Marine Pollution Bulletin 194 (2023) 115314

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Using citizen science to understand floating plastic debris distribution and abundance: A case study from the North Cornish coast (United Kingdom)

Liz Clark [a], Rebecca Allen [b], Zara L.R. Botterell [c], Beatriz Callejo [d], Brendan J. Godley [c], Clare Henry [d], David Santillo [d], Sarah E. Nelms [c,*]

[a] *Newquay Marine Group, 54 Bezant Place, Newquay TR7 1SJ, UK*
[b] *Newquay University Centre, Cornwall College, Wildflower Lane, Newquay TR7 2LZ, UK*
[c] *Centre for Ecology and Conservation, University of Exeter, Cornwall TR10 9FE, UK*
[d] *Greenpeace Research Laboratories, Innovation Centre Phase 2, University of Exeter, Devon, EX4 4RN, UK*

ARTICLE INFO

Keywords:
Citizen science
Microplastics
UK
Plastic pollution
Marine debris
North Atlantic

ABSTRACT

Citizen science is now commonly employed to collect data on plastic pollution and is recognised as a valuable tool for furthering our understanding of the issue. Few studies, however, use citizen science to gather information on water-borne plastic debris. Here, citizen scientists adopted a globally standardised methodology to sample the sea-surface for small (1-5 mm) floating plastic debris off the Cornish coast (UK). Twenty-eight trawls were conducted along five routes, intersecting two Marine Protected Areas. Of the 509 putative plastic items, fragments were most common (64 %), then line (19 %), foam (7 %), film (6 %), and pellets (4 %). Fourier-transform infrared spectroscopy identified the most common polymer type as polyethylene (31 %), then nylon (12 %), polypropylene (8 %), polyamide (5 %) and polystyrene (3 %). This study provides the first globally comparative baseline of floating plastic debris for the region (mean: 8512 items km^{-2}), whilst contributing to an international dataset aimed at understanding plastic abundance and distribution worldwide.

1. Introduction

The rapid and continuing rise in the production, consumption, and mismanagement of plastic has led to growing concerns about its potential to cause harm (Horton, 2022). Of particular concern are microplastics which, due to their small size (<5 mm; Thompson et al., 2004) are bioavailable to organisms across a variety of trophic levels (Botterell et al., 2019; Nelms et al., 2018; Wilcox et al., 2015), and once ingested, may lead to lethal and sub-lethal effects, such as physical injury, malnutrition and exposure to chemical contaminants, such as persistent organics pollutants (POPs) and heavy metals (Wright et al., 2013).

Microplastics are classified into two main categories: primary and secondary. Primary microplastics are manufactured for multiple purposes, including the creation of new plastic products (e.g., pre-production pellets or 'nurdles'; Boucher and Friot, 2017), for use in water treatment processes (e.g., biobeads) or in cosmetics (Napper et al., 2015). Secondary microplastics are formed from breakdown of larger macroplastics (>5 mm in size), which fragment into smaller pieces due physical, biological and chemical processes, such as wave action and ultraviolet radiation from sunlight (Fendall and Sewell, 2009; Ryan et al., 2009).

Efforts to understand the sources, distribution and abundance of microplastics in the marine environment have increased in recent years and it is now apparent that they are ubiquitous, having been found in seawater, at the surface and at depth, in sediments and sea ice around the world (Barnes et al., 2009; Obbard et al., 2014). Whilst sediment and sea ice may be viewed as microplastics sinks, trapping particles and sequestering them for varying amounts of time, seawater, and its movement in currents, can transport microplastics over vast distances (Lebreton and Borrero, 2013; Mountford and Morales Maqueda, 2021; Woodall et al., 2014). This is particularly the case for buoyant plastic items that are less dense than seawater, and this mobility is one of the factors that makes understanding the pathway and fate of plastic debris so challenging. Yet it is essential if we are to manage and reduce plastic pollution; monitoring the at-sea abundance of floating plastic debris can inform our understanding of its spatial and temporal extent, for example 'hot spots' of high concentrations or seasonal variations in movement (van Sebille et al., 2015). It can also help identify potential sources of

---

* Corresponding author.
E-mail address: s.nelms@exeter.ac.uk (S.E. Nelms).

https://doi.org/10.1016/j.marpolbul.2023.115314
Received 16 May 2023; Received in revised form 13 July 2023; Accepted 16 July 2023

plastic pollution and provide evidence to inform policies aimed at reducing input (Rochman et al., 2016).

One of the most widely used methods for sampling large volumes of surface seawater for microplastics is to conduct trawls by towing a fine mesh net, with mesh sizes usually 330–335 μm, beside or behind a vessel (Hidalgo-Ruz et al., 2012; Lindeque et al., 2020). The net devices most commonly used for microplastics sampling are neuston nets and manta trawls, the latter of which has become the preferred option due to its greater reliability with respect to precision of sampling height within the water column due to its stability and buoyancy (Pasquier et al., 2022). The net of the manta trawl is held open by a rectangular metal frame which has a wing-like structure either side of the opening to stabilise the net and allow for sampling of the top 15–25 cm of seawater (Pasquier et al., 2022). In the past, this technique was mainly used by professional plastic pollution researchers but since becoming more accessible for use by non-governmental organisations (NGOs) and other stakeholders, non-expert volunteers, or citizen scientists, are increasingly involved in surveys to monitor at-sea microplastic abundance and distribution (Setälä et al., 2022).

The use of citizen science to collect data on plastic pollution, particularly land-based macroplastics, is now relatively common (Nelms et al., 2020). Not only does utilising a volunteer workforce alleviate some of the logistical and financial constraints that would be incurred if professional scientists were employed, it can also raise awareness and encourage the public to take an active role in finding solutions (Nelms et al., 2022; Rambonnet et al., 2019; Zettler et al., 2017). To date, very few projects utilise citizen scientists to gather data on microplastics, most likely due to the more technical nature of the sampling techniques and fears over contamination (Setälä et al., 2022). Recent studies from surface waters of the Baltic Sea, however, have found that well planned and supervised sampling by citizens can provide good quality samples that can be used to complement microplastics monitoring efforts (Gewert et al., 2017; Setälä et al., 2022).

The 5 Gyres Institute is a non-profit organisation that developed a protocol, enabling citizen scientists to conduct microplastics surveys in their region (www.5gyres.org/trawl-resources; last accessed 08 February 2023). In this study, citizen scientists adopted this globally standardised 5 Gyres Trawl For Plastic project methodology to sample the sea-surface waters off the north coast of Cornwall (United Kingdom), including sections of two Marine Protected Areas (MPAs), for small (1–5 mm) floating plastic debris. The aims of this study were two-fold; first, to collect information on the distribution, abundance and characteristics of small floating debris which can used for generating a local baseline as well as comparing with existing global datasets; and second to engage with and educate members of the local community on the issue of plastic pollution by training volunteers to conduct microplastics surveys.

2. Materials and methods

2.1. Study area

Cornwall is a county situated at the western tip of England's south-west peninsula (UK) and is exposed to prevailing winds and currents from the northeast Atlantic. The coastal region is heavily frequented by beach users, particularly during the summer months, with an estimated five million tourists visiting the region every year (Gaskell et al., 2021). In addition, fishing is an important part of the local economy, with fishing activity occurring throughout the year (Trundle et al., 2018).

Sea surface trawls for microplastics (1–5 mm) were conducted along five routes off the coast of north Cornwall (Fig. 1). Two of the five routes (referred to as POLPIP and STAPIP, hereafter routes A and B) are part of regular Marine Life and Human Activity Surveys conducted by The Cornwall Seal Group Research Trust. These survey routes were originally chosen due to their proximity to grey seal (*Halichoerus grypus*) haul out areas and wildlife hotspots. The remaining three (Park Head, Off Shore and Bawdin Rocks, hereafter routes C, D and E respectively) were chosen to cover the section of the north Cornish coast adequately whilst providing some contrasts in trawl areas (e.g., trawling 6 nm offshore and adjacent to beaches).

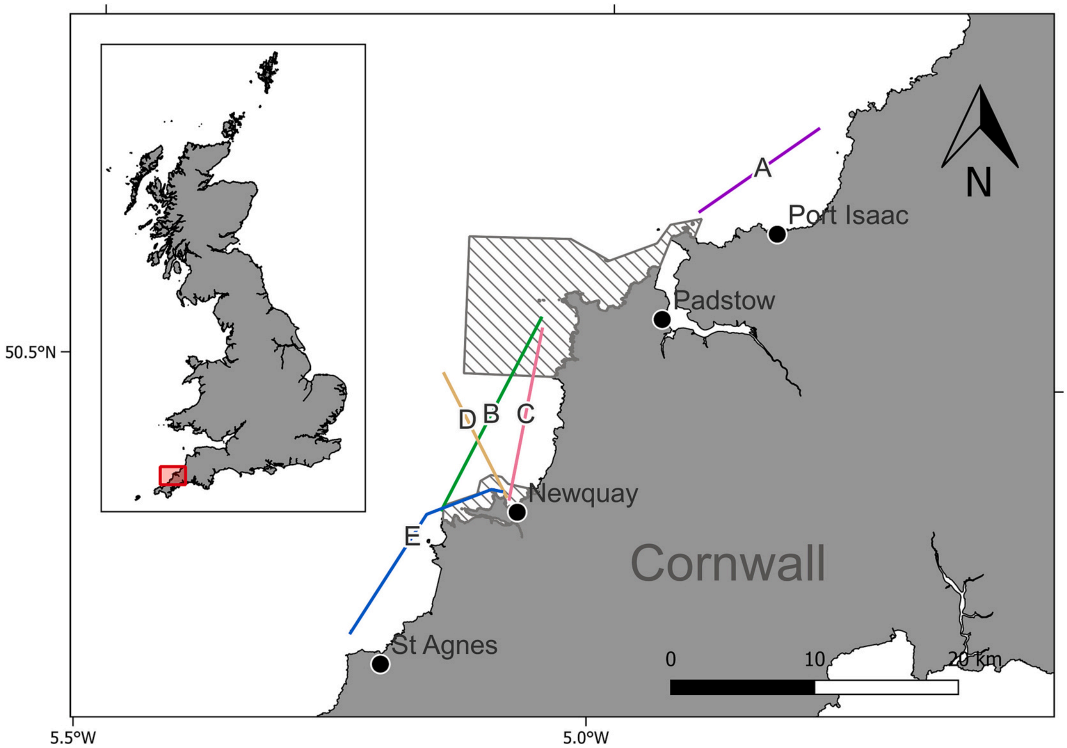

Fig. 1. Map of the north Cornwall coast and the five routes of microplastics sampling sea surface trawls (A=POLPIP, B=STAPIP, C=Park Head, D=Off Shore and E=Bawdin Rocks). Hashed polygons represent the two Marine Protected Areas, Newquay Marine Conservation Zone (MCZ) and Padstow and Surrounds MCZ.

2.2. Sample collection

Twenty-eight trawls were conducted between April 2018 and January 2020. The number of trawls per month and survey route varied due to factors, such as weather conditions and the outbreak of COVID-19 (see Supplementary material Table S1).

A High-Speed Mini Trawl (HSMT; Supplementary material Fig. S1a) was used to sample surface seawater for microplastics. The HSMT is of similar design to a Manta trawl but smaller and lighter. An aluminium rectangular frame opening of 10 cm × 60 cm is connected to a 4 m long net with a mesh size of 333 μm and a cod end. The HSMT was deployed from the vessel, a 10 m Blyth catamaran, outside of the wake zone on the leeward side to avoid turbulence created by the boat movement, which could potentially force any floating plastic debris below the surface (Supplementary material Fig. S1b). A davit arm was used to position the trawl tow line away from the side of the vessel, which towed the HSMT approximately 36 m behind the boat.

The HSMT was towed for 60–185 min, for between 10,556 m and 33,336 m, and at an average speed of 6 knots ($\sim$3 m s^{-1}), dependent on conditions, as per the 5 Gyres protocol. Surveys were only conducted in sea state 4 or below (Beaufort Scale). At the end of each tow, the contents of the cod end were poured through a 1 mm metal sieve rinsed with distilled water, covered with aluminium foil and left to dry.

2.3. Contamination control

Due to the citizen science nature of this study, only suspected microplastics larger than 1 mm and smaller than 5 mm were included for further analysis to avoid processing items that may have been a result of contamination. To minimise contamination as much as possible, several steps were taken. Firstly, the HSMT was towed alongside side the vessel rather than behind to avoid any boat-based debris (i.e. paint fragments) from entering the net (see Supplemental material Fig. S1b). A non-shedding rope was used to attach the trawl to the vessel and all other fixings were metal. No fibres matching the rope (silver/translucent) were found in the samples. Volunteers wore white cotton laboratory coats whilst processing the samples to avoid contamination from their clothing. No matching fibres were found within the samples.

2.4. Microplastic identification

Each sieve was visually inspected and all visible, potentially synthetic, items were collected and categorised by size class; micro <5 mm and macro >5 mm. The hot needle test (de Witte et al., 2014) was used to distinguish between synthetic and organic items; under a 1000× USB digital camera microscope a hot needle, heated using a lit candle, was applied to the suspected plastic item. If it appeared to melt on contact with the needle, it was deemed to be synthetic and potentially plastic. All putative plastic particles were then categorised by type (Fragment, Film, Foam, Pellet, and Line) and enumerated (Eriksen et al., 2013, 2014).

2.5. Polymer analysis

To confirm the polymer type of the suspected microplastics, Fourier-transform infrared (FTIR) spectroscopy was conducted on all visible items from a randomly selected (i.e. not chosen based on any specific characteristics) subset of 18 of the 28 trawl samples using a PerkinElmer Spectrum 2 spectrometer equipped with a universal diamond Attenuated Total Reflectance (ATR) attachment. Each fragment or fibre was manipulated using pre-cleaned forceps and placed onto the centre of the crystal surface (after precleaning the surface with analytical grade ethanol), before applying a consistent force using the sample clamp. FTIR spectra (mid-infrared) were obtained for each candidate microplastic piece by scanning in the wave number range 4000–650 cm^{-1}, at a resolution of 4 cm^{-1}, and acquiring a minimum of four scans per item (up to a maximum of 16 scans per item for some samples in order to obtain clearer spectra). All spectra obtained were processed using PerkinElmer's Spectrum™ 10 software (version 10.5.4.738), enabling post-acquisition background subtraction and normalisation of the data and subsequent comparison against a number of commercially available spectral libraries covering polymers, polymer additives and adhesives (adhes.dlb, Atrpolym.dlb, ATRSPE~1.DLB, fibres.dlb, IntPoly.spl, poly1.dlb, polyadd1.dlb and POLYMER.DLB), as used by (D'Souza et al., 2020).

Only readings with a confidence level of 70 % or greater and for which identification could be further verified through careful visual inspection of the spectrum (Lusher et al., 2013), were accepted as being reliably identified. To minimise the potential for misidentification, plastic pieces yielding match qualities below this confidence level were classified as 'unidentified', even if their spectra showed a number of diagnostic characteristics typical of known polymers.

2.6. Statistical analysis

To account for the variation in area covered by each trawl and provide a metric that is comparable with similar studies, the data were standardised to estimate the number of microplastics per km^2 by multiplying the width of the trawl opening (10 cm) by the transect length (range: 10.6–33.3 km; (Collignon et al., 2012; Gewert et al., 2017). The number of plastic items recorded during each trawl was then divided by the area surveyed (width × transect length).

In addition, the plastic abundance per volume of water trawled (plastic items m^{-3}) was calculated by multiplying the trawl opening area (0.1 × 0.6 m) by 0.5 by transect length. The factor of 0.5 was applied to account for only the lower half of the trawl opening being submerged during sampling (Baldwin et al., 2016; Gewert et al., 2017). It should be noted that variations in factors such as boat speed, currents and sea conditions mean that calculations such as those above are estimations and the actual volume of water sampled may differ.

Generalised linear mixed-effects models (GLMMs) were used to examine the spatial and temporal patterns in the abundance of suspected microplastics (items km^{-2}; GLMM; 'lme4' package for R). Year was used as a random effect in the model to account for the unbalanced survey frequency and region, season and month were incorporated as fixed effects. The normality of the dependent variable was assessed using a Q-Q plot and determined to be non-normal. As such, various error families and link functions were trailed and the model with the lowest AIC score chosen for subsequent use (family = Gamma, link = "sqrt"). Model selection to identify the most influential fixed effects was based on AIC score and *p*-value of Analysis of Variance (ANOVA) used to compare between models (Supplementary Material Table S2 and S3). Statistical significance was set at a probability level (α) of 0.05. Seasons were defined as; spring (March–May), summer (June–August), autumn (September–November), winter (December–February). Data analysis was conducted using the statistical software, R (R Core Team, 2022).

2.7. Citizen scientist participation and training

This project was co-ordinated by the lead author (LC) and conducted by 84 volunteers (Supplementary material Table S4) from groups in the Cornwall Marine Microplastic Coalition (CMMR) comprising Polzeath Marine Conservation Group, The Cornwall Seal Group Research Trust, St Agnes Marine Conservation Group, Newquay Sea Safaris and Fishing, and Cornwall College Newquay. Volunteers received free training and were recruited mainly through social media campaigns. The volunteer roles were deploying and monitoring the HSMT, dismantling and rinsing equipment, and analysing the samples for potential microplastics. Some volunteers partook in all these roles, other volunteers helped with one or two roles. The FTIR and statistical analyses were conducted by trained professional scientists.

3. Results

3.1. Abundance, distribution and temporal trends

Suspected plastic items were found in every trawl sample ($n = 28$) with 509 items recorded in total. The mean number of plastic items m^{-2} across all trawls was 0.0085 (SD ± 0.0064 items m^{-2}, range 0.013–0.0269 items m^{-2}) with an estimated 8515 plastic items km^{-2} (SD ± 6383 items km^{-2}; range 1350–26,875 items km^{-2}; see Supplementary material Table S5 for volumetric abundance).

There was some variation in abundance among the routes; route B had the highest density of suspected microplastics with an average of 12,244 items km^{-2} of surface seawater (SD ± 12,899 items km^{-2}) followed by route C (10,569 items km^{-2}; SD ± 7079 items km^{-2}), route E (8104 items km^{-2}; SD ± 6846 items km^{-2}), route A (6658 items km^{-2}; SD ± 2577 items km^{-2}) and route D (6161 items km^{-2}; SD ± 3699 items km^{-2}; Supplementary Material Table S5). The results of the generalised linear mixed-effects model (GLMM), however, demonstrated that trawl route did not influence microplastic abundance (removing Route from the model had no significant effect; $p \geq 0.69$; Supplementary materials Table S2 and S3).

Temporally, the month in which sampling took place had a strong effect on the abundance of suspected plastic items ($p = 0.008$; Supplementary material Table S6). In particular, March showed the highest significantly different abundance of suspected microplastics (15,187 items km^{-2}). Conversely, June and May exhibited the lowest levels (3093 and 2925 items km^{-2}, respectively; Fig. 2a; Supplementary material Table S6). When the data were aggregated by season, however, any temporal signal was lost (Fig. 2b).

3.2. Characteristics

Plastic items of every shape category were identified (Supplementary material Fig. S2). Fragments were most common (64 %; $n = 324$), followed by line (19 %; $n = 99$), foam (7 % $n = 36$), film (6 %; $n = 30$) and pellets (4 %; $n = 20$; Fig. 3a).

Of the 357 suspected plastic items analysed using FTIR spectroscopy, >60 % ($n = 218$) were reliably confirmed to be microplastics composed of identifiable polymers (Fig. 3b). Of these, 111 (31.1 %) were identified as polyethylene, 41 (11.5 %) were nylon, 30 (8.4 %) were polypropylene, 17 (4.8 %) were other synthetic (non-nylon) polyamides, 12 (3.4 %) were polystyrene, three were poly-1-butene (0.8 %), two were chlorinated or chlorosulphonated polyethylene (0.6 %) and one of each polybutylene terephthalate and vinyl chloride/vinyl acetate copolymer (0.3 % respectively). Other, non-plastic materials were also detected at low abundances including three brightly coloured cellulose fibres, presumably modified by extrusion and dying in industrial processes, one fragment of glass fibre and one each of paraffin wax and methyl vinyl ether copolymer. Just over a third ($n = 133$; 37.3 %) of the 357 items analysed could not be identified to a sufficient degree of confidence to confirm their identity as microplastics using ATR FTIR. Although the majority of these ($n = 78$) showed many spectral characteristics typical of polymers such as polyethylene, polypropylene or nylon, the qualities of the spectra were insufficient to conclude a reliable identity (possibly as a result of degradation and/or chemical or microbial contamination of the material during exposure to environmental conditions).

4. Discussion

Globally, plastic pollution has become a ubiquitous form of anthropogenic litter capable of harming marine organisms and ecosystems (Beaumont et al., 2019; Nelms et al., 2023). Understanding the patterns and trends in regional and global plastic pollution mass and abundance is crucial for evaluating and mitigating the risks (Eriksen et al., 2023). The best-known reservoir of plastic debris is that of buoyant plastics floating at the sea surface within the global ocean (van Sebille et al., 2015). Although some areas are relatively well surveyed for plastic pollution (e.g., Western North Atlantic Ocean and Eastern North Pacific Ocean), much of the sea surface outside the gyres has not been extensively studied (van Sebille et al., 2015). This could cause potentially large errors in global estimates of the amount of floating plastic (van Sebille et al., 2015). In this study, citizen scientists sampled surface seawater for small floating plastic debris in an understudied region of the Northeast Atlantic Ocean. An average of 8512 microplastics km^{-2} was recorded across the 28 surveys conducted along the north coast of Cornwall. In comparison, Maes et al. (2017) recorded a considerably higher concentration of 19,237 plastic items km^{-2} elsewhere in UK waters (North Sea, Celtic Sea and English Channel). This difference may

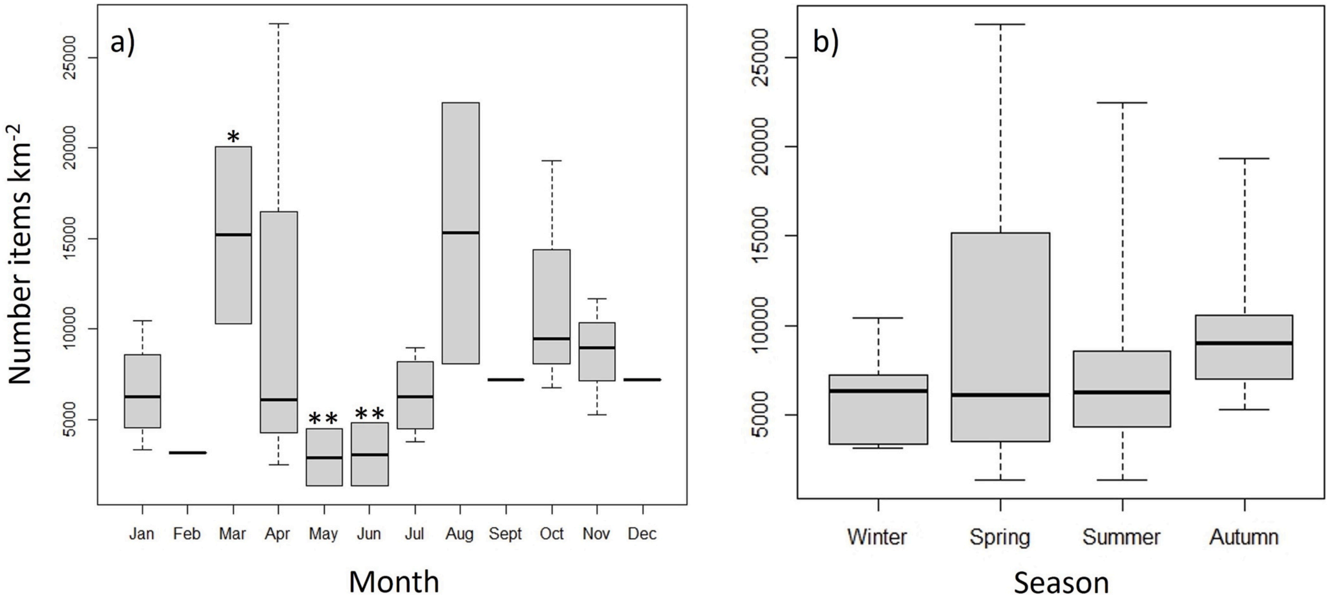

Fig. 2. Temporal patterns in microplastic abundance. Boxplots showing the number of suspected plastic items (1–5 mm) per km^2 for **a)** each trawl route across survey period and **b)** season. The horizontal black lines represent median values. The box depicts the first and third quartiles and whiskers illustrate the minimum and maximum values. Asterisks represent p-value significance codes (** = 0.001, * = 0.01).

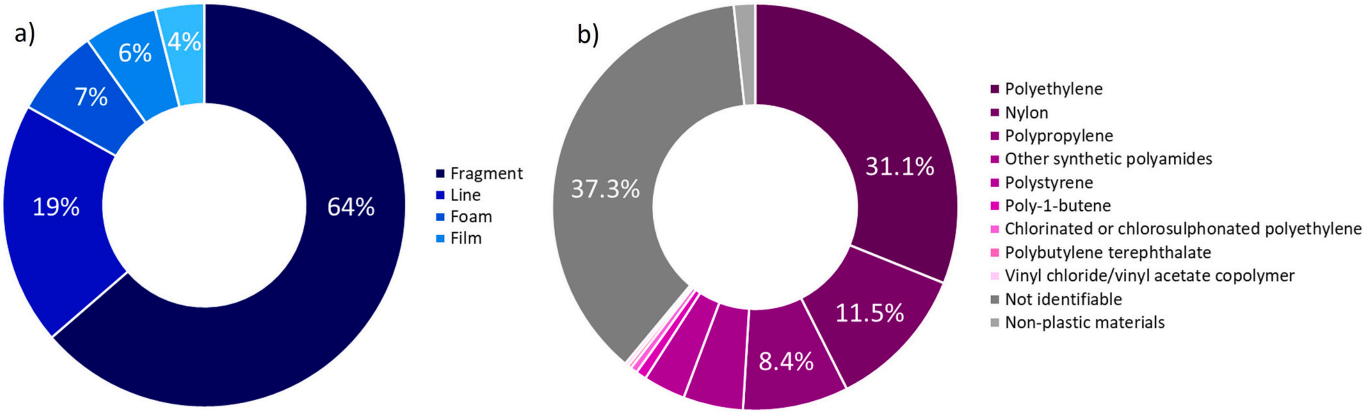

Fig. 3. Composition of floating debris. Doughnut plots showing **a)** composition by shape and **b)** composition by polymer type (for a sub-sample; $n = 18$ trawls) of synthetic items recovered from 28 trawls.

be partly explained by the difference in the size classes included in each study. For example, only plastic items between 1 and 5 mm are included in the current study, whereas Maes et al. (2017) included smaller size classes with items ranging between 0.355 and >4.75 mm. The effect of net mesh size on recorded microplastic abundances was demonstrated by Lindeque et al. (2020) who found that sampling using smaller mesh sizes resulted in the detection of significantly higher abundances of plastic;nets with a 100 μm mesh resulted in the collection of 2.5-fold and 10-fold greater microplastic concentrations compared with using 333 and 500 μm meshes, respectively (Lindeque et al., 2020). Due to the citizen science nature of this study, however, it was not possible to sample such small size classes due to logistical constraints and concerns about possible contamination from air-borne microplastics, which are generally present in the smaller size classes (Jones et al., 2022).

In terms of volumetric concentrations of synthetic items, this study recorded an average of 0.03 (±0.2) plastic items m^{-3}, whereas a study of coastal waters off Plymouth on the south coast of nearby Devon, recorded an average of 1.35 items m^{-3} (Higgins and Turner, 2023). Higgins and Turner (2023) used a 53 μm plankton net to sample surface water for microplastics which, for reasons discussed above, may explain the difference in concentrations to those recorded in the current study. In addition, the north Cornish coast is a relatively rural area with a low population density and minimal industrialisation compared to the other study sites.

Although some monthly variation was observed, season and trawl route were not found to have a significant effect on the abundance of suspected microplastics. This may be due to a variety of factors including survey effort (with fewer trawls occurring in the winter months) and environmental variation (e.g., oceanographic currents and mixing). As such, further monitoring to increase the sample size and therefore statistical power is warranted.

Four of the five trawl routes included sections within two Marine Conservation Zones; routes B, C and D are in the Newquay MCZ and route A is within the Padstow Bay and Surrounds MCZ (Fig. 1). In addition, routes E and A are located in proximity to important sites for Atlantic grey seals and seabirds, including Atlantic puffins (*Fratercula arctica*). Although the abundance of suspected microplastics is lower here than in other more polluted areas, the presence of floating debris in these areas could present a risk to marine species and ecosystems within them, particularly as small items are bioavailable to a range of taxa, including fish, seabirds and marine mammals (Nelms et al., 2023).

Fragments were the most common shapes (64 %) of suspected microplastics detected. This is most likely the result of the breakdown of larger plastic items that have been at sea for long period of time (Thompson, 2015). Polyethylene, nylon and polypropylene were the most common polymer types, as confirmed by FTIR analysis. Higgins and Turner (2023) also found polypropylene to be prevalent in coastal waters off Plymouth (UK) but found polyethylene to be less common, and did not detect any nylon items. In a similar study conducted in the Baltic Sea, Gewert et al. (2017) found the most common polymer types in surface water samples were polypropylene and polyethylene. These plastic types are known to be positively buoyant, accumulate at the water surface and are commonly used for single-use items. Polypropylene and polyethylene are also the main synthetic materials used for the manufacturing of ropes along with nylon and polyester (Gewert et al., 2017). The colour and size of detected microplastics were not recorded in the current study. Future studies should strive to report this information, however, as it adds to our understanding of the characteristics of plastic pollution.

The use of citizen science to better understand the abundance, distribution and sources of plastic pollution, particularly land-based macroplastics, is now widely recognised as a valuable tool (Ammendolia and Walker, 2022; Hidalgo-Ruz and Thiel, 2013; Rech et al., 2015). Studies that use citizen science to quantify at-sea plastic concentrations are much less common, however, particularly those that focus on microplastics (De Haan et al., 2022). However, the number of studies employing this technique is growing and the data they produce are contributing to global estimates of floating plastic debris, significantly expanding our knowledge of temporal trends and spatial patterns (Eriksen et al., 2023). In addition to this, citizen science projects can provide several benefits to the volunteers themselves including education, empowerment and health and well-being (De Haan et al., 2022; Zettler et al., 2017). In this study, 84 citizen scientists from a range of ages and backgrounds were involved in sample collection and processing. There were also a number of local outreach events in relation to this project to disseminate the results within the local community, further highlighting the issue of plastic pollution to the general public.

5. Conclusion

This citizen science study provides a useful baseline to which future levels of plastic pollution may be compared. Further work to explore ways by which citizen scientists can robustly collect samples of microplastics <1 mm in size would be of great benefit to future estimates. To do so would involve co-creating appropriate methodology and volunteer training which limits the likelihood of contamination. Even so, our study reiterates the utility and power of citizen science to plastic pollution research.

CRediT authorship contribution statement

Liz Clark: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Funding acquisition. **Rebecca Allen:** Writing – original draft, Writing – review & editing, Visualization. **Zara L.R. Botterell:** Writing – review & editing, Visualization. **Beatriz Callejo:** Resources, Writing – review & editing. **Brendan J. Godley:** Writing – review & editing, Visualization. **Clare Henry:** Resources, Writing – review & editing. **David Santillo:** Resources, Writing – original draft, Writing – review & editing. **Sarah E. Nelms:** Formal analysis, Writing – original draft, Writing – review & editing, Visualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Sarah Nelms reports financial support was provided by Engineering and Physical Sciences Research Council. Sarah Nelms reports financial support was provided by Natural Environment Research Council.

Data availability

Data will be made available on request.

Acknowledgements

Thank you to all our funders, supporters, and everyone in the Cornwall Marine Microplastic Coalition. We are thankful to Polzeath Marine Conservation Group, St Agnes Marine Conservation Group, and Newquay Sea Safaris and Fishing for providing funding for this collaborative work. Special thanks to Newquay Sea Safaris and Fishing for their time, low costs and enthusiasm and to The Cornwall Seal Group for permission to run the trawls alongside their surveys. We are also thankful to The Bedruthan Hotel, Sea Changers, and Natural England, who provided funds for boat charters. We are very grateful to 5 Gyres Trawl Share project who loaned the trawl, and The Eden Project for the loan of microscopes. SEN, ZLRB and BJG (University of Exeter) were supported by funding from the Engineering and Physical Sciences Research Council [EPSRC EP/S025529/1] and Natural Environment Research Council (NE/V009354/1 and NE/V005448/1). This manuscript was improved as a result of input from two anonymous referees.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2023.115314.

References

Ammendolia, J., Walker, T.R., 2022. Citizen science: a way forward in tackling the plastic pollution crisis during and beyond the COVID-19 pandemic. Sci. Total Environ. 805 https://doi.org/10.1016/j.scitotenv.2021.149957.

Baldwin, A.K., Corsi, S.R., Mason, S.A., 2016. Plastic debris in 29 Great Lakes tributaries: relations to watershed attributes and hydrology. Environ. Sci. Technol. 50, 10377–10385. https://doi.org/10.1021/acs.est.6b02917.

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philos. Trans. R. Soc. B 364, 1985–1998. https://doi.org/10.1098/rstb.2008.0205.

Beaumont, N.J., Aanesen, M., Austen, M.C., Börger, T., Clark, J.R., Cole, M., Hooper, T., Lindeque, P.K., Pascoe, C., Wyles, K.J., 2019. Global ecological, social and economic impacts of marine plastic. Mar. Pollut. Bull. 142, 189–195. https://doi.org/10.1016/j.marpolbul.2019.03.022.

Botterell, Z.L.R., Beaumont, N., Dorrington, T., Steinke, M., Thompson, R.C., Lindeque, P. K., 2019. Bioavailability and effects of microplastics on marine zooplankton: a review. Environ. Pollut. 245, 98–110. https://doi.org/10.1016/j.envpol.2018.10.065.

Boucher, J., Friot, D., 2017. Primary Microplastics in the Oceans: A Global Evaluation of Sources. https://doi.org/10.2305/IUCN.CH.2017.01.en.

Collignon, A., Hecq, J.H., Glagani, F., Voisin, P., Collard, F., Goffart, A., 2012. Neustonic microplastic and zooplankton in the North Western Mediterranean Sea. Mar. Pollut. Bull. 64, 861–864. https://doi.org/10.1016/j.marpolbul.2012.01.011.

De Haan, W.P., Uviedo, O., Ballesteros, M., Canales, Í., Curto, X., Guart, M., Higueras, S., Molina, A., Sanchez-Vidal, A., 2022. Floating microplastic loads in the nearshore revealed through citizen science. Environ. Res. Lett. 17 https://doi.org/10.1088/1748-9326/ac5df1.

de Witte, B., Devriese, L., Bekaert, K., Hoffman, S., Vandermeersch, G., Cooreman, K., Robbens, J., 2014. Quality assessment of the blue mussel (Mytilus edulis): comparison between commercial and wild types. Mar. Pollut. Bull. 85, 146–155. https://doi.org/10.1016/j.marpolbul.2014.06.006.

D'Souza, J.M., Windsor, F.M., Santillo, D., Ormerod, S.J., 2020. Food web transfer of plastics to an apex riverine predator. Glob. Chang. Biol. 26, 3846–3857. https://doi.org/10.1111/gcb.15139.

Eriksen, M., Maximenko, N., Thiel, M., Cummins, A., Lattin, G., Wilson, S., Hafner, J., Zellers, A., Rifman, S., 2013. Plastic pollution in the South Pacific subtropical gyre. Mar. Pollut. Bull. 68, 71–76. https://doi.org/10.1016/j.marpolbul.2012.12.021.

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G., Reisser, J., 2014. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PLoS One 9. https://doi.org/10.1371/journal.pone.0111913.

Eriksen, M., Cowger, W., Erdle, L.M., Coffin, S., Villarrubia-Gómez, P., Moore, C.J., Carpenter, E.J., Day, R.H., Thiel, M., Wilcox, C., 2023. A growing plastic smog, now estimated to be over 170 trillion plastic particles afloat in the world's oceans—urgent solutions required. PLoS One 18. https://doi.org/10.1371/journal.pone.0281596.

Fendall, L.S., Sewell, M.A., 2009. Contributing to marine pollution by washing your face: microplastics in facial cleansers. Mar. Pollut. Bull. 58, 1225–1228. https://doi.org/10.1016/j.marpolbul.2009.04.025.

Gaskell, C., Craig, N., Wills, J., Hartgroves, R., 2021. Sustaining the Environment and Visitor Economy in Cornwall.

Gewert, B., Ogonowski, M., Barth, A., MacLeod, M., 2017. Abundance and composition of near surface microplastics and plastic debris in the Stockholm Archipelago, Baltic Sea. Mar. Pollut. Bull. 120, 292–302. https://doi.org/10.1016/j.marpolbul.2017.04.062.

Hidalgo-Ruz, V., Thiel, M., 2013. Distribution and abundance of small plastic debris on beaches in the SE Pacific (Chile): a study supported by a citizen science project. Mar. Environ. Res. 87–88, 12–18. https://doi.org/10.1016/j.marenvres.2013.02.015.

Hidalgo-Ruz, V., Gutow, L., Thompson, R.C., Thiel, M., 2012. Microplastics in the marine environment: a review of the methods used for identification and quantification. Environ. Sci. Technol. 46, 3060–3075. https://doi.org/10.1021/es2031505.

Higgins, C., Turner, A., 2023. Microplastics in surface coastal waters around Plymouth, UK, and the contribution of boating and shipping activities. Sci. Total Environ. 893 https://doi.org/10.1016/j.scitotenv.2023.164695.

Horton, A.A., 2022. Plastic pollution: when do we know enough? J. Hazard. Mater. 422 https://doi.org/10.1016/j.jhazmat.2021.126885.

Jones, J.S., Guézou, A., Medor, S., Nickson, C., Savage, G., Alarcón-Ruales, D., Galloway, T.S., Muñoz-Pérez, J.P., Nelms, S.E., Porter, A., Thiel, M., Lewis, C., 2022. Microplastic distribution and composition on two Galápagos island beaches, Ecuador: verifying the use of citizen science derived data in long-term monitoring. Environ. Pollut. 311 https://doi.org/10.1016/j.envpol.2022.120011.

Lebreton, L.C.M., Borrero, J.C., 2013. Modeling the transport and accumulation floating debris generated by the 11 March 2011 Tohoku tsunami. Mar. Pollut. Bull. 66, 53–58. https://doi.org/10.1016/j.marpolbul.2012.11.013.

Lindeque, P.K., Cole, M., Coppock, R.L., Lewis, C.N., Miller, R.Z., Watts, A.J.R., Wilson-McNeal, A., Wright, S.L., Galloway, T.S., 2020. Are we underestimating microplastic abundance in the marine environment? A comparison of microplastic capture with nets of different mesh-size. Environ. Pollut. 265, 114721 https://doi.org/10.1016/j.envpol.2020.114721.

Lusher, A.L., McHugh, M., Thompson, R.C., 2013. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. Mar. Pollut. Bull. 67, 94–99.

Maes, T., van der Meulen, M.D., Devriese, L.I., Leslie, H.A., Huvet, A., Frère, L., Robbens, J., Vethaak, A.D., 2017. Microplastics baseline surveys at the water surface and in sediments of the North-East Atlantic. Front. Mar. Sci. 4 https://doi.org/10.3389/fmars.2017.00135.

Mountford, A.S., Morales Maqueda, M.A., 2021. Modeling the accumulation and transport of microplastics by sea ice. J Geophys Res Oceans 126, 1–19. https://doi.org/10.1029/2020JC016826.

Napper, I.E., Bakir, A., Rowland, S.J., Thompson, R.C., 2015. Characterisation, quantity and sorptive properties of microplastics extracted from cosmetics. Mar. Pollut. Bull. 99, 178–185. doi:https://doi.org/10.1016/j.marpolbul.2015.07.029.

Nelms, S.E., Galloway, T.S., Godley, B.J., Jarvis, D.S., Lindeque, P.K., 2018. Investigating microplastic trophic transfer in marine top predators. Environ. Pollut. 1–9 https://doi.org/10.1016/j.envpol.2018.02.016.

Nelms, S.E., Eyles, L., Godley, B.J., Richardson, P.B., Selley, H., Solandt, J.L., Witt, M.J., 2020. Investigating the distribution and regional occurrence of anthropogenic litter in English marine protected areas using 25 years of citizen-science beach clean data. Environ. Pollut. 263, 114365 https://doi.org/10.1016/j.envpol.2020.114365.

Nelms, S.E., Easman, E., Anderson, N., Berg, M., Coates, S., Crosby, A., Eisfeld-Pierantonio, S., Eyles, L., Flux, T., Gilford, E., Giner, C., Hamlet, J., Hembrow, N., Hickie, J., Hopkinson, P., Jarvis, D., Kearsley, J., Millard, J., Nunn, F., Pollitt, E., Sainsbury, A., Sayer, S., Sinclair, R., Slack, A., Smith, P., Thomas, R., Tyler, J., Walker, R., Wallerstein, C., Ward, M., Godley, B.J., 2022. The role of citizen science in addressing plastic pollution: challenges and opportunities. Environ. Sci. Pol. 128, 14–23. https://doi.org/10.1016/j.envsci.2021.11.002.

Nelms, S.E., Clark, B.L., Duncan, E.M., Germanov, E., Godley, B.J., Parton, K.J., Pham, C. K., Rodríguez, Y., 2023. Plastic pollution and marine megafauna. In: Recent Advances and Future Directions, in: Plastic Pollution in the Global Ocean. WORLD SCIENTIFIC, pp. 97–138. https://doi.org/10.1142/9789811259111_0005.

Obbard, R.W., Sadri, S., Wong, Y.Q., Khitun, A.A., Baker, I., Thompson, R.C., 2014. Global warming releases microplastic legacy frozen in Arctic Sea ice. Earths Future 2, 315–320. https://doi.org/10.1002/2014ef000240.

Pasquier, G., Doyen, P., Kazour, M., Dehaut, A., Diop, M., Duflos, G., Amara, R., 2022. Manta net: the golden method for sampling surface water microplastics in aquatic environments. Front Environ Sci. https://doi.org/10.3389/fenvs.2022.811112.

R Core Team, 2022. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Rambonnet, L., Vink, S.V.C.V., Land-Zandstra, A.M., Bosker, T., 2019. Making citizen science count: best practices and challenges of citizen science projects on plastics in aquatic environments. Mar. Pollut. Bull. 145, 271–277. https://doi.org/10.1016/j.marpolbul.2019.05.056.

Rech, S., Macaya-Caquilpán, V., Pantoja, J.F., Rivadeneira, M.M., Campodónico, C.K., Thiel, M., 2015. Sampling of riverine litter with citizen scientists — findings and recommendations. Environ. Monit. Assess. 187 https://doi.org/10.1007/s10661-015-4473-y.

Rochman, C.M., Cook, A.M., Koelmans, A.A., 2016. Plastic debris and policy: using current scientific understanding to invoke positive change. Environ. Toxicol. Chem. 35, 1617–1626. https://doi.org/10.1002/etc.3408.

Ryan, P.G., Moore, C.J., van Franeker, J.A., Moloney, C.L., 2009. Monitoring the abundance of plastic debris in the marine environment. Philosophical Transactions of the Royal Society B: Biological Sciences. https://doi.org/10.1098/rstb.2008.0207.

Setälä, O., Tirroniemi, J., Lehtiniemi, M., 2022. Testing citizen science as a tool for monitoring surface water microplastics. Environ. Monit. Assess. 194 https://doi.org/10.1007/s10661-022-10487-w.

Thompson, R.C., 2015. Microplastics in the marine environment: sources, consequences and solutions. In: Bergmann, M., Gutow, L., Klages, M. (Eds.), Marine Anthropogenic Litter. Springer International Publishing, Cham, pp. 185–200. https://doi.org/10.1007/978-3-319-16510-3_7.

Thompson, R.C., Olson, Y., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W.G., McGonigle, D., Russell, A.E., 2004. Lost at Sea: Where Is All the Plastic? Science (1979) 304, 838. doi:https://doi.org/10.1126/science.1094559.

Trundle, C., Jenkin, A., Sturgeon, S., Owen, K., Naylor, H., 2018. A brief summary of the fisheries for crustaceans in the Cornwall IFCA district. Hayle.

van Sebille, E., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D., van Franeker, J. A., Eriksen, M., Siegel, D., Galgani, F., Law, K.L., 2015. A global inventory of small floating plastic debris. Environ. Res. Lett. 10 https://doi.org/10.1088/1748-9326/10/12/124006.

Wilcox, C., Van Sebille, E., Hardesty, B.D., 2015. Threat of plastic pollution to seabirds is global, pervasive, and increasing. Proc. Natl. Acad. Sci. U. S. A. 112, 11899–11904. https://doi.org/10.1073/pnas.1502108112.

Woodall, L.C., Sanchez-Vidal, A., Canals, M., Paterson, G.L.J., Coppock, R., Sleight, V., Calafat, A., Rogers, A.D., Narayanaswamy, B.E., Thompson, R.C., 2014. The deep sea is a major sink for microplastic debris. R. Soc. Open Sci. 1, 140317. https://doi.org/10.1098/rsos.140317.

Wright, S.L., Thompson, R.C., Galloway, T.S., 2013. The physical impacts of microplastics on marine organisms: a review. Environ. Pollut. 178, 483–492. https://doi.org/10.1016/j.envpol.2013.02.031.

Zettler, E.R., Takada, H., Monteleone, B., Mallos, N., Eriksen, M., Amaral-Zettler, L.A., 2017. Incorporating citizen science to study plastics in the environment. Anal. Methods 9, 1392–1403. https://doi.org/10.1039/c6ay02716d.