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Baseline

"The great source" microplastic abundance and characteristics along the river Thames

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ABSTRACT

This study focused on quantifying the abundance of microplastics within the surface water of the River Thames, UK. Ten sites in eight areas were sampled within the tidal Thames, starting from Teddington and ending at Southend-on-Sea. Three litres of water was collected monthly at high tide from land-based structures from each site from May 2019 to May 2021. Samples underwent visual analysis for microplastics categorised based on type, colour and size. 1041 pieces were tested using Fourier transform spectroscopy to identify chemical composition and polymer type. 6401 pieces of MP were found during sampling with an average MP of 12.27 pieces L^{-1} along the river Thames. Results from this study show that microplastic abundance does not increase along the river.

The presence of plastic within the environment stems from the high demand for low-cost products (to buy and produce) and high availability. Plastics infiltrate everyday lives and are used in many industries, such as food packaging, textiles, automobile, and medical. As a result, plastic production has increased exponentially to 367 million metric tons in 2020 (Statista, 2022) since it was first discovered in 1907 in the form of Bakelite (Baekeland, 1909). However, high levels of production coupled with some plastic products being single-use and inadequate end-of-life procedures have resulted in the influx of plastic waste entering the environment.

Plastics can degrade into smaller fragments and microplastics (MPs) (<5 mm) as a result of physical, chemical and biological processes that occur within the environment, coupled with the slow degradation process of plastic, which results in an accumulation of plastic fragments of varying sizes (Group of Chief Scientific Advisors, 2019). Microplastics pose risks to organisms such as those found in aquatic environments, which have been found to ingest MPs. This negatively affects the individual's survival, fitness, reproductive system and overall health (Cole et al., 2015; Galloway et al., 2017; Lu et al., 2016; Wright et al., 2013a, 2013b). As MP's harm the overall environmental health and organisms present, a growing trend to investigate potential impacts and quantify their presence within areas. However, whilst studies focus on the aquatic environment, studies investigating rivers are lacking compared to the marine environment (Klein et al., 2015; Wagner et al., 2014; Zandaryaa, 2021).

Most plastics, including MPs, will eventually accumulate within marine environments, 80 % resulting from land-based sources (Derraik, 2002). Microplastics can also occur or enter the atmosphere directly from industrial spills, wastewater and rain runoff (Cole and Sherrington, 2016; Jambeck et al., 2015). The main pathway for these particles to enter the marine environment is rivers (Derraik, 2002). Due to the ability of plastics to be transported, they can accumulate within the water column as well as in sediments such as in a riverbed that can act as temporary sinks depending on specific characteristics within the individual river or section of the river (Blair et al., 2017; Horton et al., 2017a, 2017b; Zhao et al., 2019).

The River Thames is the longest river in England, 354 km (Bowers, 2022). It flows through southern England, passing through London, and comprises two parts; 1) non-tidal: Gloucestershire to Teddington, and 2) tidal: Teddington to Southend on Sea. The River Thames has always been used to transport items and material to the sea; in previous years, human and animal waste gave it the name "The great stink" in 1858 (Halliday and Hart-Davis, 2001). As a result, the river has been closely monitored for nitrates since the 1860s and has had its water quality

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closely monitored since the 1970s (Powers et al., 2016; Wright et al., 2002). However, the river Thames in recent studies has been noted as less polluted than in previous years for the pollutants currently investigated; however, these investigations do not consider more recent pollutants, such as plastics or MPs, which are not being transported down the river (ZSL, 2021). Microplastics have previously been reported in the River Thames. Dunn and Friends of the Earth (2019) found 84.1 pieces of MP L^{-1} at an unknown site in London, whilst Rowley et al. (2020) found 24.8 pieces of MP m^3 at Putney and 14.2 pieces m^3 at Greenwich. Whitehead et al. (2021) estimated that 100 tons of MP per year enters the Thames estuary. Whilst some studies have investigated MP abundances at individual sections of the river and its estuary, no study has focused on the entire tidal section of the river to assess MP abundances and potential sources along the stretch of the river.

This study investigates MPs abundance along the surface water of the tidal section of the River Thames, UK, continuously for two years which has previously not been carried out. The hypothesis is that MPs concentrations will be higher at Tilbury and Southend, where the Thames meets the North Sea. This is due to the potential influx of MPs along the Thames, the higher population density within the London area, and microplastic inflows from the North Sea. This study aimed to; 1) quantify the abundance of MPs along the tidal section of the River Thames and 2) investigate the MP's morphology, colour, length and polymer type to identify their potential origin or source. By providing a baseline of MP abundance along this section of the river Thames, data gathered from this study can be used to monitor MP pollution along the river in

Fig. 1. Water sampling areas along the river Thames; A) Teddington, B) Westminster, C) St Katherines Pier, D) Limehouse, E) North Woolwich, F) Barking Riverside, G) Tilbury Fort and H) Southend-on-Sea on Sea. Due to the Covid-19 pandemic, the Westminster area is made up of two sites: B1) Westminster Boating Base (pre-Covid-19) and B2) Westminster – Millennium eye (during and post-Covid-19). The North Woolwich area was also made up of two sites: E1) Tate and Lyle – Sugar factory (pre-Covid-19) and E2) Barge Road (during and post-Covid-19).

the future and potential sources of microplastics along the river Thames.

In total, ten sampling sites across eight areas were chosen along the tidal section of the Thames River, UK, from Teddington (Freshwater) to Southend-on-Sea (Marine) (Fig. 1) (Supplementary Table 1). The eight areas chosen along the Thames were Teddington lock, Westminster, St Katherines Pier, Limehouse North Woolwich, Barking Riverside Tilbury Fort and Southend. These areas were sampled once a month.

Due to the Covid-19 pandemic and subsequent lockdowns starting in March 2020, some sites (Westminster Boating Base (Westminster), Tate and Lyle (North Woolwich) and Barking Riverside) that needed access to business sites to reach the river were shut (Supplementary Table 1). As a result, other sites were sought to be close to the original sites. Westminster boating base was changed to Westminster (close to the Millennium eye). This site was found straight away, and as a result, no sampling from the Westminster area of the river Thames was missed. The Site in North Woolwich, previously Tate and Lyle, was moved to Barge Road in North Woolwich. This site took longer to find as it needed to be on the same side of the river and the same side of the Thames barrier. As a result, sampling from this area from March 2020 and resumed in august 2020 at Barge Road. The Barking Riverside site was harder to find an alternative location to sample that had access to the river 24 h a day, was on the same side of the river and was located within a short distance. As a result, no alternative could be found, so this site's data is missing during lockdown months; April–June 2020, August 2020–September 2020 and December 2020–January 2021.

Water samples were taken from land-based infrastructure at all sites (except River Lea Tributary and Limehouse Harbour) and collected monthly from May 2019 to May 2021 at high tide throughout the sampling regime. Three one-litre bottles of surface water were collected on each sampling occasion. Protocols established and discussed in Devereux et al. (2022) were followed. Water samples were collected via a Lamotte horizontal water sampler from May to August 2019, and from September 2019 to May 2021, a Pink High-density Polyethylene (HD-PE) Bucket was used due to the sampler being unable to cope with the strenuous sampling regime. Water samples were transferred into 2 L HD-PE double-lidded bottles for transport to the laboratory. Samples were filtered within one week after collection except for those taken during Covid-19 lockdowns (March 2020–June 2020; November 2020–December 2020; January 2021–February 2021); in these instances, filtration and analysis took considerably longer. However, filtering resumed once the lockdowns were lifted and the laboratory opened. During the lockdowns, samples were still taken at the site, and collection bottles were kept in a cool, dark cupboard until they could be transported to the laboratory.

Characterisation followed a 3-step process which started with visual sorting using a light microscope where suspected MPs were sorted into categories based on morphology (Fig. 2) and then further grouped into colours. Each filter was then analysed using a Keyence digital microscope at X50 magnification to identify and quantify the size range of particles to ensure they fell within the MP size >5 mm.

Due to the Covid-19 pandemic and subsequent lockdowns, laboratory time was limited. As a result, only a subsection of suspected MP (10 pieces) on each filter was measured for length and analysis by Fourier-transform infrared spectroscopy (FTIR) to ensure enough time to analyse the particles.

A subsample of 1041 pieces of suspected MPs making up 15.64 % of total MP abundance identified during visual identification was selected for polymer composition confirmation by Fourier-transform infrared

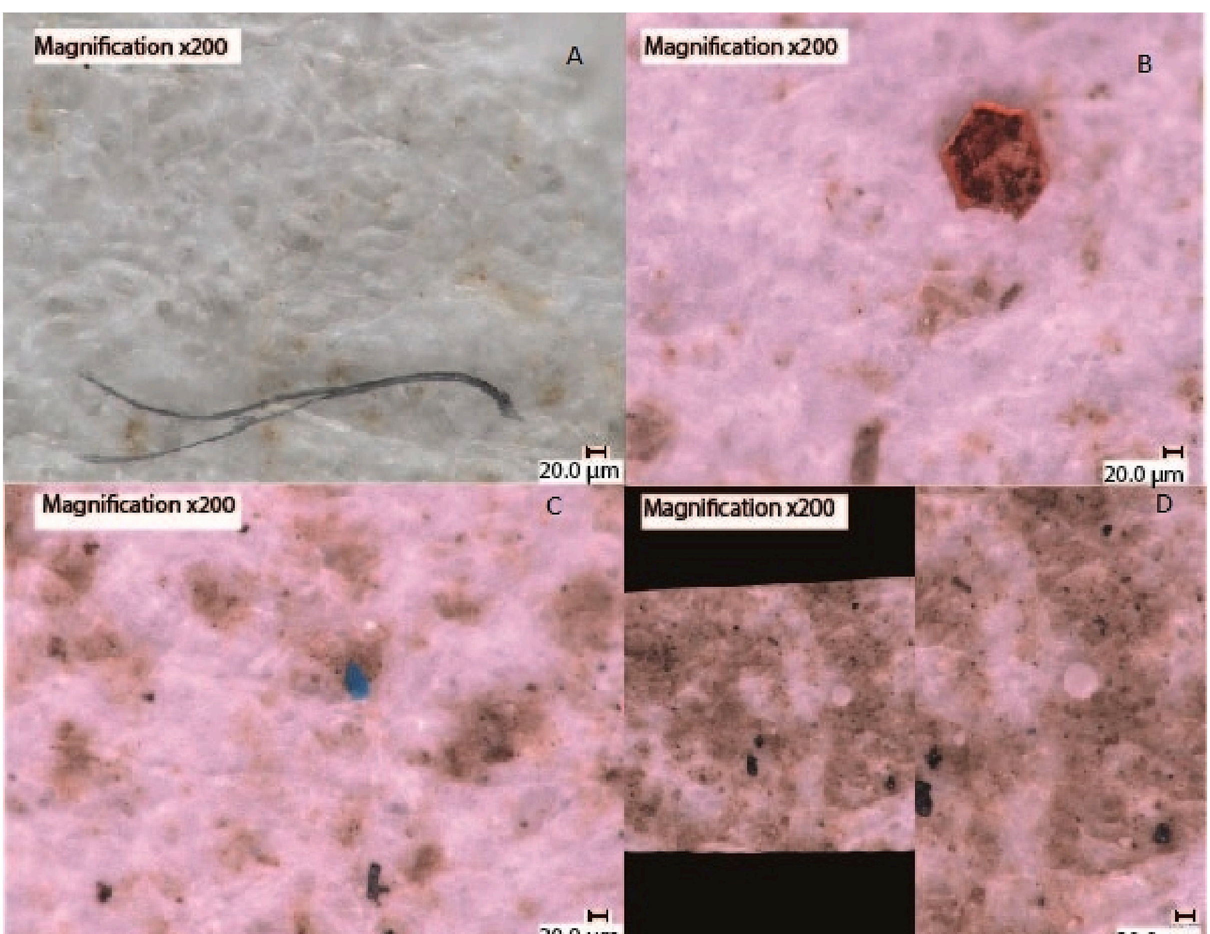

Fig. 2. Microplastic categories at ×200 magnification using a Keyence digital microscope A) fibre, b) glitter/holographic, c) fragment and d) pellet.

spectroscopy (FTIR). OpenSpecy (Cowger et al., 2020) is an open-access database that identifies spectra matches from FTIR analysis.

This study used strict health and safety protocols during field collection. Dependent on the site, some sites require more safety equipment than others. For example, Westminster Boating Base required a lifejacket to be worn whilst sampling; Tate and Lyle (North Woolwich) required a hard hat, steel toe boots and safety goggles but no lifejacket. Due to these protocols, contamination controls, such as reducing plastic use, could not be adhered to. Where possible, safety equipment, including lifejacket and hardhat, were pink in colour so that any potential contamination during sampling could be identified and considered.

Lab protocols included using personal protective equipment, including an orange lab coat, latex gloves and blue cotton face mask (during Covid). Other protocols included covering filters when not in use to avoid atmospheric contamination. Used bottles were washed with distilled water, and equipment and surfaces were cleaned before and after use. As plastic equipment was kept to a minimum, it was not always practical or possible to use an alternative. As such quality-control tests were carried out to test for potential plastic contamination. These included: 1) dampened filter paper placed on laboratory surfaces to monitor atmospheric contamination whilst filters were exposed and analysed daily (Supplementary Table 2), b) three HDPE bottles rinsed with distilled water and filtered (Supplementary Table 3), C) filtering blanks created using 3 × 3 L of distilled water passed through the filtration setup (Supplementary Table 3) D) testing the sampling equipment used for water collection (Supplementary Table 3). Visual counts were corrected by subtracting the corresponding procedural blanks to ensure contamination controls were considered.

Due to the Covid-19 pandemic, two areas (Westminster and North Woolwich) had samples taken from two sites. The two sites that made up each area were compared using ANOVA. ANOVA was also used to check each area's MP abundance, size and colour significance.

Prior to analysis, the distribution of samples was investigated using a Kolmogorov–Smirnov test. Multifactorial ANOVA with the use of Type I sums of squares to account for the unequal variances and to check for links between abundance, size and colour with the area, month and year. Post-hoc Tukey HSD tests were used to test for differences between individual factors (area, month and year).

In this study, 6401 pieces of MP in 458 L of water in the river Thames were found across the eight study areas sampled monthly from May 2019 to May to 2021. Over the course of the study, the most MPs were located at Westminster (987 pieces in 75 L of water), whilst the least were found at North Woolwich (565 pieces in 48 L of water). Barking Riverside (847 pieces in 45 L of water) had one less sample taken than North Woolwich but still had a higher total of MP than what was found on average at sites across the sampling period (800.13 pieces). This averaged out to 12.27 pieces L^{-1} found in water samples at the eight areas along the tidal section of the river.

The two sites that made up the Westminster area were compared to ensure no difference between MP abundance and types, sizes, or polymers. The only significance between sites was between colour, due to the colour red being observed in a higher abundance at Westminster Millennium Eye (50 pieces) compared to Westminster boating base (12 pieces) (ANOVA, $f_{1,24} = 5.13$, $P = 0.033$).

There was no difference between sites located in the North Woolwich area (Tate and Lyle and Barge Road) for types, sizes, and polymer except for the MPT abundance of brown-coloured plastic, which was only found at the Tate and Lyle site (5 pieces) (ANOVA, $f_{1,16} = 6.404$, $P = 0.023$).

Microplastic total abundance in this study varied throughout. The highest monthly MPT abundance was observed at Tilbury Fort in May 2019 (127.33 pieces L^{-1}), whilst the lowest abundance was observed at Limehouse in June 2020 (0.33 pieces L^{-1}). There was no significance between MPT abundance (ANOVA, $f_{7,181} = 1.104$, $P = 00.627$), microplastic fibres (MPF) (Anova, $f_{7,181} = 1.959$, $P = 0.502$) or fragments (ANOVA, $f_{7,181} = 35.08$, $P = 0.129$) between any area of the river Thames (Fig. 3). There was also no significance in MP sizes between areas (ANOVA, $f_{7,180} = 0.735$, $P = 0.643$). Whilst there appeared to be a variation of MPT abundance across the areas each month (Fig. 4), it was not significant ($F_{7,75} = 0.552$, $P = 0.818$).

The average MPT per L^{-1} decreased per year within most areas studied, excluding St Katherine (12.71 pieces L^{-1}–14.5 pieces L^{-1}) and North Woolwich (12.67 pieces L^{-1}-14.89 pieces L^{-1}), which both increased from 2019 to 2020. However, the 2021 average per L^{-1} is still lower than 2019's average per L^{-1}. The average MPT abundance along the length of the Thames through this study was 12.27 pieces L^{-1}; however, in 2019, the average MPT was 16.52 pieces L^{-1}, and by 2021 it was 5.92 pieces L^{-1} (Table 1). Whilst there appeared to be a significant variation in MPT abundance within each area across the years (2019–2021), this was not the case ($f_{1,14} = 0.565$, $P = 0.795$). There was no significant difference in MPT abundance in area * month * year ($F_{1,71} = 0.944$, $P = 0.693$).

Microplastics were classified into six shape types (fibre, fragment, bead, foam, pellet and other) (Fig. 4). The most common shape across all areas was fibres, which comprised 93.27 % of all MPs within the River Thames. Southend had the lowest abundance of MPF (55 %, 402 pieces) compared to Tilbury (92.81 %, 852 pieces), which had the highest. Fragments (11.87 %, 790 pieces) were the second most common and were found across all sites but mostly at Southend, where they made up 34.56 % (253 pieces) of the sample compared to Tilbury, which had the lowest with 5.77 % (53 pieces). All types of MPs were found at all sites sampled except beads which were not found at Westminster, St Katherine or Southend. Beads were also the least type of MP found, making up 0.18 % of all types (Fig. 4).

All MPs were further categorised by colour (Fig. 4). In total, 12 different colours were observed (blue, black, red, white, orange, yellow, transparent, brown, pink, green, purple and gold). The most commonly observed colour at all sites was black (66.68 %, 4439 pieces), followed by blue except for St Katherines (red, 79 pieces) and Southend (white, 84 pieces). The least common colour observed was Gold (0.06 %, four pieces), which was only found at Westminster (1 piece) and Limehouse (3 pieces).

In total, 29 % (1982 pieces) of all MPs found were measured for length of these; the majority (40.53 %, 1095 pieces) fell within the 0-1 mm category, followed by the 1–2 mm category (22.65 %, 449 pieces). The 4-5 mm category (2.42 %, 48 pieces) was the least abundant (Fig. 4).

A total of 1041 pieces (15.64 %) were analysed via FTIR, which included “No hit” (176 pieces) and natural (7 pieces) (Supplementary Table 3). The natural material was located at Teddington, Westminster and London Bridge. The material placed in the natural category had the appearance of fibres of varying colours; however, once scanned was identified as chitin (identified September 2020 and April 2021). Anthropogenic microfibres/particles (31 pieces) were also found, consisting of wool, cotton, flax, nylon, silk and silicone at all sites except Southend-on-Sea (Supplementary Table 4).

As a result, 827 pieces (79.44 %) were identified as 40 different types of polymers. The most commonly found polymers in the river Thames were polyvinyl chloride (PVC) (255 pieces), polystyrene (PS) (102 pieces), polychloroprene (PCP) (80 pieces), and polyethylene chlorinated (PEC) (56 pieces) and polypropylene (35 pieces). Polymers such as rubber and acrylonitrile butadiene styrene (ABS) were also found. These are considered tire wear particles (TWP) at Westminster, London Bridge and Limehouse. Biopolymers such as zein purified (1 piece, London Bridge) and alginic acid (4 pieces, Southend, London bridge and Teddington) were found only in samples from 2021.

Whilst macroplastics were not the focus of this study; they were found or observed at sample sites and within water samples. Macroplastics, mainly plastic water bottles, were present in high quantities at Limehouse harbour, especially at high tide (Supplementary Fig. 1). They were also found in water samples collected from the eight areas of the river Thames 2019–2021 (Supplementary Fig. 2). A selection of these was identified via FTIR the top three polymers identified were PCP, PVC,

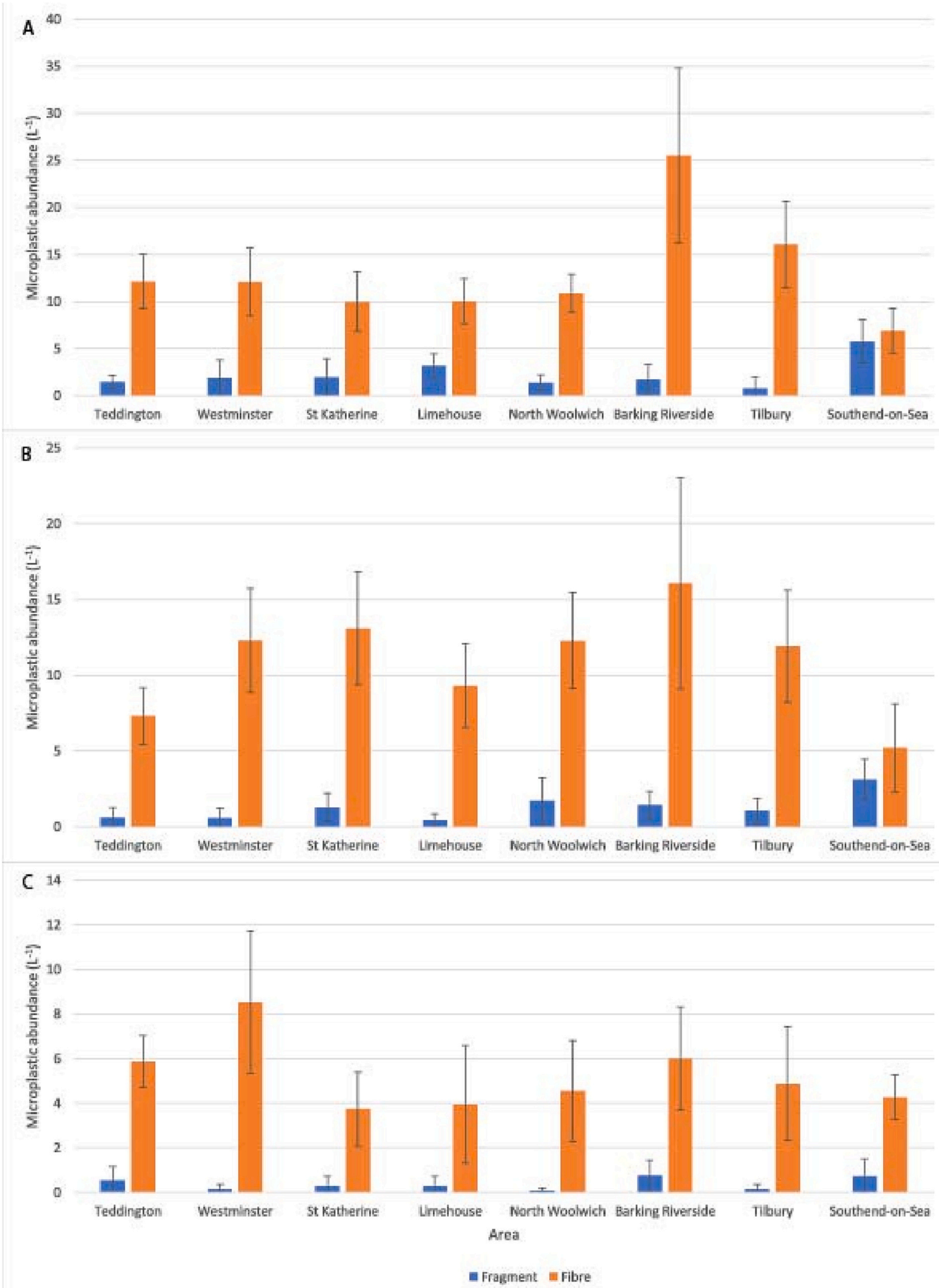

Fig. 3. Average microplastic fibres and fragment abundances (L^{-1}) (±stderr/SE) found within water samples at the eight areas along the river Thames; A) 2019, B) 2020 and C) 2021.

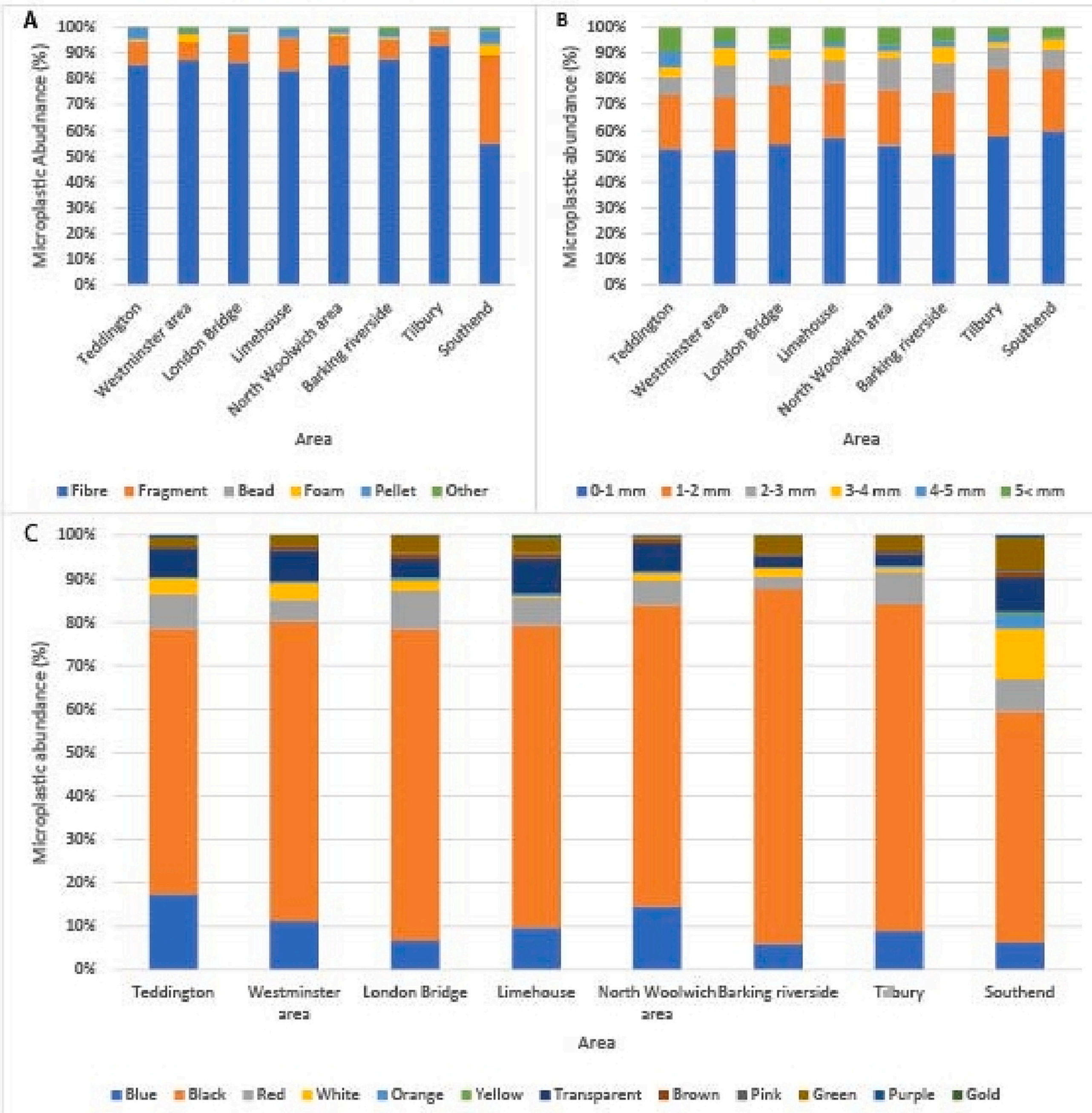

Fig. 4. Microplastic abundances (%) found within water samples at the eight areas sampled along the river Thames during 2019–2021 A) MP type, B) size, and C) colour. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and PP (Supplementary Fig. 2).

Rivers are widely reported as one of the central transport systems of MPs entering oceans from land-based sources (Ding et al., 2019; Lebreton et al., 2017; Mishra et al., 2019). However, there is a lack of studies that focus on rivers. As a result, the number of MPs transported through rivers is unknown. When combining river dynamics (i.e., hydrology and tides) with the sinking and resuspension of MPs within a river system, the total abundance of MPs within a specific time and area becomes unpredictable.

As shown in this study and previous studies, microplastic quantity varies between and within the study sites across the river Thames over the sampling period. The highest concentration was found at Westminster and the lowest at North Woolwich. The low abundance at North Woolwich could be explained by the amount of sampling missed due to the Covid-19 pandemic and having to find another site within proximity. However, Barking Riverside is missing one sample more than North Woolwich but had a higher MP total found at the site between 2019 and 2021. These sites are next to each other, the high MPT and average at Barking Riverside compared to North Woolwich, but a similar amount of water samples taken suggests there is a major source of MPs close to Barking Riverside, possibly Beckton Sewage treatment plant.

There was a 2.4 % increase in MP L^{-1} average abundances from Teddington to Southend overall from 2019 to 2021; however, this varied yearly and monthly across the area with no apparent pattern and was statistically insignificant. As a result, the hypothesis that MP abundance increases along the river's length cannot be supported. However, there was a decrease in average MP abundance between Barking Riverside and Southend, which ranged from 26.71 to 52 % between 2019 and 2021.

Table 1
Average microplastic total (MPT) per litre (L^{-1}) of water collected in the 8 sampling areas along the river Thames during the study period (2019–2021).

Areas	Average MPT (L^{-1}) 2019–2021 (±stderr/SE)	Average MPT (L^{-1}) 2019 (±stderr/SE)	Average MPT (L^{-1}) 2020 (±stderr/SE)	Average MPT (L^{-1}) 2021 (±stderr/SE)
Teddington	10.01 (3.78)	15.13 (3.73)	8.1 (3.71)	6.4 (4.05)
Westminster	13.17 (5.09)	15.67 (4.92)	13.36 (5.68)	8.73 (3.93)
St Katherine	11.85 (4.42)	12.71 (4.11)	14.5 (5.43)	6 (2.48)
Limehouse	10.15 (3.86)	14.3 (5.22)	9.83 (3.66)	4.2 (2.18)
North Woolwich	11.14 (5.49)	12.67 (5.78)	14.89 (6.04)	4.8 (1.82)
Barking Riverside	18.82 (5.39)	29.56 (5.74)	19 (5.38)	7 (3.86)
Tilbury	12.75 (5.35)	17.21 (7.61)	12.94 (4.64)	5.2 (2.86)
Southend-on-Sea	10.25 (2.93)	14.88 (4.60)	9 (2.65)	5.13 (0.85)

This decrease in MP L^{-1} may be due to the increase in width and depth as the river travels from Teddington to Southend, which is supported by Rowley et al. (2020), who noted that the number of plastic per cubic meter was higher at Putney compared to Greenwich but that overall plastic load per second was higher Greenwich due to the river being wider at this point.

However, microplastic monthly abundance at sites along the river Thames varied from 0.33 to 127.33 L^{-1}. However, in 2019–2021, the areas averaged 10.01–18.83 L^{-1}. There was no trend evident within this study that suggested particular months or areas had an impact on MP abundance. MP abundances across all sites did decrease yearly from 2019 to 2021, although not significantly, the only exceptions being in 2020, where St Katherine and North Woolwich had a higher yearly MP abundance than in 2019. This decrease, although not significant in MP abundance across all sites, is most likely due to the impact of the Covid-19 pandemic and subsequent changes in human behaviour due to national lockdowns reducing littering (Devereux et al., 2023).

Previous studies on the river Thames shows a range in MPT abundances from; 508 pieces L^{-1} (Devereux et al., 2022), 84.1 pieces L^{-1} (Dunn and Friends of the Earth, 2019), 24.8 m^{-3} (Putney) and 14.2 m^{-3} (Greenwich) and 8–36.7 particles m^{-3} (Rowley et al., 2020). The previous studies on the river Thames range from one sample at an unknown site, daily samples for 9 days at one site and monthly samples from June to October 2017 at two sites. This study showed monthly variation at sites higher and lower than previous studies except for Devereux et al. (2022). The yearly average MPT L^{-1} across all areas varied from 4.2 L^{-1} (Limehouse, 2021) to 29.56 L^{-1} (Barking Riverside, 2019) with a total average of 12.27 pieces L^{-1} across the river Thames (2019–2021). When these figures were compared to previous studies on the river, they were lower than Dunn and Friends of the Earth (2019) but higher than Rowley et al. (2020). This highlights an important issue within microplastic studies and being able to compare data without a standardised method and sampling routine. In comparison with rivers worldwide, the results obtained from this study appear to be higher than studies conducted on the Yangtze river, China, which had 0.5–10.2 particles L^{-1} (Zhao et al., 2014), river Rhine, Germany, 0.05–8.3 particles m^{-3} (Mani et al., 2019), and the Hudson river, USA 0.98 particles L^{-1} (Miller et al., 2017). However, they are lower than Los Angeles River USA (13.7 L^{-1}) (Moore et al., 2011); river Marne, France, 398 particles L^{-1} (Dris et al., 2015); Yellow River, China (380–1392 L^{-1}) (Han et al., 2020) and the Saigon river, Vietnam (172–519 L^{-1}) (Lahens et al., 2018).

Secondary MPs, particularly MPFs, are the most dominant form of MP found in all aquatic environments (Gago et al., 2018; Rebelein et al., 2021; Woods et al., 2018). This is especially the case when looking at MPF abundance within river systems, with some studies showing that 99 % of MPs found within rivers are fibres (Kiss et al., 2021; Napper et al., 2021). This was the case with this study, with fibres accounting for 93.27 % of MPs. Fragments were second highest and most commonly found at Southend-on-Sea. This may be due to their polymer density and, as such, being found lower in the water column or, as shown in Horton et al. (2017a, 2017b), these types may be lower than fibres due to sinking and being found in higher amounts in sediments of the River Thames. Compared to the sites along the river, where samples contained mostly fibres, Southend-on-Sea blended fragments and fibres representative of the plastic soup found within oceans (Suaria et al., 2016).

Total MPF concentrations are reportedly higher closer to shores than offshore (Lusher et al., 2014; Nel and Froneman, 2015), which has been linked to wastewater from washing machines or laundry water, WWTP and STP (Browne et al., 2011; Galvão et al., 2020; Ramasamy and Subramanian, 2021; Yang et al., 2019). This may explain why the Southend-on-Sea fibre content was the lowest compared to MPs. However, it is also possible that the constant wave action and turbidity at Southend-on-Sea resuspends fragments and fibres, so there is a more mixed MP concentration. It is also possible that the high MP abundances found at Tilbury and Barking Riverside may be due to their proximity to sewage treatment plants or outlets. Barking Riverside, for example, is close to Beckton STW, the largest STW in Europe, serving 4 million people in north and east London (Grassly, 2022). In 2021 it discharged 12 times for a total of 26.6 h, according to Thames Water (2022), whilst the Tideway CSO, which is in the same area, spilled 13 times for 81 h (France, 2021). Tilbury has 3 points on the same side of the river, two discharge points and one CSO; however, all 3, as of 2021, are not monitored. On the opposite side of the river, there are 6 points, including Gravesend WWTP; in 2021, it spilled 60 times for a total of 235 h, the Empress Rd CSO overspilled 25 times for 75 h, High street Gravesend CSO spilled eight times for 8 h, Crowley Court CSO spilled 41 times for 72 h whilst Tower pier CSO spilled 51 times for 100 h (France, 2021). Whilst this data is readily available, the dates of the overspill are not. As a result, this data cannot be used to correlate MP abundances with possible releases other than a possible reason for a change in yearly MPT abundances.

The distribution of plastic pollution can vary due to environmental factors such as wind, river depth, flow speed, salinity and vegetation, as well as the plastics' size, shape and buoyancy, so whilst sewage treatment plants may be one explanation for high levels of MP abundances at Barking Riverside especially, a combination of factors may still be the cause for the fluctuation in MP abundances across all sites along the river Thames, however with a lower amount of samples taken in this area compared to North Woolwich which had the smallest amount of MP found through this study, whilst this area had a higher than average MP total this seems unlikely.

Black was the most dominant colour; this is supported by other studies conducted within the river Thames. For example, McGoran et al. (2017) found black fibres were the most dominant type found in European flounder and European smelt found within the river Thames.

The abundance and nature (colour, types, sizes) of fibres and fragments within this study suggest that the majority of MP abundance within the River Thames is secondary MPs resulting from the fragmentation of consumer-based products such as textiles and packaging. This hypothesis is supported by the FTIR analysis carried out during this study which found that the highest polymer abundances were identified as PVC, PS, PCP, PEC and PP. However, these were expected as they are the most commonly produced polymers worldwide. Other types of polymers identified were acrylonitrile, butadiene and styrene (ABS), which are consistent with the composition of tires (Kole et al., 2017), found at Westminster, London Bridge and Limehouse. Thus, some plastic within the river Thames has come from tires, particularly within London, where the study site is close to the main roads. One Swedish report (Verschoor et al., 2016) estimated that 500 tons of TWP directly enter surface water, whilst 1300 tons can enter via sewage systems from road run-off. More information is needed regarding preventative measures as it is not sustainable or realistic to ban cars and remove all asphalt roads. Instead, it may be more practical to improve sewage systems and their ability to remove microplastics from these systems.

As well as polymers, anthropogenic material was also identified during this study. Although they were not the focus of this study, it is still important to investigate and record these materials as they can still pose a risk to the environmental and biological health of the waterways they are found within. Anthropogenic materials can still pose a risk due to the dyes and chemicals used in the textiles and manufacturing industry to prolong their life (Bikker et al., 2020; Dris et al., 2018; Remy et al., 2015).

Materials placed in the natural category were all identified as chitin, found in the exoskeletons of insects, fungi, invertebrates, and fish (Elieh-Ali-Komi and Hamblin, 2016). However, upon further investigation, chitin is also used as a biopolymer with or without other materials such as silk, alginate, poly-lactic acid or collagen (Salaberria et al., 2015). Chitin appears to be used in wound management, drug delivery and cosmetics (Singh et al., 2017). However, it has also been used to make a plastic film for packaging similar to PET (Material District, 2018; Yu et al., 2020). Chitin appears to be a new and upcoming polymer used within packaging within the UK. However, a closer examination of the material found in the Thames is needed to explore if this was the case.

Biopolymers were also found in water samples, such as alginic acid, which can be used in food packaging (Khalil et al., 2017), and zein purified, which can be used in paper coating and food packaging (Jones et al., 2020; Patnode et al., 2022).

Many studies (Browne et al., 2011; Devereux et al., 2021; Devereux et al., 2022; Lusher et al., 2020) have expressed the numerous possibilities of contamination whilst all possible precautions were taken to limit the exposure of sample contamination it is not possible to rule out.

These findings correlate with other studies on the MP abundance in rivers, including previous studies on the Thames. Microplastics were found at all sites within every sample that was collected and did not increase in abundance along the river. The results in this study can be used as a baseline for the presence of MP pollution within the tidal river Thames and be used to examine MP transport from rivers to the sea. This study also records MP pollution at these sites and potential sources, notably sewage – laundry, road particulates, and litter degradation. The majority of MP found in this study can be attributed to secondary MPs and sources such as PVC, PS, and PE used for packaging, textiles and within the building industry. The high presence of fibres in this study suggests that sewage and wastewater are likely significant sources of microplastics into the river. To the best of this author's knowledge, this is the first baseline study on the microplastic abundance in the tidal section of the river Thames and will be of interest to policymakers and reducing plastic pollution. This baseline can be used for future monitoring of microplastics within the river, especially when investigating the effectiveness of future actions and policies to reduce microplastics from land-based sources entering rivers.

CRediT authorship contribution statement

Ria Devereux: Conceptualization, Methodology, Investigation, Writing – original draft. **Bamdad Ayati:** Supervision, Writing – review & editing. **Elizabeth Kebede Westhead:** Supervision, Writing – review & editing. **Ravindra Jayaratne:** Supervision, Writing – review & editing. **Darryl Newport:** Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors are unable or have chosen not to specify which data has been used.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2023.114965.

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