The effects of wet wipe pollution on the Asian clam, *Corbicula fluminea* (Mollusca: Bivalvia) in the River Thames, London

K.A. McCoy [a, b] *, D.J. Hodgson [a, b], P.F. Clark [b], D. Morritt [a]

[a] *Department of Biological Sciences, School of Life Sciences and the Environment, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK*
[b] *Department of Life Sciences, The Natural History Museum, Cromwell Road, London SW7 5BD, UK*

A B S T R A C T

The aim of the present study was to evaluate “flushable” and “non-flushable” wet wipes as a source of plastic pollution in the River Thames at Hammersmith, London and the impacts they have on the invasive Asian clam, *Corbicula fluminea*, in this watercourse. Surveys were conducted to assess whether the density of wet wipes along the foreshore upstream of Hammersmith Bridge affected the distribution of *C. fluminea*. High densities of wet wipes were associated with low numbers of clams and vice versa. The maximum wet wipe density recorded was 143 wipes m^{-2} and maximum clam density 151 individuals m^{-2}. Clams adjacent to the wet wipe reefs were found to contain synthetic polymers including polypropylene (57%), polyethylene (9%), polyallomer (8%), nylon (8%) and polyester (3%). Some of these polymers may have originated from the wet wipe reefs.

Keywords:
Wet wipes
Microplastic pollution
Corbicula fluminea
River Thames
FTIR spectroscopy
London

*Corresponding author.

E-mail address: Katherine.McCoy.2015@live.rhul.ac.uk (K. McCoy)

1. Introduction

The working daytime population of central London is ca. 10 million people (Piggott, 2015) and according to Barnes et al. (2009) areas with a higher population density are often more affected by plastic pollution. In London, the high population density and its associated plastic waste (Morritt et al., 2014; McGoran et al., 2017, 2018) have significantly polluted the River Thames. Due to the tidal nature of the Thames, downstream (east) of Teddington Lock, plastic debris is able to accumulate along certain reaches of the river on account of it being deposited on the foreshore with tidal cycles (Thompson et al., 2009). Thames21, a charity working in improve the Thames waterways, conduct a biannual 'Big Count' survey to quantify the amount and types of plastics found along the foreshore of the river. Roughly, one-third of the plastic found are toiletry items including wet wipes which comprise 18% of the total litter recorded by Thames21 (2019). Another Thames study (Morritt et al., 2014) found sanitary items ca. 22% of total litter recorded. These toiletry items originate from sewage effluent which overflows into the Thames. The overflows also distribute large numbers of microbeads and synthetic fibres (Horton et al., 2017; Mintenig et al., 2017). While sewage treatment works have the potential to remove ~98% of synthetic fibres, many are still released into the watercourse due to such high population densities (Mintenig et al., 2017; Munoz et al., 2018). This is a particular issue after rainfall when the antique treatment works can only deal with small amounts of precipitation by releasing it and sewage directly into the Thames without processing.

Synthetic fibres are the most abundant form of plastic pollution found in marine environments and sediments, in particular, are a sink for microplastics (Thompson et al., 2004; Wright et al., 2013). Previous studies have demonstrated the ingestion of synthetic microfibres by some Thames fish species such as the European smelt, *Osmerus eperlanus*, the European flounder, *Platichthys flesus* and roach *Rutilus rutilus* (Horton et al., 2018; McGoran et al., 2017, 2018). The studies by McGoran et al. (2017, 2018) found that fibres were the most dominant form of ingested microplastic. Of the fish sampled, benthic species ingested more plastics than pelagic. This could potentially be due to their close association with sediment containing microplastics and may be inadvertently consumed when feeding on prey (McGoran et al., 2018). Horton et al. (2018) also found that fibres were the most abundant form of microplastic comprising 75% of all those sampled. All polymers identified were either polyethylene, polypropylene or polyester. These materials are all components of wet wipes; a non-woven cloth that once introduced to waterways can breakdown to release microplastic fibres (Horton et al., 2018; Munoz et al., 2018).

The Asian clam, *Corbicula fluminea* has been studied in Chinese rivers to monitor plastic pollution through the ingestion of microplastics, most notably microfibres (Su et al., 2018). These clams are highly efficient filter feeders, filtering up to 1L of water per hour (Silverman et al., 1995) and inhabit superficial sedimentary layers by burrowing using their foot and shell (Baudrimont et al., 1997). These clams are an edible species and, as the soft tissue is consumed whole, they provide a direct pathway for the ingestion of microplastics by humans (Su et al., 2018). Originating from south-eastern Asia, *Corbicula fluminea* is an invasive species in the UK that was first recorded in 1998 (Elliott and zu Ermgassen, 2008). It has previously been identified at 4 locations along the River Thames, in West London (Elliott and zu Ermgassen, 2008) and provides an ideal model to assess the potential impacts of plastic pollution.

The current study identified *C. fluminea* at a new location along the tidal Thames on the south bank, just upstream (west) of Hammersmith Bridge, that is impacted by a nearby sewage outlet on the north bank and has high densities of plastic pollution in the form of wet wipes and sanitary towels (Fig. 1). The site is on an inside bend of the river, meaning the downstream water velocity is reduced at this point. Consequently, plastic debris suspended in the water column is deposited on the foreshore and subsequently exposed at low tide (Graf and Blanckaert, 2002). A slipway used by St. Paul's School Rowing Club potentially acts further in slowing water flow around the bend of the river, causing wet wipes to be deposited on the downstream side of the foreshore towards Hammersmith Bridge. Here, an investigation was undertaken to determine the density of wet wipes along the foreshore and to assess whether this affects the distribution of the *C. fluminea* population at this site. This study also examined whether microfibres from the wet wipes or other microplastics were being captured by the clams. Based on preliminary observations, it was expected that there would be a significant reduction in the abundance of *C. fluminea* where densities of wet wipes are higher. From previous literature, including the work of Su et al. (2018), it was also expected that the clams would filter the surrounding Thames water and contain microfibres, similar in polymer composition to that of the wet wipes and sanitary items that are accumulating on the south bank foreshore.

2. Methods & materials

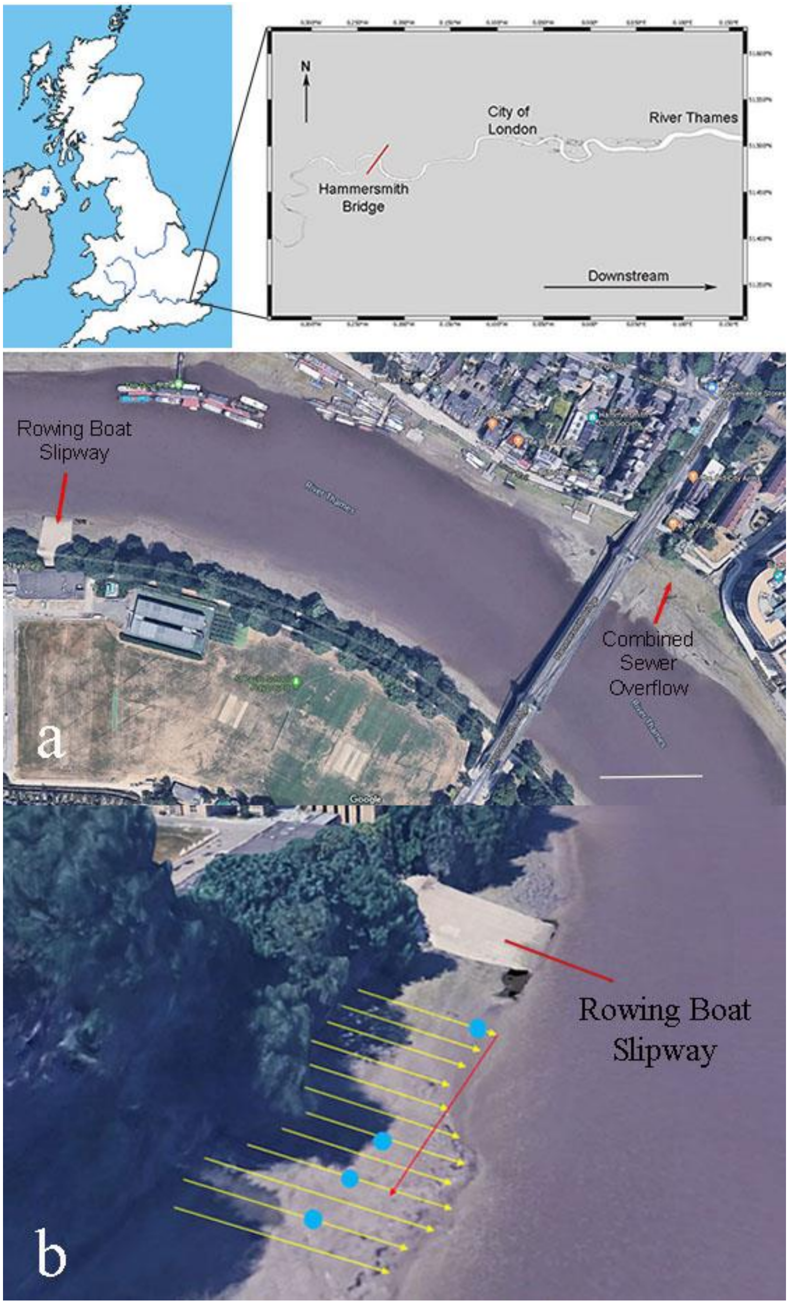


Fig. 1. (a) The sampling site along the south bank of the River Thames at Hammersmith Bridge. To the far right is the rowing boat slipway of St Paul's School that was used as a distance marker for transects which were set out eastward (downstream) of this point towards the bridge. Scale bar = 60m. **(b)** Layout of the 12 transects along Hammersmith south bank foreshore: yellow arrows indicate where wet wipe surveys were conducted (section 2.2), blue dots indicate where clam samples were collected along the same tidal height (section 2.3) and the red arrow indicates where clam densities were measured along the same tidal height (2.4) (Google Earth Pro).

2.1. Survey site

Field surveys were conducted along the foreshore of the south bank, just upstream of Hammersmith Bridge (51˚29'17.574" N 000˚13'55.217" W; Fig. 1a), on the River Thames between February and May 2019. This site is located adjacent to the Hammersmith Pumping Station (HPS) which discharges untreated sewage effluent into the river via the combined sewer overflow, due to a limited sewage capacity when precipitation levels are increased (Fig. 3). Thus the survey site is likely to be exposed to HPS effluent. This section of the foreshore was selected based on Thames21 methodology for their Big Count so that the data collected would be comparable with previous studies. During sampling, mounds of wet wipes and other debris were observed and appeared to alter the topography of the foreshore by forming reefs.

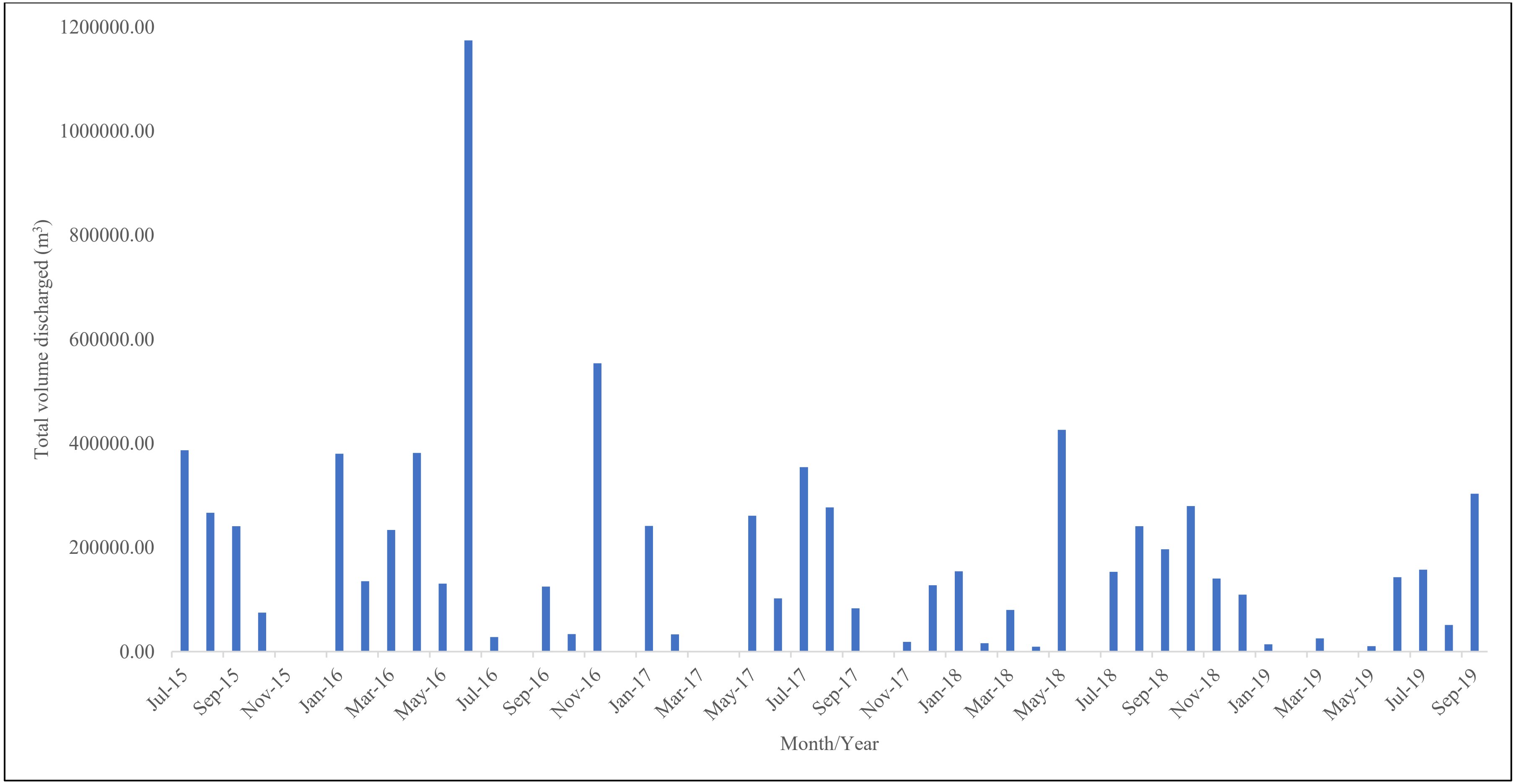


Fig. 2. The amount of sewage discharged (in cubic metres or tonnes) by Hammersmith Pumping Station into the western tideway of the River Thames between July 2015 - September 2019 (Thames Water data).

2.2. Wet wipe surveys

A total of 12 transects were arranged along the foreshore at the Hammersmith sampling site during low tide. The transects were laid from the bottom of the bricked bank where it meets the shoreline to the low water line at 5m intervals between 45–100m from the rowing slipway (Fig. 1b). Quadrats (1m^2) were then placed along each transect at 5m intervals. At each quadrat, the number of wet wipes present was recorded along with the number of sanitary items and other miscellaneous plastics. Wet wipes were found by counting those present on the surface and by using a hand trowel to make shallow excavations at each quadrat down-shore from the distance mark. All wipes down to a depth of ~4cm inside the 1m^2 quadrat were pulled out of the sediment and counted as well as any that protruded into the quadrat. Fragmented wet wipes were counted as individuals. Only a limited number of transects were completed within one tidal cycle, so data were collected over 5 days (11th, 18th, 26th February; 5th, 8th March 2019). Differences in tidal heights restricted the number of quadrats that could be completed on each visit, as some days only allowed for measures to be made down to 20m from the riverbank.

2.3. Corbicula fluminea surveys

The density of wet wipes and live clams (no empty shells) were counted within 0.5m^2 quadrats. Twenty-four quadrats were placed at ca. 2m intervals between 45m and 85m from the slipway along the same tidal height of the foreshore, and the total number of wet wipes and the total number of clams counted per 0.5m^2 quadrat. Quadrats were placed at a distance of 25.4–30.3m from the bank along the same tidal height. The range of 45–85m was selected as previous surveys showed that this area had the greatest variation in the density of wet wipes. Wet wipes and clams were counted as per the methods outlined in section 2.2.

2.4. Corbicula fluminea sampling

Asian clams were collected from the survey site in March 2019 and used for laboratory analysis. These were gathered at horizontal distance points 45m, 70m, 85m and 95m downstream from the slipway. For each of these 4 stations, a total of 3 quadrats were placed at low tide at times of 1000hrs, 1100hrs and 1145hrs (2 hours 13 minutes, 1 hour 13 minutes and 28 minutes respectively) before the predicted time of low water at 1213hrs based on Port of London Authority 2019 tide tables. A total of 8 clam samples were collected from the south bank foreshore at Hammersmith Bridge; 1 sample at 45m from the slipway, 2 at 70m, 3 at 85m and 2 at 90m. Due to the shape of the river and the foreshore, collecting clams at the same distance measured from the riverbank would have resulted in environmental heterogeneity across samples. Therefore the clams were gathered from the same tidal height, as determined by marking the height of the receding tide with stakes, and consequently, each collection point was comparable.

The presence or absence of *C. fluminea* was recorded for each of the 12 quadrats in total and if present, samples of clams were collected. Only live clams were counted and collected with empty shells being disregarded. This meant that different numbers of clams were collected from each of the 4 stations due to presence/absence. Where possible, a minimum of 30 individuals were collected per quadrat, washed *in situ* with Thames water to remove sediment using a sieve, transported back to the laboratory in clean plastic bags and stored in a laboratory freezer prior to further analyses. A control sample of 12 clams was collected from Chelsea Embankment (North Bank of Thames, just upstream (west) of Albert Bridge) on the 1st May 2019. This was used a site for comparison, as wet wipes were absent from the foreshore. Due to their smaller population size, it was not possible to collect large quantities of clams at this location.

2.5. Sample processing

In the laboratory, all clams were again washed with filtered deionized water (10µm) to remove residual sediment and any microplastics adhered on the surface of the shell. The shell width of each clam was recorded to the nearest 0.01mm using digital Vernier callipers. The soft tissue of each bivalve was dissected out of the shell with a new scalpel blade, cleaned once more with filtered water (10µm) to remove microplastics potentially present in the shell. The clam tissue was then dried by blotting with tissue paper, transferred to 50mL Falcon tubes and frozen at -20˚C to await further analysis. The soft tissue wet weight of each individual was weighed to the nearest 0.0001g and digested in 50mL of 10% potassium hydroxide. The solutions were then mixed and kept at 60˚C in an oven for approximately 12hrs. After this time, the samples were filtered through individual 10 µm Cyclopore™

Polycarbonate Membrane Filters using a Millipore vacuum filtration system. The filters containing organic/synthetic debris were placed in Petri dishes and sealed with Parafilm, prior to further analysis.

2.6. Polymer identification

The filtered clam digestions were observed under a Nikon stereomicroscope (model C-LEDS) to identify any microparticles including potential microplastics. All particles that appeared to be sediment or chitin films were not counted. Microparticles were counted on the Petri dish and categorised by colour and shape (i.e., fibre/film). Due to their minute size, the length of each microparticle could not be measured. An AutoIMAGE Perkin-Elmer Fourier Transform Infrared Spectroscopy (FTIR) at the Natural History Museum (NHM) was used to analyse a sub-sample of microparticles, including microplastic fibres to identify polymer composition. Approximately 20% of the total counted particles from digestions were separated and analysed as a sub-sample due to handling limitations. These particles were placed under an FTIR microscope and visualised using AutoImage Microscope, the aperture recorded, and the material identified using Spectrum Spectrometer containing a spectra library compiled by NHM staff. The spectrum produced by each particle was compared with that of the library by examining the peaks produced to find the most appropriate matches. The percentage match was recorded along with whether the particle was organic, synthetic or semi-synthetic. Those that did not produce a comparable spectrum were disregarded and recorded as ‘n/a’. Particles recorded as semi-synthetic were labelled as such if FTIR identified them as either as viscose, chipboard or cellophane.

2.7. Wet wipe sampling

Samples of wet wipes and sanitary items were collected from the study site. These items were placed in plastic bags and transported to the laboratory where they were washed with filtered water (10µm) and stored in bags for later analysis. Clear fibres were extracted from each of these items using tweezers to pick out single fibres in order to analyse the types of polymers present using FTIR. All 10 of the extracted fibres were analysed as per the method outlined in section 2.6.

2.8. Experimental quality control

In order to remove contamination from all water used, reverse osmosis water was filtered through 10µm Cyclopore™ Polycarbonate Membrane Filters using a Millipore vacuum filtration system. Laboratory coats made of 100% cotton were worn to eliminate polyester fibres as a source of contamination. Eco nitrile gloves were worn at all times in order to prevent any further outside microplastic contamination. All dissections, digestions and filtrations were carried out under a laminar flow hood, Airstream® ESCO Class II Biohazard Safety cabinet, model number AC2-4E1. The 10% KOH solution was filtered through a 10µm polycarbonate membrane in a vacuum filtration system prior to use. An open Petri dish containing a damp polycarbonate filter was placed under the laminar flow hood during filtration as an atmospheric control. These could then later be compared with isolated microplastics from digestions and filtrations. Any control dishes that contained synthetic/semi-synthetic particles were accounted for by subtracting the fraction (if significant i.e., > 0.5) from the total count of that material from the samples.

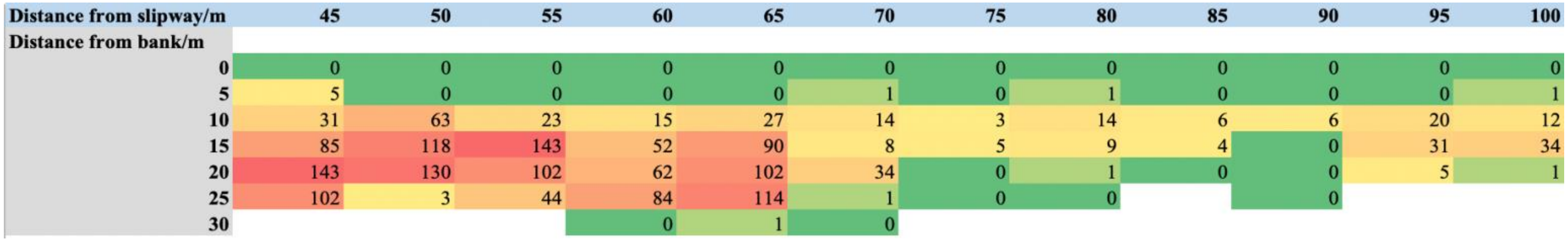
2.9. Statistical Analysis

All statistical analyses were performed using the software R, version 3.4.1. Using data collected from wet wipe surveys (Table 1), a series of correlation tests were used to assess whether there was a relationship between the distance from the slipway or distance from the riverbank and the average number of wet wipes per m^2. A Shapiro-Wilk test was used on the data for each of the different variables to test whether the data were normally distributed. If data were normally distributed, then a Pearson's Correlation was performed, however, if not then a Spearman's Rank Correlation was used as a non-parametric alternative. This was repeated for 2018 and 2017 data provided by Thames21.

The same process was used to assess whether there was a relationship between the distance from the slipway and the number of Asian clams sampled per $0.5m^2$ and again to test for a relationship between the number of wet wipes and the number of clams per $0.5m^2$. After finding that there was a linear relationship between the number of wet wipes and the density of clams, a linear regression was used to determine the relationship between these variables.

Pivot tables were used in Microsoft Excel to compare all data recorded for FTIR analysis of microparticles. This was followed by correlation tests which were conducted to assess the potential relationships between different variables and the distribution of microparticles and microplastics contained in *C. fluminea*. These variables included the dry soft tissue weight (g) of each individual, the distance from the slipway at which the sample was collected and the number of wet wipes present at each distance. A Pearson's correlation was selected for data that were normally distributed and a Spearman's rank used as a non-parametric alternative for non-normal data.

3. Results



Distance from slipway/m	45	50	55	60	65	70	75	80	85	90	95	100
Distance from bank/m												
0	0	0	0	0	0	0	0	0	0	0	0	0
5	5	0	0	0	0	1	0	1	0	0	0	1
10	31	63	23	15	27	14	3	14	6	6	20	12
15	85	118	143	52	90	8	5	9	4	0	31	34
20	143	130	102	62	102	34	0	1	0	0	5	1
25	102	3	44	84	114	1	0	0		0		
30				0	1	0						

Table 1.

The number of wet wipes counted per m^2 along 12 transects of the Hammersmith foreshore, measured from the riverbank down to low water at 5m intervals.

3.1. Wet wipe surveys

The counts of wet wipes along 12 transects (Fig. 1b) on the Hammersmith south bank foreshore can be seen in Table 1. These results provide an overview of wet wipe distribution along the foreshore by showing densities indicated as a heat map. A colour scale of red through to green indicates areas of high to low densities of wet wipes accordingly. Table 1 is similar to those produced in both 2017 and 2018 from Thames21 data, showing that the highest densities of wet wipes appear to be closer to the slipway and further down the shore between 15–25m. Further data collected by Thames21 shows that one of the largest wet wipe mounds has in fact increased in height by 0.7m between 2014–2018 and a further 0.7m between September 2018 and May 2019. This increased in spite of efforts by Thames21 to remove thousands of wet wipes during their annual Big Count which saw a total of 23,000 wet wipes collected on 23rd March 2019.

The data from each year (2017–2019) were used to assess whether there was a relationship between the average number of wet wipes counted per m^2 and the distance from the rowing slipway. There was a weak negative correlation of in 2017 (Spearman's rank correlation = -0.31; S = 110, p = 0.46). In 2018 there was a stronger negative correlation (95% CI: -0.98 and -0.72, Pearson's correlation = -0.92; t = -7.16, d.f. = 9, $p < 0.01$). There was also a strong negative correlation in 2019 (Spearman's rank correlation = -0.73; S = 494, p = 0.01). These results indicate that the average density of wet wipes decreases with increasing distance from the slipway (Fig. 3a). Gaps in the data for 2017 may account for the insignificant correlation for this year. There was an outlier at 45m where there was a markedly lower average number of wet wipes than other years which may have skewed the data.

The average number of wet wipes per m^2 was also compared with the measured distance from the riverbank to assess whether there was a correlation between the two variables (Fig. 3b). In 2017 there appeared to be a strong positive correlation (Spearman's rank correlation = 0.82; S = 512.87, $p < 0.01$). The data for 2018 showed a strong positive correlation (Pearson's correlation = 0.81; t = 4.80, d.f. = 12, $p < 0.01$). The weak positive correlation found in 2019 was non-significant (Pearson's correlation = 0.35; t = 0.83, d.f. = 5, p = 0.44).

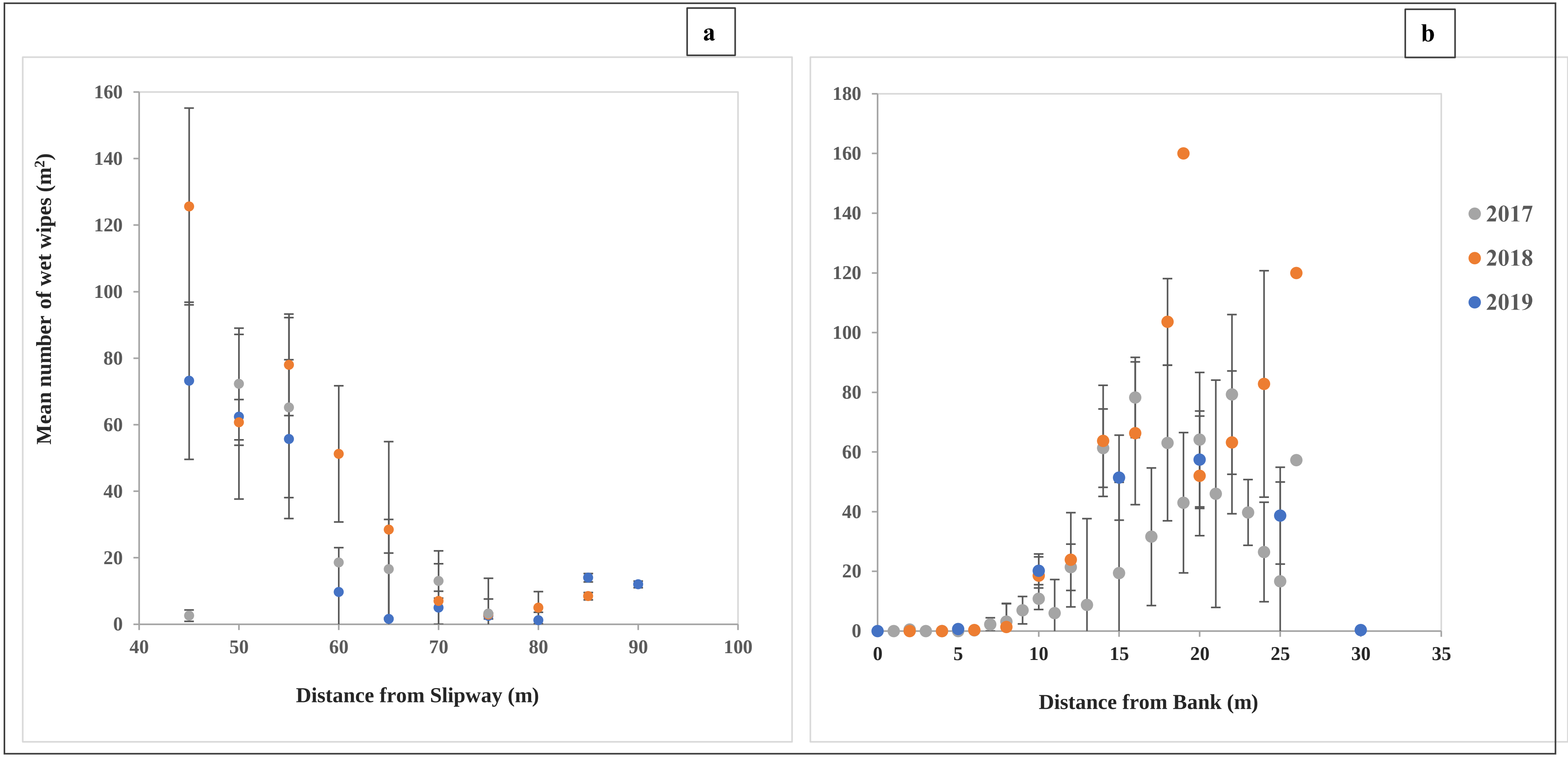


Fig. 3. The average number of wet wipes per m^2 along 12 transects of the Hammersmith south bank foreshore. **(a)** 5m intervals from the rowing slipway. **(b)** 5m intervals from the bottom of the riverbank down to low water.

3.2. Corbicula fluminea density and distribution

The density of *C. fluminea* appeared to be much higher further down the foreshore towards low water when assessing the presence or absence of them at each quadrat leading to low tide. In addition, there were greater abundances of *C. fluminea* further downstream and away from the rowing slipway, where there were fewer wet wipes in general along this part of the foreshore. This was also supported by additional sampling to assess clam densities in the area.

There was a significant positive correlation between the approximate distance from the rowing slipway and the number of clams per $0.5m^2$ with the greatest density of clams found at 80m from the slipway with 151 per $0.5m^2$ (Fig. 4; Spearman's rank correlation = 0.56; S = 1020.6, $p < 0.01$). Therefore, the null hypothesis can be rejected. These results parallel those shown in Fig. 3a, which are supported by the negative correlation of -0.73 (section 3.1) between the distance from the rowing slipway and the average number of wet wipes per $0.5m^2$. These data suggest an inverse relationship between the number of wet wipes and the density of clams per quadrat.

Where there are higher counts of wet wipes there a few or no clams. In comparison, clams occurred in numbers at locations with few or no wet wipes. There was negative correlation between the number of wet wipes and the number of clams present per $0.5m^2$ quadrat (Fig. 4b; Spearman's rank correlation = -0.76; S = 4052.50, $p < 0.01$). The retention time of wet wipes on the foreshore may also influence the apparent correlation however, this could not be determined.

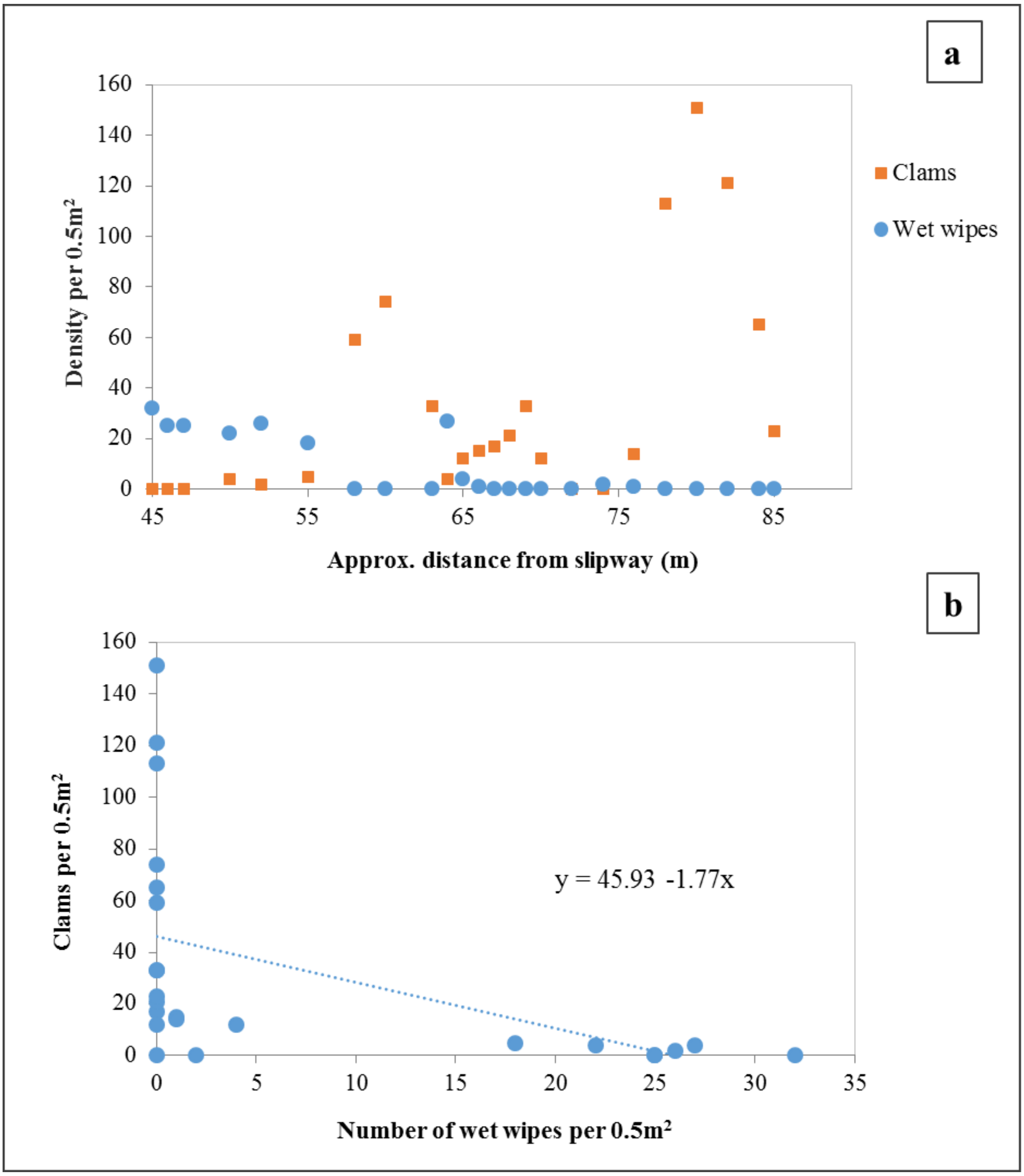


Fig. 4. The number of *C. fluminea* and wet wipes per 0.5m^2 surveyed in 2019 **(a)** with increasing distance from the rowing slipway at the same tidal height (between 25.4m at 85m from the slipway and 30.3m at 45m from the slipway) along the Hammersmith foreshore. **(b)** with linear regression fitted trendline (adjusted R^2 = 0.2).

3.3. Polymer identification

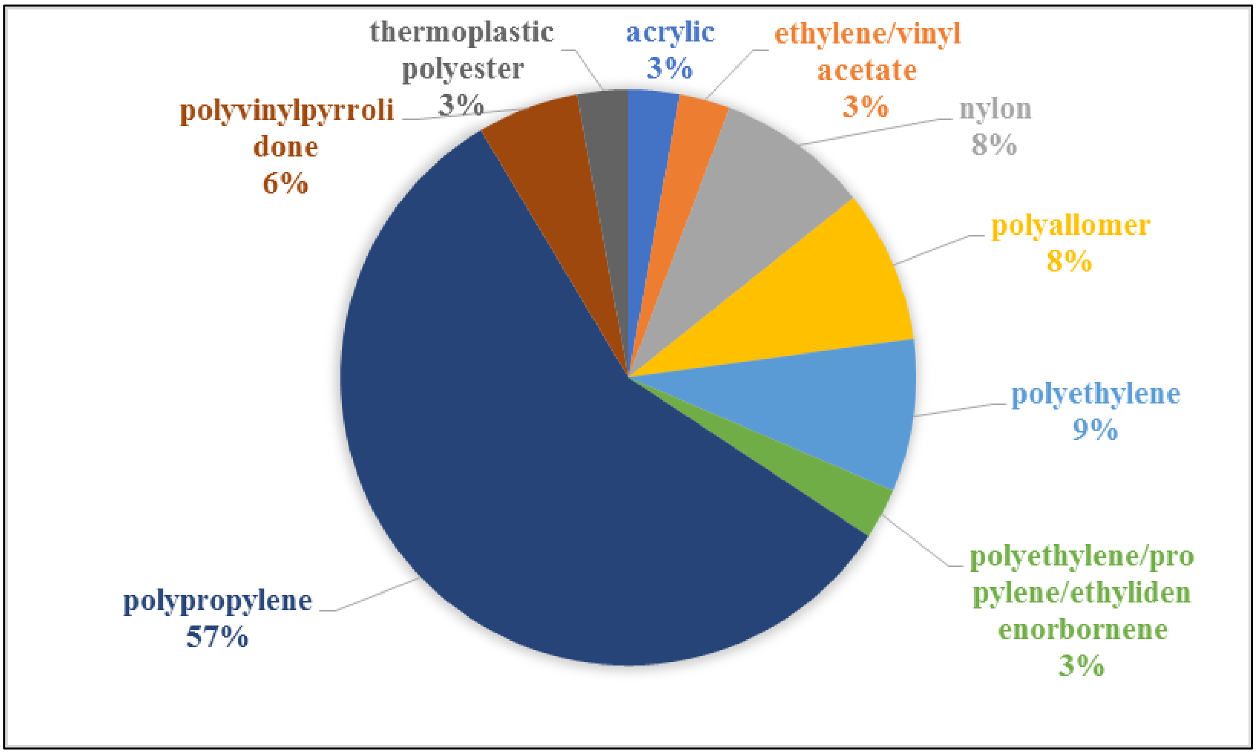


Fig. 5. The types of polymers found from a sample of N=35 synthetic fibres/fragments identified using FTIR spectroscopy of 281 microparticles extracted from the digested soft tissue of *C. fluminea*.

A total of 1404 microparticles were identified from the 9 samples of digested clams (N = 227) with a range of 0-24 particles counted per individual clam (an average of 6.40 particles per individual discounting control samples). All particles were classified as fibres, apart from two that were considered to be film. Of these, 281 were analysed using FTIR spectroscopy. All particles were categorised as either synthetic, semi-synthetic, organic or n/a (see above) with 12% identified as synthetic, 38% as semi-synthetic, 40% as organic and 10% as undescribed due to inability to identify them. Nine different types of synthetic polymer (N = 35) were identified from the samples analysed as shown in Fig. 5. There was an average of 0.77 synthetic particles per individual.

3.4 Polymer content

The soft tissue weight of each clam was compared with the total number of microparticles that were extracted after filtration. The test indicated a weak, but significant correlation of (Spearman's rank correlation = 0.27; S = 12083, $p < 0.01$). The weak correlation may be explained by the characteristically small size range of *C. fluminea* resulting in a range in soft tissue weight of 0.1126g to 2.6748g. There were no significant correlations between the distance from the slipway with the total number of particles for each of the 4 stations; with the proportion of synthetic particles for each of the 4 stations; and with the average number of particles per individual clam per station (Pearson's correlation, $p > 0.05$ in all cases).

All 5 of the clear fibres from the wet wipes were identified as polyester and the 5 clear from the sanitary items were identified as polypropylene or polyallomer/polypropylene. Polyethylene/propylene is found in the top sheets of sanitary pads, and polyethylene is also found in the back sheets (Woeller and Hochwalt, 2015). These results, along with those shown in Fig. 5, would suggest that the clams at this site predominantly contain fibres which potentially originate from sanitary items as opposed to wet wipes, among other possible sources.

A total of 7 microparticles were analysed from the Chelsea Embankment control sample using FTIR. None were identified as synthetic. This is in keeping with the lack of wet wipes at this site, so it was not expected that any fibres identified were of potential wet wipe origin. Four of these fibres, however, were identified as viscose (a cellulose-based material), which is commonly found in sanitary items, another major contributor to pollution on the Hammersmith foreshore (Always, 2019; Woeller and Hochwalt, 2015). Out of 8 control Petri dishes used during sampling, only two were found to contain microparticles and each one only contained 1 particle per Petri dish. One of these particles was too small for FTIR analysis, the other was identified as viscose. The control dish containing the viscose fibre was used during digestions of two samples. Of those samples, 24 other viscose fibres were identified, leaving a ratio of 1 in 24 (0.04) as a potential source of contamination. This ratio was considered insignificant as a source of contamination and therefore was not deducted from the final count.

4. Discussion

4.1. Wet wipe surveys

The distance of the transect downstream from the rowing slipway appeared to negatively affect the number of wet wipes counted, with higher numbers being found nearer the rowing slipway. The reason for higher levels of deposition at this section of the foreshore is most likely due to the reduced velocity on the inside bend causing deposition at the apex of the bend on this inner side (Graf and Blanckaert, 2002).

The positive correlation between the distance from the riverbank and the abundance of wet wipes is most likely explained by variations in the sediment down the foreshore. At the top of the foreshore near the bank, there was much more shingle and drier sediment, due to reduced tidal immersion at this height. This means that wet wipes are unlikely to be deposited in this area. Wipes are therefore deposited further down the foreshore at ~15–25m, where they combine with other objects such as leaf litter and anthropogenic litter in general to form these reefs. There were fewer wet wipes after 25m down the foreshore, potentially due to a much higher immersion time. The weak correlation found for the two variables in 2019 may be explained by a reduced number of replicate quadrats down the foreshore as they were only placed every 5m.

The methods used in 2019 were an adaptation of Thames21 methodology from previous years. Previous years data employed a less systematic approach, with different numbers of transects and quadrats laid out at uneven intervals. This was so surveys could target areas with the highest densities in order to provide a better estimate of the total number of wet wipes. The sampling method in 2019 used transects set out at 5m intervals along the foreshore and sampling quadrats at 5m intervals from the bank down to the low water line, effectively a grid. Seasonality may also account for variations in the data, as levels of rainfall may determine the number of wet wipes that are deposited along the foreshore due to flooding or changes in the river's current speed.

4.2. Bivalve density and distribution

The presence and absence of *C. fluminea* in relation to the distance from the riverbank indicated a wider distribution of clams at heights further down the foreshore at ca. 30–35m. This was the lowest height for low water sampled, with greater tidal exposure, and most likely had a higher abundance of clams due to a greater immersion time needed for their characteristic filter feeding. The results show that there were greater densities of *C. fluminea* the further away from the slipway which is paralleled by low densities of wet wipes further from the slipway, thus supporting the hypothesis that the density of clams is higher where wet wipe densities are lower. In addition, there were almost no *C. fluminea* present in areas with a large abundance of wet wipes. This suggests that the wet wipes are causing a physical disturbance to the distribution of *C. fluminea*, as has been demonstrated in other studies (Aloy et al., 2011; Green et al., 2015; Richards and Beger, 2011). This interaction is not surprising because wet wipes cause a smothering effect as outlined by Goldberg (1997). The accumulation of plastics covering sediments creates a blanketing effect which can result in anoxia by inhibiting gas exchange/redox potential between river water and sediment pore water (Goldberg, 1997; Green et al., 2015). This has been observed when studying the surface sediments beneath wet wipe accumulations where a black layer of anoxic sediment can be observed. Clams inhabit areas near the surface of sediment in order to filter feed from the water column (Sousa et al., 2008). Therefore, the anoxic layer produced by wet wipe smothering makes this area uninhabitable for the clams.

4.3. Polymer content

The results from FTIR analysis indicate that *C. fluminea* along the foreshore at Hammersmith contain small quantities of synthetic fibres with an apparent lack of wet wipe-related polymers. No significant relationship was found between the distance from the slipway and the proportion of synthetic particles in each of the 4 stations although this may be, in part, due to the limited number of samples used in these analyses.

There were few *C. fluminea* individuals present where wet wipe abundance was high, almost a presence or absence distribution. Interestingly there was a higher number of particles where there were fewer wet wipes. The absence of wet wipes and subsequently the lack of synthetic fibres in clams from the Chelsea Embankment control site, support the hypothesis that the wet wipes and other plastic debris found at Hammersmith are the possible sources of synthetic polymers found in *C. fluminea*. It was expected that the soft tissue weight of the individual clams would be positively correlated with the number of particles (Welden et al., 2018), but this was not the case in the present study.

Both ‘flushable’ and ‘non-flushable’ wet wipes have been found to contain polyester (PET). In addition, ‘flushable’ wipes are known to contain many more synthetic fibres such as high-density polyethylene (HDPE), polyethylene/vinyl acetate (PEVA/EVA), polypropylene (PP), low-density polyethylene (LDPE), expanded polystyrene (EPS) and polyurethane (PU; Munoz et al., 2018). Therefore, it was expected that some, if not all, of these polymers, would be identified from the wet wipes forming the reefs at Hammersmith. The samples of wet wipes and sanitary towels collected from the Hammersmith foreshore only appeared to contain PET and PP fibres respectively, although other polymers being present cannot be discounted. Flushable and non-flushable wet wipes both contain PET and flushable wipes also contain PP, HDPE and PEVA/EVA all of which were captured by the clams (Munoz et al., 2018). The term captured is used, as this study did not isolate the gut of the organisms sampled, and therefore it is uncertain whether the route of microplastic entry was ingestion. This would suggest that the fibres being captured by the clams have potentially been released by wet wipes on the foreshore and in the water column. PP and viscose fibres/particles were two of the most abundant fibres identified. PP, which accounted for 57% of all synthetic fibres/particles were also identified in every fibre analysed from the sample of sanitary items. Another potential source of fibres is from clothing in domestic washing machines which feed directly into waterways, and in a single wash, a garment can shed over 1900 fibres (Browne et al., 2011).

Variations in the amounts of particles contained by individual *C. fluminea* may be explained by a number of factors. Some of the clams may have fed more recently in relation to when they were sampled meaning their gut contents were likely to include more microplastics than those that have had time for gut depuration. Su et al., (2018) found *C. fluminea* showed relatively high retention of microplastic fibres. Future research would benefit from depuration studies to assess gut retention times of microplastics in *C. fluminea.* Seasonality may affect the number of microplastics captured by the clams. Studies have demonstrated that marine species such as *Lepidorhumbos boscii* and *Nephrops norvegicus* were found to ingest fewer plastic items in winter (Welden and Cowie, 2016; Vassilopoulou and Haralabous, 2008). Bivalves are potentially one of the groups most impacted by microplastic pollution and have therefore been used widely as bioindicators (Li et al., 2019; Ward et al., 2019). Clams have a wide distribution, are easily accessible, in abundance and are sessile (Li et al., 2019). Therefore, *C. fluminea* is a valuable indicator of freshwater plastic pollution due to their inability to discriminate between microplastics and other particles during feeding activities and within the digestive system (Su et al., 2018). The effects of capturing and potentially ingesting synthetic polymers have not been demonstrated in the present study, as was the case for Su et al. (2018), but this species is relatively understudied. More research would be needed to assess the potential physiological effects of microplastic ingestion by *C. fluminea*.

4.4. Wider implications

While there were only small amounts of captured microplastics observed in *C. fluminea* examined for the present study there is evidence for a clear physical effect of wet wipe accumulation on the distribution of the clams. Both fibre capture and physical impact on the habitat have potential implications for other species, including native species, that are of a greater conservation concern such as the depressed river mussel *Pseudanodonta complanata* and the pearl mussel *Margaritifera margaritifera* (ZSL, 2018).

5. Conclusions

This study is the first to demonstrate how wet wipes, as a form of plastic pollution, can affect organisms in the River Thames. Accumulations of wet wipes have the potential to affect the distribution of aquatic biota most likely due to the physical disturbance to the environment. This disturbance also conceivably reduces the feeding activity of *C. fluminea*. Furthermore, this invasive species may act as a valuable indicator of plastic pollution in the Thames and by implication the potential impacts on other Thames biota. As such the study provides valuable information for the conservation of biodiversity in the river. Research conducted by Thames21 and Thames Tideway suggests that the problem is increasing in severity, with one of the largest wet wipe mounds showing a height increase of 1.4m since 2014. Our results provide further evidence for the environmental impacts caused by the inappropriate disposal of wet wipes and similar products and the need for greater public awareness of these impacts, improved labelling on packages and appropriate legislation.

Acknowledgements

The authors would like to thank AJ McConville at Thames21 for providing data and methodologies used in this research. We are extremely grateful to Karen Carter and the Group Legal and Data Protection Team at Thames Water, for providing the Hammersmith SPS outfall data for figure 2. We would also like to acknowledge the following people for their assistance during data collection: Emma Humphreys-Williams, Alex McGoran, and George Paton. This research was not funded by any agencies from the public, commercial or non-profit sectors.

References

Aloy, A.B., Vallejo Jr., B.M., Juinio-Meñez, M.A., 2011. Increased plastic litter cover affects the foraging activity of the sandy intertidal gastropod *Nassarius pullus*. Mar. Poll. Bull. 62, 1772–1779. https://doi.org/10.1016/j.marpolbul.2011.05.021

Always, 2019. What ingredients are in Always pads? [online] Available at: https://always.com/en-us/about-us/what-ingredients-are-in-always-pads (accessed: 31/7/19)

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulationand fragmentation of plastic debris in global environments. Phil. Trans. R. Soc. Lond. Ser. B 364, 1985–1998. http://rstb.royalsocietypublishing.org/content/royptb/364/1526/1985.full.pdf

Baudrimont, M., Metivaud, J., Maury-Brachet, R., Ribeyre, F., Boudou, A., 1997. Bioaccumulation and metallothionein response in the Asiatic clam (*Corbicula fluminea*) after experimental exposure to cadmium and inorganic mercury. Environ. Toxicol. Chem. 16, 2096–2105. https://doi.org/10.1002/etc.5620161016

Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., Thompson, R., 2011. Accumulation of microplastics on shorelines worldwide: sources and sinks. Environ. Sci. Technol. 45, 9175–9179. https://pubs.acs.org/doi/pdf/10.1021/es201811s?rand=qwm74inn

Elliott, P., zu Ermgassen, P. S. E., 2008. The Asian clam (*Corbicula fluminea*) in the River Thames, London, England. Aquat. Invas. 3, 54–60. https://doi.org/10.3391/ai.2008.3.1.9 GESAMP, 2015. Sources, fate and effects of microplastics in the marine environment: a global assessment.

[online] Available from: http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/pdf/GESAMP_microplastics%20full%20study.pdf (accessed: 26/11/18)

Goldberg, E.D., 1997. Plasticizing the seafloor: an overview. Environ. Technol. 18, 195–202. https://doi.org/10.1080/09593331808616527

Graf, W.H., Blanckaert, K., 2002. Flow around bends in rivers. New trends in water and environmental engineering for safety and life: eco-compatible solutions for aquatic environments Capri (Italy). [online] Available from: https://www.researchgate.net/publication/37451836_Flow_around_bends_in_rivers (accessed: 24/2/19)

Green, D.S., Boots, B., Blockley, D.J., Rocha, C., Thompson, R. 2015. Impacts of discarded plastic bags on marine assemblages and ecosystem functioning. Environ. Sci. Technol. 49, 5380–5389. https://pubs.acs.org/doi/pdf/10.1021/acs.est.5b00277?rand=8f8ueowb

Horton, A.A., Svendsen, C., Williams, R.J., Spurgeon, D.J., Lahive, E., 2017. Large microplastic particles in sediments of tributaries of the River Thames, UK – abundance, sources and methods for effective quantification. Mar. Poll. Bull. 114, 218–226. https://doi.org/10.1016/j.marpolbul.2016.09.004

Horton, A.A., Jürgens, M.D., Lahive, E., van Bodegom, P.M., Vijver, M.G., 2018. The influence of exposure and physiology on microplastic ingestion by the freshwater fish *Rutilus rutilus* (Roach) in the River Thames, UK. Environ. Poll. 236, 188–194. https://doi.org/10.1016/j.envpol.2018.01.044

Li, J., Lusher, A. L., Rotchell, J. M., Deudero, S., Turra, A., Bråte, I. L. N., Sun. C., Hossain, M. S., Li., Q., Kolandhasamy, P., Shi, H., 2019. Using mussel as a global bioindicator of coastal microplastic pollution. Environ. Poll. 244, 522–533. https://doi.org/10.1016/j.envpol.2018.10.032

McGoran, A.R., Clark, P.F., Morritt, D., 2017. Presence of microplastic in the digestive tracts of European flounder, *Platichthys flesus*, and European smelt, *Osmerus eperlanus*, from the River Thames. Environ. Poll. 220, 744–751. http://dx.doi.org/10.1016/j.envpol.2016.09.078

McGoran, A.R., Cowie, P.R., Clark, P.F., McEvoy, J.P., Morritt, D., 2018. Ingestion of plastic by fish: a comparison of Thames estuary and Firth of Clyde populations. Mar. Poll. Bull. 137, 12–23. https://doi.org/10.1016/j.marpolbul.2018.09.054

Mintenig, S.M., Int-Veen, I., Löder, M.G.J., Primpke, S., Gerdts, G., 2017. Identification of microplastic in effluents of waste water treatment plants using focal plane array-based micro-fourier-transform infrared imaging. Water Res. 108, 365–372. https://doi.org/10.1016/j.watres.2016.11.015

Morritt, D., Stefanoudis, P.V., Pearce, D. Crimmen, O.A., Clark, P.F., 2014. Plastic in the Thames: a river runs through it. Mar. Poll. Bull. 78, 196–200. https://doi.org/10.1002/aqc.2779

Munoz, L.P., Baez, A.G., McKinney, D., Garelick, H., 2018. Characterisation of "flushable" and "non-flushable" commercial wet wipes using microRaman, FTIR spectroscopy and fluorescence microscopy: to flush or not to flush. Environ. Sci. Poll. Res. 25, 20268–20279. https://doi.org/10.1007/s11356-018-2400-9

Piggott, G., 2015. Daytime population of London 2014. [online] Available from: https://data.london.gov.uk/blog/daytime-population-of-london-2014/ (accessed: 28/6/19)

Richards, T., Beger, M., 2011. A quantification of the standing stock of macro-debris in Majuro lagoon and its effect on hard coral communities. Mar. Poll. Bull. 62, 1693–1701. https://doi.org/10.1016/j.marpolbul.2011.06.003

Silverman H., Achberger E.C., Lynn J.W., Deitz T.H., 1995. Filtration and utilisation of laboratory-cultured bacteria by *Dreissena polymorpha*, *Corbicula fluminea* and *Carunculina texasensis*. Biol. Bull. 189, 308–319. https://doi.org/10.2307/1542148

Sousa, R., Antunes, C. and Guilhermino, L., 2008. Ecology of the invasive Asian clam *Corbicula fluminea* (Müller, 1774) in aquatic ecosystems: an overview. Intern. J. Limnol. 44, 85–94. https://doi.org/10.1051/limn:2008017

Su, L., Cai. H., Kolandhasamy, P., Wu, C., Rochman, C.M., Shi, H., 2018. Using the Asian clam as an indicator of microplastic pollution in freshwater ecosystems. Environ. Poll. 234, 347–355. https://doi.org/10.1016/j.envpol.2017.11.075

Thames21, 2019. Pollution monitoring results. [online] Available from: https://www.thames21.org.uk/thames-river-watch/pollution-monitoring-results/ (accessed 11/8/19)

Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S., John, A.W.G., McGonigle, D., Russell, A.E., 2004. Lost at sea: where is all the plastic? Science 304, 838. https://doi.org/10.1126/science.1094559

Thompson, R.C., Moore, C.J., vom Saal, F.S., Swan, S.H., 2009. Plastics, the environment and human health: current consensus and future trends. Phil. Trans. R. Soc. Lond, Ser. B 364, 2153–2166. https://doi.org/10.1098/rstb.2009.0053

Vassilopoulou, V., Haralabous, J., 2008. Effects of sexual maturity and feeding on condition of a deep-sea flatfish, *Lepidorhombus boscii*, in north-eastern Mediterranean waters. J. Nat. Hist. 42, 695–720. https://doi.org/10.1080/00222930701835647

Ward, J. E., Zhao, S., Holohan, B.A., Mladinich, K.M., Griffin, T.W., Wozniak. J., Shumway, S.E., 2019. Selective ingestion and egestion of plastic particles by the blue mussel (*Mytilus edulis*) and Eastern oyster (*Crassostrea virginica*): implications for using bivalves as bioindicators of microplastic pollution. Environ. Sci. Technol. 53, 8776–8784. https://pubs.acs.org/doi/10.1021/acs.est.9b02073

Welden, N.A.C., Cowie, P.R., 2016. Environment and gut morphology influence microplastic retention in langoustine, *Nephrops norvegicus*. Environ. Poll. 214, 859–865. https://doi.org/10.1016/j.envpol.2016.03.067

Welden, N.A., Abylkhani, B., Howarth, L.M., 2018. The effects of trophic transfer and environmental factors on microplastic uptake by plaice, *Pleuronectes plastessa*, and spider crab, *Maja squinado*. Environ. Poll. 239, 351–358. https://doi.org/10.1016/j.envpol.2018.03.110

Woeller, K. E. and Hochwalt, A. E., 2015. Safety assessment of sanitary pads with a polymeric foam absorbent core. Reg. Toxicol. Pharmacol. 73, 419-424. https://doi.org/10.1016/j.yrtph.2015.07.028

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

ZSL, 2018. ZSL's freshwater mussel survey in the upper tidal Thames. [online] Available at: https://www.zsl.org/sites/default/files/media/2018-06/INNS%20Survey%20Report_ZSL%202017_Final_07.02.18_0.pdf (accessed: 6/8/19)