# Microplastics in the sediments of a UK urban lake

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**Abstract**

While studies on microplastics in the marine environment show their wide-distribution, persistence and contamination of biota, the freshwater environment remains comparatively neglected. Where studies on freshwaters have been undertaken these have been on riverine systems or very large lakes. We present data on the distribution of microplastic particles in the sediments of Edgbaston Pool, a shallow eutrophic lake in central Birmingham, UK. These data provide, to our knowledge, the first assessment of microplastic concentrations in the sediments of either a small or an urban lake and the first for any lake in the UK. Maximum concentrations reached 25 – 30 particles per 100g dried sediment (equivalent to low hundreds $kg^{-1}$) and hence are comparable with reported river sediment studies. Fibres and films were the most common types of microplastic observed. Spatial distributions appear to be due to similar factors to other lake studies (i.e. location of inflow; prevailing wind directions; propensity for biofouling; distribution of macroplastic debris) and add to the growing burden of evidence for microplastic ubiquity in all environments.

**Keywords:** lake sediments; litter; microplastics; plastics; urban lakes

**Capsule**: This paper presents the first microplastics data for UK lake sediments and, more broadly, for small and urban lakes, thereby contributing to the growing burden of evidence for microplastic ubiquity.

## Introduction

In recent years there has been increasing concern over the scale and impacts of plastic debris in the world's oceans. Since the 1950s an estimated 1 billion tonnes of plastic have been discarded and of the 280 million tonnes of plastics now produced annually (Rochman and Browne, 2013), more than 10% ends up in the marine environment (Cole et al., 2011), either by being intentionally or unintentionally discarded or being wind-blown from terrestrial sources. Such debris can cause entanglement in a number of species from cetaceans to crustaceans as well as suffocation and problems via ingestion (blockage of digestive tracts; internal wounding; satiation) in many aquatic fauna (Codina-García et al., 2013; Derraik, 2002; Gregory, 2009), transport of species via colonisation (Zettler et al., 2013) and pollutant transfer (Teuten et al., 2007). Plastic debris is likely to persist for hundreds of years (Bergmann and Klages, 2012; O'Brine and Thompson, 2010) and even longer in polar or deep-sea environments (Woodall et al., 2014). With predicted estimates of an additional 33 billion tonnes of plastic production by 2050 (Rochman and Browne, 2013) and 99% of all seabird species to have ingested plastic by the same date (Wilcox et al., 2015), environmental impacts are likely to continue for many decades.

Much of the attention on large plastic debris in the marine environment has focussed on their concentration in oceanic gyres (Moore et al., 2001) but recently, it has been suggested that observed levels of plastics in marine ecosystems are not able to account for expected inputs, i.e. that some plastic has been 'lost'. This may be explained by photo-, physical or biological degradation into smaller secondary plastic particles, or 'microplastics' which pass through the nets used for sampling larger plastic debris (Cózar et al., 2014; Thompson et al., 2004). While definitions for microplastics vary they are typically considered to be less than 5 mm in one dimension (Eerkes-Medrano et al., 2015; Horton et al., 2017). Primary microplastics (i.e. those generated to be this size) include plastic resin pellets, the raw material used for manufacturing, unintentionally released during manufacturing and transport and carried by surface run-off and rivers to the ocean, or to the ocean directly (Holmes et al., 2011; Mato et al., 2001). However, primary microplastics are also used as abrasives in personal care products (Gregory, 1996) or from shedding during the laundry of synthetic textiles (Napper and Thompson, 2016) and may pass unchanged through standard waste water treatment facilities (Engler, 2012).

Environmental impacts of microplastics, again principally observed in marine studies, include direct and indirect ingestion (filter feeders and feeders of organic particles in mud are especially at risk) (Teuten et al., 2009); transfer of pollutants through food chains (including plastic additives as well as contaminants adsorbed onto surfaces such as trace metals (Holmes et al 2011), PAHs, PCBs, organochlorine pesticides (Mato et al 2001; Cole et al 2011) and brominated flame retardants (Engler, 2012; Zarfl and Matthies, 2010); and species transfer via colonization of plastics as a novel habitat (Zettler et al 2013).

However, while a considerable amount of recent work is now available for microplastics in the marine environment, there have been relatively few studies on freshwaters although early indications are that their presence is likely to be as equally pervasive (Eerkes-Medrano et al 2015). All lake studies have so far focused on very large waterbodies, with a number of studies focused on the Laurentian Great Lakes where the locations of urban and industrial centres have accounted for microplastic distributions in shoreline sediments (Corcoran et al., 2015; Driedger et al., 2015; Faure et al., 2015; Zbyszewski and Corcoran, 2011) and in surface waters (Eriksen et al., 2013). Similar distributions have also been observed in surface waters of other large lakes, which are more removed from urban settings, such as Lake Hovsgol, Mongolia (Free et al., 2014) and Lake Garda, Italy where microplastic distributions in shore-line sediments were related to wind-induced surface circulation patterns and fishing activities (Imhof et al., 2013). In rivers, microplastics in sediments from the Rhine-Main system in Germany (Klein et al., 2015) and the St Lawrence River in Canada (Castañeda et al., 2014) were also related to urban locations. Lechner et al (2014) demonstrated the scale of contamination in major rivers by estimating that more than 1500 tonnes of microplastics enter the Black Sea each year via the River Danube alone. Sanchez et al (2014) reported the presence of microplastics in the digestive tracts of the gudgeon (*Gobio gobio*), a sedentary cyprinid, in a number of French rivers. In the United Kingdom, studies on plastics in freshwaters have, to date, been only restricted to rivers. Morritt et al. (2014) compared the scale of submerged versus floating macroplastic debris in the River Thames showing sewage treatment works to be major sources while Horton et al. (2017a) indicated sewage as well as road and land run-off as sources of microplastics in River Thames sediments.

These studies indicate the importance of urban centres as sources of both macro- and microplastic contamination to freshwaters, a situation which is only likely to be exacerbated as urban areas and populations continue to expand over coming decades. Therefore, it may be expected that urban lakes would receive higher levels of microplastics from both inflowing streams draining residential, commercial and industrial areas, as well as via degradation of wind-blown macroplastic debris and possibly atmospheric deposition (Dris et al., 2016). However, no published data exist for microplastics in urban lakes. Here, we present data demonstrating the abundance and distribution of both macroplastic debris and microplastics in the surface sediments of an urban lake in central Birmingham, UK. To our knowledge this is the first microplastic study for a UK lake and, more broadly, the first such study for either a small or an urban lake.

## Methods

*Sample site*

Edgbaston Pool (52.4552°N; 01.9212° W) is located 3 km from the centre of Birmingham. It is 127 m above sea level, has a surface area of 7.2 ha and a maximum depth of 2.5 m found towards the southern end near the dam wall (Figure 1a). The lake was formed by the damming of Chad Brook, a small stream which enters from the north. This provided power for water mills, forming an Upper (the current pool) and a Lower Edgbaston Pool which is now infilled and overgrown. The mill is known to have existed by 1557 when it was used as a fulling mill. In the 17$^{th}$ century the mill was being used for blade-making which continued to the mid-19$^{th}$ century when it became used for gold and silver rolling (Turner et al 2013). From 1875 the mill was no longer used and the pool is shown as a 'fish pond' on early-20$^{th}$ century maps. While once surrounded by industry, the lake is now bordered by the Winterborne Botanic Gardens to the west and Edgbaston Golf Course to the east. The lake and surrounding area was given SSSI (site of special scientific interest) status in 1986 for the diverse woodland and wetland habitats around its margins. The main outflow is in the south-east corner of the lake. An additional outflow exists in the south-west corner but usually remains dry. The catchment area is shown in Supplementary Information (Figure S1).

*Sampling methods*

A sediment sampling transect was established at four locations around the perimeter of Edgbaston Pool. Transects were perpendicular to the shoreline and established by fixing a rope on land close to the water edge and attaching this to a buoyed anchor line off-shore. Given the shallow shelving nature of the lake bathymetry (Figure 1), samples were taken at each 0.5m depth to 1.5m (labelled A-D; e.g. T1A, T1B etc.). At the northern end of the lake the shallow water depths precluded establishing a transect with any significant depth difference within 50m of the lake shore (Figure 1), so Transect 3 was treated as a surface sample only (T3A). However, because of the shallow nature of this part of the lake, extra surface sediment samples were taken to provide greater spatial coverage. In addition to these transects 11 surface sediment samples were collected at approximately 150m intervals around the lake perimeter except for the northern end where samples were more closely located. Surface sediment samples were taken as close as possible to the shore where clear sediment accumulation was visible.

At each sampling point, a sediment sample was collected from the boat using an HTH gravity corer (Renberg and Hansson, 2008) fitted with a sample tube with an internal diameter of 7.8 cm. The top 10cm of each core was collected from each location. Radiometric chronologies for recent sediment cores from Edgbaston Pool indicate sediment accumulations of between 0.8 – 1.6 cm $yr^{-1}$ (Turner et al., 2013; Yang et al., 2016) such that each surface sample approximately represented the most recent 10 years of accumulation. Also, at each sampling location, a visual assessment of macroplastic debris on the lake bottom was undertaken using a bathyscope from the boat. Finally, all litter was collected from 5 m either side of the start of each transect in order to determine the proportion that plastic contributes to overall debris in each location. These items were stored separately.

*Microplastic extraction from lake sediments*

There is no established standard method for the extraction of microplastics from either marine or freshwater sediments (Horton et al 2017b) although in recent reviews of marine studies (Hidalgo-Ruz et al., 2012; van Cauwenberghe et al., 2015) consensus seems to be moving towards a combination of size- and density separation. Sieving may result in size distribution artefacts, especially with such different particle morphologies as fibres and fragments, but given the nature of the collected sedimentary material it was important to remove as much larger material as possible. 100g of each sediment sample was sieved, first through a 1mm and then a 500µm sieve. There is no universal size-classification of microplastics but these ranges have been used regularly in previous studies (e.g. Hidalgo-Ruz et al., 2012; van Cauwenberghe et al 2015). Each sieve's contents were washed several times with water to ensure no smaller particles remained. All material passing through the sieves was stored in case it was required at a later date. No removal of organic material by chemical means was attempted. Both >1 mm and 500 µm – 1 mm size fractions were then density separated using water allowing the separation of polystyrene, polyethylene and polypropylene (Hidalgo-Ruz et al., 2012; Zhang et al., 2015). This was undertaken twice. All floating material and particulates from the sieves suspected as being plastic were transferred to glass microscope slides for identification.

*Plastic identification*

Microplastic particles were identified under the binocular microscope (x40) using physical properties (e.g. texture, flexibility) as well as colour and structure (Song et al., 2015). No organic or cellular structure should be visible while fibres should be equally thick along their entire length and should, similarly, retain the same colour all the way along (Hidalgo-Ruz et al., 2012). Microplastics were then categorised into size, type, shape, colour, pliability, and degradation stage (Song et al., 2015). Visual inspection by low-powered microscopy has been considered a recommended identification approach by some plastic-debris programs (e.g. US National Oceanic and Atmospheric Administration (NOAA); Masura et al., 2015). While Fourier-transform infrared (FT-IR) (Hidalgo-Ruz et al., 2012; Song et al 2015) and Raman spectroscopy (Horton et al 2017a) are becoming more widely used in the identification of microplastics extracted from marine and freshwater sediments (despite their drawbacks (Horton et al., 2017b)), such facilities were not available to this study. While we acknowledge that this may lead to the mis-identification of some natural particulate matter and synthetic polymers (Thompson et al 2004) especially among smaller particulates (Eriksen et al 2013), the use of microscopy to identify microplastics has been reported as resulting in abundances that are not significantly different from spectroscopic methods (Song et al., 2015).

*Contamination avoidance*

There is high likelihood of post-sampling contamination of fibres in samples due to their ubiquity (Woodall et al., 2015) and they generally form a large percentage of microplastics recovered from environmental samples. Clothing made from synthetic fibres was avoided and clothing was covered with cotton laboratory coats throughout sample handling. All samples and the laboratory area used for handling samples were also covered as much as possible to avoid contamination. A single person handled all samples using latex gloved hands. Non-plastic equipment was used as much as possible. Any plastic equipment was viewed under the microscope for its optical properties and, following Woodall et al. (2015), was recorded. Procedural blanks were used to check for background contamination from laboratory sources via the air, clothes, sampling tools and vessels etc. These blanks ran for 2, 4 and 8 weeks over the full course of the laboratory work. Despite the controls in place, a single fibre was observed in the first and third blanks respectively.

*Macroplastics*

For each collected item various characteristics were noted: whether they were muddied, biofouled, bleached or weathered, along with a note of biota or other debris attached to their surface. The original and current colour was noted as well as the original source where possible.

## Results

*Macroplastic distribution*

A clear distribution pattern of macroplastic debris can be seen from Figure 2. Highest levels of debris occurred at sampling locations at the southern end of the lake. In the south-west, 20 debris items were collected at T1A while 11 and 10 items respectively were collected at the adjacent sites S1 and S11. In the south-east, at S2 near the main outflow, 13 debris items were collected. By contrast, all other sampling locations recorded much less. S3 and S5 on the eastern side and T3A in the north-west had 5 or 6 items; S7, S9 and T4A in the north and west had 2 or 3, while all other sites (located in the northern half of the lake) had no macroplastic debris at the sampling locations although debris was clearly visible amongst the fringing reeds at S10 on the western side.

Similarly, a greater variety of plastic debris items was recorded in the south and south-west (Figure 2). Plastic bottle caps, cosmetics tubes, syringes, clothing and Styrofoam were only recorded in the south and south-west locations while the main debris items in the rest of the lake were plastic shopping bags. Food-wrappers and plastic films were more common being found in the south and south-west as well as north-west locations.

The most heavily bio-fouled debris were submerged plastic shopping bags collected in the northern and eastern locations. It may be that the large surface areas of these items and the shallow, open nature of the lake margins at these locations made conditions more favorable to bio-fouling. By contrast, sites S1, T1A and S2 in the south showed the least amount of bio-fouling and lowest levels of degradation. This suggests that these items may have been transported rapidly to this area. In this part of the lake, bio-fouling may be reduced as it is permanently shaded by an over-hanging tree canopy. Alternatively, as this was the area of greatest quantity and variety of debris items, this could indicate an alternative or additional source of litter to the rest of the lake. A footpath runs adjacent to the southern end of the waterbody and so any litter discarded here could remain in these areas. However, this footpath is only accessed from the Botanical Gardens and so this direct littering is considered unlikely to be a major additional source.

*Microplastic distribution*

Plastic films and fibres were the most common microplastics found in the surface sediments and Figure 3(a, b respectively) shows their distribution around Edgbaston Pool. All data are presented as numbers of microplastic particles per 100g dried sediment. As with macroplastic debris, microplastic films showed elevated concentrations in the southern parts of the lake with respect to the north, with lowest concentrations at S7 and S8 closest to the northern Chad Brook inflow, at T3A in the north-west and at S4 in the east. However, in contrast to the macroplastic distribution, microplastic films also showed elevated concentrations down the eastern side of the lake with highest concentrations at S2 and S3, the two southern-most locations on that side. These along with T1A in the south-west showed the highest microplastic film concentrations in the lake.

Microplastic fibres were also high at T1A in the south-west but low elsewhere in the south with elevated concentrations down the eastern side from S7 to S3. Lowest concentrations of fibres were observed in the south-east near the outflow (2) and down the western side of the lake.

*Transects*

The highest concentration of total microplastics were found in T1A (26 per 100g dried sediment; equivalent to 260 $kg^{-1}$) at a level comparable to that found in many river sediments (see Horton et al., 2017b for a review). In Transects 2 and 4, only microplastic fibres and films were found. In transect 1 a greater diversity was found in the shallowest, near-shore sample (i.e. ‘foam’ and ‘fragment’ microplastics) and only fibres were found at greater distance from the shore and at greater depths. This was the steepest transect (Figure 1a) and the greater microplastic diversity near-shore may reflect the greater prevalence of macroplastic debris degrading *in situ* at this location. No macroplastic debris were observed on Transect 1 away from the shore. The concentration of both microplastic fibres and total microplastic particles decreased away from the shore although concentrations at 100 cm and 150 cm depth were the same (Figure 4). Transect 4 also shows a maximum microplastic concentration nearest to shore for both total microplastic and for each of the particle types (fibres and films) while concentrations are the same at the two deeper locations further from shore. By contrast, Transect 2 midway along the eastern side of the lake shows no pattern with depth or distance from shore for total microplastic or fibre concentrations, although micoplastic film concentrations show a decline with depth (Figure 4). Overall, there is a greater negative correlation between depth and microplastic films ($r^2$ = -0.45) than for fibres ($r^2$ = -0.17), although neither are significant.

## Discussion

*Sources of microplastics*

The distribution of the macro- and microplastics around, and within, Edgbaston Pool can provide some indication as to their provenance. Primary microplastics include ‘raw’ plastic resin pellets, abrasives in personal care products and fibres produced during the laundry of synthetic textiles which pass through waste water treatment facilities (Napper and Thompson 2016). Of these particle-types, only fibres were found in the sediments of Edgbaston Pool and they are also the most common type of microplastic particle observed in marine (e.g. Woodall et al 2015) and river sediments (Horton et al 2017a).

Elevated concentrations of fibres were found predominantly down the eastern side of the lake and as there are no sources around the lake itself, this suggests possible inputs via the inflow of Chad Brook in the north-east with prevailing wind directions helping prevent any spreading across the lake to the west (Figure 1c). If microplastics in the inflow behaved like other suspended particulate matter, then it may be expected that highest concentrations would occur nearest to where the stream enters the lake due to the reduction in water velocity and the subsequent deposition of particulate load from the stream-waters. This is not observed as highest concentrations occur mid-way down the eastern side between the inflow and outflow streams. Hence, it maybe that due to their lower density, with respect to other sedimentary material, microplastics remain suspended for longer and are deposited beyond the immediate shallow inflow area in the main part of the lake, or only later once they have been bio-fouled sufficiently to sink. There are no sewage treatment works in the catchment of Chad Brook so it is unlikely that sewage outfall is a major source of these particles. However, the stream does run through residential areas, allotments and school grounds (Figure S1) and so the use of sewage-based fertilisers cannot be entirely ruled out (Browne et al., 2011). Very little information exists for the distributions of microplastics in terrestrial systems (Horton et al 2017b), let alone the transfer of these particles from terrestrial to aquatic sites and other sources typical of densely populated urban areas may be more likely. For example, construction materials, artificial turf and household dust may all be sources (Dris et al 2017; Horton et al 2017b) as well as atmospheric deposition (Dris et al. 2016) and run-off from roads (vehicle-derived plastics; road paints; deposition to the road surface; degradation of road-side debris) via storm drains.

Microplastic films, by contrast, are more likely to be secondary microplastics produced by the degradation of larger, flexible plastic packaging, defined by the World Economic Forum as bags, films, foils, pallet shrouds, pouches, blister packs, and envelopes (WEF, 2016). Degradation of this type of plastic occurs via mechanical disintegration, from photodegradation with UV penetration, oxidation of the plastic structure, and hydrolytic weathering (Law et al., 2010). As a consequence it may be expected that greater concentrations and diversity of microplastic films and fragments occur where macroplastic debris diversity and prevalence is also highest, and this is observed in Edgbaston Pool sediments.

Small lake systems are less dynamic than marine environments where much of the microplastic studies have been undertaken to date. Especially in small, sheltered and urban lakes such as Edgbaston Pool there are no strong currents and very limited wave action to cause physical breakdown of macroplastic debris (Eerkes–Medrano et al. 2015). Therefore, photolytic- and bio-degradation are likely to be the main processes of macroplastic breakdown although rapid biofouling may hinder UV penetration to the plastic surface (O'Brine and Thompson, 2010). Water depths in Edgbaston Pool are shallow and so relatively warm, and light penetrates to the lake bed across much of the lake area (Turner et al 2013). Biofouling does not occur at a constant rate for all microplastics, but is dependent upon the size of a particle (Bagaeva and Chubarenko, 2016; Wright et al., 2013). Fibres with an estimated diameter of 30-100 microns have the largest surface area for a given mass of all microplastics, (Bagaeva and Chubarenko, 2016) and are therefore more likely to biofoul and sink which may explain the distribution of fibres down the eastern side of the lake. This may also explain the apparent lack of other types of microplastics found in the sediment samples. As spherical debris such as pellets and microbeads have a lower surface area to volume ratio, they are likely to remain buoyant for longer, and so may be transported out of Edgbaston Pool via surface currents before they lose their buoyancy (Fazey and Ryan, 2016).

These biofouling dynamics similarly apply to macroplastic debris but are also dependent upon the characteristics of the polymer, including surface energy, texture and solidity (Wright et al., 2013). Wright et al. (2013) found that polyethylene food bags took only a week to establish a complete surface biofilm in the marine environment, which by the third week had grown sufficiently to reduce density and cause the plastics to sink below the sea surface. In lakes, biofouling rates are likely to vary depending on nutrient availability, water turbulence and temperature while the presence of, especially organic, particles to act as substrates for micro-organism growth is also considered important (Melo and Bott, 1997). Therefore, Edgbaston Pool is likely to have comparatively high biofouling rates due to its status as a shallow, eutrophic lake susceptible to algal blooms in the summer months (Turner et al., 2013) and this may explain both the spatial variation in the types of macroplastics and the extent of biofouling around Edgbaston Pool. Plastic bags were predominantly found at the northern end of the lake (and not further south than S3) while biofouling was also greatest in the north (Figure 1d). Hence, plastic bags deposited in the north of the lake, either wind-blown from elsewhere or via Chad Brook will enter shallow and warm waters with greater exposure to light. Here, they would become quickly biofouled and sink. It is unlikely that submerged, heavily bio-fouled plastics would move across the lake with currents below the water surface as occurs in river systems

(Morritt et al 2014) due to the extensive plant growth across the lake bed (Turner et al 2013) and hence they are likely to remain in this area and eventually degrade *in situ* to microplastic films which may then be transported by water currents to other parts of the lake and/or become incorporated into the sediment record. Given the nature of the Edgbaston Pool catchment, macroplastics could also become trapped in Chad Brook and biofouled in the stream prior to being transported to the northern end of the lake during periods of high flow. This could also explain the distribution of heavily biofouled materials at that end of the lake.

Macroplastic debris in southern parts of the lake were largely exposed above the waterline (Figure 1d) and exhibited low levels of bio-fouling. Exposure to the air and greater levels of light may lead to rapid corrosion of the polymer mix (Cole et al 2011) and *in situ* fragmentation by photodegradation. This would explain the larger diversity of both macro- and microplastic in this part of the lake. This debris may either be recent, being dropped by visitors from the nearby footpath, or possibly washed in via Chad Brook and rapidly transported across the lake without sinking. Although the cyclical sinking and re-floating of debris has been recorded in the ocean after de-fouling by foraging organisms (Andrady, 2011; Wright et al., 2013) it is unlikely that debris would be cleaned to such an extent as observed here (Figure 1d). While wind-blown sources cannot be ruled out for lighter packaging materials and plastic bags, it is not likely for other items such as plastic bottles, syringes and rope found in this southern part of the lake (see Figure 2b).

In summary, macroplastic debris may be dropped at the southern end of Edgbaston Pool by visitors using the footpath, or transported via Chad Brook in the north, while lighter items could be wind-blown from surrounding areas. The source of microplastic fibres is unknown but is most likely to be from sources surrounding Chad Brook while other microplastics are likely to be secondary particles resulting from the degradation of larger debris within the lake either by biodegradation or by corrosion following prolonged exposure to air and light in southern areas. Atmospheric deposition as a source of microplastics in urban areas (Dris et al 2016) cannot be ruled out but we have no data for this from this site.

*Microplastic distribution*

Eerkes-Medrano et al. (2015) provide a review of microplastics in freshwaters and summarise the factors influencing microplastic distributions from the available literature, although, as mentioned above, the number of studies are relatively few and include only very large lakes. Briefly, the factors suggested are: human population density distribution (e.g. Eriksen et al. 2013; Zbyszewki and

Corcoran, 2011); water residence time; size of water body; waste management and amount of sewerage overflow; wind-driven surface currents (e.g. Zbyszewki and Corcoran 2011; Imhof et al. 2013); waves leading to resuspension; the density, shape and size of particles themselves; degree of fouling.

While some of the factors identified from these large lake studies likely transfer to all standing water bodies (e.g. degree of biofouling; particle characteristics), some are not relevant for small lakes such as Edgbaston Pool. For example, while urban lakes are likely to receive higher levels of macro- and microplastic contamination than rural sites, the population density will be the same for the whole lake. Similarly, the reduced fetch of small lakes will result in reduced wave-action which is further mitigated in lakes like Edgbaston Pool by the surrounding emergent macrophyte beds. Hence, from our study we suggest the factors influencing the distribution of microplastics within the sediments of small lakes includes:

i) **Lake characteristics:** including presence of inflow streams (providing connectivity to catchment sources upstream); trophic status (rapidity of biofouling and linked to sediment accumulation rate (see below); water column transparency (allowing algal growth on submerged materials as well as UV penetration for photodegradation); shoreline characteristics (bathymetry and shoreline macrophyte growth which allow the trapping of macroplastic debris in shallow areas and increase the energy required to resuspend sedimentary material from within beds).

ii) **Sediment accumulation**: distribution of accumulating sediments is strongly linked to lake bathymetry and basin morphology (Hilton et al., 1986) but will control the likelihood of resuspension and transport of deposited material including microplastics; sediment accumulation rate (controls the speed of burial of deposited material and is more rapid in eutrophic lakes (Rose et al., 2011)

iii) **Sources of macroplastic debris**: proximity to wind-blown sources (tips; dumps etc); lake location in urban or rural settings; proximity to public access and rights-of-way.

iv) **Prevailing winds and inflows** creating water movement and preferential distribution as well as sources for atmospheric deposition of microplastics directly (Dris et al 2016).

v) **Microplastic properties:** for example, surface area and texture (controlling the prevalence for biofouling); density (controlling sinking and resurfacing following de-fouling and movement on the surface and within the water column).

Interestingly, and further to the factors outlined by Eerkes-Medrano et al. (2015), Free et al (2014) demonstrate a decreasing concentration of microplastics with distance from the shore in open-water trawls in Lake Hovsgol, Mongolia and hence agree with our transect data although at a significantly larger scale. Similarly, they also suggested that prevailing winds and surface circulation affected microplastic distributions especially near the outflow where microplastic particles were concentrated. They found an absence of cosmetic microbeads and thought this to be due to the lack of waste water treatment facilities around the lake and highlighted the importance of UV penetration through the water column for photodegradation of submerged debris. Corcoran et al (2015) suggest that proximity to inflows, the plume of inflow sediments and basin morphology effect microplastic distribution in Lake Ontario and indicate a role for basin morphology with respect to sediment accumulation zones. This latter factor was also highlighted by van Cauwenberghe et al (2015) for marine sediments where the relationship between microplastic abundance and organic content (percentage of total organic carbon- %TOC) and the sediment fine fraction (<63μm) support the hypothesis that microplastics accumulate in sedimentary depositional areas. While these distributions seem sensible given the sources of microplastics at these sites and at Edgbaston Pool, further research is required to determine whether these distributions exist more broadly in lake systems. Furthermore, the factors controlling distributions of plastics in lakes are likely to change throughout the degradation process and it may be that, until final burial, it is worth perceiving microplastics as having a relatively fluid relationship with the habitat around them in which their properties, and the factors influencing their movement, are subject to change.

## Conclusions

These data from Edgbaston Pool represent the first sediment microplastic concentrations for either a small or an urban lake. Concentrations are relatively low compared to the limited number of other freshwater sediment studies but spatial distributions appear to be due to similar factors determined in large waterbodies e.g. site-specific lake characteristics; distribution and rate of sediment accumulation; sources of macroplastic debris; prevailing wind directions; relationship with inflow streams and the properties of the microplastic particles themselves. In comparison with marine studies, the extraction of microplastics is likely to be more problematic for lake sediments due to the increased prevalence of organic matter and the greater discolouration of the microplastics, possibly resulting in an underestimate of particle concentrations. However, these data, along with the growing number of other examples from other freshwater systems appear to suggest that microplastic contamination is an ubiquitous problem, although further work is required to determine its scale and extent. The need to address the impacts of macro- and microplastic debris is therefore not only a marine problem and there is a need to consider how inland waters and terrestrial systems (Horton et al 2017b) may also be protected. River discharge is well-known as a source of plastics to the sea (Lechner et al., 2014; Sadri and Thompson, 2014) but increasing evidence suggests that this, along with wind-blown debris and deliberate and accidental dumping of litter, is also a significant route for lakes. As with a number of other pollutants affecting freshwaters these are likely to be exacerbated in urban areas.

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**Figure captions**

**Figure 1.** (a) Bathymetric map of Edgbaston Pool showing sampling locations (surface sediments S1-S11) and transects (T1-T4). (b) Location of the lake in the UK. (c) Wind rose diagram for Birmingham (hours per year from indicated direction). Data from www.metoblue.co

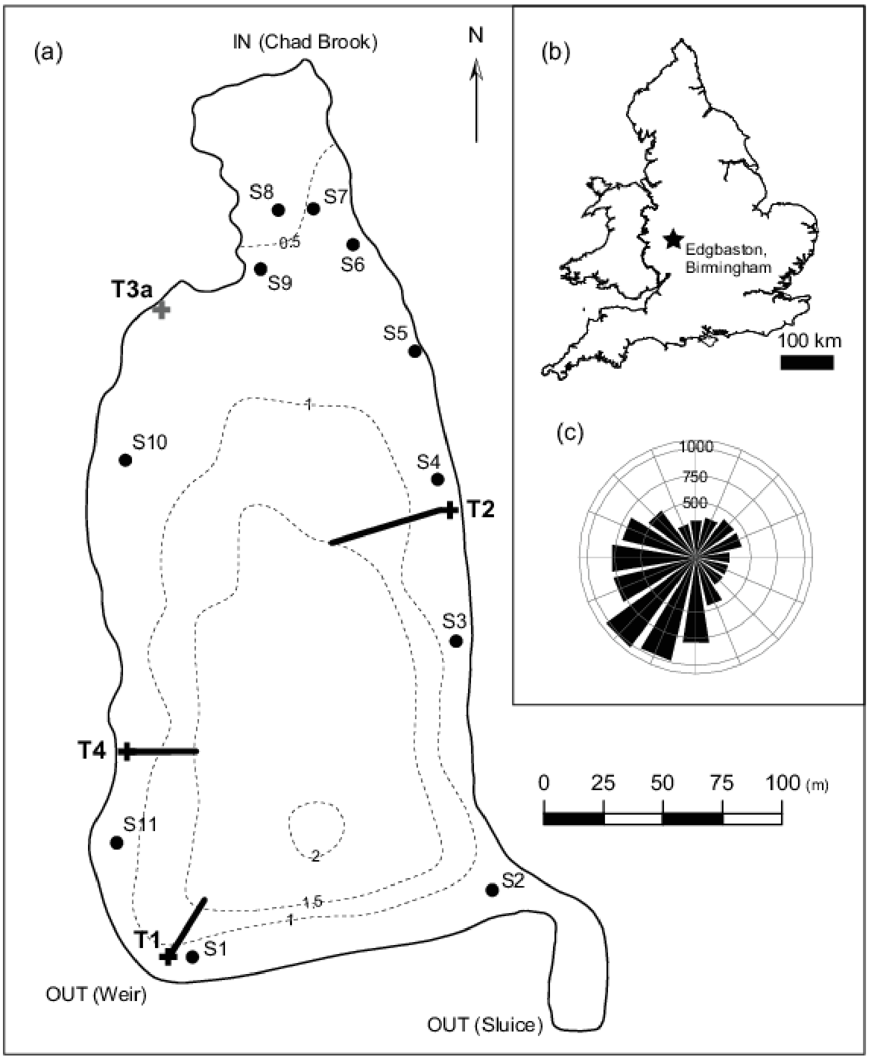


**Figure 1**(d) Clockwise from top left. Photograph of the Edgabston Pool looking north; a Mute swan's (*Cygnus olor*) nest at the southern end of the lake incorporating plastic debris; retrieval of a heavily biofouled plastic bag retrieved from the northern end of the lake during sampling; accumulation of debris at the southern end. (All photographs: Simon Turner).

**Figure 2**. Macroplastic distribution in Edgbaston Pool. (a) Number of debris items found at each sampling location and (b) abundance divided by debris type.

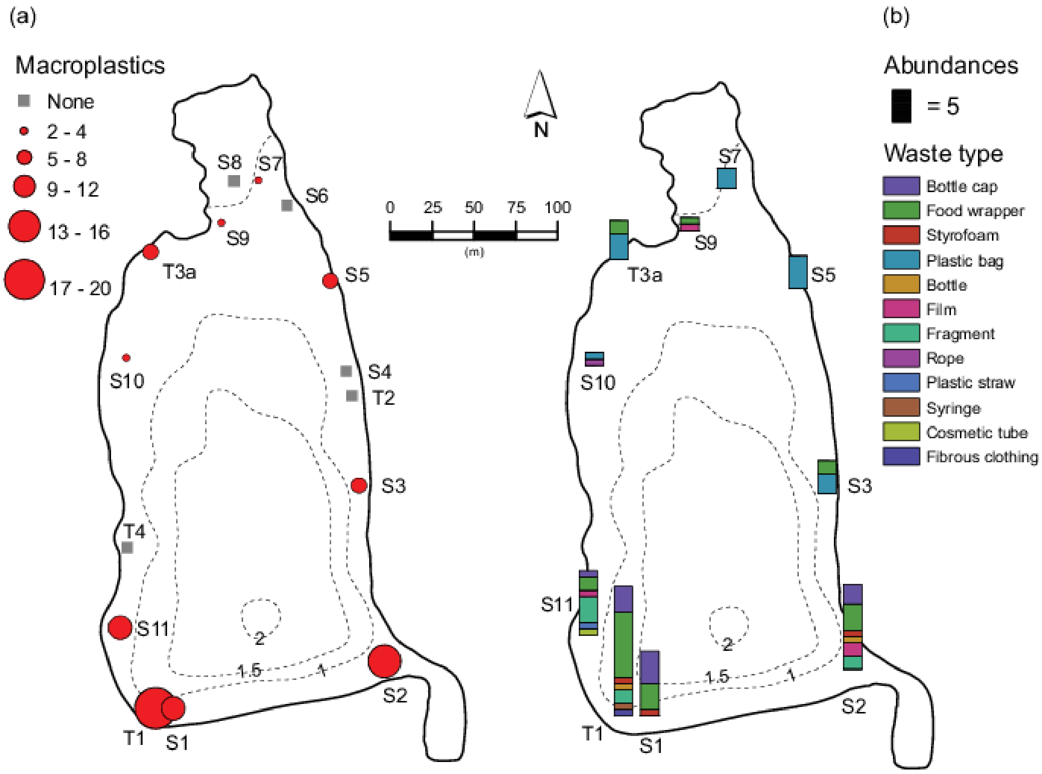


**Figure 3**. Microplastic concentrations (number particles / 100g dried sediment) in the surface sediments of Edgbaston Pool. (a) Microplastic films and (b) fibres

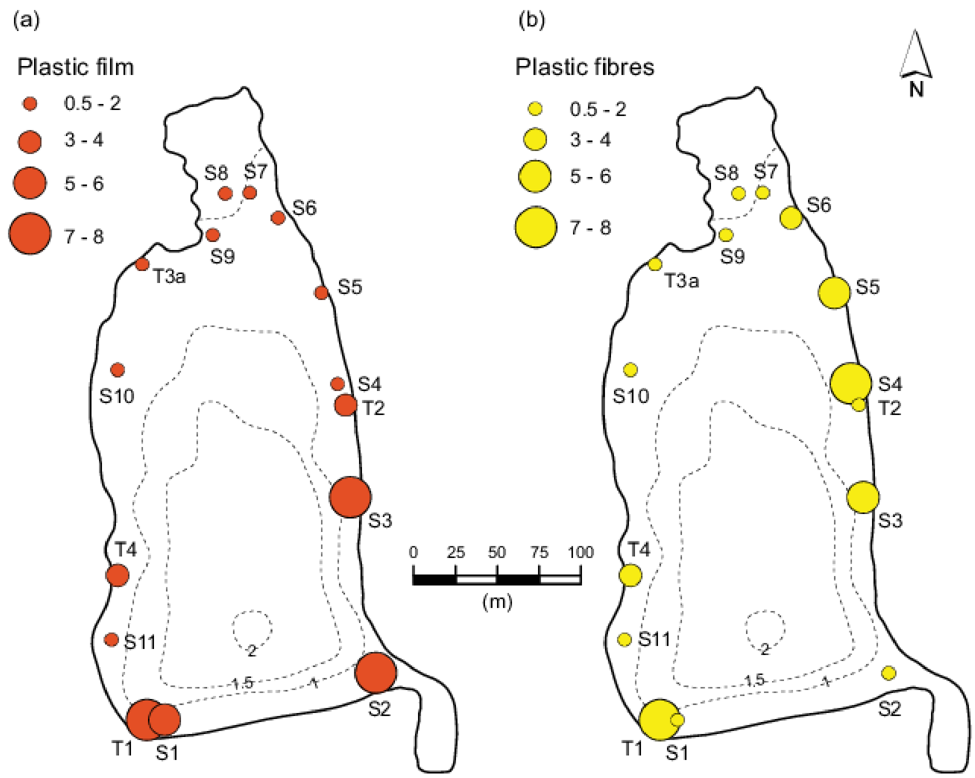
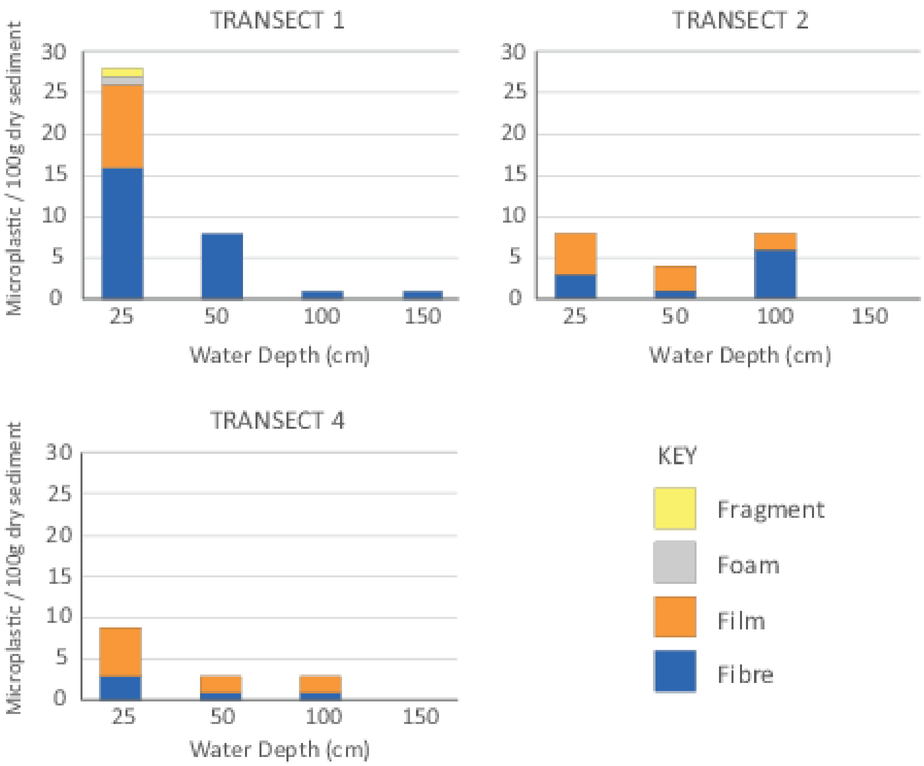
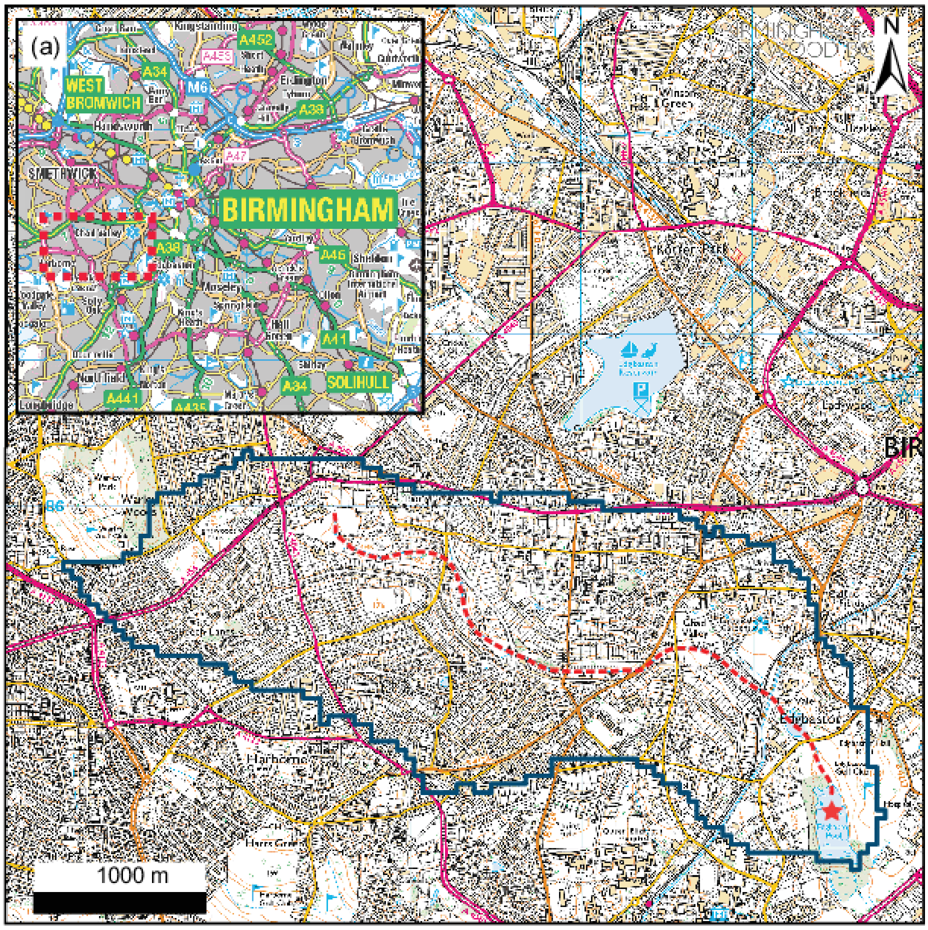


**Figure 4.** Microplastic concentrations (number particles / 100g dried sediment) subdivided by type in transect sediment samples of Edgbaston Pool.



**Supplementary Information.**

**Figure S1.** (a) Location of Edgbaston Pool catchment (dashed rectangle) in SW Birmingham. Main map shows Edgbaston Pool (red star) and its catchment area (blue line) derived from OS Panorama dataset. Dashed red line on main map indicates the route of Chad Brook inflow stream.

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