducted on all data sets to determine whether parametric or non-parametric statistical analyses were appropriate. Univariate (Kruskal Wallis test) and multivariate (Principal Component Analysis) analyses were conducted to determine whether sampling occurred in the Benguela and Canary Upwelling Ecosystems. Correlation analyses were performed to determine whether there were any correlations between individual environmental variables and microplastic abundance. A generalized additive model (GAM) was also developed to determine which environmental variables had an effect on microplastic abundance.

3. Results

3.1. Quality control

Microplastics were not found in the (i) air contamination controls set up during sample collection ($n = 4$), (ii) method blanks set up during vacuum filtration of distilled water ($n = 8$), and (iii) air contamination controls set up during visual identification ($n = 76$). This indicates that microplastics were not introduced into the samples either as a result of airborne contamination or as a result of contamination during the vacuum filtration process. Airborne contamination by microplastics

Please cite this article as: Kanhai, L.D.K., et al., Microplastic abundance, distribution and composition along a latitudinal gradient in the Atlantic Ocean, Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.12.025